Final Report for the Grasslands, Forage and Soil Research Partnership

AHDB Dairy Grasslands, Forage and Soils Research Partnership

Report prepared for AHDB Dairy

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Executive Summary

The Grassland, Forage and Soils Research Partnership was a five year research partnership led by SRUC that existed from June 2011 through to the end of May 2016.

Leadership of the core areas of research was divided between SRUC Dairy Research and Innovation Centre (SRUC), Harper Adams University and Centre for Dairy Research (CEDAR) University of Reading. Contributions from the other sub-contractors have been crucial to ensuring that the Partnership delivered its research goals with the establishment of demonstration farms to highlight the various research areas (BGS); development of the farm economic model (Teagasc); analysis of grass cultivar data to aid the farmer in variety selection (NIAB) and to investigate variation in fresh grass samples along with providing advice in the general research areas (AFBI).

The overall objectives of the research partnership (RP) were to conduct research activity to:

- produce more milk from cheaper home-grown grass and forage
- target the genetic improvement of grass varieties with a greater relevance to GB farmers
- apply soil management and plant nutrient techniques (including animal slurries) to improve the growth and utilisation of grass and forage crops
- provide more detailed information on energy and protein content of crops to allow more accurately formulated diets to increase feed conversion efficiency
- develop out-wintering systems that are more cost effective than housing
- investigate precision farming technology that better measures dry matter production.

It was agreed that the partnership work would be divided into six work packages (WPs).

Work package 1 was a management package ensuring the efficient management of the research partnership and effective channels of communication with AHDB Dairy. Monthly reports containing updates on each WP were submitted to AHDB Dairy; these include information on the progress of the individual projects within each WP area and highlighted issues that might be discussed at quarterly meetings.

A management group, consisting of WP leaders plus C. Reynolds (UoR), had regular conference calls to review progress against milestones and met three times a year with AHDB Dairy research and extension staff to discuss the projects and results.

There was an annual meeting of the WP leaders and C. Reynolds plus representatives of all the sub-contractors and AHDB Dairy staff to update results on the relevant projects and discuss further work in areas of interest to the dairy industry.

As WP 1 was purely management of the other packages a WP template has not been completed and the WP descriptions and results only cover WP’s 2, 3a, 3b, 4 and 5.

A sixth WP (at the end of the report) covers the work that was started in the last year of the partnership and will run beyond the end of the May 2016 which is part of a PhD studentship. The results of this work, once completed, will be submitted to AHDB Dairy as a separate report.

Work Package	
1	Management
2	Knowledge exchange and dairy systems modelling
3a	Optimising grassland management
3b	Conserved forage production and evaluation
4	Outwintering for replacement heifers reared for low or high input milk production systems
5	Improving soil management
6	Description and effect of function fibre in forages on rumen function, performance and health of UK dairy cows

AHDB Dairy Research Partnership Final Report – Individual Work Package reports

Work package title:	**WP 2: Knowledge Exchange and Dairy Systems Modelling**		
Start date (mm-yyyy):	06-2011	**Actual (£)**	422.7k
End date (mm-yyyy):	05-2016	**Planned cost (£)**	422.7K
Name & organisation of principal investigator (PI):	Paul Hargreaves Scotland's Rural College (SRUC)		
Collaborators:	BGS, SRUC and Teagasc.		

A. Overview by work package leader

Underpinning rationale: Demonstration Farms and KE events.
Many dairy farmers learn from seeing techniques applied in the context of a commercial farm. Whilst it is not always possible to conduct replicated experimental work on-farm, the approach of taking practical techniques and concepts from research work and demonstrating these on commercial dairy units allows for useful knowledge exchange (KE).
The demonstration farm approach was employed to provide KE opportunities outside of written technical information and scientific research literature. This enabled successive events to be held on farm ensuring that, over several visits, a progression of the results from various interventions could clearly be shown. This allowed the opportunity to display the practical application of research findings from across the WPs, with questions asked and conclusions drawn about topics in the context of farmers and their own farms.
In addition to this, large Research Day events were held at the sites of the three main organisations in the research partnership (RP). These took place over the five years of the partnership to highlight the work that was being undertaken, creating a practical showcase of how the research could be implemented on-farm. Feedback from stakeholders at these events ensured that direction of the research and any future work remained relevant to the industry.
Dairy System Modelling.
As exhibited by the milk price volatility in recent years, GB dairy farmers face fundamental changes in their economic environment. The ability to survive in a volatile market will depend on information being available to enable informed decisions on the economic implications of changing management practices on farm. An adaptation of an established model (Teagasc, Moorepark Dairy Systems Model (MDSM)) using contemporary data from SRUC's Langhill herd (Langhill biological and production data across two genotypes, and two feeding systems, from 2006-2010) and modified to represent a high production, all year round calving system, was used to help investigate a number of economic and production scenarios.

Work package objectives: The objectives of this work package covered three areas:

a) demonstrate to the UK dairy farming community the practical and conceptual outcomes of studies undertaken in the research partnership
b) account for farmer feedback and input in the development of future work that address UK dairy farmer needs
c) adapt the Teagasc, Moorepark Dairy Systems Model (MDSM) as a stochastic dairy systems model to have the ability to analyse and investigate current and possible future UK dairy management.

Progress and development: These quite separate objectives were fulfilled through two distinct routes. The KE on the demonstration farms, taking the lead from the more detailed research coming from the workpackages (WPs), was complimented by the large events

arranged at the main partnership sites.
The modelling work was completed by the adaptation of the existing MDSM model using data provided by the Langhill Herd and associated systems studies from Crichton Royal Farm (SRUC).
Both these areas of the WP achieved their objectives and milestones on budget, with further work generated from the studies. The demonstration farms proved popular, with an attendance of between 20 and 50 farmers at most events. Useful summary guides to the research were produced that linked work undertaken on the farm (soil compaction and alleviation, slurry use, lucerne, reseeding, seed mixtures, controlled traffic and outwintering) to the more in-depth research carried out elsewhere in the partnership. These results were made available at meetings on the farm and on-line at both the BGS and AHDB Dairy websites. Articles in the press and presentations on the use of demonstration farms were delivered at national and international conferences.

B. Executive summary 1) Demonstration Farms.

Background and Objectives: The demonstration farm approach served to provide KE opportunities outside of written technical information and scientific research literature presented at specific conferences. The geographic locations of the demonstration farms were specifically chosen in areas of GB at a distance from the main research sites to ensure ideas and results from the experimental studies would be disseminated to farmers across GB. Work on demonstration farms enabled successive events to be held, allowing opportunities for the practical application of the workpackages research findings and changes to be shown over a number of visits.

Technical approach: Over the lifetime of the research partnership, five demonstration farms were sourced by BGS, in conjunction with AHDB Dairy (Table 2.1.1). There were two farms for years 3 and 4, and two different farms for years 4 and 5; an extra farm was established in years 3 and 4 to replace a farm that had only been available during year 3. Farms were identified in Cheshire, Devon and Cornwall (Years 2 and 3) and Yorkshire and Cornwall (Years 4 and 5). The demonstration topics were agreed with AHDB Dairy in the context of the experimental results from WP3a, 3b, 4 and 5. Demonstration activities were co-ordinated by BGS (in conjunction with AHDB Dairy) and demonstration events held to communicate the findings to a farmer (or trade) audience.

Table 2.1.1. Farm and location with the demonstration topic.

Farm	Topic
Holmes Chapel, Cheshire	Soil compaction, slurry management
Yarm, Yorkshire	Soil compaction, controlled traffic
Exeter, Devon	Soil compaction, grass variety selection
St Ayres, Devon	Soil compaction, slurry management
St Ives, Cornwall	Soil compaction, outwintering
Truro, Cornwall	Lucerne

Key results: Once the farm trials were established, events were organised with an average of 36 attendees; these included closed visits for local discussion groups. Additional open day visits attracted a larger attendance with, on average 41 attendees. It was estimated that approximately 97% of the attendees for each event were farmers (Table 2.1.2).
The results from the farm trials showed a number of outcomes that supplemented the scientific research, such as a reduction in DM yield for areas that had suffered soil compaction at the Lower Brenton demonstration farm in Devon.

Table 2.1.2. Dates of visits to partnership demonstration farms with number of attendees

Date of	Farm and location	Theme /workpackage	Number of Attendees

Event			
April 2013	Lower Brenton, Devon	Soil compaction, reseeding and nutrients	70
July 2013	The Orchards, Cheshire	Soil compaction, alleviation and nutrients	40
July 2013	Lower Brenton, Devon	Soil compaction, reseeding and nutrients (closed meeting)	12
October 2013	The Orchards, Cheshire	Soil compaction, alleviation and nutrients	25
June 2014	Crathorne Estate, Yarm	Soil compaction and alleviation	52
July 2014	Chynoweth Farm, Truro	Lucerne; growing and costs	48
July 2014	The Orchards, Cheshire	Slurry and soil compaction/alleviation	38
July 2014	The Orchards, Cheshire	Soil compaction (closed meeting with organic farming group)	6
September 2014	Trink Dairy, Cornwall	Soil compaction and outwintering	64
September 2014	Home Farm, Devon	Slurry separation and surface aeration	51
November 2014	Chynoweth Farm, Truro	Crude protein and lucerne	54
November 2014	Corps House Farm, Yarm	Soil management workshop	28
June 2015	Crathorne Estate, Yarm	Soil compaction, alleviation and re-seeding	31
July 2015	Chynoweth Farm, Truro	Lucerne event	25
August 2015	Trink Dairy, Cornwall	Healthy Soils event	31
August 2015	Home Farm, Devon	Healthy Soils event	30
November 2015	Chynoweth Farm, Truro	Lucerne; crude protein feeding	40
November 2015	Crathorne Estate, Yarm	Soil compaction and controlled traffic	14
	Total	**18 meetings**	**659 attendees**

Soil compaction was also investigated at the demonstration farm in Devon showing the effect of sward lifting on improving DM yield, supporting findings from WP5 and the use of slurry application with soil aeration to improve yield. Soil aeration and sward lifting either individually or together were investigated at the Cheshire demonstration farm with a greater DM yield seen for the combination of slitting and sward lifting for a pasture that had been affected by compaction. A further demonstration at this farm showed that a combination of slurry and fertiliser achieved better growth compared to either fertiliser or injected slurry, supporting findings from WP3a. The demonstration farm in Cornwall looked at soil compaction and again showed that compaction affected the DM yield of the first cut after compaction (20% reduction for both animal trampling and tractor compaction). In a separate out-wintering demonstration on the same farm it was shown that forage type (grass, kale or fodder beet) had no effect on animal performance but regular weighing was crucial to achieve target LWG, echoing the findings of WP4. In Yorkshire, the farm provided an effective demonstration of the practical challenges and benefits in implementing controlled traffic techniques for silage management to support findings from WP5.

Farmer messages: The farmer messages were based on both the work done at the individual demonstration farms and the research from the partnership. The information booklet produced for each demonstration farm proved popular with the attendees of the meetings. The enthusiasm of the farmers involved in running the trials on their demonstration farms reflected the interest in the meetings. The quality of the information on offer to the farming community improved from the early years of the partnership, due to a) more emphasis on the use of the demonstration farms as a focus of reporting the outcomes from the whole of the RP, b) more information to impart as the partnership progressed and c) the build-up of useful field demonstrations with their own results and practical data on the farms.

Further exploitation: Information and results have been published on both the BGS and AHDB Dairy websites. The demonstration farm network has shown a positive impact in terms of KE with interest in the on farm demonstrations. Booklets explaining the trials and providing results from the farm demonstration and linking in the partnership research work were produced for each of the demonstration farm meetings. Research posters and papers on the value of demonstration farms were presented at two international conferences. The demonstration farms also provided a test site for the cross- sector AHDB Healthy Grassland Soils assessment, with a number of the farms being used to train farmers in soil structural assessment and soil health.
During the course of the RP there were 18 specific AHDB Dairy-BGS organised visits at the demonstration farms, however the farms also hosted a number of farmer meetings for industry and local grassland societies. This widened the results of the RP beyond AHDB-BGS specific meetings.

B. Executive summary 2) Knowledge exchange.

Background and Objectives: It was recognised, within the RP, that the KE approach needed to be relevant to the GB dairy farming community. Research findings from the experimental work undertaken at the main sites of the RP (SRUC Dumfries, HAU and UoR) were communicated as directly as possible to encourage implementation of practical changes to improve competitiveness and efficiency.
The objectives were to:

- provide a focus for the research being undertaken in the rest of the partnership
- run demonstrations of techniques being investigated as part of the main research work
- provide information and changes in demonstrations to allow repeat visits to farms to assess progress and results.

Technical approach: The three main RP sites were made available for up to ten visits by groups led by Extension Officer's (EO's) during each year of the partnership. Two major AHDB Dairy led events and one event involving AHDB Dairy were proposed each year across the three main partnership sites during the first three years. As the experimental work progressed and the trial work on the demonstration farms produced results, the events were more focused on the demonstration farms and at combined AHDB Dairy Research Days. These Research Days promoted research from both RP's. More novel methods of disseminating results from the RP were investigated such as webinars being presented live on-line, covering subjects such as soil compaction and alleviation, animal forage and nutrition and soil health.

Key results: The larger events allowed a greater opportunity to discuss, showcase and interpret the breadth of research across the RP. The ability to discuss a number of important but potentially not closely related research areas covered by an overarching topic (forage, grass and soil) was useful in order to encourage a wider message on practical research based changes that could be implemented on farm.

Table 2.2.1. Date, locations, themes and number of attendees at the larger events at the partnership main sites.

Date of Event	Partnership site	Theme/workpackage	Number of Attendees
May 2012	SRUC Dumfries	SRUC Open Day (soil compaction, slurry and forage)	100 attendees
February 2013	SRUC Dumfries	Video webinar (soils, compaction and alleviation)	80 signed up with 48 attending live.

March 2013	UoR	AHDB Partnership research day (NIRS grass:clover, Lucerne nutrition and soil compaction)	126 attendees including farming press.
September 2013	HAU	AHDB Research Day (out-wintering, soil compaction and lucerne)	122 attendees
November 2013	SRUC Dumfries	AHDB Research Day (Lucerne, soils and slurry use)	130 attendees
May 2014	SRUC	Open Farm – Dairy farmer of the Year event	109 attendees
July 2014	Trenault Farm, Launceston	AHDB Research Day (Soils, grass varieties and slurry)	86 attendees
October 2014	Bankhead Farm, Chester	AHDB Research Day (Lucerne and outwintering)	130 attendees
January 2015	HAU	Webinar on nutrition; lucerne and crude protein	78 attendees
March 2015	University of Nottingham	Internal RP conference (Demonstration farms, economic modelling, soils, precision farming, grass varieties, outwintering and development of NIRS equations for grass/clover)	50 attendees
June 2015	Pembrokeshire	AHDB Research Day (soil compaction, slurry management)	208 attendee
October 2015	Hall Farm, Norfolk	AHDB Research Day (soil compaction, lucerne)	51 attendees
March 2016	Kegworth, Derbyshire	Research Conference for both research partnerships (Out-wintering, cut and carry, lucerne, soils and grass varieties)	264 attendees
May 2016	SRUC	ScotGrass	Over 3000 attendees
June 2016	Headley Hall, York	AHDB Grass Research Day (soil compaction, grass varieties)	82 attendees
		Total Research Days + DIG	**1177**
		Total	**4584**

The ability of the researchers to engage with the farmers and for farmers to feedback on how easily results could be adapted was invaluable. Discussions with farmers and researchers ensured that any future work would be relevant to the industry.

Farmer messages: Farmer messages for the larger events came from the work presented from the individual research WPs. In the context of this report these will be discussed within each individual WP area.

Further exploitation: The large KE events allowed the results of the research partnership to be communicated to farmers and other stakeholder groups, as soon as these had been analysed. This allowed a much quicker exploitation of the key messages from the research than the more usual presentations at scientific conferences and briefing documents. The AHDB Research Booklet that was produced to ensure the early dissemination of data from the various WPs gave a valuable overview of the research and the breadth of the subjects being investigated. This resource could be used at other farmer meetings to stimulate discussion of partnership research activity.

B. Executive summary 3) Economic Systems Modelling – Model development.

Background and Objectives: The UK is a significant producer of milk (3rd largest in the European Union and 9th largest in the world (House of Commons Library, 2010)) with the profitability in dairy farming, as with other businesses, being the value of the output minus the costs of production. The profitability of a dairy system is determined greatly by the economic environment (milk price, feed costs, etc.) as well as the relative availability of key factors of production (land, labour, etc.) and the level of available productivity to utilise resources efficiently. In recent years production costs such as feed, fuel and fertilisers have tended to increase while farm gate milk prices have not risen at the same pace (AHDB Dairy Datum 2012; Defra, 2013). Some UK farmers have chosen to increase output in order to dilute the costs of production (AHDB Dairy, 2013). It is essential that all dairy farming systems should be economically evaluated and optimised to utilise all resources within the enterprise efficiently.

Technical approach: Langhill experimental data were used to adapt and parameterise the Moorepark Dairy Systems Model (MDSM) from a low input seasonal grass based system (spring calving) to a high input dairy system with an all year round calving pattern. This allowed a full economic comparison of contrasting and alternative grass based systems (two systems: low forage (LF) and high forage (HF) and either permanently housed or grazing and housed). Parameterisation allowed assessment of the effects of system inputs, genetic strain and animal health as well as animal or system change. The adapted MDSM model combined animal performance, economic and production efficiency and allowed investigation into the consequences of varying milk price and concentrate cost. A stochastic simulation was used to identify the risks associated with dairying in contrasting production systems for 200 cow herds, representing the two feed systems (low and high forage) across two genetic merits (select (S) and average (C)). Scenarios were designed to simulate a farm based on two basic assumptions; 1) land availability was limited to 80 ha, with cow numbers adjusted with the relationship between energy supply and energy demand while fully utilising the land area (S1) and 2) herd size fixed (200 cows) and land area adjusted to meet the energy requirements (S2). Each system had 10 t/ha DM of grass available for grazing or silage (the only feed produced on the farm) and for economic comparison the systems had the same base milk price of 30 pence per litre (ppl). The fresh weight purchased concentrate price was £275 t for the HF system, while the LF concentrate was 10% more expensive to take account of the higher spec concentrate used. Land not utilised by the dairy system was leased out.

Key results: The dairy systems simulation model developed allowed a full economic comparison of contrasting dairy systems and generated results consistent with other benchmarking analysis.
The systems analysis highlighted the impact of high feed costs on farm profitability, noting that at low milk - feed price ratios, feeding high volumes of purchased concentrates is unsustainable, resulting in a negative profit margin (Figure 2.3.1). Consequently placing an emphasis on home-grown forages at periods of low milk – concentrate price ratios, particularly when using average genetic merit cows, is important.
Similarly selecting for animals with improved genetic merit (for milk fat and protein kg) resulted in greater economic return regardless of management system, allowing for greater resilience of the business to fluctuating feed-milk price ratios.

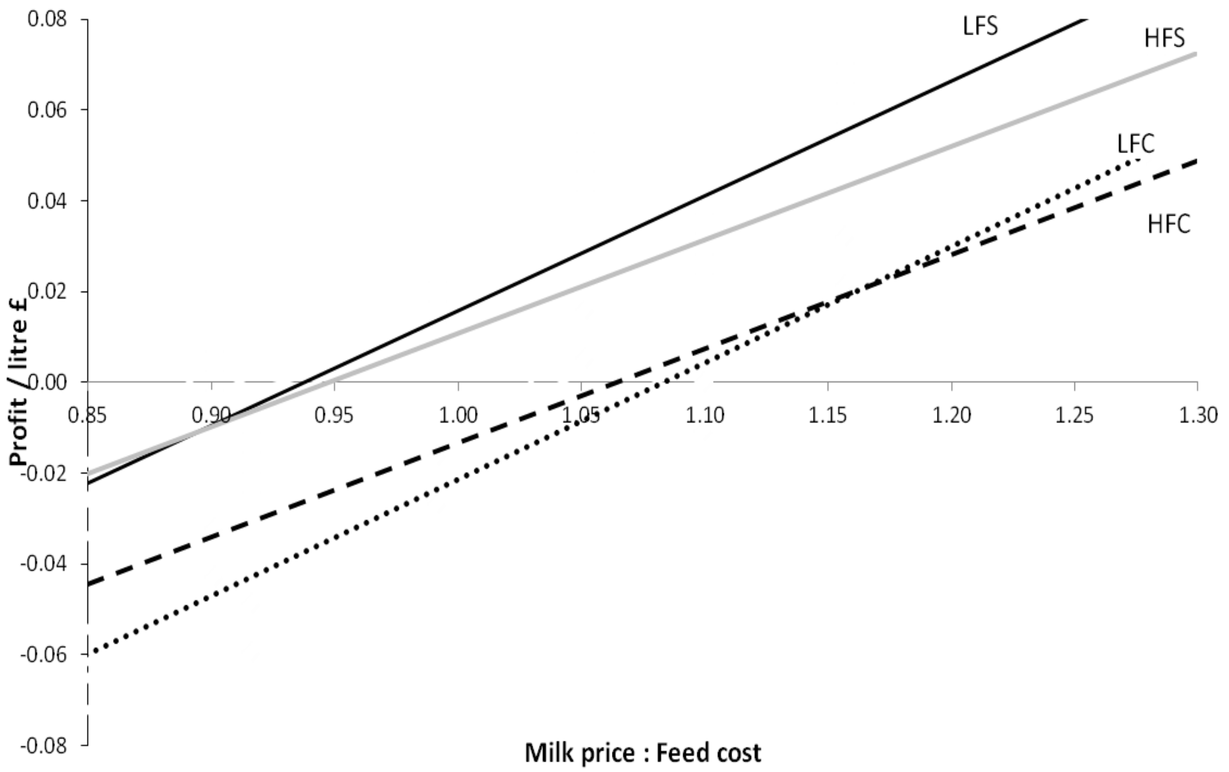

Figure 2.3.1. Dairy system per litre profitability at a range of milk price to feed cost ratios (HFC=High Forage Control, HFS=High Forage Select, LFC=Low Forage Control, LFS=Low Forage Select).

Farmer messages: The main messages were:

- On average, animals of a select genetic merit for fat and protein kg (S) achieve 4p more profit for every litre produced than average merit cows (C) in an all year round housed, low forage system, and 2ppl more within a composite, high forage system.
- Average genetic merit cows (C) consuming a high forage diet plus grazing can be profitable however losses are made when this genotype is confined and fed high levels of concentrates.
- Systems which utilize high levels of imported concentrate feeds producing large milk volumes can be more vulnerable in circumstances where purchased feed costs are high and the milk price offered is low.

Further exploitation: The modelling work was associated with a PhD that further analysed the outputs from the Moorepark model. Closer working and co-operation with the developers of the model should ensure further useful results from utilising the MDSM in combination with research data to achieve information valuable to the dairy industry.

B. Executive summary 4) Economic Systems Modelling – Herd replacement

Background and Objectives: Monitoring and minimising the expense of herd depreciation is one area of dairy production systems where farmers have the capacity to control costs and can implement management modifications. When focusing on variable costs of production, replacement costs are generally second only to feed and forage outlays contributing c. 25% of the total costs of production. Large variations in replacement rates on GB farms suggests there is significant scope to reduce production costs; recent data suggests a UK median replacement rate of 25% (interquartile range of 10%) (Hanks and Kossaibati, 2013).
Reducing replacement rates has the combined effects of increasing outputs by increasing the

age profile of the herds as well as reducing costs on farm. This study aimed to:

- Quantify the financial and production effects of decreasing replacement rate
- Illustrate the effects of reducing replacement rates within AYR housed and composite dairy production systems
- Describe the effects of reduced replacement rates across UK average and improved merit genotypes of Holstein Friesian cows.

Technical approach: Herd production data from a long-term feeding system experiment (SRUC's at Crichton Royal Farm in Dumfries) was used to model the economic performance of each dairy management regime. The experimental data formed part of a long-term farm systems study carried out to assess the effect of genetic line (select (S) and control (C)) × feeding system interactions (high and low forage). The data was analysed using the adapted Moorepark model for year round calving and three times a day milking. Milk yields and milk composition for genotypes within feed systems were modelled for an average group for each month of calving, rather than for individual cows. The systems were designed to allow each genetic line to express its potential within each feed system largely unrestricted by any limitation in feed supply. Average body weight and body weight change for milking cows during lactation were also calculated for each genotype within the different feed systems and included in the model. Within the model all heifer replacements were brought onto the farm.
Replacement rates used in the simulation for the C and S genotypes were comparable to the AHDB Dairy Milkbench average replacement rates for composite and high producing herds with similar production characteristics. The proportion of cows removed from the herd included cows that failed to become pregnant, voluntary culls and cow mortality. For economic analysis, parity structure was calculated to be representative of an actual replacement rate due to involuntary culling rate plus 10% of the remaining herd which were culled for voluntary reasons.
Replacement rates applied in fertility scenarios ranged from 22% to 32%, with S herds attracting rates of 24%, 28% and 32% and rates for C cows of 22%, 26% and 30%. A 2% replacement difference between the S and C genotypes was applied to represent actual differences found between the herds during experimental conditions. Simulations represented a feasible range of replacement rates found within composite and high output systems on UK dairy farms (DairyCo, 2014). The replacement rate was annually as the model generated annual accounts output for the whole herd milk production.
Calving patterns for the C and S genotypes were calculated as the proportion of cows within each genotype and parity that calved in each month throughout the year. This was adjusted by parity structure, with an equal number of cows calving in each month to simulate an all year round calving pattern.
Scenarios were tested for a simulated dairy holding with land area of 80ha, farming with a herd of 200 cows. One scenario with a herd size of 430 cows was carried out within the LFS system. Sensitivity analysis was also undertaken to investigate the economic implications of milk price volatility on overall profitability at the various replacement rates. Base milk prices included in the sensitivity analysis were set at 24ppl, 27ppl and 30ppl, similar to long term historic variations in the UK.

Key results: Table 2.4.1 highlights the differences in per litre and per cow profits between herds of diverse genetic merits within varied feed systems at a range of replacement rates. The table shows that the effect on overall profitability of improving herd replacement rate by 1% differs depending on feeding system, genotype and herd size. Improving culling rate equates to lower replacement costs as a proportion of total variable costs, for example half a percent fewer replacement costs per 1% improvement in an LFS system. Reducing replacement rate by 1% when herd size is increased from 200 to 430 cows within a low forage AYR housed system increased profits from milk sales by 1ppl. This is because fixed costs were diluted by a larger number of animals and this reduction stemmed from less labour requirements per cow within the larger herd.

Table 2.4.1. Anticipated increases in profit (per litre and per cow) when a 1% reduction in replacement rate is achieved for AYR housed and composite herds, of improved and average genetic merits at a base milk price of 30ppl.

Housing	Feeding System	Genotype	Herd Size	Profit increase	
				Per litre (p)	Per cow (£)
AYR Housed	Low Forage	Select	200	0.30	£ 30
AYR Housed	Low Forage	Control	200	0.36	£ 27
Composite	High Forage	Select	200	0.43	£ 34
Composite	High Forage	Control	200	0.47	£ 32
AYR Housed	Low Forage	Select	430	1.00	£ 30

Farmer messages: The main farmer messages were:

- Reducing replacement rates by 1% in a herd of improved merit Holstein Friesian cows could increase profits by up to 0.30ppl in a low forage diet, AYR housed system and 0.43ppl in a high forage diet, composite system (housed for part of the year).
- In a 200 cow herd of improved genetic merit animals, the effect of reducing replacement rate by 1% (or 2 cows) per year could effectively increase profits per cow by £30 in an AYR housed system with a Low Forage diet and £34 in a composite system, with a High Forage diet housed for part of the year.
- Reducing replacement rates by 1% or 2 cows in an average genetic merit herd of Holstein Friesian cows can increase profits by £27 per cow or 0.36ppl in an AYR housed herd consuming a Low Forage diet to £32 per cow or 0.47ppl in a composite system eating a High Forage diet.

Further exploitation: The model outcomes allow a farm manager to make decisions based on model simulations of real data, with a consideration of how variable costs could be controlled by minimising the cost of herd replacement. The modelling work was associated with a PhD that further analysed the outputs from the Moorepark model. The outcomes from this research will feed into AHDB Dairy's Calf to Calving campaign.

B. Executive summary 5) Economic Systems Modelling – Milk purchasing schedule scenarios

Background and Objectives: Dairy farmers contend with decision making in an environment of uncertainties and complex future forecasts, for example changeable local weather patterns, fluctuating feed costs, variable milk yields and associated revenue volatility. Estimates of potential income can be further obscured by complex milk purchasing contract schedules which can be time consuming and challenging to decipher.

Milk purchasing schedules differ within and between processors, with incentives being offered dependent upon the quantity and quality of the milk, however milk purchasing agreements are often not straightforward and many different components of contracts exist. Any potential dairy system effect on profitability would be challenging for farmers to disentangle amongst base and variable payments for liquid, butterfat and protein as well as bonuses and penalties associated with volume, hygiene and seasonality.

Analysis of farm level profitability of dairy enterprises has highlighted that high yields are not the sole driver of profit, efficient milk production is possible within a range of management regimes as long as key determinants of profit within that system are managed well (AHDB, 2014).This report applies a series of milk purchasing schedules to the Moorepark Dairy System Model (MDSM) outputs generated by research farm data drawn from a range of dairy management types.

- The aim of this work was to outline potential revenues and costs generated from high and low forage dairy management systems, across two genetic lines within liquid and cheese contract types to emphasis any differences in profitability.

Technical approach: Scenarios run using the model developed in B 2.3 demonstrated the effect on profitability of different milk pricing models. The effect on profitability of two different milk pricing models (a liquid schedule and a cheese schedule) within and across fully housed (all year round (AYR)), grazing and composite milk production systems, attaining a 30ppl base price when farming with 200 Holstein Friesian cows was evaluated.

Key results: Results quantified revenue differences across pricing and production systems (Table 2.5.1). Average genetic merit control cows were only profitable (achieving £0.01/kg) when managed in a high forage, composite system and with a liquid schedule, otherwise losses of over £0.02/kg milk were estimated. Housing a group of average UK merit (control) cows and feeding a low forage diet could lead to total costs of £0.35/kg. Table 2.5.1 highlights £/kg fixed and variable costs as well as differences in profitability across milk contracts within the various dairy systems.
The modelled results provide information to farm managers who have an opportunity to alter their management regime or purchasing contract. With an equivalent herd size, differences in profitability exist within system types and between contract types with the composite select system achieving the most profit in all contract types. The base milk price was not the sole determinant of profit, as trade offs existed between land availability and costs of imported feeds. Farm managers, with careful planning, should be in a position to match their preferred feeding and housing regime to the most beneficial contract.

Table 2.5.1. Anticipated per kg profit associated with a Liquid or Cheese schedule alongside estimated fixed and variable costs for control and select merit cows in a housed or composite system.

Dairy System	Feeding System	Genetic Merit	Fixed Costs	Variable Costs	Liquid Schedule	Compositional or 'Cheese'
			Costs £/kg		Profit £/kg	
AYR Housed	Low Forage	Select	0.07	0.25	0.01	-0.005
Composite	Low Forage	Select	0.09	0.20	0.03	0.02
AYR Housed	High Forage	Control	0.08	0.27	-0.03	-0.06
Composite	High Forage	Control	0.10	0.21	0.01	-0.02

Farmer messages: The main messages for the farmer were:
- High production select merit cows managed in a composite system with total costs of £0.29/kg achieved the highest per kg profit with a liquid schedule. For composite systems a liquid schedule could attain profits of £0.03/kg and a cheese schedule £0.02/kg
- A select merit cow in an AYR housed system fed a low forage diet could cost £0.32/kg to manage and would only be profitable on a liquid schedule. Within this low forage, AYR housed management system, a liquid contract could attain profits of £0.01/kg however losses of £0.005/kg were estimated within a cheese schedule.

Further exploitation: The modelling work was associated with a PhD that further analysed the outputs from the Moorepark model. Closer working with the developers of the model should ensure further projects beneficial to the industry in the future. The results of this work also fed into recent AHDB Market Information's analysis investigating relationships between system type and contract to assist farmers in optimizing milk contracts.

C. Delivery against milestones - tabulate achievement of milestones against targets set. List any deviations or agreed changes in direction, and their impact on the project (if applicable, describe how the work differs from that originally proposed and describe how the changes have impacted on the work package. Include changes to

objectives and work plan / budget, changes to the team or other constraints. Explain any discrepancy between planned worked and achieved work, and corrective actions taken.

K.E. and Modelling (WP2)	**Progress, deviations and corrective actions**
Milestone 2i Formalise links with British Grassland Society to assist in disseminating information and selecting commercial demonstration farms (Q2, Yr1).	The British Grassland Society was formalised as a sub-contractor at the commencement of the research partnership.
Deliverable 2.1.1 Select and set-up commercial demonstration farms through BGS and in conjunction with the Research Partnership. There will be two demonstration farms during Yrs3 and 4 and a further two farms during Yrs4 and 5.	Two potential demonstration farms identified and soil and slurry demonstrations started for farmer visits during Yr3 and Yr4. As one farm only participated during Yr3, a third farm was selected for Yrs4 and 5 along with two new demonstration farms.
Deliverable 2.1.2 Forty to fifty visitors to the demonstration farms each year of operation.	There were over one hundred visitors during each year of the operation of the demonstration farms.
Milestone 2ii Large 'Open Days' visits at one of the partnership research centres each year (Yr5).	There were large events of research open days organised each year of the partnership at one of the research partner's sites. KE activities also included webinars to allow remote access to the research and presentation of the results. There were also a number of joint events at the three main research partner sites to help encourage interaction between farmers and researchers i.e. ScotGrass at SRUC.
Milestone 2iii Development of a farm systems model based on year round calving (Q4, Yr2).	Working with Teagasc, Moorepark an adapted year round calving model was developed from the seasonal spring calving model (Moorepark Dairy Systems Model).
Deliverable 2.3.1 Test the year round calving model using data from the SRUC system trials for high and average genetic merit cows.	The newly developed model was tested and a report of the sensitivity testing submitted to AHDB Dairy Sept 2013.
Milestone 2iv Scenarios of fertility costs for herds of high and average genetic merit that were either housed all year or partially housed and grazed, tested with the developed model.	The model was run for the scenarios with sensitivity testing for the reduction of replacement rates.
Deliverable 2.4.1 Report of the outcomes of the scenarios and sensitivity testing of the data runs for a reduction in the replacement rates either per cow or price per litre.	Report of the various outcomes of the scenarios and sensitivity testing submitted to AHDB Dairy Feb 2016.
Milestone 2v Scenarios for different milk purchasing schedules and sensitivity testing for a liquid milk and cheese schedule on a year round housed and partially housed herds.	The model was run for the scenarios with sensitivity testing for the genetic merit and forage costs.

Deliverable 2.5.1 Report on the modelled outcomes of the different milk purchasing schedules and effect on farm profit.	Report of the outcomes of the modelled scenarios on farm profit submitted to AHDB Dairy April 2016.

D. Outputs (List and fully reference all outputs which document and promote the findings of this work. Describe any further outputs or follow-up initiatives anticipated after 31 May 2016).
D (I) Experimental/project reports to AHDB
Booklets were produced for each of the demonstration farm meetings. These explained the work at the specific farm together with the results from the on farm trials linked to the results being produced from the research work within the partnership. Devon Demo Farm booklet (Apr 2013) Cheshire Demo Farm booklet (Jul 2013) Yarm Demo farm Yorkshire booklet (Jun 2014) Turo Demo Farm booklet (Jul 2014) Cheshire demo farm updated booklet (Jul 2014) Trink Demo Farm booklet (Sep 2014) Devon demo farm updated booklet (Sep 2014) A general research partnership booklet was produced using results from the various WPs which were used to give an overview of the breadth and quality of the work being undertaken. This booklet was used at the research open days. AHDB Dairy Report ‘Model Development & Economic Comparison of Dairy Systems’ submitted September 2013. AHDB Dairy Report ‘Financial effect of alternative milk pricing regimes across grazing, housed and composite dairy systems’ submitted in April 2016. AHDB Dairy Report ‘Economic effect of reproductive efficiency improvement within diverse dairy systems’ submitted February 2016.
D (II) Scientific publications (accepted or submitted; peer reviewed conference proceedings etc.)
Evans, C. and McConnell, D.A. (June 2015). Lucerne as an alternative protein source in southwest England: a Demo Farm perspective. Poster presentation to European Grassland Federation. McConnell, D.A. and Evans, C. (June 2015). Alleviating soil compaction can increase grassland productivity: a demonstration project. Poster presentation to European Grassland Federation. Evans, C, McConnell, D.A. and Roberts, D.J. (July 2015). Demonstrating Research in Practice. International Farm Management Congress, Quebec. Poster presentation. Presentation to Research Partnership conference (March 2015) Demo Farms – demonstrating

research in practice. Nottingham University.

March, M., Roberts, D.J., Wilson, R. and Stott, A.W. (2014). Robustness of diverse dairy systems. Geosciences Conference, Edinburgh.

March, M., Roberts, D.J., Wilson, R. and Stott, A.W. (2014). Robustness of diverse dairy systems. SRUC Post Graduate Conference, Edinburgh.

March, M., Roberts, D.J., Wilson, R. and Stott, A.W. (2014). Evaluating the robustness of diverse dairy systems. Tyndall Post Graduate Conference, Manchester.

March, M., Roberts, D.J., Wilson, R. and Stott, A.W. (2014). Evaluating the robustness of diverse dairy systems. Crichton Campus, Post Graduate Conference, Dumfries.

March, M., Roberts, D.J., Ryan, W. and Shalloo, L. (2015). Application of a dynamic, interactive model to evaluate the impact of genotype and feed system on farm profitability. Research partnership Conference, Nottingham University.

March, M., Roberts, D.J., Wilson, R. and Stott, A.W. (2016). Evaluating the robustness of diverse dairy systems. SRUC Post Graduate Conference, Edinburgh.

March, M., Roberts, D.J., Wilson, R. and Stott, A.W. (2016). Evaluating the robustness of diverse dairy systems. Geosciences, Post Graduate Conference, Edinburgh.

March, M., Shalloo, L., Roberts, D.J. and Ryan, W. (2016). Economic evaluation of Holstein Friesian strains within composite and housed UK dairy systems. Livestock Science, under review.

D (III) Knowledge transfer (national and international workshops, farmer/industry meetings, media articles etc.)

Farmer- industry meetings

Meeting	Location	Date	Attendees
18 demonstration farm meetings (see Table 2.1.1)	Various	Apr 13 – Nov 15	659
FWAG meeting	Devon	Feb 15	70
Internal research conference	University of Nottingham	Mar 15	50
DIG Conference – Economic presentation	Kegworth	Mar 16	264
		Total	**1043**

Farming Press

Title	Media	Date
Soil management crucial for productive swards –demo farms	Farm Business	May 13
Cheshire meeting report	Farmers Guardian	Aug 13
Soil management on demonstration farm	Grass and Forage Farmer	Dec 13
Getting more from grass – Cheshire demonstration farm	British Dairying	Jun 14
Overcoming soil compaction critical when pushing milk from forage (Yarm)	Farmers Weekly	Jul 14
Lucerne lifts home-grown protein levels	Farmers Weekly	Sep 14
Demonstration farm update	Grass and Forage Farmer	Jan 15

Demonstrating research in practice	Grass and Forage Farmer	May 15
Lucerne demonstration farm report	Grass and Forage Farmer	Sep 15
Tramlines in silage fields	Farmers Weekly	Feb 16

Online

Title	Media	Date
DairyCo-BGS demo farms show research into practice	AHDB Dairy website	Mar 13
Video – Rob Taverner Demo Farmer	YouTube	May 13
Cheshire demo farm – event write up	AHDB Dairy website	Jul 13
Yorkshire demo farm – event write up	Forage for Knowledge	Jul 14
Farmers consider Lucerne for sustainable high protein forage options	Forage for Knowledge	Jul 14
Digging the dirt on soil compaction and out-wintering	Forage for Knowledge BGS website	Sep 14
Making the most of muck and mud for profit	BGS website	Sep 14
Demo farms, research into practice	BGS website	Feb 15
Drilling lucerne – establishment is key	Forage for Knowledge Farming Futures	Aug 15
Healthy soils - demo farm update	BGS e-newsletter	Aug 15
Video - Controlled Traffic Farming	YouTube	Oct 15
Controlled Traffic Farming	Forage for Knowledge	Oct 15

E. Benefits of the research results to the British dairy sector

E (I) Economic benefits (describe, and wherever possible quantify, potential financial benefits at farm level, and/or to the industry as a whole)

The main economic benefits from the demonstration farms and the research open days are presented in relation to the work undertaken across the partnership WPs. However, the demonstration farms and larger events allowed a focal point to discuss results with farmers and provide advice on how the research results could be implemented on farm and any subsequent effects on farm profitability.
The development of a model that incorporates year round calving and different levels of genetic merit is important to allow comparisons to be made without the additional cost of funding lengthy research trials. The model allows profit from a variety of systems to be evaluated easily and potentially best practice developed for the most profitable. The effect of alternative milk pricing schemes showed that average merit control cows were only profitable (achieving £0.01/kg) when managed in a high forage composite system and with a liquid schedule, otherwise losses of over £0.02/kg milk were estimated. Housing a group of average UK merit cows on a low forage diet, could lead to costs of £0.35/kg.
The fertility, herd replacement modelling scenario showed that in a herd of 200 Holstein Friesian dairy cows of select merit, reducing replacements by 2 cows per year can effectively increase profits per cow by £30 in a low forage, AYR housed system and £34 in a high forage, composite system. Reducing replacement rates by 1% or 2 cows in an average genetic merit herd can increase profits by £27/cow or 0.36ppl in a low forage, AYR housed herd and £32/cow or 0.47ppl in a high forage, composite system.

E (II) Sustainability benefits (How will outputs support sector sustainability in the long-term? Will the activity support sustainability in other ways such as improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)

Improving soil structural health and nutrient use efficiencies on farm, through improved use of

manures and fertilisers is crucial to improving environmental sustainability on GB dairy farms. Each of the demonstration farms focused on areas of either soil management, nitrogen use efficiency or manure management, providing the latest research results and information to farmers to assist in the improvement of environmental sustainability on farm. The use of the demonstration farms in development of tools and training of farmers and industry personnel in soil structural assessment also helped develop the skills base within the industry. The inclusion of some of the demonstrations farms in an RB209 validation project also assisted in the development of new fertiliser recommendations for grassland which again will support improved nutrient use efficiency. A focus on the benefits and challenges of home-grown proteins (lucerne) and on managing outwintering fields to avoid soil damage at the Cornwall demonstration farm also increased farmer awareness on strategies to improve the image of dairy farming. Similarly the modelling activity undertaken in this work package provided information on the financial impact and business resilience of changing management practices on farm, providing knowledge to help improve the economic sustainability of GB dairy farms. The modelling work also contributed to skills development in the industry facilitating a PhD studentship, in conjunction with SRUC and Edinburgh University based at SRUC Dumfries.
E (III) Policy making (Describe how the work informs policy, leads to better decision making, or addresses wider societal concerns)
The KE events allowed policy makers the opportunity to discuss with the researchers how the results provided from the WPs across the research partnership could influence farming practice and future policy. In addition, the demonstration farm events allowed greater links to be made with government organisations such as Catchment Sensitive Farming again feeding in both farmer views and current research to policy makers.
E (IV) Supply chain (Does the work address supply chain constraints or opportunities)
The demonstration farm activity allowed new research to be shared not only with farmers but also with the wider agricultural industry with meetings also attended professionals working within the industry, further expanding the potential reach of the research. The modelling work undertaken in this work package feeds in to current AHDB Market Information activity and through this channel may be used to inform future discussions on milk contracts and producer-processor relationships with industry organisations.

F. **Leverage and added value** (Detail all additional funding sources and collaborations nationally or internationally. Has this activity contributed to applications for further research in this area? Has the work contributed to improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)
As previously mentioned, some of the demonstration farms where involved in a DEFRA funded project to validate the existing RB209 fertiliser recommendations for England and Wales. This has led to the creation of new grassland N recommendations, which will be launched by AHDB in 2017. Similarly involvement of the demonstration farms in the creation of the cross-sector AHDB Healthy Grassland Soils resources has added considerable value through helping develop user friendly field based resources. Collaboration with the British Grassland Society for the demonstration farms project has also helped expand the reach of AHDB research and development activity to a wider range of farmers and industry professionals who in some cases have had little previous engagement with AHDB. The modelling work contributed towards a PhD studentship jointly supervised by SRUC and University of Edinburgh. The modelling work provided funds for a modeller position for 2 years.

Work package title:	WP 3a: Optimising grassland management		
Start date (mm-yyyy):	01-10-2011	Actual (£)	£479.2k
End date (mm-yyyy):	01-05-2016	Planned cost (£)	£479.2k
Name & organisation of principal investigator (PI):	Dave Roberts Scotland’s Rural College (SRUC)		
Collaborators:	HAU, NIAB and AFBI		

A. Overview by work package leader

Underpinning rationale: Grazed and ensiled ryegrass pastures remain the main feed source for dairy cows within GB, and the temperate climate of north-west Europe ensures GB has a competitive advantage in growing and utilising pasture. With an increasing global dairy cow population, particularly in countries with limited forage production capability, competition for, and volatility in the price of imported feedstuffs is set to rise. Similarly there are now long term concerns over global food supply for a growing human population and increased focus is being placed on the use of edible grains in livestock diets. This is likely to encourage greater utilization of non-human edible products such as grass, in ruminant productions systems.

In GB, well managed perennial ryegrass pastures remain the cheapest source of feed for dairy cows and previous AHDB Dairy benchmarking analysis has highlighted a negative relationship between milk production from forage and farm cost of production (AHDB, 2013). However, trends over the past decade highlight static or declining milk from forage production on UK dairy farms, despite overall increases in milk yield (CAFRE 2014, AHDB 2015). In the past decade, milk yield has risen by 7% to 8146 litres per cow however in the same period milk from forage production has fallen by 12% to 2281 litres per cow (Promar, 2016). The current extended depression in farm-gate milk price, has further highlighted the importance of maximising production and utilisation of pasture on farm. A greater focus on forage has been evident in the industry (as indicated by upturns in milk from forage production to 2516 litres per cow in the first half of 2016) as farmers seek to cut production costs. Nonetheless, grassland productivity and utilisation remain suboptimal in GB with estimates of grass productivity (7.9t DM/ha) and utilisation (6.3t DM/ha) significantly below the genetic potential of modern day perennial ryegrass species (c. 15 -18 t DM/ha). There is significant scope to improve grassland management practices on GB dairy farms to improve farm profitability; this improvement must be underpinned by relevant research to provide a sound evidence base.

The extensive grassland research undertaken in the UK and Ireland in the 1980’s and 1990’s (and summarised in this work package (see B.4)) has provided an excellent foundation for GB dairy systems in previous years. However in recent years, changes in GB dairy systems characterised by increases in milk yield per cow, larger herd sizes, higher input costs for grassland (seed and fertiliser) and increased climatic variability, have meant considerable knowledge gaps in modern day grassland management for GB dairy farms have emerged. These include: The role and economics of fresh grass in the diet of high yielding cows, through both grazing and cut and carry systems

- The application of composite traits to better target selection of perennial ryegrass varieties to individual farm requirements
- The role of slurry separation in supporting grazed and ensiled grass production
- The relevance of current fresh grass analysis techniques to in-field conditions.

Work package objectives: To address these knowledge gaps, the objectives of this work package were several-fold:

a) To examine the possibility of making better use of grass variety testing information, either by producing a series of indices for different dairy farming systems or to provide more understandable information on individual traits

b) To bring together information from literature on grassland; dairy research and provide the latest information for AHDB to update their publications on the subject
c) To investigate the use of separated and whole slurry as the sole fertilizer nutrient for the growing of grass for silage and grazing
d) To compare the intake and performance of dairy cows fed fresh grass indoors (cut and carry system) with cows fed a TMR or grazing
e) To investigate grazing strategies with high yielding dairy cows which are still housed for a large proportion of the day
f) To improve understanding of the impact of sampling technique of the nutritional value of fresh grass throughout the growing season.

Approach: To examine these objectives a series of experiments were conducted at 3 sites: SRUC, HAU and AFBI (Hillsborough).
The use of separated slurry and whole slurry as the fertiliser input for growing both grass silage and grazing was investigated at SRUC; these used grassland plots for the silage yield, with the separated or whole slurry either applied mechanically or manually, to assess the grass dry matter yield, quality and N recovery compared to inorganic fertiliser (ammonium nitrate). The evaluation of grazed grass yield from the use of separated, whole slurry and inorganic fertiliser equivalent was assessed through rotation grazing of paddocks on N recovery and milk yield.
The effect of the addition of fresh cut grass to the ration of high yielding dairy cows was determined through two experiments at SRUC; the first quantified changes to feed intake, milk yield and quality from the addition of fresh cut grass to the feed rations of housed cows compared with a TMR. The second studied the feed intake, milk yield and quality of a replacement of the TMR ration with fresh cut grass compared to full TMR ration or grazing with TMR supplement. Both studies considered behavioural and economic consequences of the changes in diet.
A feed trial at HAU determined effects on feed intake, milk yield and quality and liveweight of high yielding dairy cows presented with a number of grazing and TMR forage options. The behaviour of the different groups were considered along with the financial implications.
The effect of the method of harvesting and storage of fresh grass samples were investigated at AFBI through over a number of sampling times through the growing season and a range of storage temperatures, conditions and duration on the resultant NIRS values.
Alongside these experiments, NIAB conducted an extensive analysis of grass variety data and evaluated data with different farm scenario models.
A systematic review of published literature was also undertaken to provide AHDB with information to update advisory information.

Delivery: The delivery milestones were met, with the exception of the submission of PhD by Chris Henry, although the reports to AHDB were submitted. Findings from the work in WP3a have been disseminated at farmers meeting, research data, conferences and in the farming press.

B. Executive summary 1) Best use of information from grass variety testing

Background and Objectives: Over the past half century grass cultivar breeding programmes have resulted in significant advances in the potential yield and quality of modern day varieties (Wilkins et al. 2010). In practice however, much of this potential has not been realised with grassland production estimates for the average dairy farm equivalent to 8 t DM/ha/annum, less than 60% of that which can be achieved by modern day varieties.
In England and Wales, independent information on the performance of perennial ryegrass (*Lolium perenne*) varieties is presented to farmers and industry through the Recommended Grass and Clover Lists (RGCL) testing programme. This programme undertakes variety evaluation trials across five sites in England and Wales, assessing varieties for both production (yield and quality) and fitness (winter hardiness, disease resistance, ground cover) traits under

both cutting and grazing management regimes. Individual variety performance data is assessed by a panel of experts and a subset of the best varieties is put forward for recommendation on the RGCL. New lists are published on an annual basis and distributed to farmers in England and Wales. A condensed version of the data is available in a 'Farmer Handbook' with the full trial data presented in a 'Merchant's guide'. These lists receive good uptake within the industry; in a recent AHDB reseeding survey 71% of 130 grassland farmers consulted the RGCL when selecting varieties (AHDB, 2016). Despite this, only 42% of the survey's respondents felt confident when selecting grass varieties suitable for their purpose and many (26.5%) opted to outsource this decision (AHDB, 2016).
To facilitate better uptake of improved grass genetics and grass variety trial data, some countries have developed a composite financial index to rank grass varieties (e.g. Pasture Profit Index, Ireland and Forage Value Index, New Zealand). The uptake of these indices has been aided by the widespread prevalence of one management system (spring calving) for dairy production in these countries. In contrast the wide range of management systems present in GB, provide a significant challenge to implementing one economic index for grass varieties however there may be value in creating multiple composite indices for a range of management to support GB grassland farmers in selecting grass varieties. Similarly, due to the climatic regional differences that exist across England and Wales there may be value in developing 'region-specific' indices. This project aimed to:

- Investigate the suitability of the existing national and recommended list testing programme data to support the development of multi-trait and regional indices
- Investigate the potential of creating multi-trait indices for grass varieties to distinguish varieties which are better suited to different management systems (e.g. silage, extended grazing)
- Explore the potential of creating economic indices for grass variety performance under these different management systems
- Provide more information on correlations between individual grass variety traits.

Technical approach:
A survey was conducted across the grass industry and farmers to provide information on the desired weighing of traits for specific grassland management scenarios. Subsequently three extreme management scenarios were designed to examine the principle of creating multi-trait indices (Table 3a.1.1).

Table 3a.1.1. Weighting for the three management scenarios agreed by industry representatives.

	Key Relationships	Early Grazing Scenario	All Season Scenario	Silage Scenario	1st + 2nd
1	Total Yield				
2	Early Grazing Yield	80%	20%		
3	D value	10%	20%	10%	(5% + 5%)
4	All Season Grazing	10%		10%	
5	Autumn Yield		20%		
6	1st & 2nd Cons Cut			80%	(50% + 30%)
	Early Summer Grazing		20%		
	Late Summer Grazing		20%		

Perennial ryegrass yield data for both simulated grazing and conservation managements, data for winter hardiness, crown rust, drechslera and mildew were obtained from BSPB. Data was extracted from the 1996 to 2010 (up to and including the 2011 harvest) sown trials. Data for each characteristic was scaled to allow multiple traits to be combined into one composite index. Each variety mean was presented as its difference from the overall mean. This was presented as a percentage of the least significance difference (lsd) and was calculated using the formula: (variety mean – overall mean)/(lsd *100).

A farm economic model can be used to calculate the impact of changes in individual traits on farm profitability and hence this can be used to assign an economic value to each trait. As no such model currently exists for the range GB dairy systems, and to test proof of concept, the economic weightings from the Irish Pasture Profit Index were matched against the data from the national and recommended list testing database.

Key results:

Correlation analysis

Analysis of the correlations between individual grass breeding traits suggested:

- Under silage management, there was a negative correlation between both total yield (P<0.001; R^2 = -0.414) and first cut yield (P<0.001; R^2 = -0.661), and grass digestibility. For every additional 400kg DM yield achieved at first cut, grass quality fell by 1 D-value. Considering the trait 'ME yield' can be useful for farmers wanting a balance between yield and quality.
- Varieties with higher yields under silage management tend to exhibit higher yields under grazing management (P<0.001; R^2 =0.343) however there is considerable variation between varieties
- High quality varieties under silage management also exhibited digestibility under simulated grazing (P<0.001; 1st cut R^2 = 0.524, 2nd cut R^2 = 0.615)
- There is limited evidence to suggest that selecting for higher yielding grasses under grazing or silage management will reduce long-term sward persistency
- There is limited evidence of any correlation between cultivar yield or quality, on winter hardiness or disease resistance

Composite traits

The current recommended list dataset can support the development of composite indices however limited winter hardiness and disease data inhibits the generation of region specific indices. Indeed, the development of composite, multi-trait indices for different grassland management scenarios based on expert opinion is feasible and allows varieties to be ranked accordingly.

In each scenario a small number of varieties (1 - 3) performed significantly better than the average. A greater diversity in the number of varieties performing significantly better than the average of the dataset is most likely a permutation of the recommended list selection procedure. Because the recommended list is a subset of varieties which have excluded the worst performing cultivars the potential for composite indices to differentiate between varieties is somewhat reduced. Nonetheless there was a range of varieties which performed significantly better than the worst performing variety for that index (30 – 40) suggesting there is significant variability within the rankings to justify a ranking tool.

Economic analysis

Following some modification, it was feasible to use the sub-indices weightings from the Pasture Profit Index, established in Ireland to create an economic index for silage and grazing management. Under silage management the best performing variety was deemed to contribute an additional £59/ha/yr compared with the average of the group, while the worst performing variety under silage management contributed £48/ha/yr less than the average of the group and £107/ha/yr less than the top performing variety. Under grazing management, the highest ranked variety had an economic value of +£127/ha/yr relative to the mean of the group, while the worst performing variety had a value of -£133/ha/yr relative to the average. This displays a wide range in potential profit margin when using both these individual varieties under one management system. These were highly correlated with the previously developed silage and early season grazing scenarios, respectively.

Farmer messages: The main farmer messages were:

- Given there appears to be little difference between the top performing varieties, it may be

sufficient to focus on encouraging farmers to select varieties towards the top half of the RL.
- Selecting solely for high yielding varieties under silage management can result in lower quality swards. Considering the trait 'ME yield' can be useful for farmers wanting a balance between yield and quality.
- It is important to match seasonal grass growth to individual farm demand. Varieties with high first cut yields and/or high early spring grazing yields can suffer performance drops later in the season compared to varieties with lower yields in the early season.
- Varieties with high yields under silage management had high yields under grazing management, similarly high quality varieties under silage management also exhibited high quality traits under grazing.
- There is limited evidence to suggest that selecting for higher yielding grasses under grazing or silage management will reduce long-term sward persistency or impact negatively on disease resistance

Further exploitation: For those who wish to add an economic cost, an interactive website where growing option, inputs and weightings can all be entered by the end user may offer additional value.
In response to limited regional disease data in recent years, BSPB have now commissioned two new disease surveillance sites across England.

B. Executive summary 2) Evaluation of the use of slurry for grass silage production

Background and Objectives: With increasing herd sizes on GB dairy farms, and environmental legislation such as nitrogen vulnerable zone (NVZ) regulations coming into force on many dairy farms, there is a requirement for novel slurry management techniques such as low emission spreading techniques and slurry separation to deal with the increased slurry storage capacity requirements. In addition, increasing volatility in the cost of artificial fertilisers will require improved use of nutrients on farm, particularly organic manures. There are a number of potential benefits through improving the utilisation of slurry as a grassland fertiliser, including reduced reliance on purchased fertiliser (and hence a reduced cost of production), reduced loss of nutrients to the environment and healthier soils. Similarly there are a number of factors which can influence nutrient use efficiency from applied manures, such as, rate of application, method of application and characteristics of the slurry e.g. dry matter content. Separating slurry into solid and liquid fractions is one way to produce products with nutrient profiles that better meet the requirements of grassland and reduce storage capacity requirements. However little is known about both the effect of slurry separation on the nutritive value of separated slurry, or the grass growth response to separated slurry. The objective of this study was to investigate the herbage response to using separated dairy cow slurry as a grassland fertiliser and compare this to the performance of whole slurry and inorganic fertiliser (ammonium nitrate).

Technical approach: Two experiments were undertaken; the first using machinery to apply slurry (MCH, 2012-2013), the second to manually apply the slurry to small plots (MAN, 2013-2014). In both experiments twelve slurry treatments were applied three times a year for two years to grass plots that were cut three times a year for silage. Treatments were replicated three times with 48 plots in each experiment. Dairy cattle slurry was separated using a Sperrin cylinder separator (SP1000). The twelve slurry treatments consisted of a factorial design: separated liquid fraction (L) or whole slurry (W) applied by shallow injection (I) or dribble bar (D) at rates of 10,000, 20,000 or 30,000 kg/ha. As a comparison, replicated plots were also established with three rates of manually applied ammonium nitrate (F) (aiming to supply the same total N as the three rates of L) and a 'no fertiliser' control. Herbage was harvested with a Haldrup plot harvester (Haldrup 1500; Løgstor, Denmark) at a cutting height of 4 cm from a 1.45 m strip running down the centre of each plot (lengthways). Samples were taken at each harvest and analysed for dry matter, crude protein, ash, modified acid detergent (MAD) fibre, metabolisable energy (ME) and D-value. Apparent nitrogen recovery (ANR) (kg N in herbage per kg available N applied) (Lalor et al., 2011) was calculated for each treatment at each harvest.

Key results: Slurry separation had a significant effect on the chemical profile of slurry. Slurry DM was reduced by separation by 38% and 34% for MCH and MAN, respectively (Table 3a.2.1). In addition, separation increased slurry pH in both experiments. Ammonia concentration was reduced by 11% and 8% for MCH and MAN, respectively. However, some impacts of separation where not consistent and highlighted the need to regularly undertake slurry analysis to obtain an accurate reading of the nutritive value of slurry. For example, total K_2O in slurry was only affected for MAN where it was reduced by 8% by separation. No difference was seen in total N content, total P_2O_5 content and water soluble phosphorus (WSP) for both experiments.
There was no significant impact of slurry separation on grass dry matter yield throughout the season with both slurry treatments returning 17kg DM of grass for each kilogram of available N applied. Similarly, artificial fertiliser returned 14kg DM of grass per kilogram of available N applied. Consequently, a 25m^3 application of slurry was equivalent to 33kg N applied as fertiliser.
Slurry separation did not affect herbage quality however the artificial fertiliser application resulted in higher grass crude protein concentrations and as a result the apparent N recovery was double that of the slurry treatments (0.88 vs 0.41). There was no effect of spreading technique on herbage yield or quality.

Table 3a.2.1. Analysis of the mechanical (MCH) and manually (MAN) applied slurry as whole, liquid, fertiliser and control.

	MCH			MAN		
Variable	Whole slurry	Liquid slurry	p-value	Whole slurry	Liquid slurry	p-value
DM (g kg^{-1})	54	34	<0.001	56	37	<0.001
pH	7.6	7.9	<0.001	7.7	8.0	<0.001
Ash (g (kg DM)$^{-1}$)	207	239	0.168	202	246	0.003
Total N (g kg^{-1})	2.3	2.2	0.469	2.6	2.5	0.330
Ammonia (g kg^{-1})	1.2	1.0	0.029	1.4	1.2	0.041
Total P_2O_5 (g kg^{-1})	0.9	0.8	0.054	1.0	1.0	0.340
Total K_2O (g kg^{-1})	2.4	2.3	0.116	2.6	2.4	0.004
WSP (g (kg DM)$^{-1}$)	2.7	3.4	0.672	3.4	4.2	0.440

Values in the same row with different superscripts are significantly different ($P < 0.05$)

Farmer messages: The main messages were:

- The effect of separation techniques on the nutritive value of slurry can vary from farm to farm and over time. As a result it is important to test separated slurry to get an accurate measure of nutrient content and availability.
- Grass grown with the liquid fraction from separated slurry exhibits comparable performance to whole slurry.
- An 25m^3/ha application of separated slurry to grass grown for silage can result in similar performance as that from an application of 33kg N/ha fertiliser. This results in a fertiliser cost saving of over £20/ha.
- Nitrogen recovery was similar from slurry spread via dribble bar and shallow injection spreading technologies.

Further exploitation: The results from this trial have been used to inform the latest revision of RB209 The Fertiliser Manual and have been communicated to farmers at events and via digital media and press.

B. Executive summary 3) Utilisation of grazed grass grown with nutrients from slurry

Background and Objectives: Improving the internal nutrient cycle efficiencies of dairy farms can increase their environmental and financial sustainability. This can be achieved through various mechanisms including: reducing the loss of nutrients to the environment such as through ammonia volatilisation, surface runoff and leaching; and importantly by decreasing the volume of purchased fertiliser required to sustain herbage growth through better use of on-farm organic manures.
Previous research investigating the use of slurry on grazing ground has shown that applying slurry by shallow injection can improve the resultant grazing performance relative to splash plate application (Laws et al. 1996). However, shallow injection cannot be used on around 30% of UK soils due to issues such as gradient and stones (Webb et al., 2006) hence other application methods may be more widely applicable. For example Dale et al. (2012) showed that inorganic fertiliser inputs can be reduced by replacing a portion with cattle slurry (applied by trailing shoe) without adversely affecting dairy cow performance. In addition to optimising the application method of slurry to grazing ground, the separation of slurry into liquid and solid fractions is an option which may increase the potential for using slurry on grazing ground. Using the liquid fraction of the separated slurry may reduce the risk of adverse grazing behaviour effects (Rodhe, 2003) and increase herbage response to slurry (Bittman et al., 2011) due to increased rates of soil infiltration (Møller et al., 2000). The use of the liquid fraction of separated slurry as a grazed grassland fertiliser has not previously been directly compared with whole slurry from the same source. The experiment reported here evaluated the use of separated slurry as a grassland fertiliser (administered via dribble bar) for rotationally grazed dairy cow pasture. Its performance was compared to whole slurry and ammonium nitrate fertiliser, with application rates aiming to balance the treatments by ammonia N applied.

Technical approach: Thirty six, 48 hour 0.33ha paddocks were established in four adjacent grazing fields and allocated to one of three treatments: nutrients applied via whole slurry (W), nutrients applied via liquid slurry (L) and artificial fertiliser as ammonia nitrate fertiliser (F). Treatment paddocks were established after first cut silage in May 2013, prior to the first treatment applications on 14th June 2013. Slurry from the herd of dairy cows was obtained from a slatted tank underneath the holding. The slurry was mechanically separated using a Sperrin cylinder screen separator (SP1000) and applied 18 – 24 days prior to grazing. Slurry applications were made using a dribble bar approach simulated by using an injector (Veenhuis) without lowering the injection apparatus to the ground. The cumulative N applications were:

	Whole slurry	Liquid fraction	Fertiliser
Total N (kg/ha)	133.4	126.6	71.8
Ammonia (kg/ha)	68.9	50.2	71.8

Thirty-six mid to late lactation Holstein Friesian dairy cows (13 primiparous, 23 multiparous) were selected and allocated to triples balanced for days in milk (mean= 280 d, s.d.= 81 d), parity (mean= 2.6, s.d.= 1.9) and pre-experimental yield (mean= 32.3kg/d, s.d.= 5.6) and live weight (mean= 571kg, s.d.= 63). One cow from each triple was allocated to each of three groups then each of these groups was randomly allocated to a treatment. Excess grass cover was managed via a ‘put and take’ approach, based on a cow dry matter allocation of 15kg DM/cow/day. Grass growth and utilisation, apparent available nitrogen recovery, grazing behaviour and animal performance were assessed.

Key results: The use of separated slurry on dairy cow grazing pastures resulted in comparable grass growth and utilisation, animal performance and nitrogen efficiency as that

observed from artificial fertiliser (Table 3a.3.1).
In contrast, N efficiency was poorer on paddock fertilised with whole slurry as the sole source of nutrients, as indicated by the 33% reduction in apparent available N recovery. In addition ECM milk yield was lower (15.8kg/cow/d) than the separated slurry treatment (16.7kg/cow/d) and the milk yield per kilogram of available N applied was reduced by 31%. At current fertiliser prices this can equate to savings in excess of £25/ha per rotation.

Table 3a.3.1. Comparison of sward and animal performance on pastures treated with whole slurry, separated slurry or inorganic fertiliser.

	Whole slurry	Separated slurry	Fertiliser	p-value
Grass growth (kg DM/kg available N)	31.9^{a}	45.4^{b}	38.2^{ab}	0.002
Apparent N recovery (kg N /kg available N applied)	0.78^{a}	1.17^{b}	1.23^{b}	<0.001
Grass DMI (kg DM/cow/d)	17.0	19.0	17.5	NS
Residual grass cover (kg DM/ha)	1365	1415	1440	NS
ECM yield (kg/cow/d)	15.8^{a}	16.7^{b}	16.3^{ab}	0.024
Milk yield/kg available N (kg/kg N)	26.4^{a}	38.3^{b}	32.7^{ab}	0.027

Values in the same row with different superscripts are significantly different ($P < 0.05$)

The application of slurry to grazing pasture had no negative impact on herbage intake per cow or paddock residual grass cover over the course of the experiment. However, a higher step count (4311 vs 3937 steps/cow/day) and reduced proportion of time spent lying (45.5 vs 49.2%) on cows grazing whole slurry fertilised pastures compared to separated (L) slurry, suggests an increase in browsing behaviour.

Farmer messages: The main messages were:

- Grass growth and animal performance on pastures grown with nutrients from separated slurry and applied via dribble bar technology are comparable to that of artificial fertiliser
- Whole slurry can be used on grazing pasture without impacting on grass DMI however the N recovery and milk yield responses are likely to be somewhat lower than that of separated slurry.
- The use of slurry on grazing pastures can result in fertiliser savings of up to £25 per hectare per rotation.

Further exploitation: These results are particularly important for policy makers, environment agencies and farmers within NVZs. The use of slurry on grazing fields will become increasingly important as dairy farmers seek to maximise nutrient use efficiency and cut input costs. There has been associated work, funded by Defra, on the greenhouse gases from grassland receiving different amounts of animals' manures.

B. Executive summary 4) Literature review on the maximisation of forage intake from grazed grass

Background and Objectives: Throughout the 1980's and 1990's an extensive body of research was undertaken in north-west Europe, building a foundation of knowledge for managing grassland dairy systems in the UK. With changing dairy systems in GB, characterised by increases in milk yield per cow, larger herd sizes, higher input costs for grassland (seed and fertiliser) and increased climatic variability, it is important that existing knowledge be collated and any research gaps identified.
Forage intake by dairy cows and the effects on milk production is a complex system that has been investigated on a number of levels. There are distinct research areas each with a further number

of interacting variables that can have an influence. These range from nutrients that affect grass yield through forage varieties to the behaviour and genetic make-up of the animal; all of which may have some influence on the milk production. The objective was to undertake a systematic literature review of the literature and identify the main themes.

Technical approach: A systematic literature review was undertaken to draw together research under the theme of 'Maximising Forage Intake from Grazed Grass'. This review was to consider the published literature from 1970 to 2011. The areas covered by the review were:
1. Grazed grass intake (dairy) – youngstock and milking animals – and dry cows.
2. Countries/regions to include: UK, Ireland, USA, Europe.
3. Grass variety in relation to intake.
4. Grass management e.g. reseeding policy, extended grazing.
5. Grass mixtures, especially white clover.
7. Animals – age, breed, stage of lactation.
8. Maximising grass intake (including palatability factors) to maximise milk yield.

An initial search of literature, using the Web of Knowledge data bases from 1970 to the end of 2011 was done using the following specific search terms: dairy and grass clover (542), dairy and reseeding (21), dairy cows and drinking water (278), dairy cows and water drinking (278), dairy grazing and climate change (66), dairy milk production and grazed grass (742), extra grazing allowance (15), grass intake and dairy cows (1786), grass yield and milk yield (1837), grazed grass and milk yield (504), grazing and reseeding (188). After screening for relevance from the article title this gave 831 papers from a total of 6257 papers.
The abstracts of the 831 papers were then extracted from the data bases or through online searches and a detailed review of these gave 300 papers of relevance. Once these papers' relevance had been confirmed with AHDB Dairy they were incorporated into a draft document under the following headings: Animal Behaviour (25), Animal Breeding (24), Animal Performance (32), Climate Change (15), Diet Manipulation (5), Feeding at Grass (36), Grassland Systems (1), Herbage Genetics (8), Measuring Yield of Grass (1), Milk Production (32), Palatability (6), Pasture Management/Animal Management (78), Sward Fertilisation (35) and Water Supply Intake (2).

Key results: The key results were:
- Herbage legumes have a higher feed value than grasses, but their main benefit to livestock is from enhanced intake. Animal performance benefits reach a maximum when clover content is around 60% of the DM in the diet.
- Later heading ryegrass varieties resulted in higher grass dry matter intake (DMI) and milk production compared with varieties with a difference in ploidy.
- There is little evidence that perennial ryegrass varieties with a high sugar content have a significant effect on grass DMI and milk production.
- Application of sodium to pasture can improve herbage DMI and milk production, particularly in cows of low production potential.
- Daily herbage allowance (DHA) per cow for determining herbage DMI and milk production is more sensible than grass height alone. It should be the DHA of green leaf dry matter, not the DHA of total herbage DM that should be considered. Green leaf mass is optimised by high stocking rates in spring.
- Bite mass and biting rate tend to be highest in the afternoon. There is some evidence that providing a fresh paddock at this time of day increases grass DMI.
- Feeding a forage supplement can reduce grazing efficiency.

The research shows consistently that cows with the highest genetic potential for milk production tend to exhibit the highest grass DMI (and milk yield). This is true within the Holstein-Friesian (HF) breed and in comparisons between HF and other breeds. However, there is clear evidence that this production advantage is associated with greater loss of live weight and body condition score, and poorer fertility performance.

Well-managed grazed herbage, unsupplemented, can support average milk yields per cow of 20-22 kg/day over the whole season. With high yielding cows milk yields of up to 30 kg/day are possible without supplementation, but only over a short period and by mobilising significant levels of energy reserves. With this type of cow, in order to achieve a satisfactory combination of high milk yield per cow, even with good sward utilisation and high levels of output per hectare, concentrate supplementation is required from turnout.

Further exploitation: Twelve summary information sheets were produced for AHDB Dairy and covered common questions relating to grassland forage and milk production, providing information on areas not currently covered by other AHDB Dairy grass resources. The findings of the review were used to fine tune and in some cases develop the suite of grass projects outlined in this research partnership. The results of the review were also shared with collaborative organisations in Ireland and Australasia and informed discussions on research gaps and priorities in this area. This review considered publications up to 2011, since then there have been further publications especially in areas such as automatic milking which should be considered in any update.

B. Executive summary 5) Investigating the effects of increasing the proportion of fresh grass in the diet of high yielding dairy cows using cut and carry feeding systems

Background and Objectives: Feed and forage costs remain the single largest driver of profit on GB dairy farms (AHDB Dairy, 2013). The use of grazed pasture for dairy cows can result in lower-cost feeding systems (Peyraud and Delaby, 2001), and the majority of GB dairy farms are located in areas with significant potential for high herbage production. Whilst there is a significant body of research, both past and present, being undertaken into maximising the utilisation of fresh grass on extensive grazing dairy systems, our knowledge of the role of fresh herbage in the diet of high yielding cows remains limited.
Research has shown that the supply of fresh herbage alone is insufficient to support optimal dry matter intake (DMI) and consequently, milk production in high yielding cows (Leaver, 1985; McGilloway and Mayne, 1996; Kolvar and Muller, 1998). Although grazing strategies such as increasing pasture allowance can encourage higher levels of DMI (Bargo, 2002), low pasture utilisation reduces both forage quality and cost-effectiveness of the feeding system. Cut and carry systems, where grass is cut daily and fed to housed cows, may be one potential mechanism by which it is possible to achieve a balance between high pasture utilisation and lowering dietary feed costs. However, to truly determine the potential benefit of cut and carry systems, the capacity of fresh grass to meet the nutritional demands of the high yielding cow (relative to conserved forages) and consequently the optimum level of inclusion on fresh grass in the diet must first be examined.
This project aimed to:

- Quantify changes to total feed intake, milk yield and milk quality resulting from adding fresh grass to the ration of high yielding dairy cows
- Determine the effects of manipulating the proportion of fresh grass added to the ration on total feed intake, milk yield and milk quality
- Understand any behavioural changes resulting from a change in diet which may contribute towards shifts in feed intake, milk yields and milk quality
- Quantify the economic costs and benefits of adding fresh grass to the diet.

Technical approach: Forty-eight recently calved, high yielding (defined as >30kg/cow/day), Holstein-Friesian dairy cows were allocated to one of three treatments for a 16 week period:

1. Control: 100% TMR based on grass silage, maize silage, straw and concentrates.
2. 25% Grass: TMR mixed with 25% fresh grass on a DM basis.
3. 50% Grass: TMR mixed with 50% fresh grass on a DM basis.

Grass was harvested daily, at a target cover of 2600 – 2800 kg DM/ha and mixed with TMR in a feeding wagon for approximately two to three minutes. Following a two week transition period, cow performance, feed intake, cow behaviour and the cost benefit of including fresh grass in the diet was measured.

Key results: Feed intake and cow performance results are presented in Table 3a.5.1.

Table 3a.5.1. Feed intake, milk production and quality values for cut and carry replacement of TMR.

	100% TMR		**25% Grass**		**50% Grass**	
	mean	**s.e.**	**mean**	**s.e.**	**mean**	**s.e.**
Milk yields (kg/d)	35.7^{a}	0.37	30.2^{b}	0.52	31.4^{b}	0.46
Protein (%)	3.00^{a}	0.01	2.98^{a}	0.01	2.89^{a}	0.02
Butterfat (%)	3.34^{a}	0.04	3.51^{a}	0.06	3.40^{a}	0.05
FW intake (kg/d)	54.0^{a}	0.39	72.1^{b}	0.77	88.6^{c}	1.38
DM intake (kg/d)	20.1^{a}	0.26	19.3^{a}	0.21	18.0^{a}	0.29
Time spent ruminating (%)	48.8^{a}	2.28	38.5^{b}	1.95	38.2^{b}	2.79

Values in the same row with different superscripts are significantly different ($P < 0.05$)

- Milk yields from cows where cut and carry grass was included in the diet lower than milk yields from TMR-fed cows, by an average of 4.3 – 5.5 kg per day
- There were no consistent differences in milk quality, body condition scores or cow weights between the diets
- Intakes of feed by fresh weight were highest for 50% grass-fed cows, lower for 25% grass-fed cows and were lowest for TMR-fed cows, however, intakes of dry matter were lowest for 50% grass-fed cows, higher for 25% grass-fed cows and highest for TMR-fed cows
- Grass-fed cows spent less time ruminating than TMR-fed cows. This, coupled with higher intakes of lower nutritional quality feed, is likely to have reduced milk yields
- 50% grass-fed cows can deliver a higher margin over feed costs than those only fed TMR depending on the relative costs of grass and TMR production as well as the prevailing milk selling price

Farmer messages:
- Including fresh grass in the diet of high-yielding dairy cows via cut and carry systems can cause a reduction in milk yield compared to TMR, particularly in low grass dry matter situations.
- Despite this, including fresh grass in the diet of high yielding cows left a higher economic surplus, particularly at times of low milk price.
- If operating cut and carry systems, regularly assessment of fresh grass is important to adjust the amount of fresh grass offered and minimise variability in cow DM intake.

Further exploitation: The results from this study suggested that including fresh grass in the diet of high yielding cows reduced feeding costs and left a higher margin over purchased feeds than TMR only feeding. This provided evidence to farmers, currently operating or considering cut and carry systems, along with the rationale for a subsequent trial comparing grazing and cut and carry systems for high yielding cows.
A survey of current on-farm practice for cut and carry systems was conducted and the results used to guide both this and a subsequent research project.

B. Executive summary 6) A comparison of grazing and cut and carry systems to

determine the optimal method of including fresh grass in the diet of high yielding dairy cows
Background and Objectives: Cut and carry systems, where fresh grass is cut daily and fed to housed cows, are used across mainland Europe, however, their use in GB has been limited. Anecdotal evidence from the industry would suggest that there has been a recent expression of interest in cut and carry practices, possibly in part due to the variability of weather patterns experienced in GB over recent seasons. Cut and carry systems have a number of perceived benefits including: optimising grassland utilization, reducing soil damage and nutrient loss, access to land away from the grazing platform and offering greater control over the diet (Meul, 2012). They can also be advantageous in times of adverse weather conditions and on farms where robotic milking parlours are installed. In GB, a total mixed ration (TMR) feeding system is the preferred option on many high yielding systems however there is the potential to reduce input costs through the replacement of TMR with fresh grass. Previous research (Work package 3a, executive summary 5) investigated the effects of increasing the proportion of grass in the diets of high yielding cows on milk yields, milk quality and on profitability, using a cut and carry feeding system. We compared groups of cows fed 100% TMR, 25% grass (75% TMR) and 50% grass (50% TMR). When dairy cows were fed 25% or 50% of their diet as freshly cut grass, cows consumed more feed and produced an average of 5 kg per day less milk than those fed 100% TMR, but feed production costs were considerably lower. However, it is currently unclear to what extent cut and carry feeding systems benefit milk yields and profitability when compared with grazing. This experiment aimed to examine the effects of replacing a proportion of TMR in the diet of dairy cows with either grass delivered via a cut and carry system, or grazing on: • Total feed intake, milk yield and milk quality • Underlying drivers of changes to milk yields or quality, such as shifts in dry matter intakes, changes in feed quality or changes to animal behaviour. • The economic costs and benefits of the three different feeding systems; 100% TMR feeding, cut and carry feeding (with TMR supplementation) and grazing (with TMR supplementation). **Technical approach:** Forty-eight Holstein- Friesian dairy cows (average days in milk = 110 days; milk yield = 38 kg/cow/day) were allocated to one of three dietary treatments as part of a 12 week continuous design experiment. • Control: Total Mixed Ration (TMR) based on grass silage, maize silage and concentrates. • Cut and carry: Fresh grass fed to housed cows for two windows between the morning and afternoon milking, and between the afternoon and evening milking. TMR fed *ad-libitum* overnight. • Grazing: Cows grazed for two time periods between the morning and afternoon milking, and between the afternoon and evening milking. TMR fed *ad-libitum* overnight. Perennial Ryegrass (Lolium perenne) was harvested daily at approximately 9 am using specific cut and carry machinery and fed to the cut and carry group following the morning milking. At that time, (after morning milking) the grazing group group was allowed out to graze at pasture. Pasture area, which was allocated on a daily basis limited using electric fences according to their intake potential. Animal performance, feed intake, grassland utilisation and the economics of each system was assessed. **Key results:** Over the 12 weeks the TMR fed group produced a mean milk yield greater (P<0.001) than both the cut and carry or the grazing groups by 1.39 and 1.61 kg/cow/d, respectively (Table 3.a.6.1). There were a number of significant differences in the milk

composition between the three treatment groups over the 12 weeks of monitoring. These included a significant reduction in mean butterfat content of the milk produced by the grass grazed group compared to those fed TMR ($P<0.001$). The mean protein content of the milk produced over the twelve weeks of the treatments was greatest for the cut and carry group compared to the TMR fed group ($P<0.001$) and the grass grazed group ($P<0.001$). Total FW intakes averaged 96.8 kg/d, 91 kg/d and 58 kg/d for the grass grazed, cut and carry and the TMR-fed groups, respectively. DM intakes showed no significant difference in intake with averages of 24.1 kg/d, 23.0 kg/d and 23.2 kg/d for the grazed grass, cut and carry and the TMR-fed groups, respectively.

Table 3a.6.1: Effect of feeding system on cow performance, intakes and economic margin over the duration of the experiment.

	100% TMR		Cut and Carry		Grass Grazed	
	mean	s.e.m	mean	s.e.m	mean	s.e.m
Milk yields (kg/day)	36.3^a	(±0.3)	34.9^b	(±0.3)	34.7^b	(±0.4)
Protein (g/kg)	32.8^a	(±0.7)	33.7^b	(±0.3)	31.5^c	(±0.6)
Fat (g/kg)	38.5^a	(±0.9)	38.1^a	(±0.5)	33.7^b	(±0.7)
FW intake (kg/day)	57.9^a	(±0.9)	91.1^b	(±1.4)	97.7^c	(±2.9)
DM intake (kg/day)	23.2	(±0.2)	23.0	(±0.3)	24.2	(±1.3)
Grass DM intake (kg/day)	--	--	6.0	(±0.3)	8.4	(±0.4)
Ruminating (% of time)	42.0	(±3.1)	44.8	(±2.3)	37.0	(±2.6)
Margin over feed* (£/day)	2.20	-	2.24	-	2.40	-

Means with different superscripts are statistically different ($P<0.05$)
*Margin over feed per cow per day where TMR costs £84.12/tonne and grass costs £15/tonne to produce. Land and machinery costs are also included and a milk price of 22ppl was used

Farmer messages: The main messages were:

- Replacing TMR with grazed grass or cut and carry grass, reduced milk production by 1.6 and 1.4l/cow/day respectively, when compared to cows fed TMR only. However, the cost of TMR compared to grass in the diet meant that the TMR only diet was the least profitable over a range of milk prices from 17 to 35 ppl, despite the higher milk production.
- Milk production from cows offered TMR only was far more consistent over the 12 weeks of experiment. This is probably due to reduced variation in dry matter content of the diet and consequently dry matter intake, relative to cows offered grass.
- The economic viability of incorporating grass into the diet of the dairy cow for a given farm will depend on the relative costs of grass and TMR in their business. Other benefits such as reduced exposure fluctuations in feed prices on the international market and the technical ability of the farm to manage grass also need to be considered.

Further exploitation: The findings of this study were applicable to farms which house cows during the summer months and showed that fresh grass can be included in the ration. These experiments only considered two specific comparisons; there are many other variables which will exist on commercial farms including: chop length of grass, grass variety, frequency of feeding, which would merit investigation.

B. Executive summary 7) Effect of time of access to pasture and level of total mixed ration offered on the performance, behaviour and grass intake of high yielding dairy cows

Background and Objectives: Some farmers in the Netherlands and Germany are currently incentivised by milk companies to graze milking cows for a minimum of six hours per day, while in Scandinavia, legislation requires cows to have access to pasture for at least six hours during the summer months. In the UK, some milk companies also require cows to be grazed for at least 100 days. Despite these requirements, relatively little is known about the effects of duration of grazing on the performance, health and welfare of high yielding cows. Previous research at Harper Adams University (HAU) as part of the Health, Welfare and Nutrition Partnership (Mufungwe et al., 2014) has reported that grazing high yielding (ca. 40 kg/d) dairy cows either in the morning or evening for 7 hours or longer reduced milk yield unless a total mixed ration (TMR) was also provided in the field. Providing access to a TMR in the field may not however, be a practical solution on many dairy farms. Behavioural studies at HAU (e.g. Charlton et al., 2011a,b; Motupalli et al., 2014), have also revealed that when given a choice to be inside or at pasture, cows rapidly consume a meal of TMR following milking before going out to grass, a strategy that either maintained or increased milk yield compared to continuously housed cows. Turning high yielding cows out to pasture if they have limited access to TMR (and are therefore hungry) may also increase the intake of grazed grass and subsequently reduce feed costs whilst maintaining milk yield. The objective of this study was to determine in high yielding cows the effects of various periods of restriction of access to a total mixed ration prior to grazing on grass intake, performance and behaviour.

Technical approach: Fifty six cows that were (mean ± SE) 89 (± 5.3) days post-partum and yielding 44.7 (± 0.42) kg/d were allocated to one of four treatments:

- **C:** Cows housed indoors all the time with ad libitum access to TMR
- **G:** Cows at pasture for 6 h immediately following morning milking and then housed
- **DG:** Cows with access to TMR for 1 h following morning milking, then at pasture for 6 h, then housed
- **LT:** Cows offered TMR to 75% ad libitum intake, then at pasture for 6 h immediately post morning milking, then housed

Twenty eight cows were used in each of two periods of 28 days duration, with milk yield, composition and TMR intake recorded during the final 7 days. Grass intake was estimated using the *n*-alkane technique. Grazing behaviour was measured manually for 16 h over 2 separate days and by activity monitors.

Key results:
Grass intake was highest (P<0.05) in cows receiving LT at 3.5 kg DM/d compared to a mean value of 2.2 kg DM in G and DG. Total DM intake was similar in cows receiving C, G or DG (mean value of 26.5 kg/d), and was approximately 2.7 kg DM/d higher than cows receiving LT.

Table 3a.7.1: Intake and milk performance of dairy cows receiving different grazing treatments

	C	G	DG	LT	s.e.d.	*P*-value
DM intake						
TMR, kg/d	26.9^{c}	23.7^{b}	24.7^{b}	20.3^{a}	0.697	<0.001
Grass, kg/d	---	2.35^{a}	1.98^{a}	3.48^{b}	0.449	0.006
Total kg/d	26.9^{b}	26.0^{b}	26.7^{b}	23.8^{a}	0.524	<0.001
Milk yield, kg/d	45.7^{b}	44.2^{ab}	44.9^{b}	41.7^{a}	0.993	0.001
Milk fat, g/kg	30.6	32.7	31.3	33.7	0.175	0.293
Milk protein, g/kg	2.97	2.91	2.89	2.94	0.056	0.492
Live weight change, kg/d	0.86^{b}	0.31^{a}	0.41^{ab}	0.09^{a}	0.177	<0.001
Milk C18:3n-3, g/100g FA	0.31^{a}	0.40^{b}	0.40^{b}	0.41^{b}	0.022	<0.001
Grazing time (%)	---	40.9 ± 4.3	40.2 ± 3.4	47.7 ± 3.2		0.292

Values in the same row with different superscripts are significantly different (P < 0.05)

Milk yield was similar in cows receiving C, G or DG, with a mean value of 44.9 kg/d, whereas yield was lower (P<0.05) in cows fed LT compared to C or DG. There was no effect (P>0.05) of treatment on milk fat or protein content, whereas milk protein and lactose yield was higher (P<0.05) in cows fed C than LT.
Manual behaviour observations revealed that, on average, the cows spent 42.9% of their time grazing, 32.7% ruminating, 1.4% drinking and 22.9% idle whilst at pasture. There was a significant difference (P<0.001) between C cows compared to G, LT and DG (Table 2) in all behavioural activities. Control cows spent at least 55 min/d longer lying down, had 3 additional lying bouts per day, and these Lying bouts were, on average shorter than for cows in G, LT and DG (P<0.001). There were no significant differences in behavioural activity between cows in treatment groups G, LT and DG.
Compared with continuous housing (C), providing access to grazing for 6 hrs/day with ad libitum access to TMR when inside (G and DG), could save between 20-35 p/cow/day. As there were no significant differences in milk yield between C, G or DG, this could improve margins by approximately 20 to 35p/cow/day. For a 130 cow herd of high yielding cows over a 100 day grazing period, this could decrease feed costs by between £2600 and £4500. The lowest daily feed costs were associated with LT, which were approximately 60 to100 p/cow/day less than C. Milk yield was however, 4 kg/day less in LT than C, which could reduce milk sales by between 75-120 p/cow/day.

Farmer messages: The main messages were:

- Providing access to pasture for 6 hrs/day between morning and afternoon milking will not have a major impact on daily DM intake, milk yield, composition or live weight change, but can reduce feed costs by 20 to 35p/cow/day
- Having access to pasture for 6 hrs/day and limiting TMR intake to 75% of ad libitum will result in the highest pasture intake, but this will not be sufficient to compensate for the lower TMR intake, and milk performance will be reduced.

Further exploitation: The findings are applicable for top farmers who wish to maintain high yields whilst allowing cows access to pasture. The information will also be useful to policy makers, milk purchasers and farm assurance schemes who wish to develop standards for partial housing systems for dairy herds.

B. Executive summary 8) Assessment of methods for sending and storing fresh grass samples for analysis

Background and Objectives: Accurate and reliable fresh grass analysis is an essential component when managing grass swards. Under grazing management nutritional analysis of fresh grass can allow farmers to more accurately tailor purchased concentrates to meet cow requirement. Similarly in silage systems, accurate grass analysis assists farmers seeking to optimise grass quality at cutting time. Near infrared spectroscopy (NIRS) is a cheap and rapid method of analysis forages. However, although NIRS can accurately predict the nutritional composition of fresh grass, many factors may contribute to changes in the composition of grass between the time of harvest and its analysis in the laboratory. For example, harvesting technique, storage temperature, storage duration and the conditions under which the sample is stored might all be expected to result in changes in grass composition. In an ideal situation, grass for analysis would be harvested at a consistent height (representative of sward grazing/cutting height), maintained at a constant temperature and in an environment that minimises changes in composition until delivered to the laboratory. The subsequent analysis would be completed within as short a time period following harvest as possible. However, in practice grass samples may be harvested by a range of techniques and subject to a range of storage conditions, temperatures and durations of storage, before arriving in the laboratory, especially if sent by post. The impact of these factors on the nutrient content of fresh grass, as

determined by NIRS, remains largely unknown, and yet if significant changes do take place during storage, this could challenge the validity of the laboratory analysis.
The objective of the present study was to examine the effect of harvest technique, storage duration, storage temperature and storage conditions on the composition of fresh grass analysed by NIRS.

Technical approach: Two sets of plots were established within a perennial ryegrass sward, the first to provide grass samples representative of a sward for grazing (simulated grazing), and the second to provide grass samples representative of a sward for harvesting silage (simulated silage).Twenty-six treatments were examined at each harvest. Treatments were as follows: Harvesting technique (n = 2: Pluck or Cut), Storage duration (n = 3: Immediate analysis, 24-hour or 48-hour), Storage temperature (n = 2: Ambient or Chilled) and Storage conditions (n = 3: Air present, Air excluded or Breathable (bags with holes punched in them)). The 'Storage temperature' and 'Storage condition' treatments were applied to the 24-hour and 48-hour Storage duration treatments only. At each experimental harvest each treatment was replicated five times, resulting in 130 grass samples being analysed at each harvest.
For each replicate within each treatment, approximately 200 g of grass (+/- 10 g) was removed from the bulk sample and placed, unchopped, into a pre-labelled, pre-prepared grip seal bag (20.0 x 27.5 cm). With the Immediate analysis treatment (Pluck and Cut treatments), these bags were squeezed lightly to remove excess air, and sealed. The remaining 24 treatments involved grass being subjected to three different 'bag' Storage conditions, namely 'Air present', 'Air excluded' and 'Breathable' Samples were subsequently analyses for dry matter (DM), metabolisable energy (ME), water soluble carbohydrates (WSC), crude protein, acid digestible fibre (ADF) and nitrate content using NIRS.

Key results: The main results were:

- Samples from the simulated grazing swards which were stored for 48-hours prior to analysis, had a lower WSC (9 g/kg DM) and ME content (0.12 MJ/kg DM) and a higher ADF content (6 g/kg DM) than those subject to immediate analysis. Samples analysed after 24-hours did not differ from those subject to immediate analysis.
- Samples from the simulated grazing swards which were stored at ambient temperature prior to analysis, had a lower WSC (12 g/kg DM) and ME content (0.17 MJ/kg DM) compared to those subject to Immediate analysis.
- Samples from the simulated grazing swards which were stored under 'Breathable' conditions had a lower ME content (0.10 MJ/kg DM) and higher ADF content (5 g/kg DM) than those subject to immediate analysis or stored with Air present or Air excluded.
- Grass from simulated silage swards, and subject to Immediate analysis, did not differ in composition from that analysed after either 24-hour or 48-hours storage.
- Grass from simulated silage swards, and stored Chilled, had a higher WSC (18 g/kg DM) and ME content (0.26 MJ/kg DM), and a lower ADF and nitrate N content, compared to that stored at Ambient temperature.
- Grass from simulated silage swards which were stored under Breathable conditions had a lower ME (0.18 MJ/kg DM) and WSC (7 g/kg DM) content and a higher ADF content (11 g/kg DM), than that stored with Air present or Air excluded.

Farmer messages: The main messages were:

- The technique used to harvest samples from grass swards will influence the composition of the grass when analysed in a laboratory. This is largely due to the impact of sampling technique on the height that the sample is harvested. Hand 'plucking' is likely to result in a more variable sample than is obtained by 'cutting' at a consistent height. To improve the consistency of sample analysis, farmers are advised to collect grass samples for analysis by cutting (scissors or hand shears), rather than plucking.
- Grass samples from a grazing sward are more susceptible to changes in composition

post-harvest than samples from silage swards.

- Delaying the time between sampling and analysis by more than 24-hours can have an impact on the composition of the sample. Similarly, samples are more likely to deteriorate when stored at room temperature than when stored in a fridge. Samples also deteriorate more when stored in plastic bags which are open to the air, than in sealed plastic bags.
- The ideal scenario is for samples to be stored in sealed self grip bags in a fridge at 4^{o}C, and analysed within 24-hours of harvest.

Further exploitation: The information should be used by farmers, consultants and laboratories as part of a best practice SOP along with sampling in the field and laboratory analytical techniques to provide farmers with as accurate analysis as possible. The results of this study have been distributed to the Forage Analytical Assurance group to assist with this.

C. Delivery against milestones - tabulate achievement of milestones against targets set. List any deviations or agreed changes in direction, and their impact on the project (if applicable, describe how the work differs from that originally proposed and describe how the changes have impacted on the work package. Include changes to objectives and work plan / budget, changes to the team or other constraints. Explain any discrepancy between planned worked and achieved work, and corrective actions taken.

Grassland (WP3a)	**Progress, deviations and corrective actions**
Best use of information from grass variety testing. Achieve industry support for grass indices project (Y1/Q2). Review year 1 work and agree on way forward (Y2/Q2). Review year 2 work and agree on way forward (Y3/Q2) Submit final report (Y5/Q2)	Industry support achieved on time with meeting in December 2011 An agreement on revised work delayed until May 2013, no adverse effects on project. Agreement on progress, January 2014. Final report submitted to AHDB Dairy, September 2015
Evaluation of the use of slurry for grass silage production. Establish experimental plots at SAC with differing amounts of slurry (Y1/Q1). Establish slurry plot experiments at SAC (Y1/Q3). Report on 2012 results (Y2/Q2). Agree 2013 experimental protocol (Y2/Q3) Report on 2013 results (Y3/Q2). Final analysis of data and thesis submitted (Y4/Q3).	Postponed establishment, until year 2 at request of DairyCo Establishment of plots achieved on time in Feb 2012. Report on 2012 results, submitted to AHDB Dairy in Dec 2012. Proposed protocol submitted for 2013 experiments in Jan 2013, agreement achieved to start experiment on time. Report on 2013 results submitted to AHDB Dairy in March 2014, delay due to late reporting of slurry analyses. Final data analysis completed in March 2015, thesis submission December 2015, awaiting corrections to thesis.
Utilisation of grazed grass grown with nutrients from slurry Start slurry grazing experiment at SAC (Y1/Q4). Report on 2012 experiment (Y2/Q3). Agree 2013 experimental protocol (Y2/Q3). Report on 2013 experiment (Y3/Q3).	Slurry/grazing experiment started on time by May 2012. Report on 2012 experiment submitted in Dec 2012 – due to extreme rainfall in 2012 the experiment was not completed. An additional experiment on ‘cut and carry’ was undertaken to replace this experiment.

Final analysis of data and thesis submitted (Y4/Q3).	Proposed protocol submitted in Jan 2013 for the 2013 experimental work, agreement achieved to start experiment on time. Report on 2013 experiment submitted to AHDB Dairy in Jan 2014 Data analysis completed March 2015, for PhD thesis submission Dec 2015, awaiting corrections to thesis.
Literature review on the maximisation of forage intake from grazed grass. Deliver draft report (Y1/Q3). Final report to be submitted (Y2/Q3). Draft answers to practical questions (Y4/Q2).	Final report delivered in Feb 2012 Revised final report submitted in Feb 2013. Questions and answers based on the literature review were submitted in October 2014.
'Cut and carry' feeding experiments Agree protocol for 2014 experiment (Y3/Q3) Submit final report on 2014 experiment (Y4/Q2). Agree protocol for 2015 experiment (Y4/Q3). Submit final report on 2015 experiment (Y5/Q2).	Protocol agreed in March 2014. Final report submitted in November 2014. Protocol for 2015 experiment agreed in April 2015. Final report submitted to AHDB Dairy in January 2016.
Strategies for grazing high yielding dairy cows with controlled grazing times. Agree protocol for experiment (Y4/Q3). Submit final report on experiment (Y5/Q2).	Protocol for experiment agreed with AHDB Dairy in April 2015. Final report submitted to AHDB Dairy on time
Assessment of methods for sending and storing fresh grass samples for analysis. Agree protocol for the experiment (Y4/Q3). Submit final report on experiment (Y5/Q2).	Agreed protocol with AHDB Dairy in April 2015. Final report submitted to AHDB Dairy, on time
Use of digestate from anaerobic digester as a fertiliser on grassland	Work did not proceed after request from DairyCo to consider other areas of work (replaced by grazing experiment at HAU)

D. Outputs (List and fully reference all outputs which document and promote the findings of this work. Describe any further outputs or follow-up initiatives anticipated after 31 May 2016).

D (I) Experimental/project reports to AHDB

How Farmers can best use information from grass variety testing, Haidee Philpott, Andy Horwell and Jo Matthews Sept 2015

Evaluation of the use of slurry for grass silage production. Chris Henry and David Roberts December 2012

Evaluation of the use of slurry for grass silage production Year 2. Chris Henry and David Roberts March 2014

Utilisation of grazed grass grown with nutrients from slurry, Experiment 1. Chris Henry and David Roberts December 2012

Utilisation of grazed grass grown with nutrients from slurry, Experiment 2. Chris Henry and David Roberts January 2014

Literature Review Maximizing Forage Intake from Grazed Grass. David Younie, Paul Hargreaves, Jennifer Flockhart, David Roberts January 2013

Grazed grass forage review questions 1 – 12. Paul Hargreaves, Jennifer Flockhart, David Roberts October 2014

Cut and carry: Investigating the effects of increasing the proportion of grass in the diets of high yielding dairy cows. Mark Lee and David Roberts. November 2014

Cut and Carry: Investigating the value of fresh grass in the diet of the high yielding dairy cow. Paul Hargreaves, Mark Lee, David Bell and David Roberts April 2016

Effect of time of access to pasture and level of total mixed ration offered on the performance, behaviour and grass intake of high yielding dairy cows. Liam A. Sinclair, Norton Atkins, Mark S. Rutter, Claire Cianchi, Carrie Gauld, Sarah Williams and Gemma Charlton. April 2016

Impact of harvesting technique, storage technique and storage duration on the composition of fresh grass. Andrew Dale, Alan Gordon, John Archer and Conrad Ferris. January 2016

D (II) Scientific publications (accepted or submitted; peer reviewed conference proceedings etc.)

Henry C. and Roberts D.J. (2013) Effects of slurry separation and shallow injection on herbage. BGS 11th Research Conference Proceedings

Henry C. and Roberts D.J. (2014) Effect of mechanically separated dairy cow slurry on grazing performance. European Grassland Federation Conference

Lee, M and Roberts, D.J. (2014). Cut and carry: should we feed more fresh grass to high yielding dairy cows? Early Career Researchers in Agriculture Conference – Edinburgh, May 2014

Flockhart J.F and Roberts D.J. (2015). Feeding of fresh grass as part of a TMR to housed dairy cows. BGS 12th Research Conference Proceedings, Aberystwyth.

Lee, M.A., Flockhart, J.F. and Roberts, D.J. (2015). Rapid estimation of the dry matter content of fresh grass using a microwave oven. BGS 12th Research Conference Proceedings, Aberystwyth.

Dale A.J., Gordon A.W., Archer J. and Ferris C.P. (2016). Impact of harvesting and storage technique, and duration of storage, on the composition of fresh grass when analysed using near infrared reflectance spectroscopy. Submitted to Grass and Forage Science

D (III) Knowledge transfer (national and international workshops, farmer/industry meetings, media articles etc.)

Farmer – Industry Meetings

Meeting	Location	Date	Attendees
Slurry separation meeting	Stranraer	Mar 13	20
Research Day – poster	Reading	Mar 13	126
Research Day	Dumfries	Nov 13	130

BGS Spring Farm Walk	Cornwall	Apr 14	150
Demo Farm meeting	Cheshire	Jul 14	38
Grasslands UK Seminar – Cut and carry	Somerset	May 15	40
NE Scotland Dairy Event – Cut and carry	Aberdeenshire	Jun 15	30
RGCL Project Board Meeting – Grass indices	Evesham	Nov 15	10
AHDB DIG Conference – Cut and carry, fresh grass analysis	Kegworth	Mar 16	264
ScotGrass – Cut and carry	Dumfries	May 16	3000
		Total	**3808**

Farming press

Title	Media	Date
Recognising the value of separated slurry	Farmers Guardian	Jul 13
Survey reveals £109/t difference in the cost of growing grass	Farmers Weekly	May 14
Research project to evaluate grass nutrition	Shropshire Star	Jul 14
Study of grass for high-yielders	Farm Business	Aug 14
Reducing feed costs	Farming Monthly	Feb 15
Add grass to mix for high-yielding cows	Shropshire Star	Jul 15
Grass and the high yielding dairy cow	British Dairying	Jul 15
Knowledge trail: cut and carry	Farm Week	Mar 16
Considerable savings from zero grazing	The Scottish Farmer	May 16
Cut and carry feeding fresh grass to dairy cows	The Scottish Farmer	May 16
Reducing feed costs with cut and carry	Farmers Guardian	May 16

Online

Title	Media	Date
Video - Managing slurry storage	AHDB Dairy YouTube	Mar 13
Do you zero-graze?	Forage for Knowledge	Mar 14
The value of grass for high yielding cows	Forage for Knowledge	Jun 14
Reducing feed costs	Forage for Knowledge	Feb 15
Grass samples – how do you take yours?	Forage for Knowledge	Feb 16
Timing is everything when it comes to grazing	Forage for Knowledge	Feb 16
Graze tightly now and keep it up through the season	Forage for Knowledge	Mar 16
The ins and outs of cut and carry	Forage for Knowledge	May 16

E. Benefits of the research results to the British dairy sector

E (I) Economic benefits (describe, and wherever possible quantify, potential financial benefits at farm level, and/or to the industry as a whole)

Slurry separation
The use of separated slurry for both grazing and silage production was found to result in comparable sward performance to artificial fertiliser whilst offering a cost saving of £60 – 75/ha/yr in reduced purchased fertiliser requirements.

Cut and Carry systems
Whether cut and carry systems are economically viable for a given farm will depend on a comparison of the relative costs of grass and TMR production. Although the inclusion of fresh grass in high-yielding dairy cow diets via cut and carry reduced milk yield, the corresponding reduction in feed costs offered a higher margin over feed costs than 100% TMR feeding. This was particularly true at times of low milk price, the inclusion of 50% fresh grass leaving the

highest margin over feed costs below milk prices of 24ppl.
A subsequent experiment highlighted again the potential cost savings offered by cut and carry techniques, reducing feed costs by 35p/cow/day. Again, however this was accompanied by a 1.4l/cow/day reduction in milk yield. Nonetheless, this still offered a greater economic return of times of low milk price compared to 100% TMR feeding. At a milk price of 22ppl, feeding fresh grass via cut and carry throughout the daytime resulted in an extra profit of £1080 for a 150 cow herd, over a 6 month grazing season.

<u>Grazing high yielding dairy cows</u>

Similarly the economic impact of grazing high yielding cows will vary from farm to farm and depend on grazing conditions, cow energy requirements and previous exposure to grazing.
In experiments undertaken at SRUC, grazing high yielding cows resulted in a yield reduction of 1.6litres/cow/day, however, feed costs were also reduced by 56p/cow/day. Consequently below a milk price of 35ppl it was more economical to graze cows for two-thirds of the day compared to TMR feeding. This gave an extra profit (compared to 100% TMR feeding) of £5400 for a 150 cow herd, over a 6 month grazing season.
In contrast at HAU, where cows are housed for most of the year, giving high yielding cows access to pasture for 6 hrs/day and limiting TMR intake to 75% of ad libitum lowered feed costs by 35p/cow/day. However this reduction was not sufficient to cover the loss revenue associated with the 4kg/cow/d reduction in milk yield.

<u>Fresh grass analysis</u>

Accurate analysis of fresh grass for both silage and grazing swards also assists in reducing feed costs. Under grazing management, grass metabolisable energy (ME) content was up to 0.17MJ/kg DM lower when tested 48 hours after sampling compared with that tested immediately. Although this may not appear a large difference in grass quality, over the season this under-prediction of grass ME content results in an added purchased concentrate cost of £1663 per 150 cow herd (assuming a 200 day grazing season with average dry matter intake = 15kg/cow/day and concentrate cost = £250/t).

E (II) Sustainability benefits (How will outputs support sector sustainability in the long-term? Will the activity support sustainability in other ways such as improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)

The experimental work supported 4 undergraduate student projects from SRUC and Glasgow University, 2 MSc projects and one additional PhD studentship, funded by RESAS.
With the volatility in milk prices it is essential that farmers reduce production costs, optimising the use of slurry and including fresh grass in rations are both ways to reduce costs. Farmers who have a greater focus on grazing within their systems will require better information from seed merchants on different grass varieties and information on analysis of fresh grass, information on both these subjects are included in experimental reports.
Farmers who are housing cows during the summer, or considering this system, may come under pressure from milk buyers to allow some access to pasture. This work provides detailed information on strategies for grazing high yielding dairy cows with controlled grazing times.

E (III) Policy making (Describe how the work informs policy, leads to better decision making, or addresses wider societal concerns)

The two main policy areas addressed by this research are:

- Nitrate Vulnerable Zones and the improved use of slurry as a fertiliser within grassland based systems
- Welfare of continuously housed dairy cows

These are also issues of wider public concern and the experimental results will help in the understanding, development and discussion of these areas.

E (IV) Supply chain (Does the work address supply chain constraints or opportunities)

Areas of the work addresses the supply chain with the nutrient supply from the slurry application and grazing having implications for contractors who work with slurry, manufactures

of slurry separation equipment and cut and carry cutting equipment if they are seeking opportunities to promote cut and carry. Plant breeders and seed sellers would benefit from the information provided from the variety indices work to help breeders focus of areas were improvements in variety characteristics would be helpful and the cost effectiveness of certain varieties in areas of the UK.

F. Leverage and added value (Detail all additional funding sources and collaborations nationally or internationally. Has this activity contributed to applications for further research in this area? Has the work contributed to improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)
The work on slurry as a fertiliser for grassland was conducted because it was an area which was not funded by the supply industry. The experimental plots have also been used by SRUC and Glasgow Caledonian University to measure the effects of slurry application methods on greenhouse gas production. The cut and carry experimental results are being considered as part of a 5 year RESAS funded systems study, if approved this will start in 2017. The results from the separated slurry trials have also been used to inform the revision of RB209 The Fertiliser Manual.

Work package title:	**WP 3b: Conserved Forage Production and Evaluation**		
Start date (mm-yyyy):	10-2011	**Actual (£)**	£615k
End date (mm-yyyy):	06-2016	**Planned cost (£)**	£615k
Name & organisation of principal investigator (PI):	Liam A Sinclair Harper Adams University (HAU)		
Collaborators:	UoR, SRUC and HAU.		

A. Overview by work package leader

Underpinning rationale: Increased global demand for soya and other protein sources in association with considerable fluctuations in their availability and price has increased the importance of home grown forages in the diet of UK dairy cows. Predicted changes in the UK climate may also reduce the reliance on traditional conserved forages in favour of new and novel crops previously considered as alternative. Forage legumes are of particular interest in this context because of their low fertiliser requirements and high protein content (Fraser et al., 2001).

Clover is the most widely grown forage legume in the UK, with over 70% of UK grassland farms incorporating clover in their swards (DEFRA, 2015). However, there is a knowledge gap in the prediction of the nutritive value of silages that contain a high proportion of clover. Currently prediction equations for mixed clover/grass silages are based on grass silage, but there have been reports that this can result in variable and inaccurate analysis and that equations specifically derived for mixed clover/grass silages are required. A more accurate forage analysis will improve diet formulation and reduce feed costs.

Lucerne (alfalfa, *Medicago sativa*) is the most widely cultivated legume in the world (FAO 2006). It is popular in many parts of the United States and Europe and complements well the low protein content found in maize silage (Broderick et al., 2007; Brito and Broderick, 2006). Despite this, lucerne has received relatively little commercial uptake by GB dairy farmers. This may be due to the climatic conditions required to successfully grow the crop, lack of reliable information on the nutritive value of this forage for accurate diet formulation, or insufficient advice on the most appropriate date of harvest, ensilage, chop length, inclusion and supplementation under GB conditions. At the beginning of the research partnership, a lucerne growers meeting was conducted to identify the key challenges to growing this crop in GB, and subsequently the knowledge gaps dairy farmers had when growing and feeding lucerne. The experiments listed in Executive summary 2 – 4 where formulated in response to the knowledge gaps identified at this meeting.

Forage peas are also of interest as they are an annual legume that grows well in temperate regions and establishes rapidly in the spring (Adesogan et al., 2004). The protein in peas, as in other legumes, is however, often utilised inefficiently because it is highly degradable in the rumen (Mustafa et al., 2000; Sinclair et al., 2009). Tannins are natural compounds that can reduce the degradation of protein in the rumen and thereby increase the rumen by-pass protein content of forages (Sinclair et al., 2009). Condensed tannins are naturally present in certain varieties of peas. Hydrolysable tannins may be added to legumes such as red clover or lucerne either at ensiling or feed out. To date there is little information available on the effect of either condensed or hydrolysable tannins on animal performance or nitrogen efficiency.

Finally, maize silage forms the major winter forage component on many UK dairy farms and a body of research has identified optimal means to grow, ensile and feed (e.g. Bell et al., 2007; Keady et al., 2008; Phipps et al., 2000). This information has not been collated into a form that can be translated to dairy farmers or to inform future research priorities.

Work package objectives: The objectives of this work package were several-fold:

a) develop and implement reliable near infrared spectroscopy (NIRS) equations to predict

b) the nutritive value (ME and the degradability of DM and N) of mixed silages with a high proportion of clover

b) determine the effect of the inclusion of lucerne silage in the diet of UK dairy cows on performance, milk composition, rumen health, N efficiency, and diet costs
c) determine the effect of the inclusion of forage peas differing in their tannin content and the addition of tannins to red clover and lucerne silages in the diet of high yielding dairy cows on performance, N efficiency and diet costs
d) conduct a comprehensive review of the published studies on establishing, growing, ensiling and feeding maize to dairy cows, and highlight research gaps.

Approach: To examine these objectives a series of studies were conducted at 3 principal sites: Harper Adams University (HAU), SRUC and the University of Reading (UoR) across a number of seasons. This was undertaken to provide a geographical coverage of the country and reflect differences in growing and feeding practices and account for seasonal differences. Evaluation of the nutritive value of clover-grass silages (Executive Summary 1) reported that the current grass NIRS equations were suitable to predict some nutritional components in grass-clover silages including digestibilty, other components were under-predicted, notably crude protein and protein degradability. New equations have been developed for grass-clover silages that will provide dairy farmers with a more accurate analysis, improving the accuracy of diet formulation and decreasing feed cost.
To evaluate the effect of site, time and means of establishment of lucerne, plot studies were conducted at the 3 sites over 2 years (Executive Summary 2). Establishment in the spring was successful at all 3 sites, but establishment in autumn was very variable. There was little benefit to under-sowing on initial or subsequent DM yield or crop establishment. Five feeding studies were conducted across all 3 sites to evaluate the effect of including lucerne silage in the diet (Executive summaries 3-5). Main findings include that replacing grass silage with lucerne increases DM intake, but not a maize silage based ration. Indeed, when lucerne replaces maize at above 60% of the forage DM, intake declines. There is little effect of feeding lucerne on milk yield or composition, except at very high inclusion rates when performance of cows fed maize silage based rations will decline. A longer chop length of lucerne will increase rumination time and ruminal pH but only at a high inclusion rate. A shorter chop length improves intake and performance. The major benefits to lucerne are savings in fertilizer and feed protein costs, but the extent will vary with input prices.
When compared to high quality grass silage, feeding forage peas resulted in a lower intake and milk yield, but due to the lower growing and feed costs, savings of 0.3 to 0.5ppl were possible (Executive Summary 6). There was little benefit to the level of condensed tannin in the peas on cow performance. Compared to red clover, feeding lucerne increased intake, but had little effect on milk performance or live weight change (Executive Summary 7). The addition of hydrolysable tannins at ensiling did not increase milk yield or composition. Finally a review of peer reviewed and grey literature reported a body of research on growing and feeding maize silage (Executive Summary 8), although agronomy is mainly based on commercial sources. There is a lack of information on varieties suitable for use in marginal areas and on the application of precision farming techniques to maize, particularly in relation to organic manures.

Delivery: All studies met or exceeded their objectives and achieved their milestones. Problems with securing clover silages at UoR delayed this project and due to the timing of the studies the second report from SRUC on lucerne is still outstanding (submission date 9th Dec 2016). Findings from the studies have been disseminated at farmer meetings, research days, conferences, technical conferences and academic conferences. Additionally, findings have been reported extensively through the farming press.

B. Executive summary 1) Near Infra-Red Spectroscopy for Grass-Clover Silages in the UK

Background and Objectives: Near Infra-Red Spectroscopy (NIRS) is a relatively rapid and inexpensive technique that is routinely used to provide nutritional analysis of silage and other livestock feeds in the dairy and beef industries. However, obtaining accurate results requires robust calibrations.

Clover is thought to be present within grass swards on 70% of UK farms, and therefore is likely to be the most widely-grown forage legume in the UK (DEFRA, 2015). However, currently UK laboratories do not offer a bespoke NIRS equation for clover-grass mixtures and the grass calibration is the most relevant option. A preliminary study has shown that the current NIRS analysis available for use on grass silages in the UK showed poor prediction accuracy of crude protein, pH and lactic acid when used on mixtures containing both clover and grass (Davies et al., 2012). Creating a new calibration equation poses challenges because of the nature of these silages being mixtures of two (or more) species, meaning that the resulting equation must be able to deal with a broad spectrum of sample composition. One potential solution to this, which requires further investigation, is to use the clover content of the silage as a 'correction factor' in a calibration equation to more accurately predict higher protein levels, although accurate determination of the clover content is challenging.

The objectives of this study were to test the current NIRS equation (based on grass silages) for accuracy when used on a large and diverse range of clover-grass silage samples and, if required, to use the nutritional composition, *in vivo* digestibility and *in sacco* degradability measurements obtained from the sample set to update the current NIRS calibration equations (or provide a correction factor).

Technical approach: In total, 94 clover/grass silages of varying composition were sourced from commercial farms throughout the UK and brought to the Centre for Dairy Research (CEDAR), Arborfield, for processing. Farm and crop details were recorded for each farm using a farmer questionnaire. Once a sample arrived at CEDAR, it was chopped in a feeder wagon (if the sample was an unchopped bale silage) and stored frozen (-20°C) until required. A sub-sample of each silage was then sent to the Agri-Food and Biosciences Institute (AFBI, Hillsborough, Northern Ireland) where the chemical composition of the silages was determined using UKAS accredited methods, and Trouw Nutrition (Ashbourne, Derbyshire) for fibre analysis. Additionally, samples were manually speciated into clover, ryegrass and other species. The whole tract digestibility of the silages were determined in sheep and the *in situ* degradability determined using rumen cannulated Holstein-Friesian dairy cattle (Ørskov and McDonald, 1979).

Key results: Clover-grass mixtures can vary greatly in nutritional composition. In this sample set, higher concentration of clover in the sample correlated with higher dry matter and nitrogen, and lower digestibility and volatile content, however, environmental and management factors also played a key role. Questionnaire results relating to this sample set indicated that perennial and hybrid ryegrasses were most commonly sown with clover (red or white), and that substantial fertilisation (either organic or inorganic) was often applied to the sward. The majority of farmers who filled in the questionnaire were unable to estimate the concentration of clover in the crop to within ±10%DM. This highlighted the need for a tool to assist farmers in identifying the composition of species in their sward. The current equations for grass NIRS analysis were tested. While some variables were predicted with good accuracy (including digestibility), others were poorly predicted; notably crude protein and protein degradability. Indeed, predicted crude protein content was on average 1.24% lower using NIRS analysis compared with wet chemistry. Bias for these variables increased with clover concentration (Figure 3b.1.1).

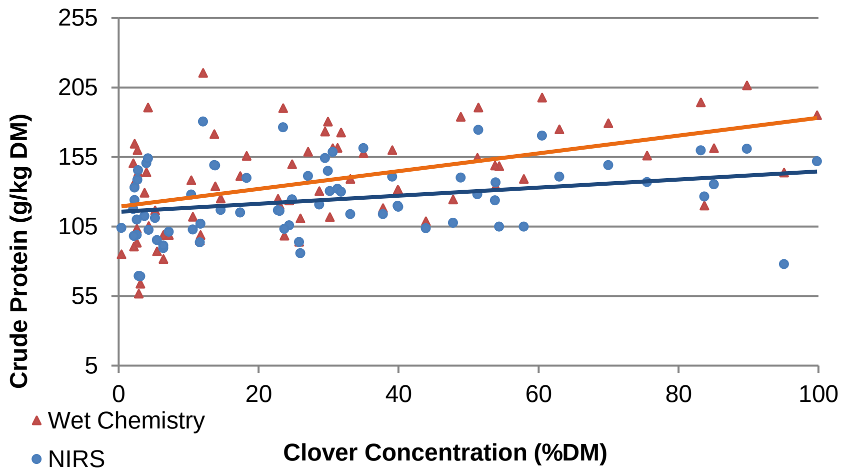

Figure 3b.1.1 Effect of clover concentration on silage crude protein content as determined by NIRS and wet chemistry

New equations were produced that predicted all variables with increased accuracy relative to using the grass NIRS equations, based on a relatively small blind validation test. It is the recommendation of this report that the new equations be introduced as an alternative option for silages known to contain clover. Further investigation into the possibility of combining the new data with the original grass data should be carried out to see if a 'one size fits all' equation could be produced. A new equation that predicts clover concentration in a sample has been produced that is able to predict bands of clover concentration (e.g. high, medium, low). However, further development will still be required before it can be relied upon to predict with sufficient accuracy for use as a correction factor to the grass equation.

Farmer messages:

- Clover-grass mixtures vary greatly in their proportion of grass to clover and their nutritional composition.
- Farmer judgement of clover content in a sward/silage is generally inaccurate.
- Samples with a clover concentration greater than 50%DM tended to have very different nutritional composition than the low clover concentration samples, for example, high clover concentration samples were higher in dry matter and nitrogen, lower in digestibility and degradability and lower in volatile content.
- On average predicted crude protein content was 1.24% lower in grass-clover silages using NIRS compared with wet chemistry.
- New equations have been developed for silages from grass-clover swards and are currently being integrated into the main analytical laboratory protocols.

Further exploitation: The greater accuracy obtained using the new equations needs to be further exploited by ensuring that the feed industry is aware of the development and improvement in accuracy. This is being achieved through a close working relationship with the Forage Analytical Assurance group, and ensuring that the equations are incorporated into the main analytical laboratories. The current grass NIRS equations were suitable to predict some nutritional components in mixed swards, but not others. The findings also need to be highlighted to farmers so that they are aware of the potential savings which may be obtained from a greater utilisation of home grown forage and reduction in purchased feed costs. Few farmers were able to estimate the amount of clover in their crop with accuracy, highlighting the need for a method of rapidly determining clover concentration for use as a farm management tool. The findings from this study are also of direct benefit to beef and sheep farmers and a strategy to raise awareness with these groups is required.

B. Executive summary 2) Effect of sowing date and under sowing with spring barley on the yield, quality and persistency of lucerne in the UK

Background and Objectives: Lucerne has received a relatively low commercial uptake by UK dairy farmers. One reason for this may be that the crop can be slow and difficult to establish, as during the seedling stage it prioritises the allocation of dry matter resources to the root and crown resulting in low rates of above ground biomass accumulation until the crop is fully established (Sim et al., 2015). In UK conditions both spring and late summer sowing take place commercially in response to rotational demands and workloads however little work has been undertaken to establish optimum lucerne agronomy practices for GB conditions. Time of sowing studies elsewhere, have shown that shoot dry matter yields in the second season can be reduced by late summer sowing in the previous year due to an incomplete establishment process the previous autumn (Justes et al., 2002, Moot et al., 2012, and Thiebeau et al., 2011). Sim et al., (2015) concluded that in New Zealand, in order to maximise shoot yield, lucerne should be sown in spring to allow sufficient time to build root and crown biomass.
Another problematic aspect of establishment is weed control, with herbicide approvals for the crop being very limited. Therefore, in practice, forage legumes are sometimes established with a companion crop to suppress weeds which take advantage of the slow establishment of the lucerne. Companion crops may increase the yield of forage harvested in the establishment season but likewise may have the potential to decrease yield in the following year if they cause any reduction in the establishment success of the lucerne. There is limited information available across the globe on the effect of sowing lucerne with companion crops on either lucerne establishment or subsequent performance. Consequently the objectives of the study were to:

- determine the effect of sowing date (late summer versus spring) on yield and quality of lucerne in UK conditions during the establishment season and the season following it
- determine the effect of under sowing lucerne with a spring barley companion crop (at the spring sowing time) on yield and quality of lucerne in UK conditions during the establishment season and the season following it.

Technical approach: Trial plots at three sites (Shropshire, Berkshire and Dumfries) were established from 2012 to 2014. At each of the three sites randomised trials were conducted with three treatments: late summer sown lucerne, spring sown lucerne only and spring sown lucerne with spring barley. The plots were sown using practices reflecting commercial farm activity in GB. The plots were harvested at an approximate early bud stage in the year of establishment, and the year following, and dry matter yield determined. Dried samples were sent for laboratory determination of crude protein and neutral detergent fibre NDF.

Key results: Spring sowing was more reliable in terms of successfully establishing a crop across all three sites and seasons, with 100% of spring sown crops making it through to harvest, compared with only 29% of late summer establishments successfully harvested. In most cases, late summer sowings failed to establish, however, an excessive weed burden also resulted in one sowing not taken through to harvest. When spring and late summer lucerne was established in the same calendar year, the late summer treatment exhibited significantly lower annual dry matter yield (P<0.05) in the following season. Crude protein was also significantly (P<0.05) lower from the late summer treatment (16.6%) compared to the spring sown (19.6%) treatment. Similarly, in the first year of harvest, there was no significant difference (P>0.05) in the dry matter yield of the 2014 spring sown plots (3.57t DM/ha) compared to those established in late summer 2013 (3.12t DM/ha).
Across four spring sowings there was only one occasion on which the companion crop of spring barley significantly increased dry matter yield at first cut in the establishment season when compared to single species stands of lucerne. Similarly, there was no consistent benefit in crude protein or NDF across sites. It can therefore be concluded that there was no consistent benefit in dry matter yield or quality from a companion crop of spring barley.

Farmer messages

- Spring sowing is more reliable than late summer/autumn sowing in terms of successfully establishing a crop.
- There is no consistent advantage or disadvantage in terms of yield or quality in the season of establishment in planting lucerne with a companion crop of spring barley.
- Late summer sowings effectively take 12 months to match the productivity and quality of spring sowings as they are likely to continue partitioning resources to the root and crown in the following spring and therefore there is no advantage to late summer sowing.

Further exploitation: The results from this work have already been the focus of several press articles and on-farm knowledge transfer days. The findings will also be incorporated into the AHDB Dairy Growing and Feeding Lucerne booklet. Direct targeting of seed and agronomy companies should also be exploited because this is a primary route of getting information to dairy farmers. The results produced are also of direct benefit to beef and sheep farmers who are considering lucerne and should be incorporated into the AHDB Beef and Lamb KE strategy.

B. Executive summary 3) Lucerne silage as a replacement for grass and maize silage for high yielding dairy cows

Background and Objectives: Lucerne (alfalfa, *Medicago sativa*) is the most widely cultivated legume in the world (FAO 2006) and may be grazed, preserved as hay or ensiled. It is popular in many parts of the United States and Europe as it has a low fertiliser requirement but is high in protein and complements well the low protein content found in maize and whole crop cereal silages (Broderick et al., 2007; Brito and Broderick, 2006). Studies in the United States have shown that compared with red clover, lucerne silage results in an increase in dry matter (DM) intake, milk yield, milk fat and protein levels (Broderick et al., 2007). Feeding mixtures of lucerne and maize silage generally results in an decrease in DM intake, milk yield and fat content compared to lucerne alone (Brito and Broderick, 2006), similar to that commonly seen in GB when mixtures of grass and maize silage are fed compared to grass silage alone (Phipps et al., 1995). Despite this, lucerne has received relatively little commercial uptake by GB dairy farmers. This may be due to the climate conditions required to successfully grow the crop, lack of reliable information on the nutritive value of this forage for accurate diet formulation or insufficient advice on the most appropriate date of harvest, ensilage, inclusion rate and supplementation under GB conditions. The objectives of the current study were to determine the effect of rate of inclusion of lucerne silage as a replacement for grass and maize silage on the intake, performance, blood metabolites and apparent whole tract digestibility in high yielding dairy cows.

Technical approach: Twenty Holstein-Friesian multiparous dairy cows received one of four dietary treatments composed of 0.55:0.45 forage to concentrates (DM basis) and within the forage the proportion of each of three forages (DM basis) was varied:

C:	0.4:0.6 grass to maize silage
L20:	0.2:0.2:0.6 lucerne to grass to maize silage
L40:	0.4:0.6 lucerne to maize silage
L60:	0.6:0.4 lucerne to maize silage

Diets were balanced for energy and protein. Cows received each diet in one of four periods in a latin square design with four periods of 28-d duration, with measurements taken during the final 7-d of each period. The lucerne silage (*vr.* Daisy) was harvested at approximately early bud and the grass silage was a first cut composed predominately of *Lolium perenne*. The maize silage (*vr*. Adept) was harvested at approximately 300 g DM/kg. Cows were milked twice daily with yield recorded at each milking and samples taken on four occasions during the final week of each period for subsequent analysis. Blood samples were taken over 2 days during the final week of each period by venepuncture at 0700, 0900, 1100 and 1300h and whole-tract digestibility was determined using acid insoluble ash as an internal marker. Summary results are presented in Table 1.

Key results: There was no effect of the rate of inclusion of lucerne on milk performance or composition, although DM intake was lower at the highest rate of lucerne inclusion (Table 3b.3.1). Plasma urea concentrations increased with the rate of inclusion of lucerne, although all values were within accepted limits. Increasing the inclusion of lucerne decreased the digestibility of organic matter and nitrogen. Increasing lucerne in the ration increased the polyunsaturated fatty acid content of milk, improving its health properties, but did not decrease the saturated fat content. The inclusion of lucerne also resulted in a reduction in the inclusion rate of soyabean meal and feed grade urea, with a maximum saving of 0.6 kg/cow/d of soyabean meal and 0.12 kg/d of feed grade urea, resulting in a potential saving of purchased feed costs of 22p/cow/day (or £4290 for a 130 cow dairy herd over a 150 day winter).

Table 3b.3.1. Intake, milk performance, apparent digestibility of OM, plasma urea and selected milk fatty acids in cows when fed diets differing in their inclusion of lucerne.

	Control	L20	L40	L60	s.e.d.	*P*-value
DM intake (kg/d)	24.5	24.9	24.5	23.4	0.40	**0.004**
Milk yield (kg/d)	42.2	40.7	40.2	40.5	0.90	0.133
Milk fat (g/kg)	41.1	40.6	40.4	41.8	0.97	0.470
Milk protein (g/kg)	30.9	30.8	31.0	30.8	0.33	0.953
Live weight change (kg/d)	0.21	0.23	0.13	0.05	0.207	0.814
Plasma urea (mmol/l)	3.16	3.24	3.82	3.92	0.140	**<0.001**
Digestibility (kg/kg)						
Organic matter	0.728	0.707	0.674	0.673	0.0157	**0.003**
Nitrogen	0.712	0.696	0.663	0.655	0.0161	**0.003**
Milk fatty acids (g/100g)						
18:2*n*-6	2.27^{a}	2.37^{b}	2.42^{b}	2.43^{b}	0.045	**0.004**
18:3*n*-3	0.32^{a}	0.34^{b}	0.36^{c}	0.42^{d}	0.010	**<0.001**
Total PUFA	3.26^{a}	3.39^{b}	3.43^{b}	3.52^{b}	0.063	**0.002**
Purchased feed costs (£/cow/d)	2.31	2.32	2.24	2.09	--	**--**

Values in the same row with different superscripts are significantly different (P < 0.05)

Farmer messages:

- Compared to a good quality first cut grass silage, there is little benefit to the cow performance from the inclusion of lucerne at between 20-60% of the forage DM when fed to high yielding cows receiving maize silage based diets.
- At high levels of inclusion of lucerne, whole tract digestibility is reduced.
- There is a benefit from the inclusion of lucerne on the polyunsaturated fatty acid content of milk, but the saturated fatty acid content may not be altered. For payment schemes based on milk fatty acid profile the effects on milk price will be small, if any.
- The inclusion of lucerne at 60% of the forage dry matter can result in a saving of 0.6 kg/cow/d of soyabean meal and 0.12 kg/d of feed grade urea reducing purchased feed costs by 22p/cow/day.
- The decision to grow lucerne as a replacement for grass silage to feed along with maize silage should be based on the suitability to grow the crop and potential savings in fertiliser and feed costs rather than an improvement in milk yield or quality.
- There may be beneficial effects of including lucerne as a replacement for 2nd or 3rd cut grass silage in maize silage based rations, but these have not been determined.

Further exploitation: The findings from this study have already been presented to farmers and nutritionists (Section D (III)). The main benefit is not on animal performance but savings in purchased feed protein costs and potentially growing costs and can further be exploited by continuing to transfer this information to industry along with the incorporation of the findings into the AHDB Dairy Growing and Feeding Lucerne booklet. Additionally, the feed cost savings obtained from including lucerne in the ration could be further exploited by also reducing dietary protein levels, although the impact on animal performance is unclear.

B. Executive summary 4) The effect of varying inclusion rate and chop length of lucerne silage in a maize silage-based total mixed ration for dairy cattle

Background and Objectives: The influence of forage chop length on dry matter intake (DMI) and milk production has been extensively studied, primarily in US research. However less is known about how chop length may interact with the inclusion rate of lucerne silage in a total mixed ration (TMR) containing maize silage. Lucerne and maize silages are complementary to each other in the diet with the former bringing rumen degradable protein and the latter containing starch that provides fermentable energy to drive microbial protein synthesis by using the ammonia and amino acids from lucerne protein degradation.
Lucerne silage has the potential as a source of physically effective neutral detergent fibre (peNDF) in diets for lactating dairy cows, as it has a fibrous stem which can encourage rumination. Higher peNDF also aids in the stimulation of rumination and chewing activity which leads to increased saliva production and particle size reduction (Clark and Armentano, 2002). Previous research has shown how varying forage particle size can effect feed DMI, milk yield and energy balance (Kononoff and Heinrichs, 2003). Whilst the shortest chop lengths allow increased DMI, they also reduce rumination, chewing time, and saliva production and as a consequence, rumen pH which may result in sub-acute rumen acidosis (Beauchemin et al., 2003). Although long particles can improve rumen pH, they also reduce the rate of dry matter (DM) digestion thus DMI, creating less efficient feed utilisation for production. Therefore the farmer must achieve a chop length which is both sufficiently long to promote healthy rumen pH while maximizing intake of digestible nutrients. The objectives of the present study were to investigate optimal proportions of lucerne silage when included with maize silage in the forage portion of the diet and the effect of varying lucerne chop length on milk production and digestive function.

Technical approach: Two experiments were conducted to assess the effect of lucerne inclusion rate and chop length when fed in a total mixed ration (TMR) with a 50:50 forage:concentrate ratio (DM) basis. The forage comprised maize and lucerne silage in proportions of either 25:75 (HL) or 75:25 (LL) (DM basis), respectively. The experiments utilised two separate cuts of lucerne silage which was harvested from the same field and stored as silage in concrete walled clamps at either a long (L) or short (S) chop length. These variables were combined in a 2x2 factorial design to give four treatments (HLL, HLS, LLL, LLS). Experiment 1 used sixteen multiparous Holstein-Friesian cows and the first-cut lucerne silage to assess the effect of treatments on feed intake, milk yield and composition in an applied commercial setting. Experiment 2 used eight Holstein-Friesian cows (of which four were fitted with rumen cannula) and second-cut lucerne silage to investigate the effects of treatment on chewing and rumination activity, DM digestibility and rumen pH.

Key results: Cows offered lucerne at a rate of 25% of forage DM, with maize silage had an increased intake (+3.2kg DM/cow/d), milk yield (+3.0kg/cow/d) and digestibility of feed nitrogen and DM when compared to those offered lucerne at 75% of forage DM. The higher lucerne inclusion rate increased feed conversion efficiency (energy corrected milk yield/DMI) when the silage dry matter was low (from 1st cut) but this effect was not seen where a higher dry matter silage was used (from 2nd cut). At 2nd cut (high DM silage), the higher lucerne inclusion rate increased rumen ammonia ($P<0.001$) and milk urea ($P<0.001$) concentrations suggesting an oversupply of rumen degradable protein relative to rumen fermentable energy.
A shorter chop length of lucerne increased feed dry matter intake (+0.9kg DM/cow/d; $P<0.02$), milk yield (+1.6kg/cow/d; $P<0.001$) and digestibility ($P<0.02$) of the diet. Therefore, shorter chop

lengths could partly mitigate the adverse effects of a high lucerne inclusion rate through improved nutrient capture and utilisation. A longer chop length of lucerne silage together with a high inclusion rate of lucerne in the diet increased rumination time and rumen pH. Lucerne chop length had no effect on rumination time and rumen pH with the lower lucerne inclusion rate.

Farmer messages:

- A high rate of inclusion of lucerne (e.g. 75% of forage DM) in a maize silage based ration will reduce intake and milk yield compared to a lower inclusion rate (e.g. 25% of forage DM), but will increase feed conversion efficiency.
- Although there are improvements in rumen pH and increased rumination time with a longer chop length there is little effect of rate of inclusion of lucerne on milk composition
- A shorter chop length will increase DM intake, milk yield and diet digestibility

Further exploitation: The findings from this study have already been presented to farmers and nutritionists (Section D (III)). The results should also be translated to forage contractors and the silage additive industry as they have a major input into the decision making process on chop length on-farm. The findings will also be incorporated into the AHDB Dairy Growing and Feeding Lucerne booklet.

B. Executive summary 5) Lucerne silage as a replacement for grass silage for high yielding dairy cows

Background and Objectives: Lucerne (alfalfa, *Medicago sativa*) is an appropriate legume to consider as an alternative forage in UK dairy rations, especially when maize silage or cereal whole crop is also fed, to balance their low crude protein content. Work in the USA has demonstrated a reduction in DMI, milk yield, milk fat and protein concentration, when lucerne silage and maize silage are fed together, compared with lucerne silage alone (Brito and Broderick, 2006). However, less is known about the effects of feeding mixtures of lucerne and grass silage. Consequently, the objectives of this study were to determine the effect of rate of inclusion of lucerne silage as a replacement for grass silage on the intake, performance, blood metabolites and apparent whole tract digestibility in high yielding dairy cows.

Technical approach: Sixteen Holstein Friesian dairy cows were fed diets containing different proportions of grass silage and lucerne silage. The forage:concentrate ratio of each diet was 0.57:0.43 and diets were balanced for energy and protein content. For each experimental ration the forage proportion was as follows, on a dry matter basis:

C: All grass silage
HL: 0.75:0.25 grass silage:lucerne silage
MM: 0.50:0.50 grass silage:lucerne silage
LH: 0.25:0.75 grass silage:lucerne silage

The animals were blocked into four balanced groups, on the basis of milk yield, live weight, days in milk and parity, and allocated at random to treatment groups. Using a 4x4 Latin square design, each cow received each of the four diets for a feeding period of 28 days, with recording of milk yields and intakes, measurement of live weight and collection of blood and faeces samples during the last 7 days of each period.

Key results: There was no significant difference in milk yield or quality, nor live weight, when the proportion of lucerne in the ration was increased (Table 3b.5.1). Increasing the proportion of dietary forage as lucerne did however increase dry matter intake by up to 4.8kg DM/cow/d. Plasma concentration of urea increased significantly with increasing level of lucerne, suggesting a reduction in nitrogen use efficiency. The inclusion of lucerne at a high rate (75% of forage) in the diet did offer the opportunity to reduce rapeseed meal requirements by

1.43kg/cow/d. However, due to the lower energy value of lucerne, this diet also required an additional 3.39kg/cow/d of rolled wheat. This resulted in an overall increase in dietary feed costs of £1.12/cow/d (0.29ppl) at the time of the trial suggesting it is uneconomical to include lucerne in dairy cow diets, where grass silage is the sole forage source.

Table 3b.5.1. Dry matter intake, milk production and composition, live weight, faecal acid-insoluble ash and plasma urea from cows fed rations with increasing levels of lucerne in the forage portion.

	C	HL	MM	LH	s.e.d.	*P*-value
Dry Matter Intake (kg/h/d)	19.8^{a}	21.2^{a}	23.4^{b}	24.6^{b}	0.83	**<0.001**
Milk yield (kg/d)	32.0	32.9	32.7	33.2	0.88	0.632
Milk fat (g/kg)	39.5	39.5	40.0	39.5	0.48	0.627
Milk protein (g/kg)	30.1	30.2	30.2	30.0	0.17	0.468
Fat yield (g/d)	1266	1303	1310	1313	34.2	0.504
Protein yield (g/d)	963	990	982	994	26.8	0.661
Live weight (kg)	641	637	644	639	7.5	0.774
Urea (mmol/l)	5.55^{a}	5.72^{ab}	6.26^{b}	6.27^{b}	0.294	**<0.05**

Values in the same row with different superscripts are significantly different ($P < 0.05$)

Farmer messages:

- The dry matter intake of a ration increases with increasing inclusion of lucerne silage, when compared to medium quality grass silage, however, there is no impact on animal performance.
- As the proportion of lucerne in the ration increases, the dry matter of faeces also rises, and acid-insoluble ash reduces. This is most likely to be associated with faster passage of feed through the digestive tract, because of the higher DMI and the consequent reduction in digestibility.
- The inclusion of lucerne in grass silage based diets results in a higher requirement for purchased energy, outweighing any bought in protein savings and resulting in higher feed costs per cow (+£1.12/cow/d in this study). This suggests it is uneconomical to include lucerne in dairy cow diets, where grass silage is the sole forage source.

Further exploitation: The findings from this study have already been presented to farmers and nutritionists (Section D (III)). This should continue and be integrated with the findings from Executive Summaries 2, 3 and 4 and incorporated into the AHDB Dairy Growing and Feeding Lucerne booklet.

B. Executive summary 6) Effect of forage peas with varying tannin content on the performance of high yielding dairy cows

Background and Objectives: High yielding dairy cows have a greater requirement for metabolisable protein and rumen undegradable (by-pass) protein to meet their requirements for milk production (Thomas, 2004). However, the protein in ensiled forages such as grass, peas, red clover and lucerne silage is low in rumen undegradable protein (Sinclair et al., 2009). Simple and cost effective means of increasing the undegradable protein content in home grown forages are therefore required.

One way of reducing protein degradation in the rumen is by using tannins. Tannins are natural phenolic compounds which bind with proteins to form a complex that is pH dependent (Aerts et al., 1999). These complexes will not break down at pH levels found within the rumen, therefore protecting the protein from rumen microbial activity, but will dissociate at the lower pH levels found in the abomasum (true stomach) allowing the protein to be absorbed in the small intestine (Fraser et al., 2001). It is therefore possible to increase the rumen undegradable protein content of forage legumes by the use of tannins (Sinclair et al., 2009). Condensed tannins are naturally present in certain legumes such as forage peas and consequently offer a practical and easy way of increasing the rumen undegradable protein supply to more readily meet the requirement of high yielding dairy cows. The objectives of this study were to determine the effect of the inclusion of forage peas differing in their tannin content in the diet of high yielding dairy cows on performance, N efficiency and diet cost.

Technical approach: Eighteen multiparous, high yielding dairy cows were fed one of three diets composed of 55:45 forage to concentrates (DM basis), with the forage proportion varying on a DM basis as follows:

Control (C):	0.33:0.66 grass to maize silage
Low tannin (LT):	0.33:0.66 low tannin peas to maize silage
High tannin (HT):	0.33:0.66 high tannin peas to maize silage

Cows received one of three dietary treatments for each of three periods in a Latin square design of 28 day duration, with measurements recorded in the final seven days. Diets where balance to supply the same energy and protein levels. Cows were milked twice daily and yield recorded at each milking during the final week of each period. Milk samples were collected on four occasions for subsequent analysis. Cow live weight and body condition score were recorded at the beginning and end of each period. Blood samples were collected over two days in the final week of each period at 0700, 0900, 1100 and 1300 h for subsequent analysis. Acid insoluble ash was used as a marker to determine whole tract digestibility.

Key results: In a maize silage based ration replacing grass silage with forage peas reduced dry matter intake, milk yield, and milk protein content (Table 3b.6.1). There was no effect in milk fat content. Additionally, the inclusion of forage peas increased plasma urea but had only a small effect on the efficiency of dietary N use. Including forage peas resulted in a saving in soya bean meal of approximately 0.4kg/cow/d and reduced feed costs by 0.3 to 0.5ppl. The inclusion of low tannin or high tannin pea silage did not affect intake, milk or milk component yield and had little effect on diet digestibility or the efficiency of dietary N use for milk production.

Table 3b.6.1 Milk performance, live weight and body condition score of cows fed diets containing grass and maize silage (C), low tannin pea and maize silage (LT) or high tannin pea and maize silage (HT).

	C	**LT**	**HT**	**s.e.d**	**P-value**
DM Intake (kg/d)	21.4^{b}	19.9^{a}	20.7^{ab}	0.37	**0.002**
Milk yield (kg/d)	40.6^{b}	38.4^{a}	38.3^{a}	0.75	**0.005**
Milk fat (g/kg)	37.5	39.6	37.9	0.12	0.165
Milk protein (g/kg)	30.8	30.2	30.1	0.26	0.045
Milk lactose, (g/kg)	45.2^{a}	45.5^{ab}	45.6^{b}	0.16	**0.026**
Live weight (kg)	647^{b}	637^{a}	643^{ab}	3.33	**0.026**
Live weight change[1] (kg/d)	0.53	0.06	0.24	0.205	0.088
Plasma urea (mmol/l)	4.10^{a}	5.34^{b}	5.43^{b}	0.301	**<0.001**
N-efficiency[2]	0.33	0.33	0.32	0.005	0.045
Digestibility (kg/kg)					
Organic matter	0.681	0.695	0.687	0.0210	0.785
Nitrogen	0.626	0.625	0.630	0.0241	0.973
Milk fatty acids, (g/100g)					
18:2 *n*-6	0.53^{b}	0.41^{a}	0.42^{a}	0.021	**<0.001**
18:3 *n*-3	0.10^{ab}	0.10^{a}	0.11^{b}	0.025	**<0.001**
Purchased feed costs, p/l	**5.7**	**5.5**	**5.7**		
Total feed costs (p/l)	**7.9**	**7.3**	**7.5**		

[1] Over 28-d period. [a,b] Means within a row with different superscript differ ($P < 0.05$). [2]Milk N output/dietary N intake

Farmer messages

- Spring grown forage peas are a rapidly growing crop that can produce over 7t DM/ha in 12 weeks, with a crude protein content of 200 g/kg DM.
- Compared to grass silage, cows fed forage peas will have a marginally lower milk yield

and milk protein yield, but there will be no effect on fat yield, or live weight change.

- There is little effect of the tannin level in forage peas on intake, milk yield, composition, efficiency of N use or milk fatty acid profile.
- Feeding spring sown forage peas can reduce feed costs by up to 0.5ppl due to savings in both purchased feed costs and the lower growing costs of forage peas.

Further exploitation: Due to this project being submitted near the end of the RP there has been limited KE with dairy farmers. The findings from this study should therefore be incorporated into future AHDB dairy KE events.

B. Executive summary 7) Effect of the addition of hydrolysable tannins to lucerne and red clover silage on the performance and diet digestibility in high yielding dairy cows

Background and Objectives: Red clover and lucerne are of particular interest to GB dairy farmers as they are legumes that grow well in temperate regions. As a consequence they reduce the requirement for artificial fertiliser and compliment the lower protein levels found in cereal based forages such as maize or whole-crop wheat silage (Salawu et al., 2002; Adesogan et al., 2004). Despite this, most of their protein is degraded in the rumen and is therefore not suitable for high yielding dairy cows. A previous study as part of this research partnership investigated the effect of condensed tannins naturally found in forage peas to reduce the degradability of protein in the rumen. Hydrolysable tannins have the advantage of being soluble and therefore can be used as an additive at ensiling or feed out. Studies conducted in sheep at Harper Adams University (Taha, 2015), has shown that the addition of hydrolysable tannins reduced the degradability of N in lucerne silage, and resulted in a significant increase in milk protein yield. The objective of this study was to determine the effects of feeding lucerne and red clover silages with the addition of tannins at ensiling on the performance, N digestibility and milk composition in high yielding dairy cows.

Technical approach: Twelve multiparous Holstein-Friesian high yielding dairy cows were fed one of four diets composed of 55:45 forage to concentrates (DM basis). The forage proportions varied on a DM basis as follows:

Lucerne control (LC):	40:60 lucerne to maize silage
Lucerne plus tannins (LT):	40:60 lucerne plus tannins to maize silage
Red clover control (RC):	40:60 red clover to maize silage
Red clover plus tannins (RT):	40:60 red clover plus tannins to maize silage

Chestnut hydrolysable tannin was added at ensiling at a rate of 25g/kg DM. Cows received one of the four dietary treatments for each of 4 periods in a Latin square design, with each period lasting 28 days and measurements recorded in the final 7 days. Cows were milk twice daily and yield recorded at each milking during the final week of each period, with samples collected on four occasions for subsequent analysis. Live weight and body condition score was recorded at the beginning and end of each period. Blood samples were collected from the jugular vein over two days in the final week. Acid insoluble ash was used as an internal marker to determine whole tract digestibility.

Key results: Feeding lucerne compared to red clover silage increased total DM intake by 2.2 kg/d but had no significant effect on milk yield. Additionally there was no effect of forage source on milk composition or live weight change or whole tract digestibility. Feeding red clover compared to lucerne silage resulted in a slightly higher content of polyunsaturated fatty acids in milk. Including hydrolysable tannins at ensiling had no effect on DM intake or milk yield, whole tract digestibility or N efficiency

Table 3.b.7.1 Milk performance, live weight and body condition score of cows fed diets containing lucerne and maize silage, lucerne plus tannins and maize silage, red

clover and maize silage or red clover plus tannins and maize silage.

	LC	LT	RC	RT	s.e.d	Forage	Tannin	FxT
DM Intake, kg/d	21.3	22.9	20.1	19.6	1.15	0.009	0.533	0.206
Milk yield, kg/d	38.2	38.5	38.6	37.2	2.24	0.781	0.739	0.606
Milk fat, g/kg	40.7	42.2	40.9	42.4	1.98	0.900	0.297	0.972
Milk protein, g/kg	34.1	34.5	33.1	33.4	0.96	0.142	0.673	0.899
Milk lactose, g/kg	49.1	48.7	49.0	48.8	0.51	0.965	0.520	0.819
Live weight, kg	644	660	657	650	25.8	0.942	0.799	0.518
Live weight change, kg/d	4.7	14.5	12.7	12.5	9.72	0.665	0.482	0.471
Digestibility, kg/kg								
Organic matter	0.695	0.660	0.699	0.699	0.0309	0.333	0.421	0.430
Nitrogen	0.640	0.594	0.617	0.604	0.0360	0.803	0.260	0.531
Milk fatty acids, g/100g								
18:2 *n*-6	0.38	0.39	0.42	0.42	0.011	<0.001	0.693	0.285
18:3 *n*-3	0.10	0.09	0.11	0.11	0.003	<0.001	0.128	0.292

[1]Main effects of forage source, tannin and their interaction (FxT)

Farmer messages:

- There is little difference between lucerne or red clover silage on performance, although cows fed lucerne will eat approximately 10% more dry matter
- Decisions on which legume to feed should therefore be based mainly on the ability to grow the crop well, as this will have the greatest effect on overall costings
- Including red clover compared to lucerne will result in a slight improvement in the fatty acid content of the milk, although the differences are comparatively small
- The inclusion of hydrolysable tannins is not an effective means to improve nitrogen use and milk performance in dairy cows yielding approximately 40 kg/d.

Further exploitation: Due to this project being submitted near the end of the RP there has been limited KE opportunity with dairy farmers. The findings from this study should therefore be incorporated into future AHDB dairy KE events.

B. Executive summary 8) Forage Maize in the UK – A Review

Background and Objectives: Maize is a key component of dairy cow diets across much of GB, with an estimated 196 000ha of maize grown in the UK in 2013, a six-fold increase in area since 1990. Although a tropical crop, advances in breeding and a warming climate have increased the potential area available in GB to support the growing of forage maize. Over the past few decades there has been a large body of applied and strategic research on growing and feeding maize silages in the UK and further afield. Some of this work has been published in scientific papers whilst other work has been published in reports to funding bodies, technical bulletins or in conference proceedings however it has not been collated.
The objectives of this study were to review literature on the main agronomic, ensiling and feeding to establish best practice and identify areas where future research should be best directed.

Technical approach: A systematic analysis of peer reviewed research papers, commercial research reports and articles that related to site suitability, establishment, agronomy, harvest, ensiling and feeding of maize to dairy cattle along with any environmental implications was undertaken at the University of Reading, and a written report produced.

Key results: Due to the climate of the UK maize has only become an established main stream crop in the last 20 to 30 years – consequently UK based research is also behind that available from the US, Europe and Australia. In many instances the research from abroad can be applied to UK conditions with a good degree of confidence, for example the extent to which nutritive

value of maize varies by variety remains similar globally. This means that feeding trials carried out in the US, for example, using ‘corn’ silage will be useful to researchers and producers in the UK and vice versa.
In the fields of agronomy and pest and disease control, it is more difficult to use research from abroad where climatic conditions are very different to those found in the UK (or elsewhere). It is in these areas where UK research is absolutely essential in order to provide UK maize growers with relevant up to date information. There has been excellent research on agronomy of maize growing in the UK and there are plenty of guides already available to growers – often free of charge. The same is true for guides to dealing with pests and diseases; although these are often produced by companies selling products, there also are independent guides available.
One area of research needed is in the area of reduced tillage methods for maize crop establishment, which has not been researched extensively for UK conditions.
Likewise an area of real concern for UK maize growers is the selection of varieties. As the UK is a marginal area for maize growing it is essential that producers have the best possible information on each variety of maize – especially when dealing with early maturing varieties. For a crop as important as maize is to the dairy industry there is some information available from NIAB trials but further yearly trials would be of benefit, akin to those conducted for wheat, where earliness of varieties is recorded. As the UK climate is seemingly set to continue to increase in temperature it would be valuable to the industry if Ontario Heat Unit measurements were calculated for sites across the UK.
Finally more work needs to be done on precision farming with regards to the use of organic manures on maize in the UK. There is often a surplus of nutrients applied to maize crops which can cause environmental problems. As there is increasing government legislation on this issue it is important that farmers are given the best advice on how to maximize the efficient use of manures, a valuable farm resource. Whilst it is encouraging that the issue is more widely understood through initiatives such as the Catchment Sensitive Farming Initiative there is still often an environmental problem with maize.

Farmer messages:

- There is a body of research available on growing and feeding maize, although much on agronomy is from commercial sources.
- Maize inclusion in diets at any rate has been shown to increase intake and milk yield of dairy cows. When maize is the main forage in a ration it is important to balance it with high protein feeds as maize is low in protein.
- The optimum DM at harvest for maize is 32-34%, as long as this is achieved before a serious frost kill.
- Ontario Heat Units need to be calculated for sites across the UK to help assess when conditions are suitable for harvest.
- An understanding of European pests and diseases is important so that if they become prevalent in the UK, producers will know what to expect and how to eliminate it.

Further exploitation: It is important to transfer the findings from this report to dairy farmers so that they are able to adopt best practice. It is also important to highlight to farmers that information in lacking on appropriate varieties (particularly for marginal areas), that agronomic advice is generally based on commercial literature than independently funded (unlike feeding studies), and that further research on minimum tillage as a means of establishment, and precision farming of maize is required, particularly for organic manures. This information can further be exploited by highlighting the areas suitable for research to government and industry, as well as other sectors of AHDB, to secure future funding and provide a more integrative funding approach. There is a lack of information on precision farming for maize, particularly in relation to organic manures.

C. Delivery against milestones - tabulate achievement of milestones against targets set.

List any deviations or agreed changes in direction, and their impact on the project (if applicable, describe how the work differs from that originally proposed and describe how the changes have impacted on the work package. Include changes to objectives and work plan / budget, changes to the team or other constraints. Explain any discrepancy between planned worked and achieved work, and corrective actions taken.

Work Package 3b – Conserved Forage Production and Utilisation	**Progress, deviations and corrective actions**
Milestone 3bi **–** Set-up experiments at Reading University to development reliable NIRS equations for predicting the OMD, ME and degradability of grass/clover silages in a two year experimental series (Q3, Yr1).	Methods of developing reliable NIRS equations established at UoR.
Deliverable 3b.1 – Publish NIRS model for the prediction of grass/clover silage OMD, ME and degradability for use in *Feed Into Milk* (Q4, Yr3).	Delayed due to difficulty in securing appropriate silages. Final report submitted to AHDB Dairy May 2016.
Milestone 3bii – Plan detail and grow lucerne for feeding experiments at UoR and SRUC (Q3, Yr2).	Lucerne established at UoR and SRUC for feeding experiments.
Milestone 3biii – Plan detail and grow lucerne for feeding experiments at HAU (Q3, Yr3).	Lucerne harvested May 2013, ahead of schedule.
Deliverable 3b.2 Report on the effects of feeding conserved lucerne in combination with either maize silage (Reading University) or grass silage and maize silage (SRUC) on the performance of high yielding dairy cows (Q4, Yr4).	Final report submitted by SRUC Feb 2015, ahead of schedule.
Milestone 3biv – Plan detail and grow lucerne for proportional feeding experiments with high yielding cows at SRUC (lucerne/grass silage) and Reading University (lucerne/maize silage) (Q3, Yr3).	Study design at SRUC changed to evaluate the effect of stage of maturity at harvest. Study commenced at SRUC winter 2015/2016
Deliverable 3b.3 Report on the effect of stage of maturity at harvest on the feeding value of lucerne silage and the performance of high yield dairy cows (Q4, Y4)	Study delayed due to due to seasonality of the study in relation to the end date of the research partnership Report to be submitted 9th Dec 2016.
Milestone 3bv **–** Plan detail and grow lucerne for chop length and inclusion rate effects on digestibility and milk yield experiment at Reading University (Q3, Yr3).	Feeding study commenced on time
Deliverable 3b.4 – Report on chop length and inclusion rate effects on digestibility and milk yield experiment at UoR (Q4, Yr4).	Final report submitted to AHDB Dairy Nov 2015.
Milestone 3bvi – Plan detail and grow lucerne for lucerne/grass silage (SRUC) and lucerne/maize silage (HAU) experiments to investigate the effects of graded inclusion rate on milk yield for high yielding dairy cows (Q3, Yr4).	Lucerne study commenced at HAU Nov 2013, ahead of schedule.
Deliverable 3b.5 Report on the impacts of graded inclusion rate of lucerne silage in	Report from HAU submitted June 2014. Final report from SRUC being prepared on

combination with grass silage (SRUC) and maize silage (HAU) on the performance of high yielding dairy cows (Q4, Yr5).	effect of stage of maturity at harvest.
Milestone 3bvii – Set-up experiment (at HAU) to study the agronomy of growing peas/beans (Q1, Yr3).	Milestone changed and research work consumed within performance study.
Deliverable 3b.6 **–** Report (HAU) on pea/bean agronomy experiment (Q2, Yr4).	Deliverable changed and consumed within performance study, which was submitted June 2016.
Milestone 3bviii – Winter sow peas and beans with different tannin contents and plan detail for milk yield experiment at HAU (Q1, Yr4).	Peas established April 2014 and harvested/ensiled in July 2014.
Deliverable 3b.7 – Report (HAU) on pea/bean/tannin effects on milk yield (Q4, Yr4).	Final report on low and high tannin peas submitted June 2016, behind schedule due to illness of the PhD student.
Milestone 3bix **–** Winter sown peas or beans and plan detail to investigate the effects of stage of harvest and inclusion rate on milk yield (Q1, Yr5).	Milestone changed to compare red clover with lucerne with or without added hydrolysable tannins. Red clover and lucerne harvested June/July 2015.
Deliverable 3b.8 – Report on the effects of harvest growth stage and inclusion rate of either peas or beans on the milk yield of high yielding dairy cows (Q4, Yr5).	Deliverable changed to compare red clover with lucerne with or without added hydrolysable tannins. Study completed, analyses being finalised and final report being prepared, but has been delayed due to the illness of the PhD student.
Milestone 3bx – Commence work on desk top review of maize agronomy and feeding (Q1, Yr2).	Work started on literature review of maize suitability, establishment, agronomy, harvest, ensiling and feeding.
Deliverable 3b.9 – Report on desk top review of maize agronomy and feeding (Q4, Yr2).	Report submitted 2013 on schedule.
Deliverable 3b.10 **–** Review and update *feeding+* (Q3, Yr4).	N/A
Deliverable 3b.11 **–** Produce forage+ (Q1, Yr5).	N/A

D. Outputs (List and fully reference all outputs which document and promote the findings of this work. Describe any further outputs or follow-up initiatives anticipated after 31 May 2016).

D (I) Experimental/project reports to AHDB

Thompson, A.L. (2016). Near Infra-Red Spectroscopy for Grass-Clover Silages in the UK.

Thompson, A.L. (2016).The effect of varying inclusion rate and chop length of lucerne silage in a maize silage-based total mixed ration for dairy cattle

Dines. L. (2016). Effect of sowing date and under sowing with spring barley on the yield, quality and persistency of lucerne in the UK

Campbell, C.E.A., Williams, S-J., Huntington, J.A. and Sinclair, L.A. (2016). Effect of forage peas with varying tannin content on the performance of high yielding dairy cows.

Roberts, D.J. and Flockhart, J. (2015). Lucerne silage as a replacement for grass silage for high yielding dairy cows.

Sinclair, L.A. and Wilson, S. (2014). Lucerne silage as a replacement for grass and maize silage for high yielding dairy cows.

Reynolds, C.K. (2013) Forage Maize in the UK – A Review

D (II) Scientific publications (accepted or submitted; peer reviewed conference proceedings etc.)

Sinclair, L.A., Edwards, R., Errington, K.A., Holdcroft, A.M. and Wright, M. (2015). Replacement of grass and maize silages with lucerne silage: effects on performance, milk fatty acid profile and digestibility in Holstein-Friesian dairy cows. *Animal* 9: 1970-1978.

Sinclair, L.A., Edwards, R., Errington, K.A., Holdcroft, A.M. and Wright, M. (2015). Replacement of grass and maize silage with lucerne in the diet of high yielding dairy cows: effect on performance and milk fatty acid profile. *Advances in Animal Biosciences* p189.

Flockhart, J.F. and Roberts, D.J. (2015). Lucerne as a replacement for grass silage in the diet of lactating dairy cows. 12th BGS Conference, Aberystwyth University.

Thomson, A. L., Reynolds, C. K., Jones, A. K., Humphries, D. J. (2016). Effect of inclusion rate and chop length of lucerne (medicago sativa) silage in a total mixed ration with maize (Zea mays) on milk yield and composition in dairy cattle. Proceedings of the British Society of Animal Science, 2016, Advances in Animal Biosciences, 120.

Thomson, A., Reynolds, C., Rymer, C., Humphries, D. (2016). The accuracy of Near Infra-red Spectroscopy analysis when used on clover-grass silages in the UK. EAAP Belfast, 2016.

Campbell, C.E.A., Huntington, J.A. and Sinclair, L.A. (2016). The replacement of grass silage with white or coloured flower forage pea silages in the diet of high yielding dairy cows and their impact on performance and milk fatty acid profile. 67th meeting of the European Association of Animal production, Belfast UK.

Sinclair, L.A. (2016). Improving the utilisation of forages in dairy cow rations. *Proceedings of the Society of Feed Technologists,* 21st April 2016, Coventry, UK.

Campbell, C.E.A., Huntington, J.A. and Sinclair, L.A. (2016). The effect of white or coloured flower pea silage as a replacement for grass silage on the performance and whole tract digestibility of high yielding dairy cows. *Advances in Animal Biosciences* p121.

D (III) Knowledge transfer (national and international workshops, farmer/industry meetings, media articles etc.)

Farmer-industry meetings

Meeting	Location	Date	Attendees
Research Day – NIRS, lucerne	Reading	Mar 13	130
Research Day – growing lucerne	Harper Adams	Sep 13	120
Research Day – feeding lucerne	Dumfries	Nov 13	120
Grass and Muck – is lucerne an option	Stoneleigh	May 14	300
Truro demo farm meeting	Cornwall	July 14	20
Recognising the value of silage	Cheshire	Nov 14	25
BCBC - Feeding the contemporary dairy cow	Telford	Jan 15	20
Grasslands UK Seminar Series	Somerset	May 15	40
Growing and feeding lucerne	Dorset	Jul 15	29
Growing and feeding lucerne	Gloucester	Aug 15	19
Research day	Norfolk	Oct 15	50

ASA meeting - Alternative forages	Dublin	Nov 15	75
Dairy Leaders conference	Coventry	Nov 15	40
Whitehorse discussion group	Dorset	Dec 15	25
PhD conference - Forage legumes for the UK dairy industry	Coventry	Dec 15	100
SOLID Conference	Bristol	Jan 16	70
DIG Conference – lucerne, grass-clover, wholecrop peas	Kegworth	Mar 16	264
Lucerne open meeting	Monmouthshire	Apr 16	30
Lucerne open meeting	Breacon	Apr 16	10
Lucerne open meeting	Leicestershire	Jun 16	15
		Total	**1502**

Farming press

Title	Media	Date
New chemical analysis of silages containing clover	Farmers Guardian	Apr 13
New developments in silage analysis	British Dairying	May 14
Lucerne factsheet	British Dairying	May 14
Lucerne could be a useful long term source of protein	Farmers Guardian	Oct 14
Research aims to improve GB lucerne establishment	Farm Business	Oct 14
Improving use of protein	British Dairying	Feb 15
Assessing potential of lucerne	British Dairying	Jun 15
Clover value has long been underestimated	Farm Business British Dairying	Mar 16

Online

Title	Media	Date
Growing and feeding lucerne	Forage for Knowledge	Aug 13
Video - Using lucerne as a forage crop	AHDB Dairy	Sep 13
Using lucerne in the GB dairy industry	Forage for Knowledge	Dec 14
Growing and Feeding Lucerne	EBLEX publication	Feb 14
Using Lucerne in the GB dairy industry	Forage for Knowledge	Mar 14
NIRS equations for grass-clover silages	Forage for Knowledge	Apr 14
Video - Students investigate use of lucerne in dairy cow diets	HAU and AHDB Dairy websites	May 14
Growing and Feeding Lucerne booklet	AHDB Dairy website	May 14
Simple steps a must for growing lucerne	The Dairy Site	May 14
The benefits of lucerne	Forage for Knowledge	Oct 14
Cheshire research day – Lucerne	Forage for Knowledge	Oct 14
Supplying sustainable protein in high yielding cow diets	BGS website	Nov 14
Webinar – feeding the contemporary dairy cow	AHDB Dairy YouTube	Jan 15
Red clover vs lucerne	Farming Futures	Jul 15
Red clover vs lucerne	Forage for Knowledge	Jul 15
Can lucerne deliver for your cows	Forage for Knowledge	Oct 15
Lucerne a real forage option	Forage for Knowledge	Oct 15
Considering your 2016 forage options	Forage for Knowledge	Oct 15

E. Benefits of the research results to the British dairy sector

E (I) Economic benefits (describe, and wherever possible quantify, potential financial benefits at farm level, and/or to the industry as a whole)
More accurate rationing of mixed clover/grass silage swards will reduce the requirement for purchased feed, reducing the environmental impact of dairy farming. Evidence based advice on when and how best to establish lucerne will also result in more successful establishment, reducing establishment costs. In a maize based ration, replacing grass silage with lucerne can result in substantial savings of between 7 and 22 p/cow/day; for a 130 cow herd this is equivalent to approximately £1400 to £4300 for a 150 day feeding period. In a grass silage based ration, the benefits of lucerne are more sensitive to the price of purchased feed and as a consequence there is likely to be an increased purchased feed cost, particularly at higher inclusion levels. For forage peas, feed costs were between 0.3 to 0.5ppl lower than grass silage, which should be offset against the lower milk yield and revenue. Leguminous crops (including peas) and pasture legumes (including lucerne and clovers) also have advantages in relation to current EU CAP funding, although whether this will continue into the future is unclear. Numerous studies have reported a benefit to feeding maize, but the cost benefit is only apparent if the crop is grown in a suitable area and the literature review provides dairy farmers with an evidence based information source to improve management.
E (II) Sustainability benefits (How will outputs support sector sustainability in the long-term? Will the activity support sustainability in other ways such as improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)
More accurate rationing of mixed clover/grass silage swards will reduce the requirement for purchased feed, reducing the environmental impact of dairy farming. Evidence based advice on when and how best to establish lucerne will result in more successful establishment in the spring, reducing the potential for poor establishment and run-off during particularly wet seasons. A longer chop length of lucerne will improve rumen pH and potentially reduce the risk of sub-acute ruminal acidosis improving cow health, although this is only likely at very high inclusions of lucerne which are associated with a reduction in DM intake and milk yield. Incorporating lucerne or forage peas into the ration will reduce the requirement for purchased protein. More appropriate advice on variety choice and agronomy of maize should improve the nutritive value at harvest, particularly in marginal growing areas. A lower reliance on nitrogen fertilisers and subsequently fossil fuels as a consequence of growing legumes will lower the carbon footprint of milk production, although quantification of this effect was outside the scope of this project. This WP has resulted in 2 x PhD studentships (1 x UoR and 1x HAU) and 10 x undergraduate student research projects (HAU).
E (III) Policy making (Describe how the work informs policy, leads to better decision making, or addresses wider societal concerns)
This work addresses wider societal concerns by substituting imported protein sources such as soyabean meal with home grown legumes. This also provides a GMO free feed source and reduces the pressure on exploiting ecosystems to grow soya in areas such as South America. Additionally, a lower reliance on nitrogen fertilisers and subsequently fossil fuels is also of benefit to the UK economy and the environment.
E (IV) Supply chain (Does the work address supply chain constraints or opportunities)
There is little evidence from the series of studies that including forage legumes such as lucerne, red clover or forage peas in the diet of dairy cows will substantially alter milk quality. Including maize may increase milk protein content and therefore enhance the cheese yield.

F. Leverage and added value (Detail all additional funding sources and collaborations nationally or internationally. Has this activity contributed to applications for further research in this area? Has the work contributed to improving skills or attracting new entrants into the

industry e.g. PhD studentships/post-docs?)
The maize review has identified areas for future research that is of relevance to government, industry and the levy bodies. The program of work in the WP has also highlighted that there is limited information on the effect of low protein diets based on high protein forages such as forage legumes on animal performance and health. The combination of these two factors could further decrease dietary feed costs and mitigate the impact of volatile world feed and oil markets on the UK dairy industry. This study has supported one PhD student at HAU and one at UoR, with an additional 10 undergraduate honours research students at HAU who have subsequently entered the agricultural industry.

Work package title:	WP 4: Out-wintering for replacement heifers reared for low or high input milk production systems		
Start date (mm-yyyy):	10-2011	**Actual (£)**	£274k
End date (mm-yyyy):	01-2016	**Planned cost (£)**	£274k
Name & organisation of principal investigator (PI):	Liam A. Sinclair Harper Adams University (HAU)		
Collaborators:	SRUC and HAU		

A. Overview by work package leader

Underpinning rationale: Out-wintering is the practice of rearing cattle outside through the winter months on a purpose built out-wintering pad, on a ‘sacrifice’ field, or using *in-situ* grazed forage (Barnes et al., 2013). These *in-situ* systems commonly use autumn saved pasture (deferred grazing) or a crop grown specifically for winter grazing (e.g. fodder beet, kale or swedes) and usually include grass silage supplementation (Barnes et al., 2013). Out-wintering replacement dairy heifers has been suggested as a low cost alternative to housing (French et al., 2009) and may help facilitate dairy herd expansion. Improving animal health and welfare is also a potential reason why dairy farmers out-winter. Offset against this, winter weather and soil conditions may increase the risk to animal health and performance during the out-wintering period and subsequent lactation (Barnes et al., 2013). Additionally, if not managed well, out-wintering systems may (and have) received criticism from the general public on welfare grounds and there is the added risk of soil damage, run off and leaching of nitrogen and phosphorus into water courses. Work has been conducted in the Republic of Ireland on out-wintering systems for spring grazing dairy cows, but little work has been conducted on the impact of out-wintering replacement heifers in low and higher output systems.

Work package objectives: The objectives of this work package were several-fold:

a) determine best practice on dairy farms that were currently out-wintering replacement heifers and disseminate this information
b) determine the effect of rearing replacement heifers on fodder beet, kale and deferred grazing for commercial, spring calving dairy herds in GB and to evaluate the effect of a mineral bolus on performance and fertility pre and post-calving
c) determine the effect of out-wintering Holstein heifers destined for a high output system on fodder beet, kale, deferred grazing or housed, in two separate geographical locations and soil types
d) determine the impact of out-wintering on indicators of animal health, welfare and soil conditions
e) quantify the impact of out-wintering on the cost of heifer rearing compared to housing.

Approach: To examine these objectives 4 studies were conducted. In the first study a questionnaire was sent to 120 dairy farmers who were known to be out-wintering (Executive Summary 1) to determine current practice, reasons for out-wintering and areas where further research should be directed. Following this, a participatory research project was conducted with 9 commercial dairy farmers spread across GB that were out-wintering replacement heifers on kale, fodder beet or deferred grazing (Executive Summary 2). These forages were chosen as they were identified as the most popular from the initial survey. Additionally, the survey identified that mineral supplementation was one of the areas requiring further research and therefore on each farm half the study heifers were reared without mineral supplementation and half with a copper/selenium/cobalt/iodine bolus. The impact of out-wintering on performance, blood mineral levels, calving difficulties and subsequent lactation performance and fertility was recorded. There was more of a difference within than between out-wintering systems, with success of the system dependent on regular monitoring of animal performance and crop availability. Supplying a mineral bolus has a small but significant benefit to body condition prior to calving, but had little effect on performance pre- or post-calving, although there was more of a benefit to heifers that had been out-wintered on kale.

Finally, two controlled studies were conducted at different locations; Harper Adams University (Shropshire; Executive Summary 3) and the SRUC (Dumfries; Executive Summary 4), to determine the effect of out-wintering in-calf Holstein heifers on pre-calving performance, behaviour, calving difficulties and subsequent lactation performance and fertility in high output systems. At Harper Adams University out-wintering on fodder beet and deferred grazing was compared with housing. At SRUC out-wintering on kale and deferred grazing was compared with housing. Variable and fixed costs were recorded at both sites. Compared to housing, out-wintering resulted in savings of approximately £150-180/heifer, without any impact on subsequent performance and fertility, although animals out-wintered on kale had a longer calving interval. This saving equates to approximately 0.5 to 0.6 ppl over the lifetime on an average UK dairy cow.

Delivery: All four studies met or exceeded their objectives, were conducted on time, achieved their milestones and were on-budget. Findings from the studies have been disseminated at farmer meetings, research days, farmer conferences and academic conferences. Additionally, findings have been reported extensively through the farming press and at technical conferences. A number of papers have been presented at academic conferences and have either been submitted or will shortly be submitted to peer review journals. The work package has also resulted in the production of a series of Youtube videos which will allow farmers to continue to access the study findings and advice on how to best manage out-wintered heifers to maintain performance targets and optimise welfare and the environment.

B. Executive summary 1) A survey of current practice among farmers out-wintering replacement dairy heifers in Great Britain

Background and Objectives: With the trend towards increasing dairy herd size (AHDB, 2015) as a means of cost effective milk production comes increasing pressure on buildings to accommodate the cattle. Options to facilitate increasing numbers of cattle in the milking herd include construction of dedicated additional heifer replacement buildings, woodchip pads (McCarrick and Drennan, 1972; Boyle et al., 2008) or purchasing down-calving replacement heifers. Another alternative, to permit dairy herd expansion without the need for major capital investment, is to out-winter replacement heifers. These low capital systems have the potential to decrease rearing costs by reducing housing, bedding and feed costs. Out-wintering is successfully conducted on a number of dairy farmers in GB, but the main reasons for out-wintering and the key factors leading to success are unclear. The objectives of the current study were to survey current practice on dairy farms that were out-wintering replacement heifers to determine best current practice so that this could be transferred to other farmers and to identify areas where farmers would like research conducted.

Technical approach: A survey was posted to 120 farmers that were known to be, or had recently practiced out-wintering of replacement heifers. The questionnaire was posted in April 2012, with a follow up sent to non-returnees at the end of April and then again at the beginning of August 2012. Telephone calls were also made to non-returnees, and an online version of the questionnaire was publicised via Twitter and a Facebook discussion ‘e-group’ dedicated to out-wintering cattle. At the close of the survey on 1 October 2012, a total of 70 usable questionnaires had been received (a return rate of 58%). The farm locations ranged from the South West of Scotland to South West England and 69% were spring calving.

Key results: Out-wintering herd characteristics are presented in Table 4.1.1. The major reason for out-wintering was to reduce the cost of heifer rearing and improve animal health and welfare, which was rated on a scale of 1 (not important) to 5 (extremely important) as 4.56 and 4.06 respectively. Grass was the most common forage being used, and was grazed at an average pasture cover of 3284kg DM/ha. The most common forage crop was kale (with a mean yield of 10.0t DM/ha), followed by fodder beet (with a mean yield of 21.2t DM/ha), although fodder beet was less commonly grazed by heifers <1 year old. Strip grazing was the most popular means of utilising out-wintering forages, being employed on 70% of farms. Big bales were the most common supplementary feed, used on over 80% of farms, and were stored in the field on the majority of farms. The wastage of supplementary feeds was regarded as low at an average of 12%, but ranged from 0 to 50%. Mineral boluses were used on 49% of farms, whilst 20% used no supplementary minerals. Strategies for dealing with severe weather for out-wintered heifers included allocating an additional area (43%) and/or offering additional feed (41%), although 40% of farmers did not consider that they needed to alter their management due to the weather. Housing of poor condition/underweight animals was conducted on 54% of farms, whilst 35% out-wintered these animals in a separate group. Fields with free draining soils and the use of a back-fence, along with a grass run-back/headland area stand-off area were viewed as the major factors to avoid poaching, whilst free draining soils and avoiding steep fields were the most important to avoid run-off. Nearly 75% of farms ploughed the fields following out-wintering, with grass subsequently being sown by 70%. The primary perceived benefit of out-wintering was to increase overall profit, and the economics of out-wintering was the aspect that the majority of farmers wished to see more research on, although several other areas were also considered very important, including mineral nutrition.

Table 4.1.1. Characteristics of farms that are out-wintering replacement dairy heifers in Great Britain (GB).

	Mean	Std. Dev.	Median	Min.	Max.
Herd size	368	206	325	35	1100
Milk yield (kg/cow/yr)	5360	1498	5188	2700	9800
Replacement rate, %	20%	5%	20%	10%	35%
Heifers < 1 year old	69	92	36	0	500
Heifers > 1 year old	95	84	80	0	360

Farmer messages: Dairy farmers that out-winter replacement heifers do the following:

- Out-winter mainly to reduce the cost of rearing heifers and improve animal health and welfare.
- Use grazed grass, kale or fodder beet, which is generally strip grazed and supplemented with big bales, straw or hay that is placed in the field prior to grazing.
- Choose free-draining soils to avoid poaching and run-off, and use a back fence. A grass run-back/headland area is also used to provide a dry lying area.
- Employ strategies for dealing with severe weather that include allocating an additional area and/or offering additional feed.
- House poor condition/underweight animals or out-winter these animals in a separate group
- Utilise over 80% of the forage crop and achieve a live weight gain of approximately 0.6 kg/head/day, and a body condition score of 3.2 at calving.

Further exploitation: The findings from this study have been used to provide best practice advice to farmers who are considering out-wintering. The research has also identified a lack of information on the impact of out-wintering on subsequent performance, particularly for high output dairy systems, and the impact of mineral supplementation. These findings can be used to provide quantitative evidence to policy makers of current practice, and strategies that dairy farmers are employing to mitigate any effect on animal health, welfare and the environment.

B. Executive summary 2) The performance of replacement, spring calving dairy heifers out-wintered on deferred grazing, kale or fodder beet on commercial dairy herds, and the influence of a trace mineral bolus

Background and Objectives: Through the winter months, grass growth and quality is insufficient to support the target levels of animal performance. However, research studies and reported commercial practice (Atkins et al., 2014) suggest that these targets can be met by feeding high energy forage brassicas (e.g. swift hybrid brassica, stubble turnips or kale) or fodder beet, provided the animals have access to baled grass silage. These systems are typically used to rear heifers (Atkins et al., 2014) or maintain dry in-calf cows for spring calving grass-based lower input systems (French et al., 2009), but their level of success on commercial dairy farms in the UK has not been evaluated.

The nutritional advantages of dedicated out-wintering forages such as kale and fodder beet may be offset by the presence of anti-nutritional factors. For example, kale has a number of anti-nutritional factors including s-methyl cysteine sulphoxide, goitrins and thiocyanates (McDonald et al., 2011). Fodder beet is high in soluble carbohydrates which are associated with acidosis and contain oxylates in the leaves which can bind calcium and affect kidney metabolism (McDonald et al., 2011). A recent survey has indicated that for housed, winter fed dairy cows that minerals are generally supplied well in excess of animal requirement (Sinclair and Atkins 2014), although the benefits of supplementation on animal performance and subsequent fertility in low input, out-wintered systems is unclear. The objectives of this study were to determine the growth and lactation performance and health of 18-24 month old, in-calf crossbred dairy heifers out-wintered on deferred grazing, kale or fodder beet on commercial herds, and to assess the effect of a trace element mineral bolus on winter animal performance, and subsequent first lactation milk production and fertility. The study also monitored the effect of rearing system on winter soil conditions.

Technical approach: Performance pre- and post-calving of heifers out-wintered in commercial herds was investigated on nine spring calving, grazing based, crossbred dairy farms that were out-wintering pregnant heifers due to calve at 24 months of age from February 2013. Three of the farms were grazing deferred grass (G), three kale (K) and three fodder beet (F). Feeding protocol, quantity of crop offered, and supplementary feed followed the commercial practice on each farm. On each farm, a sub-set of 40 Holstein-Friesian x Jersey heifers were randomly allocated to one of two treatments; either a long acting trace mineral bolus (B+; CoSeICure, Telsol Ltd, Leeds, UK), or no bolus (B-). The study heifers were managed within the larger group of non-study heifers. The farms were visited over a 12 wk period on three occasions (early November 2012), middle (prior to Christmas 2012), and end of the wintering period (end Jan/beginning February 2013) and performance and crop yield and utilisation recorded. Details of calving, health and fertility were recorded on each farm with each visited at approximately wk 10 and 19 post mean calving date and milk performance recorded.

Key results: Growth performance was very variable between and within farms during the out-wintering period, partly due to the variation in weather between sites, but also to a difference in the frequency of measuring growth rate and subsequent management. However, there was no effect of forage source or provision of a mineral bolus on animal performance, except body condition prior to calving which was slightly higher in animals receiving a bolus (Table 4.2.1). Provision of a trace mineral bolus increased blood concentrations of the minerals supplied in the bolus. There was no effect of out-wintered forage source on milk performance, but a bolus increased milk fat content and tended to increase fat corrected milk yield in early lactation, especially in herds that had grazed kale. There was no effect of treatment on health or reproductive performance, except for the overall percentage conceived at the end of the breeding period, which was higher in farms that had fed fodder beet during the rearing period.

Table 4.2.1. Performance of pregnant heifers out-wintered on grass (G), kale (K) or fodder beet (F), and either did not receive (B-) or received (B+) a trace mineral bolus.

	G	K	F	s.e.d.	*P*-value	B-	B+	s.e.d.	*P*-value
Rearing period[1]									
LWG[2] kg/d	0.18	0.42	0.15	0.234	0.492	0.25	0.25	0.024	0.968
BCS[3], wk 12	2.49	2.48	2.38	0.117	0.636	2.44	2.47	0.016	**0.035**
Plasma minerals wk 12									
Cu (mmol/l)	12.0	13.3	13.5	2.09	0.753	11.3	14.6	0.57	**<0.001**
Se (µmol/l)	0.67	0.63	0.73	0.146	0.820	0.50	0.86	0.03	**<0.001**
Lactation (wk 10)									
Milk yield (kg)	18.2	19.2	16.4	1.85	0.390	17.8	18.1	0.35	0.394
FCM[4] (kg)	18.6	19.5	17.1	1.98	0.526	18.1	18.7	0.39	0.087
Fat (g/kg)	41.7	40.2	43	0.22	0.549	40.7	42.6	0.71	**0.009**
BCS[3]	2.13	2.02	2.03	0.075	0.332	2.07	2.05	0.025	0.611
SCC[5] ($\log_{10}$)	1.74	1.76	1.81	0.086	0.605	1.78	1.76	0.043	0.593
Reproduction									
% cycling at start	76	82	53	-	>0.1	75	69	-	0.225
% return 1st service	57	57	52	-	>0.1	54	57	-	0.572
% conceived	88	86	95	-	**<0.05**	90	91	-	0.748

[1]Wk 0-12 = 1st Nov to end Jan 2013; [2]live weight gain; [3]body condition score; [4]Fat corrected milk yield; [5]somatic cell count

Farmer messages:

- There is more variation in heifer performance between individual farms than due to the out-wintered forage. Decisions on the most appropriate forage should therefore be made on soil type and crop yield
- Performance targets are more likely to be met on farms that weigh and monitor animals regularly
- Supplementing with a mineral bolus has a marginal effect on body condition prior to calving, and increases milk fat content in early lactation, especially in herds grazing kale
- There is no subsequent effect of out-wintering forage type or provision of a mineral bolus during the out-wintering period on the health or reproductive performance of first lactation cows, although there may be a benefit to providing a bolus to heifers grazing kale
- If an appropriate choice of soil type is made, there is little difference in soil conditions on farms out-wintering on grass, kale or fodder beet, with an increase in soil compaction post-grazing on all three systems.

Further exploitation: These findings can be used to inform dairy farmers who are, or are considering out-wintering replacement heifers, of the key factors to ensure success. These findings also provide quantitative evidence to inform policy makers and the general public of the management factors that commercial dairy farmers are undertaking to improve animal health, welfare, performance and the environment.

B. Executive summary 3) The effects on performance of out-wintering replacement heifers on fodder beet or deferred grazing in a high output dairy system in the West Midlands

Background and Objectives: Out-wintering systems commonly use autumn saved pasture (deferred grazing) or a crop grown specifically for winter grazing, and usually include grass silage supplementation (Atkins et al., 2014). Currently the most popular forages used for out-wintering within Great Britain are deferred grazing, kale or fodder beet, with on average 34 – 44% of dry matter intake provided as baled grass silage (Atkins *et al*., 2014). For spring calving, grazing based systems it has been reported that there is little subsequent effect on milk performance or fertility from out-wintering (Keogh *et al*., 2009a, 2009b; Kennedy *et al*., 2012; O'Driscoll *et al*., 2010). Out-wintering Holstein type heifers has the particular attraction of releasing capital and buildings that can be used for herd expansion, as well as reducing the costs of the rearing phase. The effects of out-wintering replacement Holstein heifers destined for a high output system with total mixed ration (TMR) based feeding has however, not been investigated. The objectives of this study were to determine the effects on performance of in-calf Holstein dairy heifers destined for a high output, TMR system that were out-wintered on deferred grazing, fodder beet, or housed during the winter of 2013/2014, and to record and compare the costs of rearing of each system.

Technical approach: Forty eight, 23 month old, in-calf Holstein heifers were randomly assigned to one of three treatments: out-wintered on perennial ryegrass and grass silage (G); out-wintered on fodder beet and grass silage (F); or housed and fed grass silage and concentrate (H). The two out-wintered treatments received approximately 35% of their daily DM intake as big bale silage via ring feeders. The study commenced in November 2013, with heifers continuing on their respective treatments for 13 weeks, before being housed for six weeks prior to parturition and fed a single dry cow total mixed ration (TMR). Post-partum all animals received the same lactation TMR diet with performance measured for the first 12 weeks of lactation.

Key results: Heifer live weight was similar following out-wintering on either fodder beet or grass compared with housing (Table 4.3.1). Live weight gain was high (1.10 kg/cow/d) for all treatments but was lower in animals that were out-wintered on grass. Body condition score (BCS) of heifers that received G was also lower at housing and parturition. Post-partum, mean live weight was unaffected by treatment, but mean BCS was lower in animals that received deferred grazing during the out-wintering period. Levels of blood ketones (β-hydroxybutyrate; BHB) during the out-wintering period were lowest in heifers that were housed and highest in those out-wintered on fodder beet prior to calving, but were unaffected by dietary treatment post-partum. Milk yield was not affected by out-wintering treatment, but milk fat (g/kg) was lowest and milk protein (g/kg) highest in animals that had been out-wintered on fodder beet, whereas milk somatic cell count was lower in heifers out-wintered on grass than fodder beet. There were no effects of treatments on measures of fertility. Rearing costs were calculated to be reduced by around £150/head by out-wintering, but were similar between fodder beet and deferred grazing. For deferred grazing if managed appropriately (e.g. initial cover of 3500 kg DM/ha cover grazed down to 2500 kg DM/ha and using a back fence), soil and crop damage can be limited to the immediate area of the ring feeders with little effect on subsequent crop yield.

Table 4.3.1. Performance pre and post-calving of Holstein heifers that had been out-wintered on fodder beet (F) with grass silage, perennial ryegrass (G) with grass silage, or housed (H) with grass silage and concentrates.

	F	G	H	s.e.d	P
Out-wintering period					
Initial Lwt	475	476	479	20.2	0.979
Lwt change (kg/cow/day)	1.24	0.95	1.11	0.071	**0.001**
Initial BCS	2.53	2.48	2.50	0.125	0.930
BCS change	0.08	-0.06	0.22	0.071	**0.002**
Plasma BHB (mmol/l)	0.76	0.55	0.42	0.045	**< 0.001**
Post-partum period					
Parturition Lwt (kg/cow)	560	543	565	16.5	0.390
Lwt change (kg/cow/day)	0.11	0.10	0.07	0.123	0.951
Parturition BCS	2.72	2.48	2.77	0.091	**0.007**
BCS change (0-12 wks)	-0.01	0.08	-0.18	0.103	**0.052**
Plasma BHB (mmol/l)	0.59	0.61	0.58	0.037	0.694
Milk (kg/cow/day)	30.1	31.3	30.7	0.34	0.120
Fat (g/kg)	35.4	37.1	37.9	0.40	**0.027**
Protein (g/kg)	32.1	31.2	31.6	0.17	**0.026**

SCC (10^3/ml)	54	33	45	1.1	**0.014**
Days to conception	97	103	123	23.7	0.530
Calving interval (days)	378	383	404	24.0	0.521
Total out-wintering costs (£/hd)	**143**	**157**	**294**	--	--

Farmer messages:

- In-calf Holstein heifers can be out-wintered successfully in high output dairy farms with careful planning and management without a negative impact on performance or fertility.
- Heifers grazing fodder beet with 35% of dry matter intake as grass silage, can obtain target live weight gains in winter conditions, provided allocation of feed is accurate and animal performance is monitored regularly.
- Heifers grazing grass supplemented with grass silage may have difficulty maintaining body condition score and live weight gain, particularly during January and February and if conditions are very wet. Supplementation with concentrates may therefore be required.
- If managed appropriately, out-wintering on strip grazed grass fields can be achieved without substantially damaging pasture or reducing the subsequent years grass production.
- Feed costs for out-wintering on fodder beet or deferred grazing are dependent on crop yield, but are approximately 70-80% of housed animals. The largest financial benefit from out-wintering 1-2 year old heifers is the potential savings in capital costs. In total, rearing costs can be reduced by out-wintering by approximately 50%, or £150/heifer.

Further exploitation: The findings are applicable to all dairy herds, irrespective of performance level and provide a figure for the potential cost savings from out-wintering replacement heifers. These findings also provide quantitative evidence to inform policy makers and the general public of the impact of out-wintering (when managed correctly) on animal health, welfare, performance and the environment.

B. Executive summary 4) The effects on performance of out-wintering replacement heifers on kale or deferred grazing in a high output dairy system in South West Scotland

Background and Objectives: It has been reported that there is little subsequent effect on milk performance or fertility in cattle that have been out-wintered in spring calving, predominantly grass based milk production systems (Keogh et al., 2009a, 2009b; Kennedy et al., 2012; O'Driscoll et al., 2010). However, little work has been done to evaluate the effects of out-wintering high-production heifers and assess effects on milk production, fertility, health and welfare. A recent sister study at Harper Adams University reported that heifers could be successfully out-wintered on fodder beet or deferred grazing in Central England (Atkins et al., 2015). Currently the most popular forages used for out-wintering within Great Britain are deferred grazing, kale or fodder beet (Atkins *et al*., 2014). The aim of the current study was to determine the suitability for replacement heifers destined for a high input yield 'intensive' dairy system of out-wintering on kale or grazed grass compared to housed animals in South West Scotland, and to calculate and compare the costs of production for the 3 systems.

Technical approach: Forty eight, pregnant Holstein heifers, approximately 23 month old with a predicted calving date between February and mid-April 2015 were apportioned into three groups of 16, by live weight and expected calving date. One of groups was housed (H) with a TMR ration based on grass silage and concentrates, whereas the other groups were out-wintered with one group fed kale (K) with grass silage and the other deferred grazing (G) with grass silage. The study began on the 1 December 2014 after a two week transition period with animals housed at the end of January/beginning of February 2015.The three groups were weighed on a weekly basis and blood samples taken every month, along with body condition score, mobility and body hair length. Animals from the three groups were moved to a calving area approximately 4 weeks before calving and then were monitored for body condition score, live weight, feed in-take, mobility and milk production and composition for the first 14 weeks of lactation. The fertility of heifers was assessed through the number of services, days to conception and calving interval.

Key results: The initial body condition scores were lower for the out-wintering groups compared to the housed heifers however there was no difference in liveweight gain or body condition score change between the three treatments during the outwintering period (Table 4.4.1). Levels of blood ketones (β-hydroxybutyrate; BHB) during the out-wintering period were lowest in heifers that were housed and highest in those out-wintered on kale prior to calving, but were unaffected by dietary treatment post-partum. During the first 14 weeks of lactation there were no significant differences in live weight across the three treatments, but animals that had been out-wintered gained weight, whilst those that had been housed lost weight. Heifers that had been out-wintered on grass had a higher milk yield (29.8 kg/day) than those that had been housed or out-wintered on kale (27.3 and 27.9 kg/day respectively). There were no significant differences in the milk composition for the three groups. Animals out-wintered on kale had a longer calving interval (415.5 days) compared to the housed group (369.6 days). Variable and capital costs from out-wintering on kale or deferred grazing were similar, but were on average £178/heifer less than housing.

Table 4.4.1. Performance of Holstein heifers that had been out-wintered on kale (K) with grass silage, perennial ryegrass (G) with grass silage, or housed (H) with grass silage and concentrates.

	K	G	H	s.e.d	P
Out-wintering period					
Initial Lwt	559	562	563	16.8	0.96
Lwt change, (kg/cow/day)	0.73	0.69	0.94	0.13	0.16
Initial BCS	2.53^{a}	2.53^{a}	2.63^{b}	0.09	**0.004**
BCS change	-0.05	0.03	-0.07	0.08	0.08
Plasma BHB (mmol/l)	0.36^{a}	0.41^{a}	0.55^{b}	0.02	**<0.001**
Post-partum period					
Parturition Lwt (kg/cow)	565	566	564	16.85	0.99
Lwt change (kg/cow/day)	0.21^{a}	0.17^{ab}	-0.11^{b}	0.10	**0.008**
Parturition BCS	2.39	2.46	2.44	0.10	0.77
BCS change (0-14 wks)	-0.44	-0.50	-0.42	0.10	0.68
Plasma BHB (mmol/l)	1.24	1.18	0.91	0.39	0.66
Milk, (kg/d)	27.9^{a}	29.8^{b}	27.3^{a}	0.27	**<0.001**
Fat (g/kg)	39.06	37.85	38.12	0.55	0.073
Protein, (g/kg)	30.96	30.05	30.23	0.76	0.457
SCC, (10^{3}/ml)	84.1	76.1	82.4	13.24	0.814
Days to conception	132.3	107.2	89.6	18.01	0.071
Calving interval (days)	415.5^{a}	387.2^{ab}	369.6^{b}	17.95	**0.046**
Total out-wintering costs (£/hd)	95	101	276	--	--

Farmer messages:

- In-calf Holstein heifers can be out-wintered successfully in high output dairy farms with careful planning and management without a negative impact on performance or fertility.
- Heifers grazing deferred grazing and kale with additional grass silage, can obtain target live weight gains in winter conditions, provided allocation of feed is accurate and animal performance is monitored regularly.
- Heifers may have difficulty maintaining body condition score and live weight gain, particularly during January and February when conditions are very wet and windy. Supplementation with extra grass silage may therefore be required.
- Strip grazing is important so not to damage the crop in the field prior to being presented for grazing. Off-setting the grass silage bales helped with the moving of fences.
- Feed costs for out-wintering on kale or deferred grazing are dependent on crop yield, but

were approximately 45 and 49% less than the housed animals. The largest financial benefit from out-wintering in-calf heifers was the potential savings in capital costs. Total rearing costs can be reduced over the out-wintering period by approx., 64%, or up to £178 a heifer.

Further exploitation: The results can be exploited by disseminating the findings to dairy farmers who are, or are considering out-wintering, irrespective of system. Further, the findings can be used to inform the public and policy makers of the advantages, if managed correctly, of out-wintering.

C. Delivery against milestones - tabulate achievement of milestones against targets set. List any deviations or agreed changes in direction, and their impact on the project (if applicable, describe how the work differs from that originally proposed and describe how the changes have impacted on the work package. Include changes to objectives and work plan / budget, changes to the team or other constraints. Explain any discrepancy between planned worked and achieved work, and corrective actions taken.

Out-wintering replacement heifers (WP4)	Progress, deviations and corrective actions
Milestone 4i – Agree and recruit 80 commercial farms for participatory research on out-wintering systems for heifer replacements and agree a sub-set of 16 to 20 for more detailed measurement and tracking through first lactation (Q2, Yr1).	Survey posted in April 2012 to 120 farmers that were known to be out-wintering replacement heifers, with a follow up sent to non-returnees at the end of April, and again in August 2012. Telephone calls were made to non-returnees, and an online version of the questionnaire was publicised via Twitter and a Facebook discussion 'e-group' dedicated to out-wintering cattle. A total of 70 usable questionnaires were returned (a return rate of 58%). Nine farms were identified to be used for a subsequent participatory research study.
Deliverable 4.1 – Interim report on participatory research on out-wintering heifer replacements with KT recommendations (Q1, Yr2).	Final report on survey submitted in Sept 2012 on time.
Deliverable 4.2 – Final report on participatory research on out-wintering heifers with detail of heifer performance in first lactation (Q1, Yr3).	Final report on participatory research submitted in July 2013 on time.
Milestone 4ii – Sow crops for out-wintering experiments at HAUC and SAC on heifer replacements in high input herds and effects on first lactation performance, and plan detail of treatments (Q1, Yr2 for HAUC and Year 3 for SAC).	Crops established at HAU and SRUC and protocols prepared on-time.
Deliverable 4.3 – Report on out-wintering of heifer replacements for high input dairy farms on contrasting sites and effects on first lactation performance (Q3, Yr4).	Final report submitted by HAU in April 2015 and SRUC in Feb 2016.

Deliverable 4.4 – Information from work package 4 to be included in *forage+* (Q3, Yr4).	Series of out-wintering videos prepared autumn 2015.

D. Outputs (List and fully reference all outputs which document and promote the findings of this work. Describe any further outputs or follow-up initiatives anticipated after 31 May 2016).
D (I) Experimental/project reports to AHDB
Atkins, N.E., Bleach, E.C.L. and Sinclair, L.A. (2013). A survey of current practice among farmers out-wintering replacement dairy heifers in Great Britain. http://dairy.ahdb.org.uk/resources-library/research-development/production-system/survey-of-current-practice-among-farmers-outwintering-replacement-dairy-heifers/ Atkins, N.E., Sinclair, L.A., Bleach, E.C.L. (2015). The effects on performance of out-wintering replacement heifers in a high output dairy system. http://dairy.ahdb.org.uk/media/1366225/outwintering.pdf Atkins, N.E., Sinclair, L.A., Bleach, E.C.L. and P. Hargreaves. (2015).The performance of replacement, spring calving dairy heifers out-wintered on deferred grazing, kale or fodder beet, and the influence of a trace mineral bolus. http://dairy.ahdb.org.uk/resources-library/research-development/production-system/performance-of-replacement-spring-calving-dairy-heifers-outwintered-on-different-forages/ Hargreaves, P., Roberts, D.J. and Bell, D.J. (2016). The effects on performance of out-wintering replacement heifers in a high output dairy system.
D (II) Scientific publications (accepted or submitted; peer reviewed conference proceedings etc.)
Atkins, N.E. (2013). Out-wintering. DairyCo Research Day (poster). Atkins, N.E., Walley, K., Bleach, E.C.L. and Sinclair, L.A. (2014). A survey of current practice among dairy farmers out-wintering replacement heifers in Great Britain. *Advances in Animal Biosciences* p218. Atkins, N.E., Bleach, E.C.L. and Sinclair, L.A. (2015). Performance and metabolism of replacement dairy heifers out-wintered on fodder beet or perennial ryegrass compared with winter housing in a high-output dairy system in the UK. *Journal of Dairy Science* (submitted) Atkins, N.E., Bleach, E.C.L. and Sinclair, L.A. (2015) The effects on performance of out-wintering replacement heifers in a high output dairy system. *Proceedings of the 26th annual European Grassland Federation* meeting, Wageningen, The Netherlands. Atkins, N.E., Bleach, E.C.L., Hargreaves, P.R. and Sinclair, L.A. (2015). The effects of out-wintering replacement dairy heifers on deferred grazing, kale or fodder beet without or with a trace mineral bolus on pre-calving performance in commercial spring calving herds. *Advances in Animal Biosciences* p186. Atkins, N.E., Bleach, E.C.L., Hargreaves, P.R. and Sinclair, L.A. (2015). The effects of out-wintering replacement dairy heifers on deferred grazing, kale or fodder beet without or with a trace mineral bolus on first lactation performance in commercial spring calving herds. *Advances in Animal Biosciences* p187.
D (III) Knowledge transfer (national and international workshops, farmer/industry meetings,

media articles etc.)

Throughout the lifetime of the research partnership, results from this work package have been presented at a range of farmer and industry meetings, and communicated through farming press and digital media.

Farmer-industry meetings

Meeting	Location	Date	Attendees
Out-wintering open meeting	HAU, Shropshire	Nov 12	50
Out-wintering open meeting	Hampshire	Jan 13	14
Research Day	HAU, Shropshire	Sep 13	122
Out-wintering event	HAU, Shropshire	Nov 13	26
Norfolk discussion group	Norfolk	Dec 13	12
CSF staff training workshop	York	Jan 14	75
Out-wintering open meeting	Lifton, Devon	Jan 14	75
Ankle Deep discussion group	Oxford	Feb 14	19
A survey of current practice among dairy farmers outwintering replacement heifers in GB	BSAS Nottingham	Apr 14	60
Trink demo farm meeting	Cornwall	Sep 14	64
Research Day	Chester, Cheshire	Oct 14	130
Shropshire Grassland Society	Shropshire	Jan 15	10
Youngstock open day	SRUC, Dumfries	Jan 15	20
AHDB DIG conference	Kegworth	Mar 16	264
		Total	**941**

Farming press

Title	Media	Date
Milk matters – out-wintering	Shropshire Star	Apr 13
Planning winter grazing for heifer replacements	Farmers Weekly	Aug 13
Root crops can provide a good feed option	Farmers Weekly	Dec 13
Deferred grazing can reduce winter costs	British Dairying Shropshire Star	Sep 15
High yields can survive a winter in the outdoors	Farmers Weekly	Sep 15
Out-wintering options for dairy heifers	Farmers Guardian	Oct 15
Conquering the great outdoors this winter	Farming Wales	Nov 15
Out-wintering of heifers cuts rearing costs	British Dairying	Mar 16
Deferred grazing can help reduce costs dramatically	Farmers Guardian	Aug 16
High yields can survive a winter outdoors	Farmers Weekly	Sep 16
Reducing feed costs by out-wintering	Western Mail	Oct 16

Online

Title	Media	Date
If you don’t measure it, you can’t manage it	Forage for Knowledge	Jan 14
Out-wintering cuts costs and aids dairy farmer sustainability	Farming Futures	Apr 14
Out-wintering update	Forage for Knowledge	Oct 14
Out-wintering replacement dairy heifers	Forage for Knowledge	Mar 15

Conquering the great outdoors	Forage for Knowledge	Sep 15
Video – Managing out-wintered fields	ADHB Dairy YouTube	Feb 16
Video – Managing out-wintered animals	ADHB Dairy YouTube	Feb 16
Video – Minerals for out-wintering	ADHB Dairy YouTube	Feb 16
Video - Calculating forage crop yield	ADHB Dairy YouTube	Feb 16

E. Benefits of the research results to the British dairy sector

E (I) Economic benefits (describe, and wherever possible quantify, potential financial benefits at farm level, and/or to the industry as a whole)

The farmer study clearly indicated that the major reason for out-wintering pregnant heifers was to reduce costs. This was subsequently quantified in two studies (one at HAU and SRUC), where it was calculated that there were savings in variable costs (mainly feed) of approximately £25-40/heifer. The major saving was in capital costs, at approximately £110-120/animal. The combined saving of out-wintering pregnant heifers was approximately £150-180/heifer, which equates to 0.5 to 0.6 ppl over the lifetime production of an average dairy cow. These savings were achieved without any subsequent impact on first lactation performance, health or fertility, although subsequent calving interval of heifers reared on kale was longer. Further savings could be obtained by out-wintering younger animals.

E (II) Sustainability benefits (How will outputs support sector sustainability in the long-term? Will the activity support sustainability in other ways such as improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)

These studies supported 8 BSc Agriculture undergraduate Honours Research projects at HAU, many of whom have entered dairy farming or ancillary industries. The work will also form the PhD submission by N.E Atkins. Reducing the requirement for capital will reduce the costs of production and more easily allow expansion, or for young entrants to enter the dairy industry, both facilitating economic sustainability within the dairy sector.
This work package has highlighted how good management practices when out-wintering can minimise any impact on soil structure, reducing the risk of runoff and soil erosion, contributing to improved environmental sustainability in dairy production systems.

E (III) Policy making (Describe how the work informs policy, leads to better decision making, or addresses wider societal concerns)

The findings from these studies can inform policy makers on the impact of out-wintering on the economic sustainability of dairy farming. The initial survey demonstrated that many farmers believe that the general public perceive that out-wintering reduces animal welfare and health. In contrast, farmers believed that out-wintering improves animal welfare and health, particularly by reducing respiratory disease. The series in this work package provide quantitative evidence of the effect of out-wintering on animal behaviour and health. The survey and on-farm collaborative research studies have also provided practical advice on means to improve animal welfare when out-wintering (e.g. use of straw bales to provide shelter or a dry lying area) that has been transferred to dairy farmers. Similarly, this project has collated practical experience and research on best means to avoid soil damage and run-off, such as careful selection of field location and aspect, avoiding steep slopes and grazing from the top of a field to the bottom.

E (IV) Supply chain (Does the work address supply chain constraints or opportunities)

The work highlights methods to achieve increases in herd sizes without the need for further cost of buildings. That out-wintering can be achieved for high yielding cows and there are opportunities for a variety of crops to facilitate this.

F. Leverage and added value (Detail all additional funding sources and collaborations nationally or internationally. Has this activity contributed to applications for further research in this area? Has the work contributed to improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)
These studies were funded because of a market failure in research funding for out-wintering dairy cattle. There is little commercial interest in this subject because the main beneficiaries are dairy farmers. The costs of funding rigorously conducted studies by seed or feed companies outweighed the potential return in sales. Similarly, interest in mineral manufacturers was limited. These studies will form the basis of the PhD submission by N.E. Atkins.

Work package title:	WP 5: Grassland soil management		
Start date (mm-yyyy):	06-2011	**Actual (£)**	£389.9K
End date (mm-yyyy):	05-2016	**Planned cost (£)**	£389.9K
Name & organisation of principal investigator (PI):	Paul Hargreaves Scotland's Rural College (SRUC)		
Collaborators:	SRUC, HAU, CTF Europe Ltd, Monford AG Systems Ltd and SOYL.		

A. Overview by work package leader

Underpinning rationale: With rising input costs, maximising grassland production and utilisation will be crucial to improving the economic sustainability of GB dairy farms. Healthy soil is an essential component of productive grassland systems, historically soil management on dairy farms has received limited attention. There is an extensive body of research and a wealth of resources available to support improvements in grassland soil nutrition however there is little information available on the impact of poor soil structure on the productivity and utilisation of grassland swards.

In recent years, the increasing use of heavier machinery along with the pressure to reduce costs by extending the length of the grazing season has increased the risk of damage to soil structure through compaction. This was highlighted in a recent survey of 300 grassland sites across England and Wales, in which 68% of the soils tested, exhibited signs of soil compaction. To date however, there is little evidence available on the impact of this compaction on grassland performance. In addition, higher levels of soil compaction have the added potential to increase greenhouse gas emissions, especially nitrous oxide (N_2O) and further work is required to examine the impact of compaction on nutrient efficiency and novel strategies for reducing any potential increase in N_2O. Surface aeration (spiking) and sward lifting techniques are currently used in the mitigation of soil structural damage however limited independent information currently exists on the effect of these techniques on soil structure or grassland performance.

In Britain, grassland management is generally conducted in an ad hoc manner with no conscious attempt to re-use equipment wheelings or pathways as is common practice with arable fields. Research has shown that in a single year 90% of a field can be covered by tractor/harvester/trailer wheels at least once (University of Nebraska, 1999) with a number of areas within the field receiving repeated traffic. Recent studies at Harper Adams University (HAU) in 2012, showed approximately 65% coverage during a single grass harvesting operation from forage chopper and baling operations. To minimise the potential risk of compaction, implementing controlled traffic principles may be advantageous in grassland and some initial work in Denmark has demonstrated positive impacts however its application to GB grassland farms has yet to be examined.

Development of precision technologies in agriculture may also play a key future role in grassland management. Recent developments in the use of satellite images of near infra-red reflectance of the above ground biomass have provided values for Normalised Difference Vegetation Index (NDVI) to assess the potential growth of a crop. Measurements using hand-held NDVI equipment have also shown a good indication of above ground biomass variation and could be used as a quicker, less labour intensive option, than the other current methods available. The use of ultrasonic equipment has also been suggested as an alternative less labour intensive method of sward measurement.

Work package objectives: The objectives of this work package were:

a) assess the importance of soil compaction on grassland yield and quality, enhancement of N_2O emissions and the control of N loss though gaseous emissions and leaching with the use of a nitrification inhibitor.

b) conduct an appraisal of soil compaction alleviation methods (surface aeration and sward lifting) in improving soil structure to help prevent reductions in yield loss.
c) assess variation of grass growth across a field and whether vegetative biomass can be predicted using satellite images.
d) assess hand held instruments that use either NDVI or ultrasonic measurements to quantify the grass yield variation across fields.
e) devise and demonstrate an effective Controlled Traffic Farming (CTF) system for grassland to determine the effect of repeated traffic of a 'traditional' management system on the within-field variation in grassland dry matter (DM) yield through a season.
f) consider the extended use of controlled traffic to a grassland management system with the current machinery available through the literature.

Approach: Four studies were used to address these objectives. The two of which was undertaken as sister experiments located in both southwest Scotland (SRUC) and central England (HAU) to study the effects of soil compaction. These were sites chosen for contrasting soil type (heavy poorly draining silty clay loam at SRUC and light sandy freely draining at HAU) and weather (wetter cooler at SRUC and drier warmer at HAU).Soils were compacted either by heifers trampling the areas twice for one hour, one week apart, in either the autumn (SRUC) or the spring (HAU) and mechanical compaction from a tractor (approximately 10.5t) driving over the treatment area. For three years from 2012 to 2014, the grassland was cut for silage three times a year with the DM yield and grass quality compared for any effect resulting from the soil compaction. During 2012 and 2013 the effect of the compaction on N_2O emission was monitored to see if this could be reduced by the use of a nitrification inhibitor. The potential for two soil alleviation methods (surface aeration and sward lifting) to re-introduce structure back into the soil and potentially increase yield were investigated on a sub-sample of the compacted plots at both experiments. Natural recovery of the soil was investigated during 2014 by with-holding the compaction treatments for part of the compaction areas in the autumn (SRUC) or spring (HAU).
SRUC and HAU were used to assess the use of satellite generated NDVI to predict grass biomass for three silage cuts. This work was supplemented by the use of a hand-held NDVI and an ultrasonic monitor of grassland biomass in small experimental plots at the two sites. The small plots at HAU were cut as grazing and at SRUC the assessment was undertaken on the third silage cut.
The final experimental work investigating the impact of controlled traffic farming on grassland performance (Executive Summary 4) was completed at SRUC and was combined with a literature search and economic analysis undertaken by HAU.

Delivery: All the four studies achieved their objectives with numerous detailed reports covering the areas of work. The compaction work provided support for a PhD studentship and three undergraduate projects. The results of the research have been presented at a number of scientific conferences. The results have also been extensively promoted through farmers meetings, press articles and especially for the soil compaction work, a webinar and a BBC radio interview.

B. Executive summary 1) Soil compaction and alleviation

Background and Objectives: In recent years, the increasing use of heavier machinery along with the pressure to reduce costs by extending the length of the grazing season has increased the risk of damage to soil structure through compaction. This was highlighted in a recent survey of 300 grassland sites across England and Wales, in which approximately 70% of soils tested exhibited signs of soil compaction.
Previous studies have shown that compaction of soil in arable crops has decreased crop yield and quality as well as increased the need for nitrogen (N) fertiliser to obtain the same yield as

none compacted soils. To date however, there is little evidence available on the impact of this compaction on grassland performance.
Two of the more common methods of alleviating soil compaction damage are surface aeration (slitting) or breaking up of the soil from depth (sward lifting) however, again there is little independent information on the effectiveness of these techniques at reducing the impact of compaction
This work aimed to study:

- the effect of soil compaction from animal trampling or vehicle compaction on grass yield and quality in comparison with no compaction
- the effect of two soil alleviation methods, soil slitting (aeration) and sward lifting (sub-soiling) on improvement in grass yield and quality from areas of known compaction
- effect of natural recovery compared to re-compaction was assessed as to whether this enhanced the soil structure and yield, with and without the alleviation methods.

Technical approach: The effect of soil compaction from trampling by cows and mechanical compaction, by a weighed tractor, on grassland soil structure and dry matter (DM) yield compared to an area of minimised compaction were investigated. Comparisons of any potential effects were made at two different sites; SRUC southwest Scotland and HAU, central England. These were sites chosen for contrasting soil type (heavy poorly draining silty clay loam at SRUC and light sandy freely draining at HAU) and weather (wetter cooler at SRUC and drier warmer at HAU). Each year from 2012 to 2014, the grassland was cut for silage three times a year with DM yield and grass quality compared for any effect from the soil compaction. Any changes to the soil structure were monitored through measurements of bulk density along with soil visual assessments using the Visual Evaluation of Soil Structure (VESS). In the final year, natural recovery processes were assessed by leaving one third of the study area untouched.

Key results: Significant negative effects of compaction were evident on the heavier soil at SRUC (Table 5.1.1). Compaction from animal trampling and tractor traffic resulted in a 12 and 19% reduction in first cut dry matter (DM) yield across the experiment (P<0.05). Compaction also increased soil bulk density by 20%, reducing pore space. This resulted in an increase in water retention of 14% (P<0.001) and increased the amount of nitrate-N further down the soil profile, indicate of leaching or reduced uptake by plants. There was also a 14% reduction in yield from the tractor compaction of the soil by 2104 on lighter soils at HAU.

Table 5.1.1 Effect of compaction on soil bulk density (BD; g/cm^3), water-filled pore space (WFPS;%) and first cut and total DM yield (t/ha) throughout the duration of the experiment at the SRUC site.

	Year	No compaction	Trampling	Tractor	s.e.d.	*P*-value
BD 0–10cm	2012	1.02^a	1.11^b	1.13^b	0.037	0.014
	2013	1.00	1.17	1.23	0.089	0.088
	2014	0.94^a	1.15^b	1.23^c	0.038	<0.001
WFPS 0 – 10cm	2012	71.1^a	82.8^b	88.7^b	3.39	<0.001
	2013	74.7^a	90.1^b	93.4^b	3.65	<0.001
	2014	67.8^a	84.6^b	92.8^b	8.70	0.025
1st cut DM yield	2012	4.5^b	3.9^a	3.8^a	0.28	0.035
	2013	2.8^c	2.3^b	1.7^a	0.16	0.001
	2014	8.3^b	7.9^{ab}	7.0^a	0.36	0.049
Total DM yield	2012	9.4	8.8	9.1	0.45	n/s
	2013	8.0	7.6	7.0	0.44	n/s
	2014	12.9	11.3	10.9	0.64	n/s

Different letters in the rows denotes statistical difference (P<0.05)
n/s not significant

Aeration was found to be beneficial to soil structure improving both pore space and water drainage. Sward lifting in heavier soils had a positive impact, reducing soil bulk density by 11% and 9% at the 0 – 10 and 10 – 20cm depths, respectively. Water filled pore space was also reduced by 11% on average. However, aeration did also result in an average yield reduction of 22% compared to unaerated areas (P<0.05). Consequently, it is crucial to confirm the presence and depth of soil compaction, using a visual soil assessment tool prior to undertaking aeration to avoid any unnecessary yield penalties. Natural recovery processes did result in improvements in soil bulk density within a one year time frame, however, there was limited effect on grass yield during this time period.

Farmer messages: The main messages were:

- On heavy soils, compaction from animal trampling and tractor traffic increases soil bulk density (by as much as 20%), reducing air space in the soil. Compaction also increased water retention in the soil by 14%.
- The impact of compaction on soils structure also reduced DM yields, particularly on heavy soils. The greatest reductions were evident at first cut silage (up to 19% reduction for the tractor compaction and 12% for the trampling).
- If compaction is suspected then attempt to reduce grazing numbers in wet conditions and limit tractor traffic to allow recovery. If the compaction is severe then consider alleviating the soil mechanically.
- Aeration can be beneficial to soil structure improving both pore space and water drainage. However, aeration can also reduce sward yield by up to 22%.
- Use a visual soil assessment system such as Healthy Grassland Soils to assess the soil down to a depth of 25cm for compaction problems to confirm compaction and to identify where the compaction layer is located.
- Sward lifting on soil that had no obvious compaction reduced the DM yield (13.2% decrease over the two years for the heavier soil) and would incur a cost for use.

Further exploitation: This data has been presented at numerous talks to farmers groups highlighting the loss of yield from even moderate compaction and that soil compaction, as a result of tractor traffic and animal trampling, can have an effect on different soil types (heavy and light). This gives an idea of the costs of DM yield loss through compaction and how alleviation can improve the yield of compacted soils, but only if the correct management is employed and at a suitable time of year. The use of a sward lifter will have a penalty if used in the spring and highlights the need to allow a period of sward recovery after use. Information from this work helped with development of the 'Healthy Grassland Soils' booklet produced for AHDB Dairy and Beef and Lamb. Overall, the results of this work would be of use to the beef and sheep industry to help in maintaining grassland yields and soil quality.

B. Executive summary 2) Soil compaction and greenhouse gas emissions

Background and Objectives: Nitrous oxide (N_2O) has been recognised as a major contributor to anthropogenic warming as a greenhouse gas. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report estimated the global warming potential of N_2O to be 300 times that of Carbon Dioxide (CO_2). It has been calculated that approximately 7% of the UK greenhouse gas emissions are from agriculture, with 3.5% of this figure being from N_2O, mostly from soil microbial activity in agricultural soils as a consequence of organic and inorganic fertiliser use. Grasslands are the most important source of N_2O in UK agriculture and account for approximately 28.6% of the total UK emissions.

The N_2O emissions from grassland tend to be associated with the addition of fertilisers and occur in short bursts or fluxes after application. Production of N_2O fluxes from the soil are dependent on a number of factors; both physical and biological. However, N_2O from soils is produced largely by the microbial process of denitrification and to a lesser extent by nitrification. The physical variables that can potentially increase the positive fluxes of N_2O are enhanced by the compaction of the soil as this reduces the air filled pore spaces for nitrification and

increases the water filled pore spaces where denitrification activity is more likely to occur. Previous studies have shown that the application of a nitrification inhibitor, dicyandiamide (DCD), can reduce the emissions of N_2O. DCD is water soluble and so has the advantage that it can be applied in liquid form and inhibits the initial nitrification stage.
The objectives of the study were to:

a) investigate the affect of soil compaction on levels of N_2O emissions
b) assess the use of a nitrification inhibitor (DCD) on the reduction of N_2O emissions
c) assess soil alleviation effects on N_2O emissions

Technical approach: To investigate the effect of soil compaction from trampling by cows and vehicle compaction (a weighed tractor) on grassland soil structure and N_2O emissions compared to those from an area of minimised compaction. Comparisons of any potential effects were made at two different sites; SRUC and HAU. These sites were chosen for contrasting soil type (heavy, poorly draining, silty clay loam at SRUC and light, sandy, freely draining at HAU) and weather (wetter cooler at SRUC and drier warmer at HAU). Each year for three years from 2012 to 2014, the grass was cut for silage three times a year and the N_2O emissions compared for any effect from the soil compaction. Any changes to the soil structure were monitored through measurements of bulk density along with visual assessments using the Visual Evaluation of Soil Structure (VESS). The effect of alleviation of the compacted soil through the use of surface aeration (spiking) or sward lifting on the N_2O emissions were monitored.
Fertiliser was applied three times during each year of the experiment; once as an inorganic fertiliser (Urea at 60 kg N ha) in the middle of March, with slurry applied using a trailing shoe ($30m^3$/ha) within two weeks of the first (end of May) and second (mid July) grass silage cuts.
A nitrification inhibitor, with the active ingredient dicyandiamide (DCD), was applied within one hour of each fertiliser treatment. The nitrification inhibitor was applied as a 2% solution, to give an application rate equivalent of 10 kg/ha, during the first two years of the experiment.
Gas fluxes (N_2O) were measured using two closed chamber systems on each treatment area, these were 0.2 m tall polypropylene cylinders of diameter 0.4 m and were pushed into the soil to a depth of up to 5 cm to provide a head space of approximately 0.02 m^3 on enclosure with an aluminium lid. The chambers were sampled on a fortnightly basis through the late winter, increasing to weekly sampling in the spring and then twice weekly once the fertiliser treatments were applied and continued until the late summer after the third grass cut when the sampling returned to weekly for October and stopped during November and December.

Key results: There were significantly enhanced emissions of mean N_2O from soil compaction treatments by 29% for the trampling and 60% for the tractor compactions at SRUC and 15% for the trampling and 16% for the tractor compaction at HAU over the three years of the experiment.
The use of the DCD significantly reduced N2O emissions ($P<0.01$) for all plots at SRUC and HAU by 23.2% and 47.6%, respectively over the course of the experiment.

Table 5.2.1. Accumulated N_2O emissions from compaction treatments with and without a nitrification inhibitor (DCD) at SRUC and HAU.

Treatment	Accumulated N_2O emissions (g N_2O-N /ha)		Reduction (%) between DCD addition and no DCD
	2012-13	2012-14	2012-13
SRUC			
Trampled	2509	4929	26.4 (***)
Trampled + DCD	1846		
Tractor	3312	5930	38.2 (***)
Tractor + DCD	2046		
No Compaction	2203	4108	23.2 (**)
No Compaction + DCD	1692		

HAU			
Trampled	2801	3495	47.6 (***)
Trampled + DCD	1468		
Tractor	3291	4085	46.4 (***)
Tractor + DCD	1765		
No Compaction	2718	3436	44.9 (***)
No Compaction + DCD	1497		

Sward lifting increased the emission of N_2O for approximately 8 weeks after implementation, especially for the more compacted soils. The use of a soil slitter also increased N_2O emissions for a similar length of time in the compacted soils.

Farmer messages: The main messages were:

- Compaction increased emissions of N_2O from agricultural grassland
- Increased emissions of N_2O were not consistent for the two soil types, as the heavier soil produced greater levels than the lighter soil.
- The use of a nitrification inhibitor (DCD) only accounted for a saving of up to 1.5 kg N ha and would be cost neutral at best, however it did significantly reduce N_2O emissions.
- Soil alleviation can result in an initial increased emission of N_2O especially if the soil does not have a problem with compaction. This has implications for controlling greenhouse gases, in that improving soil structure could encourage a greater release of N_2O.

Further exploitation: This work has been presented at research conferences and should help in the refining of the UK's GHG emissions factors. The use of DCD was shown to be important in controlling GHG emissions but was not a cost advantage in retaining N fertiliser and supported previous work undertaken by Defra.

B. Executive summary 3) Grassland variation, satellite monitoring and precision grass growth monitoring

Background and Objectives: With the introduction of GPS into tractor cabs there is the potential to use precision farming techniques, already used in the arable sector, for the enhancement of grassland yield through the introduction of more targeted fertiliser N (inorganic fertiliser or slurry) application. As with arable crops the challenge is defining where in the field the N needs to be delivered. Destructive sampling of even a small area of pasture, to calculate the available biomass, is both labour intensive and time consuming.
Current methods for the measurement of grassland biomass are generally manually operated with the need for time to walk the pasture on a regular basis for the measurements to be taken. Ideally, a satellite image using Normalised Difference Vegetation Index (NDVI) of the field would provide sufficient information to plan N applications based on initial grass growth. An alternative would be an instrument attached to a tractor or all terrain vehicle (ATV) that could be driven over the pasture to provide an accurate assessment of any biomass variation thereby improving the precision and efficiency of pasture monitoring and fertiliser use.
The objectives were:

a) assess measurements from a Normalised Difference Vegetation Index (NDVI) satellite image on field variation at two sites (SRUC and HAU)
b) evaluate a handheld NDVI sensor and ultrasonic grass height sensor for predicting the variation of above ground DM yield from both simulated grazing and a silage cut
c) compare the relationships with established methods of measuring grassland sward DM that are currently used by grassland farmers i.e. the rising plate meter and the sward stick.

Technical approach: Two 5 ha sites were used for the NDVI satellite study, on established

perennial ryegrass fields in 2012; one at SRUC in Dumfries and the other in central England (HAU) that had been in grass for at least three years. A 30m x 30m = 0.09 ha grid, giving 36 sampling points, was laid out across the two fields using GPS to relocate the sampling points. Three cuts of silage were taken at each site; in May, July and August (HAU) and September (SRUC). Quadrats of approximately 2 x 2 m were taken the day before each silage cut, using a harvester with a balance cell, for yield, with grab samples taken for dry matter. These were compared to NDVI satellite images of the field to assess the resolution and correlation between field measurements and NDVI estimations.
During 2013, existing small plots experiments at the two locations (SRUC and HAU), with different management and soil types, were selected to provide a range of biomass DM yields over the growing season for the assessment of the handheld NDVI and an ultrasonic sensor and compared to measurements taken with a sward stick and a rising plate meter (RPM). Grass variety plots cut to simulate grazing were used at HAU and consisted of perennial ryegrass (Lolium perenne) and timothy (Phleum pratense), with two rates of nitrogen applied (100 and 200 kg N/ha) cut approximately on a monthly basis during July to October 2013. Two sets of small plot experiments at SRUC of perennial ryegrass (both having the same overall management of three silage cuts a year) were assessed prior to the 3rd cut silage in September 2013.

Key results: The variation in grass dry matter yield clearly demonstrated there is potential to utilise precision farming techniques in grassland systems. However, although NDVI satellite maps at a field scale (5 to 8 ha) were produced capturing near infra red reflectance, the resolution of the NDVI maps, of approximately 30-50m, was not sufficient to pick up the scale of variation identified from actual ‘ground truthed’ field measurements.
When the handheld methods of above ground biomass measurements were assessed on the small experimental plots the NDVI (P<0.001) and ultrasonic height sensor (P<0.001) gave significant predictions of variation in DM yields when all the plots were considered (Table 5.3.1). The ultrasonic height sensor accounted for the greater amount of DM yield variation (76%) especially as the number of measurements increased and compared well with the RPM An equation would be needed to translate the NDVI values into a DM yield (t/ha) but the NDVI could detect different species of vegetation and this would need individual equations to account for the biomass. Sward covers over approximately 3500kg DM/ha (this figure assumes the uncut aftermath was 1500kg DM/ha) the NDVI sensor would need either an exponential equation or a change in the linear equation to account for the subsequent increased biomass.

Table 5.3.1. Mean grass cover (kg DM/ha) (assuming an uncut aftermath of 1500kg DM/ha) and correlations (R^2) for the four methods of measuring sward biomass using Rising Plate Meter, Swardstick, Ultrasonic height sensor and NDVI sensor for small plot experiments at HAU and SRUC.

Experimental Plots	Mean grass cover(kg DM/ha)	Rising Plate Meter	Swardstick	Ultrasonic height sensor	NDVI sensor
All Plots (Shropshire and Southwest Scotland)	2250	0.76 (***)	0.07 (*)	0.76 (***)	0.43 (***)

Level of significance (P<0.05 *, P<0.01 **, P<0.001 ***)
n/s no significance

Farmer messages: The main farmer messages were:

- Satellite NDVI images were not of sufficient resolution to account for the variation within a grassland field and so would not currently be of use to direct subsequent fertiliser applications.
- The infra-red Normalised Difference Vegetation Index (NDVI) sensor and the ultrasonic grass height sensor could be used to measure differences in DM yield across a field

however further equations need to be developed.

- The ultrasonic grass height sensor would need a greater number of measurements to account for field variability compared to a rising plate meter.
- None of the technologies tested gave a more accurate or reliable estimate of grass DM yield than the rising platemeter
- The NDVI gave significantly different indices for different grass species and would need discrete equations to quantify DM yield for different species.
- Sward covers over approximately 3500kg DM/ha loses linearity with NDVI measurements and so could underestimate yield.

Further exploitation: The use of satellite imagery is still being developed and the results showed that further special resolution would be needed for the smaller fields, found in UK dairy farming, to help with resolving variation across the field. Handheld equipment, either NDVI or ultrasonic measurements, to assess biomass, would provide useful measures but the cost of this equipment would need to be considered carefully against the cost of manual measurements. If the results could be easily mapped and used by the fertiliser spreader then variable rates of application could be used to target the lower yielding areas of the field. The ability of the NDVI to detect different species could be refined to identify native species within a field.

B. Executive summary 4) Controlled traffic to improve grassland yields

Background and Objectives: In the UK, grassland fieldwork is generally conducted in an “ad hoc” manner with no conscious attempt to re-use equipment wheel-ways or pathways as they are in arable fields i.e. tramlining or controlled traffic farming (CTF). Two passes from tractor compaction in autumn field conditions has been shown to reduce yield of the following years 1st cut silage by up to 19% (earlier AHDB Dairy funded compaction study (Section B5.1)). In arable agriculture a number of studies have shown that in a single year approximately 90% of a field can be covered by tractor/harvester/trailer wheels at least once with a number of areas within the field are repeatedly trafficked. More recently and specifically, studies at HAU in 2012 showed approximately 65% coverage during a single grass harvesting operation for both forage chopper and baling operations. A current study with winter wheat at HAU has shown a significant (19%) yield improvement by controlling field traffic to reduce the extent of soil compaction from field operations. Both silage yield and operational cost reduction benefits from controlled traffic have been shown with grassland in Denmark where grassland CTF systems are well developed.
The objectives were to:

a) devise and demonstrate an effective “Controlled” or “Reduced” Traffic Farming system for grassland
b) determine the effect of repeated traffic of a ‘traditional’ management system on the within-field variation and overall yield of grassland silage yield through a season
c) identify patterns of controlled traffic that will result in a net yield benefit and include other vehicles and trailer sizes and axle widths
d) determine the potential economic and environmental benefits of CTF (or Reduced TF) systems.

Technical approach: A review of the current CTF methods and research relating to grassland production was undertaken and this included developing systems for the use of current machinery in grassland management on the basis of their operation, weight and wheel widths. An experiment was conducted at SRUC Dumfries using the current machinery available, to investigate the impact of CTF and reduced traffic systems by splitting a recently reseeded 7 ha perennial ryegrass field, with a relatively uniform soil type and management history into two sections with identical layouts of 3.5 ha. The two 3.5 ha ‘fields’ were sampled on a grid system of 40 sampling points to ensure initial conformity across the field, for soil structure (soil bulk

density, soil resistance (penetrometer) and a visual evaluation of soil quality (VESS)), along with the pH, phosphorous (P) and potassium (K). The first 3.5 ha field was farmed with ‘normal’ (N) traffic management system for vehicles applying slurry, cutting and harvesting and trailers movements. The second 3.5 ha field was managed under ‘controlled traffic’ (CT) with a pattern of set wheeling’s (tramlines) established by auto-steer/tramline markers for the vehicles to travel along the length of the area and supplemented with visual markers. At harvest, the tractors and trailers carting the grass silage ran along the next parallel set of established wheelings and exited this field when fully loaded along the pre-set wheelings around the headlands.
Three silage cuts were taken (May, July and August) from each field through the year, with associated applications of fertiliser. Prior to each silage cut 40 small (2 x 2 m) areas were cut for DM; 8 cuts each from areas that had experienced vehicle passes of zero, 2, 4, 6 and 6+. The total DM off-take from each field was also measured by weighing the fresh matter in each trailer and sub-sampling for DM.
An economic analysis of the viability of CTF in grassland was undertaken by comparing the yield benefits, from both the experimental work and literature values and the costs of machine guidance systems in enabling CTF practices to be adopted.

Key results: Previous studies on UK grassland management systems have shown that random traffic during a single cut of silage resulted in a trafficked area of 65% of the field and that wheel damage can reduce yields by between 5% and 20%. A mean potential grass yield benefit of c.13% was identified.
In the experiment, the area of the field covered by wheelings was reduced by 57% from 87.4% for the N field to 30.4% for the CTF field. The soil structure was affected by the number of passes of the vehicles during management of the N and CTF fields. Soil bulk density increased, between areas of the fields that had zero vehicle passes and 6+ passes by 14.7% (P<0.001) for the N field and 18.2% (P<0.001) for the CTF field. Consequently random traffic resulted in a 0.5t DM/ha (17.6%) reduction in grass DM yield at third cut compared to CTF (Table 5.4.1).

Table 5.4.1. Total Dry Matter (DM) off-take and differences (t/ha) from the two field systems, normal (N) and controlled traffic farming (CTF).

Silage cut	Field system		Difference	s.e.d.	P value
	N	CTF			
1^{st} silage cut	5.28	5.43	0.15	0.019	0.27
2^{nd} silage cut	3.58	3.88	0.30	0.007	0.72
3^{rd} silage cut	2.34^{a}	2.84^{b}	0.50	0.001	**0.01**
Total silage	11.29	12.15	0.96		

Values in the same row with different superscripts are significantly different (P < 0.05)

Comparisons of commercial equipment currently available for CTF mechanization in grassland systems from manufacturers information, based upon mower widths of 3, 4, 5, 9 and 12m along with vehicle guidance, can reduce the range of trafficked areas from 40% to 13%.
Based upon a mean 13% increase in yield as a result of the reduction in wheel damage, reducing the trafficked area from an assumed 80% (random traffic) to 45% (CTF); this increased the potential yield by 0.53 t/ha and 0.73 t/ha for 2 and 3 cut systems, respectively. Similarly reducing the trafficked area to 15% has the potential to increase the yield by 1.00 t/ha and 1.36 t/ha for 2 and 3 cut systems respectively. These yield increases are currently valued at between £38 ha and £98 ha.

Farmer messages: The main messages were:

- CTF management use over three silage cuts increased DM yield by 13.5% (0.8 t/ha) compared to the use of a conventional traffic system. The increased number of passes of a vehicle increases soil bulk density by 15 to 18% for 6+ passes compared to zero passes.

- Employing simple changes and using existing equipment together with vehicle auto-guidance, the CTF system reduced the area covered by vehicle wheelings by 57% compared to N traffic.
- Depending on the width of the controlled traffic farming system employed, trafficked area could be reduced to 13 - 40%.
- Assuming an average increase in dry matter (DM) yield of 13%, from the absence of wheel damage, for 2 and 3 “cut” harvest systems in the UK and a reduced vehicle traffic area from 80% for a N traffic system to 45% for a CTF system this would increase the calculated yield by 0.53 t/ha for a 2 cut and 0.73 t/ha, for a 3 cut system. Similarly reducing the trafficked area further to 15% would increase the yield to 1.00 t/ha and 1.36 t/ha for a 2 and 3 cut systems, respectively. Assuming a dry matter value of £72/t DM, the above yield increases are currently valued at between £38 ha and £98 ha.
- The cost of low accuracy and non-repeatable positioning manual steered systems is calculated at less than £18.70 ha for grassland areas in excess of 100 ha and £85.50 ha for fully integrated, high accuracy systems for grassland areas in excess of 200 ha. This cost reduces to £11.40 ha for areas greater than 1500 ha cut.

Further exploitation: The data produced gives an invaluable evaluation of the benefits that can be achieved with changes in practice, incorporating current machinery and equipment, including costs for set-up. A further guide to planning controlled traffic systems for grassland using existing machinery, contractors and associated investment in the guidance technology would be a useful addition to help distill out the current information. If this was presented as a management decision tree related to cost benefits it would help those thinking of moving in the direction of a CTF system.

C. Delivery against milestones - tabulate achievement of milestones against targets set. List any deviations or agreed changes in direction, and their impact on the project (if applicable, describe how the work differs from that originally proposed and describe how the changes have impacted on the work package. Include changes to objectives and work plan / budget, changes to the team or other constraints. Explain any discrepancy between planned worked and achieved work, and corrective actions taken.

Soils and Precision Farming (WP2)	Progress, deviations and corrective actions
Milestone 5i Establishment of compaction experiments with a component of soil alleviation and greenhouse gas monitoring on two soil types (heavier soil at SRUC and lighter soil at HAU).	Experiments established with first compaction treatments in October of 2011 at SRUC and February 2012 at HAU.
Deliverable 5.1.1 Monitoring of silage DM yield for two years and re-compaction in the autumn (SRUC) or spring (HAU).	This was done each year with the application of a nitrification inhibitor after every fertiliser application. Monitoring of greenhouse gases on the various treatment plots.
Deliverable 5.1.2 Production and the submission of an annual report on the results from the yield and greenhouse gas measurements from both sites.	Reports on DM yield and greenhouse gas emissions produced on an annual basis from the results of both experimental sites submitted to AHDB Dairy May 2013.

Deliverable 5.1.3 Continuation of the experiments at both SRUC and HAU in to a third year 2013/14 to assess natural recovery from compaction on half of the compaction plots (Yr 4)	The compaction plots not used for the nitrification inhibitor use were used in the third year to assess the ability of the soil for natural recovery from compaction.
Deliverable 5.1.4 Final report on the effects of compaction and soil alleviation on DM yield over the three years of the experiment (Q2, Yr5). Greenhouse gas paper to be submitted ((Q4, Yr5).	Final report on the compaction and yield and soil alleviation effects on yield to AHDB Dairy Feb 2016. Paper to be submitted on the greenhouse gas emission in the next two months (Aug 2016).
***Milestone 5ii* a)** Set up fields that will be used for 'ground truthing' and satellite NDVI imaging in southwest Scotland (SRUC) and HAU	Two fields were allocated for grass yield sampling prior to each silage cut and images of satellite NDVI sourced from SOYL.
Deliverable 5.3 Report on the first years work to AHDB Dairy.	Report submitted to AHDB Dairy Dec 2012
Milestone 5ii b) Use existing small plot experiments at SRUC and HAU to assess the use of handheld vegetation monitoring (NDVI and ultrasonic)	The NIAB-TAG simulated grazing plots at HAU along with the slurry plots and soil compaction plots (SRUC) were used as agreed. Agreement to use an ultrasonic method of biomass measurement from Monford AG Systems Ltd
Deliverable 5.4 Report on the small plots work and research paper.	Report on the small plots work was submitted to AHDB Dairy Dec 2014. Conference proceedings, along with a poster, were presented at the BGS 12th Research Conference in Sept. 2015. A research paper was submitted to Computers and Electronics in Agriculture journal but they suggested a more grassland based journal and it is now being submitted to Grass and Forage Science.
Milestone 5iii Literature review, experimental work comparing CTF and normal traffic and a cost analysis.	The literature review and cost analysis were carried out by HAU with the experimental work at SRUC Dumfries during 2015.
Deliverable 5.3.1 report to be submitted to AHDB (Q4, Yr5).	Full report including an extra section on machinery compatibility has been submitted to AHDB Dairy May 2016. A research paper based on the meta-data from the literature review, experimental work and cost benefits will be submitted to a research journal later in Oct 2016.

D. Outputs (List and fully reference all outputs which document and promote the findings of this work. Describe any further outputs or follow-up initiatives anticipated after 31 May 2016).
D (I) Experimental/project reports to AHDB
End of first year report to AHDB Dairy on yield and greenhouse gas emissions (2012)

End of second year report to AHDB Dairy on soil compaction, alleviation and yield (2013).

End of second year report to AHDB Dairy on soil compaction, alleviation and greenhouse gas emissions (2014).

Main report on the effect of soil compaction and alleviation on DM yield and quality (2016).

Submission of research paper on soil compaction effects on yield (2016).

Submission of research paper on soil compaction effects on greenhouse gas emissions (2016).

Submission of research paper on soil alleviation and yield (2016).

Research paper on economic aspects of soil compaction and alleviation (2016).

End of project report on satellite NDVI images and grassland variation and including the continuation of the work with handheld vegetation monitoring and small plots (2015).

Re-submission of research paper on use of handheld vegetation monitoring (2016).

Submission of research paper on the use of controlled traffic (2016).

D (II) Scientific publications (accepted or submitted; peer reviewed conference proceedings etc.)

Hargreaves, P., Ball, B.C., Roberts, D.R. (2013). Grassland soil compaction: Effects on yield and nitrous oxide emissions. BSAS/BGS Conference.

Ball, BC, Hargreaves, P, Cloy, J (2013). Soil structure and greenhouse gas emissions. International Fertiliser Society, Proceedings 736, UK.

Baker, K and Bonnett, S. (2013). Mitigation and compaction effects on soil nutrient cycling processes, grass productivity and physico-chemical properties. BSSS Conference (poster).

Hargreaves, P.R., Roberts, D.J. and Ball, B.C. (2013). Soil Compaction: Challenges and remediation. Soil Association, national Soils Symposium.

Hargreaves, P., Ball, B.C., Roberts, D.R. (2014). Grassland soil compaction: Enhancing nitrous oxide emissions. 11th BGS Research Conference.

Wilson, G., Hargreaves, P. (2014). Soil compaction effects on earthworm numbers and biomass. 11th BGS Research Conference (poster).

Hargreaves, P.R., Roberts, D.J. and Ball, B.C. (2015). Effect of soil alleviation methods on grass yield. Proceedings of the 12th British Grassland Society research Conference.

Hargreaves, P.R. (2016). Squeezing the life out of your soil. AHDB DIG Conference.

Hargreaves, P.R., Chaney, K. (2015). Estimation of above ground biomass using normalised difference vegetation index. 12th British Grassland Society research Conference (poster).

Peets, S. (2016). Farm traffic: Are you taking control? AHDB DIG Conference.

Hargreaves, P.R. and Chaney, K. (2016). Predictive capability of a hand-held NDVI sensor for estimating grassland biomass. Submitted to Grass and Forage Science.

D (III) Knowledge transfer (national and international workshops, farmer/industry meetings, media articles etc.)

Farmer-industry meetings

Meeting	Location	Date	Attendees
CSF-AHDB Dairy soil compaction	Preston	May 12	10
CSF-AHDB Dairy soil compaction	Cumbria	May 12	10
RASE – Soil and Water	Stoneleigh	Nov 12	300
SRUC Pan Seminar	Edinburgh	Dec 12	55
SRUC Oatridge college Industry day	Nr Edinburgh	Jan 13	200
Barony College SRP	Dumfries	Jan 13	200
Lanarkshire farmer group	Dumfries	Mar 13	16
Research Day	Reading	Mar 13	126
AHDB Dairy Discussion Group	Dumfries	Apr 13	14
Dairy discussion group	Dumfries	May 13	13
Dairy discussion group	Dumfries	May 13	19
Research Day – Soils and PF	HAU	Sep 13	122
RASE Precision Dairying	Somerset	Oct 13	42
Research Day	Dumfries	Nov 13	122
National soils symposium	Bristol	Nov 13	75
Nottingham Grassland Society	Nottingham	Feb 14	27
BGS Spring Farm Walk	Cornwall	Apr 14	140
Grass and Muck 2014	Stoneleigh	May 14	300
Demo Farm event	Yarm	Jun 14	52
Demo Farm event	Cheshire	Jul 14	38
BSSS Presentation	Manchester	Sep 14	75
Horizon Seeds Meeting	Cheshire	Dec 14	23
Yorkshire Farming and Wildlife	Skipton	Feb 15	13
Grassland UK Seminar	Stoneleigh	May 15	24
DairyCo Research Day: efficient grassland farming – improving soils	South Wales	Jun 15	100
EU Idenways project team	Dumfries	Sep 15	8
Whitehorse discussion group	Dumfries	Oct 15	18
SRUC Muck + Slurry event	St Boswells	Feb 16	40
Ruminators discussion group	Cheshire	Feb 16	20
Glasgow students	Dumfries	Feb 16	24
AHDB Workshop	Harpenden	Apr 16	32
BGS spring walk	Gloucestershire	May 16	13
ScotGrass	Dumfries	May 16	3000
		Total	**5271**

Farming press

Title	Media	Date
Compaction: cattle worse than tractors	Farmers Guardian	Apr 13
Looking after your soil this autumn and beyond	Farmers Guardian	Oct 13
Addressing soil compaction and managing soil long term	Farmers Guardian	Oct 13
Making lighter work of soils	Scottish Farmer	Nov 13

Making lighter work of soils	Godro article	Jan 14
Research reveals high price of compacted soils	Farm Business	Feb 14
Heavy risk involved with compaction	Scottish Farmer	Mar 15
Cutting compaction	Farm Contractor and Large Scale Farmer	Apr 15
Staying alert to soil compaction in grassland	British Dairying	May 15
Effect of compaction	Dairy Farmer	Jun 15
How controlled traffic farming can help improve grass yields	Farmers Weekly	Mar 16
Wet and cold have impact on growth	Farmers Guardian	Apr 16

Online

Title	Media	Date
Repairing the damage from 2012	Forage for Knowledge and AHDB website	Feb 13
Soil compaction, assessment and alleviation	Live webinar	Feb 13
Controlling field traffic key to grass yields	Forage for Knowledge	Sep 13
Lifting soils, lifting yields	Forage for Knowledge	Dec13
Precision Farming Techniques	AHDB online video	Dec13
Soil Compaction – Grass and Muck	AHDB online video	May 14
Soil compaction	Radio 4 – Farming Today	Nov 14
Does controlled traffic farming have a place in a silage operation?	AHDB website	Jul 15
Controlled Traffic Video	AHDB youtube video	Oct 15
Controlled traffic	Forage for Knowledge	Oct 15

E. Benefits of the research results to the British dairy sector

E (I) Economic benefits (describe, and wherever possible quantify, potential financial benefits at farm level, and/or to the industry as a whole)

Minimising any potential risk of soil compaction will improve grassland productivity, reducing the requirement for purchased feedstuffs. The yield lost witnessed from compaction in these experiments (12 – 19% at first cut) was estimated to have a financial value of £72 – 114/ha. With 70% of grassland fields exhibiting signs of compaction, the potential financial implications of compaction on farms located on heavy soils would be equivalent to £7200 - £11400 per annum.

The loss in DM yield has been calculated between 5.6 and 8.4 m t/ha from trampling and 6.0 and 9.0 m t/ha from tractor traffic across England and Wales, depending on the soil type, based on the losses seen from the current experiments.

New methods of vegetation measurement and assessment of sward variation would have to balance labour costs of manual sward measurement against the cost of the electronic equipment.

Based upon a mean 13% increase in DM yield from the absence of wheel damage through the use of CTF and average dry matter yields for 2 and 3 “cut” harvest systems in the UK, reducing the trafficked area from an assumed 80% (N traffic) to 45% (CTF) increased the yield by 0.53 t/ha and 0.73 t/ha for 2 and 3 cut systems respectively. Similarly, reducing the trafficked area to 15% increased the yield to 1.00 t ha^{-1} and 1.36 t/ha for 2 and 3 cut systems, respectively (assuming a dry matter value of £72 t^{-}; the yield increases are currently valued at between £38 ha and £98 ha).

The cost of a low accuracy and non-repeatable positioning manual steered system would be less than £18.70 ha for areas in excess of 100 ha and £85.50 ha for fully integrated, high accuracy systems for areas in excess of 200 ha reducing to £11.40 ha for areas greater than 1500 ha/cut (based on the assumption of the cost of the guidance systems needed to implement CTF systems and that four guidance systems would be required to equip the harvester and the accompanying tractors).

The break-even area for implementing CTF depends upon the level of investment, the trafficked area and the number of cuts each year. This ranges from 28 ha for low accuracy, manual steered systems with a 35% trafficked area with 3 cuts a year to 250 ha for the fully integrated, high accuracy real time kinematic navigation systems, reducing to 175 ha with a trafficked area of 15%.

E (II) Sustainability benefits (How will outputs support sector sustainability in the long-term? Will the activity support sustainability in other ways such as improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)

The outputs from the WP should help sustain the yield of grassland in the longer term as any reduction in compaction would improve yield. Benefits of the use of soil alleviation techniques in improving soil strcuture were investigated and the results should be used to help inform both the use and timing of this equipment. The assessment of new methods of grassland sward production that reduces labour and increases the prediction of yield would be beneficial not only to the user of the device but also to the manufacturer. The compaction experiment at SRUC was used as a basis of a PhD studentship investigating the effects of soil to compaction on the biological component of the soil and the effect of a nitrification inhibitor on certain microbial groups. Data from the compaction experiment at SRUC, especially the greenhouse gas emissions, were used for three undergraduate projects for agricultural students.

E (III) Policy making (Describe how the work informs policy, leads to better decision making, or addresses wider societal concerns)

There is a real concern from farmers that soil compaction is an issue in the reduction in yield and there is an interest in the alleviation of these problems. The maintenance of well drained grassland should be considered to inform policy that would help reduce costs associated with soil compaction. The data provided both in the extent of the yield reduction and the cost benefits of alleviation should lead to more focused decision making and wider social concerns on soil health.

The monitoring of the associated GHG emissions from soil compaction, especially N_2O, should inform both the climate change policy relating to agricultural emissions and would help in the refining of emissions factors used in the calculation of climate change targets. These emissions data provide evidence of the importance of good soil structure for soil health.

The controlled traffic work indicates that with simple changes to grassland management yield increases can be achieved that would potentially reduce fertiliser input and loss of soil health across the whole sward. The management strategies outlined would help in decisions over equipment renewal and the cost benefits of new GPS equipment.

E (IV) Supply chain (Does the work address supply chain constraints or opportunities)

Soil compaction is a problem that not only affects the yield of the crop but that problems can occur from harvesting of the grass silage in wet conditions. This has implications for contractors and simple changes in behaviour through controlled traffic can lead to improvements in yield. The alleviation of soil compaction are potentially achieved through contractors understanding

how compaction can effect yields and how and when to undertake these management options. This is crucial to maintaining, or achieving a successful increase in yield.

F. Leverage and added value (Detail all additional funding sources and collaborations nationally or internationally. Has this activity contributed to applications for further research in this area? Has the work contributed to improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)
The work helped provide a platform for a PhD studentship funded between SRUC and Nottingham University on the biological implications of soil compaction and the effect of the nitrification inhibitor on soil microbial communities. The work also helped inform the Healthy Grassland Soils assessment tool jointly produced for AHDB Dairy and AHDB Beef and Lamb. The programme allowed three undergraduate (agriculture students) to complete final year projects by using data generated from the monitoring of the GHG production from the compaction experiments at SRUC.

Work package title:	Description and effect of functional fibre in forages on rumen function, performance and health of UK dairy cows		
Start date (mm-yyyy):	08-2015	Actual (£)	£166.5k
End date (mm-yyyy):	07-2018	Planned cost (£)	£166.5k
Name & organisation of principal investigator (PI):	Liam Sinclair Harper Adams University (HAU)		
Collaborators:	HAU and UoR		

A. Overview by work package leader

Underpinning rationale: Sustaining the increased milk production that has been witnessed in the UK over the last 25 years has required an increase in the level of concentrate supplementation and the production of high quality forages, with a trend towards lower dietary fibre levels (Beauchemin et al., 2003). The consequences of these dietary changes are an increased risk of metabolic disorders including subclinical ruminal acidosis (SARA), milk fat depression, displaced abomasum, laminitis, reduced fibre digestion and fat cow syndrome (NRC 2001). Field studies in the USA indicate that 19% of early lactation and 26% of mid-lactation dairy cows suffer from SARA (Garrett et al., 1997).

Adequate forage particle size (PS) is necessary to stimulate chewing activity and as a consequence saliva production, which is required to neutralise acid production in the rumen and result in a ruminal pH above pH 5.8 (Zebeli et al. 2012). Adequate forage particle size is also necessary to produce a ruminal fibre mat which retains smaller forage particles, thus increasing their digestion (Zebeli et al. 2006). A short chop length is however, often desired by farmers and contractors to improve consolidation at ensiling and reduce aerobic spoilage at feed out (McDonald et al., 1991). In contrast, too high a PS and physically effective fibre (peNDF) lowers the passage rate of digesta and reduces the rate of fibre degradation due to a lower surface area (Zebeli et al., 2012). This can lead to reductions in feed intake due to greater rumen fill. Additionally, too long a forage particle size promotes sorting in the feed passage, resulting in some cows receiving excess concentrates and others insufficient (Kononoff and Heinrichs, 2003). The effects of PS and peNDF in dairy cow studies are also complicated by the level of inclusion and rate of degradability of supplementary concentrates. For example the dietary response might be different when wheat is fed in replacement of maize even if the diet contains the same peNDF content.

Accurate assessment of forage PS in dairy cow diets is difficult, and current feeding tables and nutritional programs do not include this parameter, despite its importance. There are several methods currently available to assess PS and peNDF in the diet although there is no accepted standard and all have been developed for comparatively dry North American style diets based on alfalfa haylage and corn silage. As a consequence, the methods currently available to assess PS and peNDF may not be suitable for the greater range of dry matters of grass and maize silages commonly encountered in the UK, particularly for wet grass silages.

Work package objectives:

a) evaluate and develop methods to more accurately describe forage particle size and functional fibre content of grass and maize silage under GB conditions
b) characterise the range of forage particle size and functional fibre content of grass and maize silages on commercial GB dairy farms and to determine the influence of mixing and the extent of cow selection
c) evaluate the influence of forage particle size and functional fibre on rumen pH, fermentation, intake, performance and milk composition in dairy cows and examine the interaction with level and rate of degradation of supplementary sources
d) provide recommendations to dairy farmers, nutritionists and contractors on target

forage particle size to optimize rumen health and cow performance.

Approach and progress: To test these hypotheses the project has initially reviewed the literature on different methods available to characterise forage particle size for grass and maize silages across a range of dry matter contents and stages of maturity. The Penn State Particle Separator was selected as the most suitable method that is likely to be used by industry and was modified to contain an additional top pan with holes of 26.9 mm diameter. This was then followed by an on-farm survey to characterise the particle size of grass and maize silages on UK dairy farms (Executive Summary 1). The consistency of mixing of total and partial mixed rations, as well as the degree of selection post feeding was also determined. To achieve this 50 farms from Scotland to southern England were sampled (data is currently being analysed). The data generated has been used to inform the design of two controlled studies to evaluate the effect of grass and maize silage particle size on rumen fermentation, animal performance and milk fat composition. At HAU first cut grass silage with two chop lengths (short and long) have been ensiled and will be evaluated in a controlled feeding study during the winter of 2016/17 (Executive Summary 2). A second study will be conducted during the winter of 2017/18 at the UoR using fistulated dairy cows to evaluate the interaction between forage peNDF and concentrate type/level (Executive Summary 3).

Delivery: To date the project is on schedule to achieve the milestones and is within budget. The work has also received commercial support via the Society of Feed Technologists and industry. The findings from the studies will be exchanged with farmers, the feed trade and forage contractors through interaction with AHDB KE staff, demonstration days on study and research farms, reports and press releases. Presentations at events such as the Society of Feed Technologists and the Nottingham Feed Manufacturers Conference will also be used to inform industry. Finally, the findings will be published at technical conferences and as peer reviewed research papers.

B. Executive Summary 1) Particle size and physically effective fibre distribution in a range of grass and maize silages, and the efficacy of mixing and extent of diet selection of total mixed rations on UK dairy herds.

Background and Objectives: The estimation of the particle size (PS) distribution of forages in dairy rations is problematic. Various methods have been proposed to characterize feed particle distribution using different sieving methods, but there is no accepted standard. Maulfair and Heinrichs (2012) concluded that the Penn State Particle Separator (PSPS) was the most useful method to use on-farm to estimate PS and physically effective fibre. These recommendations are however, primarily based on comparatively dry North American style diets consisting of maize silage and lucerne haylage (Eastridge, 2006) and may not be suitable for the wetter range of grass and maize silages commonly encountered in the UK. Coppock *et al.* (1981) suggested that the use of TMR is an effective way to provide a homogeneous and balanced diet throughout the day. However, preferential consumption of the palatable concentrate part of the diet by dairy cows has shown to result in variability in nutrient intake; behaviour referred to as sorting activity (DeVries *et al*., 2007; Leonardi and Armentano, 2003). To reduce sorting activity, more homogeneous mixing procedure and length of mixing should be adopted for GB dairy farms. Finally, mixer wagons and mixing protocols has been shown to result in a reduction in feed intake and milk yield in diets with a longer chop length (Humphries *et al.,* 2010; Mulfair *et al.,* 2010). Heinrichs *et al.* (1999) indicated that processing by the mixer wagon prior to feed-out can have a large effect on the PS and physically effective fibre fed and the consistency of the mix. Consideration should therefore also be given to the effect of PS and consistency of mixing on the degree of diet selection and consumed by the cow and the influence of level and form of supplement on rumen metabolism, cow performance and health under GB conditions. The main aim of the study was to characterise the PS distribution of typical grass and maize silages being fed on GB dairy farms using a modified PSPS. The secondary aims of the study were to determine a) the consistency of mixing of TMR on GB dairy farms, and b) to evaluate the range of sorting of TMR using grass and grass/maize silage based rations on GB dairy farms.

Technical approach: Fifty commercial dairy herds located throughout the UK (32 in the midlands of England, 9 each in South of England and Southwest Scotland, respectively) that were feeding a range of grass and maize silages were visited in 2016. All of the herds were using a forage based total or partial TMR feeding system and contained at least 50 cows in the high producing group. Samples of TMR were collected within 5 minutes of feed out at five points along the feed face, and again four hours post feeding. Samples of grass and maize silage were collected from the silage clamps. The particle size distribution of the TMR and forage samples were determined fresh, dried and frozen-defrosted using a modified Penn State Separator with a 26.9 mm pore size pan. Additionally, samples of TMR and forages are being analysed for dry matter, crude protein, fibre and starch.

Key results: Results are currently being analysed. Out of the 50 herds, 27 fed a TMR, while the remaining 23 fed a partial mixed ration with additional concentrate fed in the parlour. Twenty four herds used a "tub" type mixer wagon, 18 a "barrel" type, 7 an "auger" design (vertical or horizontal) and one used a forage box. Total herd size ranged from 75 to 2220 animals, with a mean of 354. Average milk yield ranged from 6000 to 12500 kg/cow/year, with a mean of 9199 kg/cow/year. Out of the 50 herds, 20 were feeding in a trough and on the remaining 30 herds the average frequency of feed push up was 4.7 x/day. Feed space per cow ranged from 0.30 m/cow to 0.76 m/cow with average of 0.56 m/cow. The particle size distribution of grass silage was considerably greater than maize silage and it is therefore recommended that future studies focus on the chop length of grass silage, as this has greatest practical and commercial relevance to UK dairy farmers.

Farmer messages: Results from this study will provide farmers with the following:

- The most suitable means to determine the particle size distribution of grass, maize and TMR samples for GB dairy farms
- Mean particle size length and range for grass and maize silage on commercial dairy farms
- The proportion of dairy farms that have a consistent TMR mix and the proportion that have little/no diet selection
- Effect of mixer wagon type on the consistency of TMR mix

Further exploitation: These findings can be used to inform farmers, contractors and feed analysis laboratories of the most appropriate means to measure particle size distribution and the typical range encountered on GB dairy farms. This can also be used to inform GB dairy farmers of the best means to ensure a consistent TMR mix and to avoid diet selection. This will ensure that all dairy cows in a herd receive the same diet and minimise the risk of acidosis and ketosis.

B. Executive Summary 2) The effect of grass silage particle size when fed alone or in combination with maize silage on rumen function, intake, performance and whole tract digestibility in dairy cows

Background and Objectives: Achieving the correct PS and physically effective fibre in a ration can be reflected in the maintenance of a better environment for the growth of rumen microbes, a more efficient degradation of fibre and as a consequence an increase in milk fat content (Merten 1997, De Brabander *et al.,* 2002). Additionally, increased microbial protein synthesis in the rumen is likely to be translated into greater metabolisable protein supply to the small intestine and consequently enhance milk protein levels (Sinclair *et al.,* 2014). A short forage particle length is often desired by farmers and contractors to improve compaction in the clamp and reduce aerobic spoilage at feed out (McDonald *et al.,* 1991). A short forage particle length may also increase dry matter intake due to a reduced rumen fill. In contrast, a short forage particle length can increase the rate of volatile fatty acid production in the rumen, reduce rumination time, decrease the production of saliva and inhibit cellulolytic bacteria activity, all considered as risk factors for SARA (Zebeli *et al.,* 2012). Preliminary findings from a survey of forage particle distribution on GB dairy farms reported a large variation for grass silage, but a much smaller range of values for maize silage. As a consequence, future studies should focus on the impact of particle length of grass silage when fed alone or in combination with maize silage. The objectives of this study is therefore to determine the effect of particle size and physically effective fibre content of grass silage when fed alone or in combination with maize silage on rumen function, intake, performance, feeding behaviour and whole tract digestibility in high yielding dairy cows. Grass silage only and mixed grass silage/maize silage based diets have been selected to represent the majority of forage mixtures currently being fed to dairy cows in GB.

Technical approach: Sixteen high yielding dairy cows will be fed one of four diets in a Latin square design with four periods, each of 4 weeks of duration, with measurements undertaken during the final seven days of each period. All diets will have a forage to concentrate ratio of 55:45 (DM basis) and within the forage component, the four treatments will contain:

GS: Short particle size grass silage
GL: Long particle size grass silage
MS: Short particle size grass silage mixed with maize silage (50:50 DM basis)
ML: Long particle size grass silage mixed with maize silage (50:50 DM basis)

The diets will be balanced for metabolisable energy and metabolisable protein supply according to Thomas (2002). Rumen pH boluses will be inserted into each cow and pH monitored continuously. During the final seven days of each period intake milk yield will be determined daily and samples taken on four occasions for the subsequent determination of fat, protein, lactose and milk fatty acids. Eating and rumination behaviour will be determined manually. Whole tract digestibility of fibre will be determined using acid insoluble ash as a marker. Blood samples will also be collected to determine metabolic status.

Key results: First cut grass silages that represent the bottom and top 25% of forage particle length currently being fed on GB dairy farms have been ensiled. Preliminary analysis indicates a similar nutrient and fermentation profile for both forages, which is representative of a good quality first cut grass silage. The study will commence mid-January 2017 and last for 16 weeks.

Farmer messages: Findings from this study will provide dairy farmers with valuable information on the impact of grass silage particle length when fed alone or in combination with maize silage in GB diets on:

- Intake, rumen health, SARA and whole tract digestibility
- Milk yield and composition
- Metabolic status and health

Further exploitation: Findings from this study can be exploited by transferring the information to farmers, contractors, nutritionists and veterinarians so that grass silage is made that optimises rumen function, and improves animal health and performance.

B. Executive Summary 3) The effect of grass silage particle size and dietary starch level on rumen function, intake, performance and whole tract digestibility in dairy cows fed grass silage/maize silage based diets

Background and Objectives: Forage particle length is a key determinant of ruminal pH and the risk of sub-acute ruminal acidosis, with subsequent effects on dry matter intake, animal performance and milk composition (Zebeli et al., 2012). Other components of the diet, particularly dietary starch concentration also impact on these factors, but most work in this area has been conducted using dry, North American type diets, which are not representative of that fed on most GB dairy farms. The objectives of this study are to determine the impact of grass silage particle size when fed in combination with different dietary starch levels on rumen pH and fermentation, intake, performance, feeding behaviour and whole tract digestibility in high yielding dairy cows fed mixed grass silage/maize silage based rations. The starch levels chosen will represent the range found in the initial on-farm survey.

Technical approach: Four high yielding, rumen fistulated dairy cows will be fed one of four diets in a Latin square design with four periods, each of 4 weeks of duration, with measurements undertaken during the final seven days of each period. The four dietary treatments will be:

SL: Short particle size grass silage and low dietary starch level

SH: Short particle size grass silage and high dietary starch level

LL: Long particle size grass silage and low dietary starch level

LH: Long particle size grass silage and high dietary starch level

A typical grass:maize silage ratio of 50:50 (DM basis) will be used and a typical low and high starch level will be 100 and 250 g/kg DM respectively. All diets will contain a forage to concentrate ratio of 55:45 (DM basis) and will be balanced for metabolisable energy and metabolisable protein supply according to Thomas (2002). During the final seven days of each period rumen fluid samples will be taken over a 24 hour period and analysed for pH, volatile fatty acids and ammonia. Additionally, intake and milk yield will be determined daily and samples taken on four occasions for the subsequent determination of fat, protein and lactose. Eating and rumination behaviour will be determined manually. Whole tract digestibility of fibre will be determined by total collection.

Key results: This study will commence in September 2017 and last for 16 weeks.

Farmer messages: Findings from this study will provide dairy farmers with valuable information on the interaction between grass silage particle length and dietary starch levels on:

- Intake, rumen health, SARA and whole tract digestibility
- Milk yield and composition

Further exploitation: Findings from this study can be exploited by transferring the information to farmers, contractors, nutritionists and veterinarians so that appropriate diets can be formulated and fed that contain grass silages of varying particle length and with different dietary starch levels to optimise rumen function, animal performance and health.

C. Delivery against milestones - tabulate achievement of milestones against targets set. List any deviations or agreed changes in direction, and their impact on the project (if applicable, describe how the work differs from that originally proposed and describe how the changes have impacted on the work package. Include changes to objectives and work plan / budget, changes to the team or other constraints. Explain any discrepancy between planned worked and achieved work, and corrective actions taken.

Functional fibre for dairy cows (WP 6)	Progress, deviations and corrective actions

Milestone 6.1. Advertise and appoint PhD student: April 2015 ***Milestone 6.2.*** Evaluate/adapt current methods and select most appropriate method for future studies: April 2015 ***Deliverable 6.1.*** Produce final report on most appropriate methods: Dec 2015	PhD student appointed July 2015 Preliminary analysis conducted and Penn State Separator modified and manufactured Evaluation of most appropriate methods incorporated into main study to provide greater number of samples and statistical validity
Milestone 6.3. Collection and assessment of samples commence: Nov 2015 ***Milestone 6.4.*** Complete on farm measurements: April 2016 ***Milestone 6.5.*** Complete laboratory and statistical analysis: Oct 2016 ***Deliverable 6.2.*** Produce final report: Mar 2017	Sample collection commenced January 2016 Measurements completed May 2016 Chemical analysis at HAU complete. Starch analysis to be conducted by Frank-Wright Trouw by end January 2017 On schedule
Milestone 6.6. Ensile grass and maize silages: Nov 2016 ***Milestone 6.7.*** Commence feeding study: Dec 2016 ***Milestone 6.8.*** Complete feeding cow study: April 2017 ***Deliverable 6.3.*** Submit final report: Jan 2018	First cut grass silages ensiled May 2016, maize silage ensiled Oct 2016 Feeding study to commence January 2017 Feeding study will end May 2017 On schedule
Milestone 6.8. Ensile grass and maize silages: Nov 2016 ***Milestone 6.9.*** Commence feeding study July 2017 ***Milestone 6.10.*** Complete study: Oct 2017 ***Deliverable 6.4.*** Submit final report: June 2018.	Maize silage ensiled. Grass silage to be ensiled May 2017 On schedule On schedule On schedule

D. Outputs (List and fully reference all outputs which document and promote the findings of this work. Describe any further outputs or follow-up initiatives anticipated after 31 May 2016).
D (I) Experimental/project reports to AHDB
First due March 2017 (on schedule)
D (II) Scientific publications (accepted or submitted; peer reviewed conference proceedings etc.)
Abstract being prepared for submission to BSAS annual meeting, April 2017.
D (III) Knowledge transfer (national and international workshops, farmer/industry meetings, media articles etc.)
Cutting through chop-length confusion. Published 17th Oct 2016.https://dairy.ahdb.org.uk/news/

forage-for-knowledge-articles/2016/cutting-through-chop-length-confusion/#.WCb7Hk14i7s Presentation to Society of Feed Technologists scheduled for April 2017.

E. Benefits of the research results to the British dairy sector
E (I) Economic benefits (describe, and wherever possible quantify, potential financial benefits at farm level, and/or to the industry as a whole)
Evidence based information on the particle size distribution and the impact on rumen function and animal performance will allow more accurate diet formulation, improve animal performance and reduce culling rates. This will increase efficiency and reduce feed costs.
E (II) Sustainability benefits (How will outputs support sector sustainability in the long-term? Will the activity support sustainability in other ways such as improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)
By reducing SARA this will increase cow performance and reduce culling rates. The study is supporting 1 PhD student, has supported one B.Sc student project, and will support a further 4 student projects at HAU, all of whom have a desire to enter the dairy industry.
E (III) Policy making (Describe how the work informs policy, leads to better decision making, or addresses wider societal concerns)
By improving cow health this will reduce culling rates and improve the image of GB dairy farming.
E (IV) Supply chain (Does the work address supply chain constraints or opportunities)
It is important that this information is transferred to forage contractors as they have a major influence on chop length on-farm.

F. Leverage and added value (Detail all additional funding sources and collaborations nationally or internationally. Has this activity contributed to applications for further research in this area? Has the work contributed to improving skills or attracting new entrants into the industry e.g. PhD studentships/post-docs?)
Additional funding from the Society of Feed Technologists has been secured via the Edgar Pye Research Scholarship (worth £1750). This will be used to conduct additional analysis, particularly the starch content of the TMR rations on the 50 commercial dairy farms. Additionally, industry (Frank Wright Trouw) have offered (free of charge) to provide a NIR scan of all the TMR, grass and maize silages used in the survey.

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