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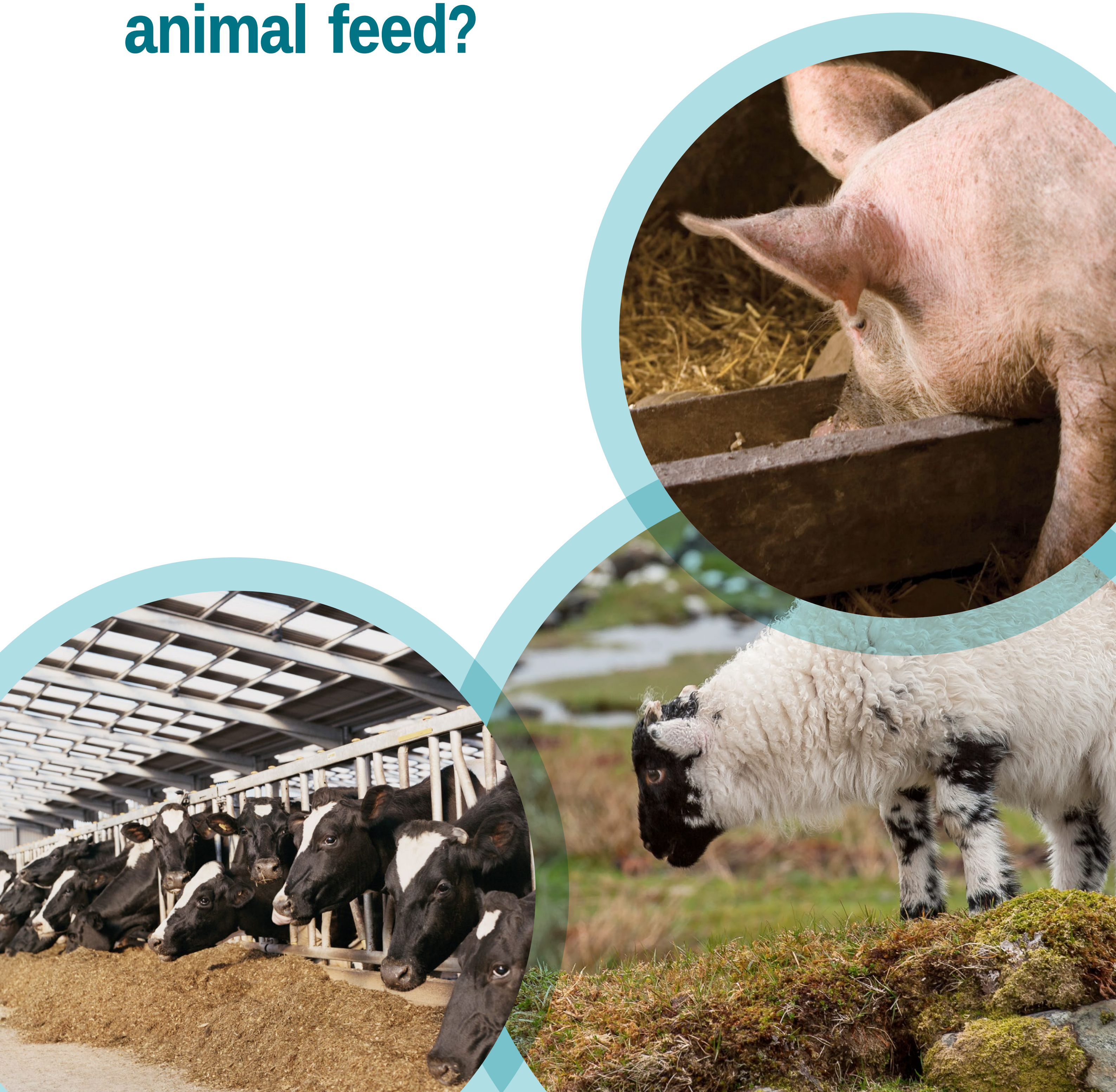
To what extent could water quality be improved by reducing the phosphorus content in animal feed?



Published by CREW: Scotland's Centre of Expertise for Waters. CREW connects research and policy, delivering objective and robust research and expert opinion to support the development and implementation of water policy in Scotland. CREW is a partnership between the James Hutton Institute and all Scottish Higher Education Institutes supported by MASTS. The Centre is funded by the Scottish Government.

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Please reference this report as follows: Gooday, R., Gittins, J., Moorhouse, D., Wheeler, K., & Wright, E. (2016) To what extent could water quality be improved by reducing the phosphorus content in animal feed? Final Report CRW2015/03.

Available online at: crew.ac.uk/publications www.crew.ac.uk/publications

Cover images courtesy of: Richard Gooday, ADAS

ISBN 978-0-902701-41-0

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Executive Summary

Key findings

- In the monogastric sector (pigs and poultry), dietary phosphorus levels have reduced in recent years due to the use of phytase enzyme in compound feeds, combined with a shortage of mineral phosphorus and thus increased prices, in and around 2008.
- There is limited scope for further change in the monogastric sector. Although it can be locally important, the sector is relatively small countrywide and so any changes are insignificant at the national level.
- In the ruminant sector, significant levels of mineral phosphorus were previously included in supplementary feeds. The increased prices of phosphorus since 2008, coupled with improved understanding of nutritional requirements have reduced its use.
- Opportunities exist to further reduce phosphorus levels, particularly in the dairy sector, where the fear of under-supplying means that many farmers still add supplementary phosphorus in mineral form.
- Reductions could be made to compound feeds supplied to ruminants. This typically requires replacing ingredients such as maize (comparatively high in phosphorus) with lower phosphorus alternatives such as soya hulls, soya bean meal and sugar beet pulp. These alternatives can be more expensive and/or need to be imported.
- Complete removal of mineral phosphorus in dairy diets could reduce national phosphorus losses by almost 1%. The reduction in excretal phosphorus may also cause soil losses to be reduced, such that the national load would be reduced by another 1-2% over the next 10-20 years as the soil phosphorus status reduces.
- Such removal of mineral phosphorus would be a cost saving to the farmer.
- Reducing the phosphorus content of compound feed to ruminants, particularly dairy cattle, could reduce the national phosphorus load by 2-3% (including the changes to soil phosphorus status). This would require an increase in the overall feed costs and the importing of feed ingredients.
- Although these reductions of up to 5% in the national phosphorus load appear small, they are comparable to estimated reductions for regulatory compliance and agri-environment scheme uptake.
- Reductions are in areas where there are more livestock, particularly intensive livestock farming, which are typically areas with greater diffuse phosphorus losses.

Background

The latest River Basin Management Plan for Scotland identifies 16% of waterbodies below good status for water quality. Rural diffuse pollution is identified as the number one water quality issue.

Phosphorus is an essential nutrient for livestock, being a constituent of bones and teeth and used for essential functions, such as energy utilisation. However, livestock may be fed diets with higher levels than are needed and any surplus will not be utilised and will be excreted, leading to the pollution of freshwaters. Thus, reducing the phosphorus content of livestock diets closer to the required levels has been identified as a potential mechanism by which to reduce rural diffuse pollution.

There are currently 1.8 million cattle in Scotland, 6.7 million sheep, 0.3 million pig places and 14.7 million poultry places, which in total excrete 28 million kg of phosphorus per year, with the cattle responsible for two thirds of this. The national annual average diffuse phosphorus load from agriculture is 2.8 million kg, with about 15% of this resulting directly from livestock – either due to excreting whilst grazing or to the application of manure. The majority of the phosphorus load entering watercourses come from the soil (74%), but the phosphorus status of the soil is partly controlled by the livestock returns so there is an indirect contribution from livestock additional to the 15%. The livestock contribution to the national phosphorus load is thus significant.

Research Undertaken

The objectives of this project were to:

- determine the current contribution of livestock to phosphorus pollution in water courses in Scotland;
- establish the current phosphorus levels within finished compound feeds and key raw materials used in livestock diets;
- establish the scope for and cost implications of feed and diet formulation changes;
- determine the impacts of any changes in livestock diets on the amount of phosphorus in excreta and the consequences of this for diffuse phosphorus pollution and water quality status in water courses;
- determine any changes to feed costs and relate these to the total costs of production for the stock or product in question (e.g. the production cost of meat, milk, eggs etc.), to assess their significance and thus the likelihood of voluntary uptake.

1.0 Introduction

1.1 Background

1.1.1 Water quality issues

The latest River Basin Management Plan (RBMP; Scottish Government, 2015) states that 16% of waterbodies are below good status for water quality, and 246 waterbodies face rural diffuse pressures. Rural diffuse pollution has been identified as the number one water quality issue. Previous water quality monitoring data in Scotland found 7% of water bodies were failing to reach good status for phosphorus (Scottish Government, 2009), although this is based on phosphorus standards which have since been revised. Agriculture contributes a significant proportion of the phosphorus loss. Controlling this loss is an important approach to improving water quality in Scotland, with a number of initiatives already in place. Diffuse Pollution General Binding Rules (GBRs) were introduced to reduce diffuse pollution. Those of most relevance for the control of phosphorus loss cover the storage and application of fertilisers, the keeping of livestock and the cultivation of land. There has been a process of awareness-raising and farm visits to provide one-to-one advice within Priority Catchments in an attempt to achieve GBR compliance and to help target additional measures available through the Scottish Rural Development Programme (SRDP).

1.1.2 Animal feed and phosphorus

One option identified for the improvement of water quality is a focus on phosphorus in livestock feed, since it is established that the nutrient content of feeds can impact upon diffuse pollution. Phosphorus is an essential nutrient for livestock. It is primarily found within the skeleton, being a constituent of bones and teeth but it also has other essential functions, such as energy utilisation. It is present in the nucleic acid fraction of living cells and is closely associated with calcium in animal metabolism. A range of symptoms, including skeletal problems are associated with phosphorus deficiency. Commercial feed formulations typically set both maximum and minimum percentage inclusion rates for phosphorus. In practice, livestock may be fed diets with higher phosphorus levels than are needed and any surplus will not be utilised. It will instead be excreted by the animal and may subsequently contribute to the pollution of freshwaters. The aim must therefore be to avoid excess phosphorus in livestock feeds and improve the utilisation of dietary phosphorus, so that environmental implications are reduced and animal performance is not adversely affected.

Standard Farming Installation Rules for larger pig and poultry farms issued by SEPA for environmental permitting purposes, state that livestock should receive diets which minimise the excretion of phosphorus (and nitrogen) whilst ensuring the correct dietary needs of the livestock are met. The rules state that lower phosphorus levels in diets will reduce phosphorus excretion and so reduce phosphorus levels in slurry and manure. For pigs, the rules state that phosphorus levels should be reduced over the production cycle. For poultry, the use of phytase enzyme should be considered as a means of increasing the availability of phosphorus from vegetable sources and thus reducing total phosphorus levels in the diet. Recommended levels are not specified for either species.

In ruminants, young fast-growing animals and lactating females have the highest phosphorus requirements, but all ruminants need to consume sufficient phosphorus to meet the needs of rumen micro-organisms. Where insufficient phosphorus is consumed, cellulose digestion, microbial protein synthesis and feed intake can all be reduced. Phosphorus deficiency can result in reduced growth rates, low milk yields and reduced fertility in cows.

1.1.3 Previous studies on phosphorus in livestock diets

A study looking at nitrogen and phosphorus excretion by UK dairy cows (Laws et al, 2004) concluded that direct adjustment of dietary phosphorus was a more effective way of reducing phosphorus excretion than reducing fertiliser phosphorus inputs to grassland. This is because the phosphorus status of the soil (and thus phosphorus content of any cropping) is relatively insensitive to short term applications of phosphorus fertiliser, particularly where soils are high in phosphorus status as is common on dairy farms. Reduction of fertiliser inputs is therefore unlikely to have any impact of the amount of phosphorus being fed to dairy cows and thus the amount of phosphorus being excreted.

A Defra funded study (Cottrill et al, 2008) noted large differences in estimated phosphorus requirements for cattle and sheep depending on the system used and this was particularly marked for older animals. This variation largely arose from differences in estimating requirements for maintenance, but they were exacerbated by a lack of data on availability of dietary phosphorus. The research indicated that actual requirements were lower than those recommended in national systems in Europe and North America and that there may be scope for reducing phosphorus intake.

A study by AgriSearch (2010) in Northern Ireland found that 70% of the phosphorus consumed by cows is transferred to manures and slurries, from where there are risks of it being washed into watercourses, after spreading. During a four-year experiment, the quantity of phosphorus was reduced by 25% during the winter and by 16% during the summer. There was no adverse effect on feed intake, milk production or milk composition and no long-term effects on blood, bones or aspects of health and welfare. Reducing the phosphorus content of dairy cow diets by 25% resulted in a 45% reduction in phosphorus excretion in the manure. Following an agreement with feed compounders, lower phosphorus diets are now being offered to farmers in Northern Ireland.

A review commissioned by BPEX (Kyriazakis, 2008) suggested that, up until 2008, the UK pig industry was using phosphorus levels in diets which were 20-35% above the recommended Nutrient Requirement Standards. Several reasons for this oversupply were identified, including the requirement for safety margins, uncertainty over the digestible phosphorus contents of feedstuffs, and the advice offered by veterinarians to maintain leg soundness in breeding stock.

A study on the environmental and economic implications of reducing phosphorus excretion in pigs (Defra, 2013) carried out a number of trials with dry outdoor sows and growing/finishing pigs to demonstrate that dietary phosphorus can be reduced on-farm without negative effects on pig performance and health. However, reductions in the phosphorus content of the diets of outdoor sows were not accompanied by a measurable reduction in faecal loading at the soil surface, possibly due to sows consuming substantial amounts of phosphorus through rooting in the soil.

In poultry, adequate phosphorus levels are important in ensuring a high rate of egg production and in skeletal development and bone strength. The latter is of particular importance to the broiler (table chicken) sector where growth rates are high. The body weight of the commercial broiler typically increases by a factor of between 40 and 50 over a six week growing period. The significance of phosphorus in poultry diets – particularly in respect of skeletal issues and laying hen nutrition is reflected in the large number of scientific studies conducted over the years.

1.2 Project objectives and scope

The objectives of this project were to:

- determine the current contribution of livestock to phosphorus pollution in water courses in Scotland;
- establish the current phosphorus levels within finished compound feeds and key raw materials used in livestock diets;
- establish the scope for and cost implications of feed and diet formulation changes;
- determine the impacts of any changes in livestock diets on the amount of phosphorus in excreta and the consequences of this for diffuse phosphorus pollution and water quality status in water courses;
- determine any changes to feed costs and relate these to the total costs of production for the stock or product in question (e.g. the production cost of meat, milk, eggs etc.), to assess their significance and thus the likelihood of voluntary uptake.

The scope of this project was restricted to the following livestock types following discussions with the project steering group:

- For dairy cattle: lactating dairy cow and replacement heifer feeds;
- For beef cattle: feeds for suckler cows, replacement heifer feeds and finisher feeds;
- For sheep: feeds during lambing
- For pigs: grower, fattener and breeder feeds;
- For poultry: pullet grower, early and late lay feeds for laying hens and grower and finisher feeds for broilers.

2.0 Phosphorus Loads in Watercourses

In order to determine the potential impacts of reducing phosphorus in livestock diets upon water quality, it was necessary to determine the current contribution of livestock to phosphorus loads in watercourses. Gooday et al (2015) produced a detailed sector and source apportionment of phosphorus (and other pollutant) loads at Water Framework Directive (WFD) waterbody scale for Scotland. The sector apportionment determined the contribution of the agricultural phosphorus load to the total load. The source apportionment provided a detailed breakdown of the agricultural load by farm type, source, source area, pathway and form. This source apportionment allowed for an assessment of the contribution of livestock excreta and manure to the total phosphorus load to surface waters, identifying water bodies where the livestock component of the phosphorus load has a significant impact on measured water quality. It is the apportionment of the agricultural load by livestock type that forms the core of the modelling methodology within this project. The livestock types recognised in the outputs of this project were Dairy, Beef, Sheep, Pig and Poultry.

The agricultural phosphorus losses in Gooday et al (2015) were derived using the PSYCHIC model (Davison et al, 2008), which was used at 1km^2 scale to determine losses per unit (of e.g. fertiliser applied, manure applied or cropping). These were area weighted to determine coefficients for each WFD waterbody. The WFD waterbody coefficients were multiplied by the number of units (of e.g. fertiliser, manure, cropping) for each WFD waterbody as determined from agricultural survey data and farm practice data. The initial 1km^2 data allowed for appropriate use of environmental variables (such as climate, soil, slope and connectivity) before integrating with the survey data which is much more robust at WFD catchment scale than at 1km2 scale. The objective of that project was to determine the impacts of General Binding Rules and the Nitrate Vulnerable Zone (NVZ) Action Programme (AP) on pollutant loads entering watercourses. The GBRs and NVZ AP were mapped to a suite of mitigation actions, which were parameterised in terms of effect, uptake and cost. Uptake data were based upon analysis of a range of datasets including evidence of compliance derived from audits, surveys and catchment walks. A number of future mitigation implementation scenarios were investigated as part of that project, but only the current day scenario (i.e. current levels of compliance) is used in this CREW project.

2.1 Calculation of agricultural phosphorus loads for 2014

The calculation of agricultural phosphorus loads in Gooday et al (2015) was based upon the 2010 agricultural census. There have been significant changes in livestock numbers since 2010, primarily for pigs where numbers have dropped by almost 25% (Table 1); the outputs have been updated to reflect these changes. This updating was based upon the changes in total phosphorus excreted by the different livestock. Due to differences in the data collection between 2010 and 2014 (primarily the use of cattle tracing scheme data for 2014, and adjustments to account for incomplete coverage of the census) changes in livestock types were aggregated by county (see Appendix 1).

Table 1 Summary changes in livestock totals (cattle and sheep) or places (pigs and poultry) from 2010 to 2014 (a more detailed breakdown for 2014 is shown in Table 2).

Stock Type	2010 Count ('000s)	2014 Count ('000s)
Cattle	1,884	1,793
Sheep	6,755	6,693
Pigs	411	316
Poultry	14,567	14,742

2.2 Spatial distribution of livestock

Annually, over 28 million kilograms of phosphorus are excreted by livestock in Scotland (Table 2). Two thirds of this is from cattle and a quarter from sheep and lambs, the remainder mostly from poultry, with a little due to pigs. The dairy livestock are concentrated in the south west of Scotland (Figure 1), whilst beef cattle are found on most agricultural land and the sheep are concentrated away from prime agricultural land. Pig farming is concentrated on the eastern edge of Scotland (Figure 2), as is poultry, but to a lesser extent, with some poultry farming in the south of Scotland.

Table 2 Livestock numbers (cattle and sheep) and places (pigs and poultry), excretal phosphorus values per head and excretal phosphorus totals summarised by livestock type detailed breakdown for 2014 is shown in Table 2).

	Stock Type	Count ('000s)	P Excreted (kg/hd)	P Excreted (t)	Percent of Sector	Percent of Overall Total
Dairy	Dairy Cows and Heifers	170	19.4	3,290	72	
	Dairy Heifers in Calf, 2 Years and Over	50	12.2	590	13	
	Dairy Heifers in Calf, less than 2 Years	60	12.2	680	15	
	Total	**270**	**-**	**4,570**		**16**
Beef	Bulls	20	9.1	180	1	
	Beef Cows and Heifers	440	13.5	5,890	42	
	Beef Heifers in Calf, 2 Years and Over	90	12.2	1,050	7	
	Beef Heifers in Calf, less than 2 Years	190	12.2	2,320	16	
	Other Cattle, 2 Years and Over	60	8.0	470	3	
	Other Cattle, less than 2 Years	200	8.0	1,610	11	
	Other Cattle, Less than 1 Year (Inc. Calves)	530	5.0	2,630	19	
	Total	**1,520**	**-**	**14,160**		**49**
Sheep	Sheep	3,420	1.8	6,160	91	
	Lambs Less than 1 Year	3,270	0.2	620	9	
	Total	**6,690**	**-**	**6,780**		**24**
Pigs	Sows in Pig and Other Sows	30	7.1	180	22	
	Gilts in Pig and Barren Sows	10	4.4	20	2	
	Gilts Not Yet in Pig	10	4.4	20	2	
	Boars	0	5.2	0	0	
	Other Pigs > 110kg	10	3.7	40	5	
	Other Pigs 80 - 110kg	40	3.7	160	20	
	Other Pigs 50 - 80kg	60	2.6	160	20	
	Other Pigs 20 - 50kg	80	2.6	200	24	
	Other Pigs < 20kg	90	0.4	40	5	
	Total	**320**	**-**	**820**		**3**
Poultry	Layers	3,820	0.2	750	31	
	Pullet	1,890	0.1	210	9	
	Broilers	7,800	0.1	1,100	45	
	Breeding Birds	1,110	0.3	330	14	
	Other Poultry	120	0.3	40	2	
	Total	**14,740**	**-**	**2,430**		**8**
	Overall Total			**28,760**		

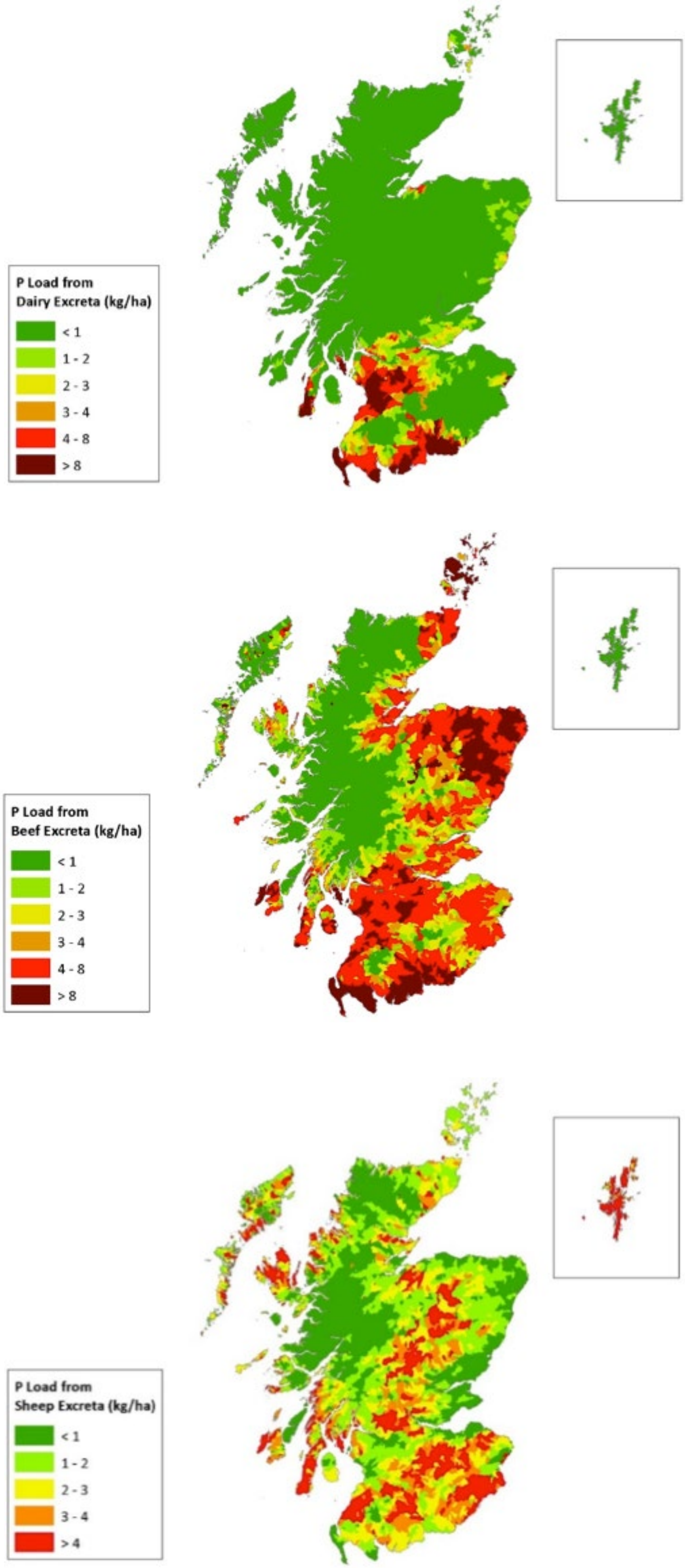
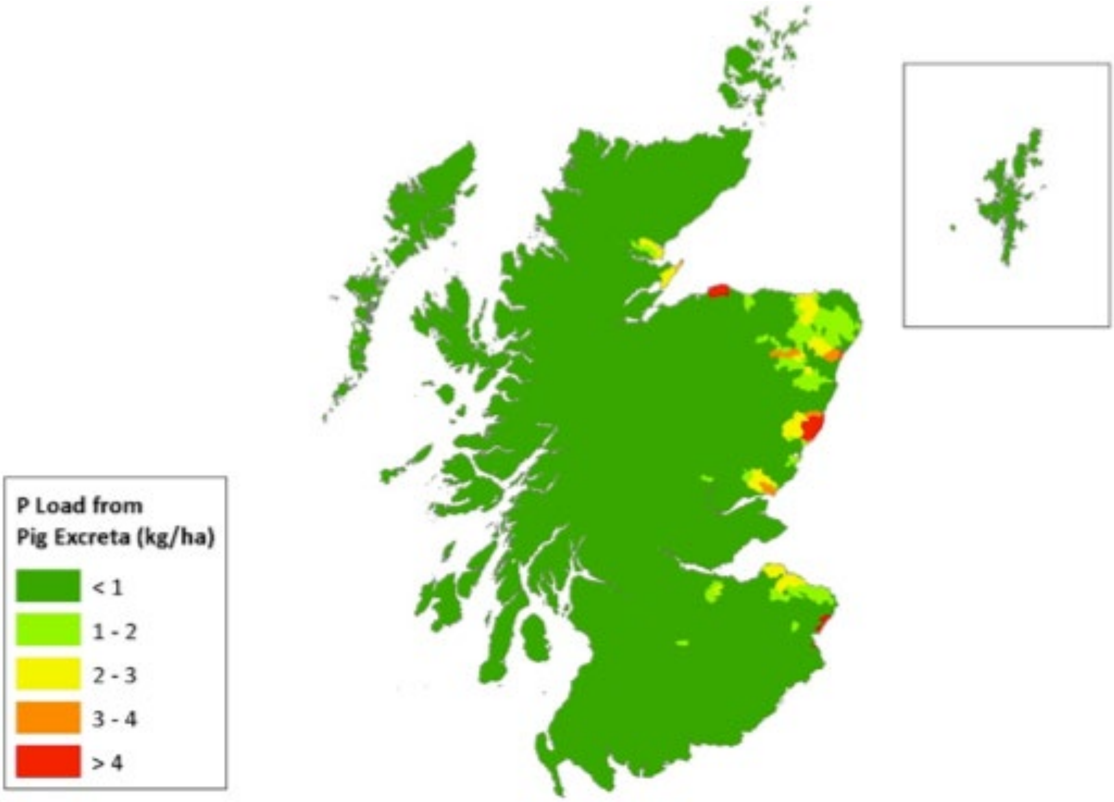


Figure 1 Phosphorus excreta from ruminants, expressed as kg per hectare of all agricultural land.



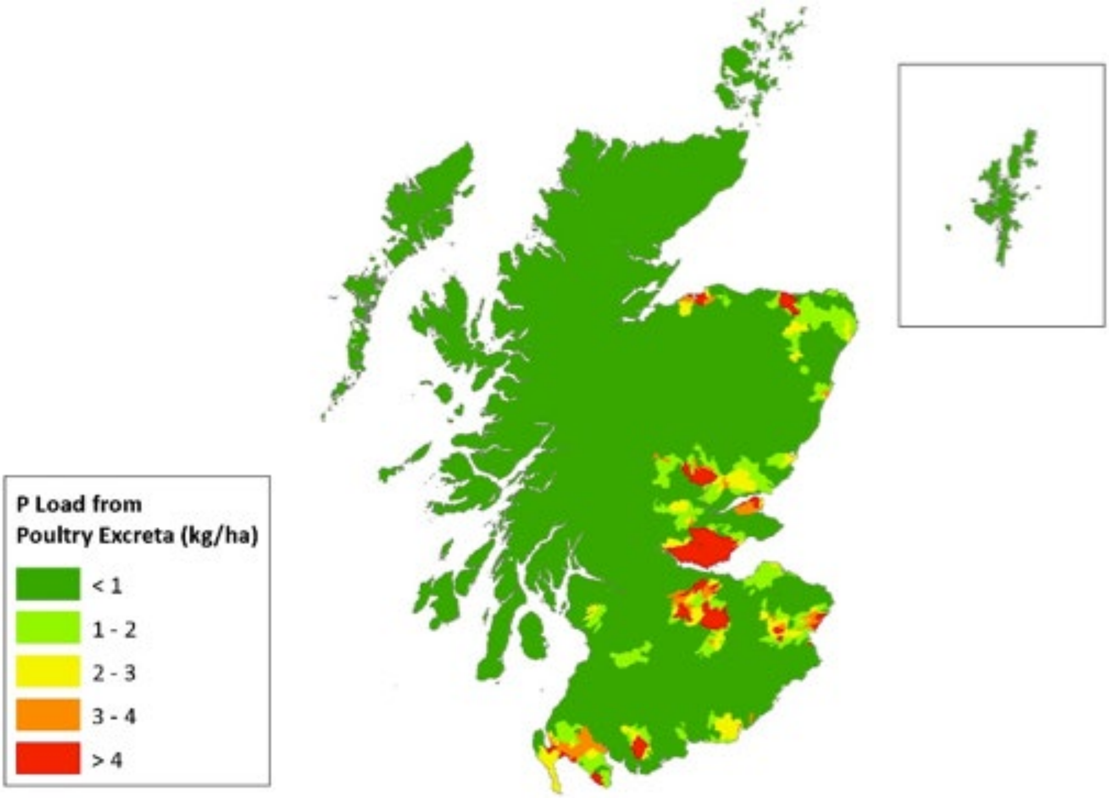


Figure 2 Phosphorus excreta from pigs and poultry, expressed as kg per hectare of all agricultural land.

2.3 Phosphorus loads and source apportionment

Based upon the outputs from Gooday et al (2015) modified for 2014 livestock numbers, agriculture contributes two thirds of the phosphorus delivered to watercourses for the whole of Scotland (Figure 3). The next most important source is sewage treatment works (18%). Figure 4 shows the apportionment of the agricultural phosphorus load for Scotland. The majority of the loss is from soils and fertiliser applications. The livestock contribution is 16%, with the largest contribution from the beef sector (7%). The contribution from each livestock sector is the phosphorus loss resulting from direct excreta in fields and any losses occurring from steadings plus losses associated with storage and application of managed manure. The soil phosphorus loss is a function of the soil phosphorus status, which is determined by the balance of phosphorus inputs (fertilisers, excreta and manure) and outputs (crop offtake and diffuse pollution). Thus livestock have an indirect impact on soil phosphorus losses, and so the soil phosphorus loss can be partly controlled through modification of livestock dietary phosphorus. Figure 5 shows the apportionment by farm type, and demonstrates how important upland livestock farming is (mainly due to this type of farming accounting for 70% of the agricultural land). Dairying is a significant source of phosphorus loss (13%) despite only occupying 4% of the land, reflecting the intensity of management.

Figure 6 shows the total phosphorus load delivered to watercourses for each waterbody. Losses in upland areas are generally small (< 0.3 kg ha^{-1}), whilst the very highest values are found near urban areas where point source inputs are significant. In other areas, phosphorus emissions are a function of soil type, rainfall and agricultural intensity. Thus phosphorus emissions are high in the western parts of Scotland where rainfall (and thus drainage) are high and in areas where soils require under-drainage, which provides a conduit for phosphorus transfer.

The agricultural contribution to this total phosphorus load is shown in Figure 7. The agricultural contribution is over 80% in many waterbodies (7,500 out of 18,000) with the lowest contributions found in urban catchments where there are significant sewage sources or in uplands where losses from montane and woodland are more significant. There are some catchments where the livestock contribution to the agricultural load is over 30% (Figure 8). The majority of these catchments tend to be those associated with cattle farming.

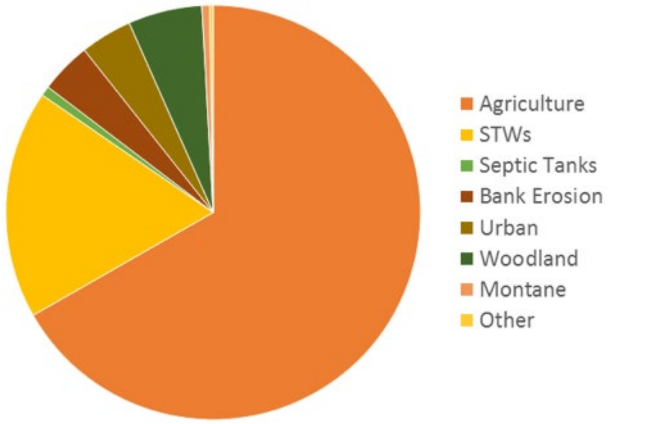


Figure 3 Sector apportionment for phosphorus delivered to watercourses in Scotland.

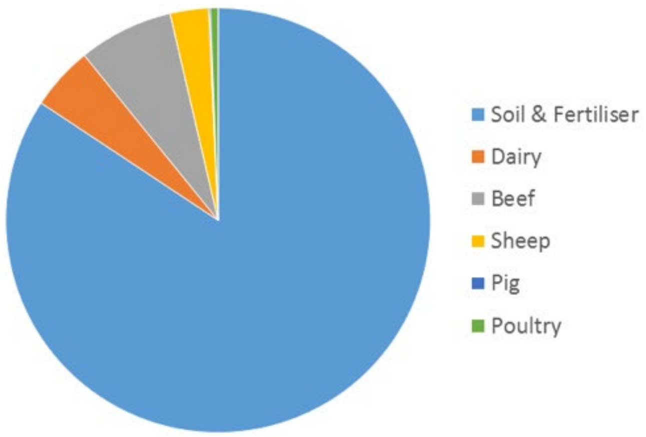


Figure 4 Apportionment by source of the agriculture phosphorus load delivered to watercourses in Scotland. The contribution from each livestock sector is the phosphorus loss resulting from direct excreta in fields and any losses occurring from steadings plus losses associated with storage and application of managed manure.

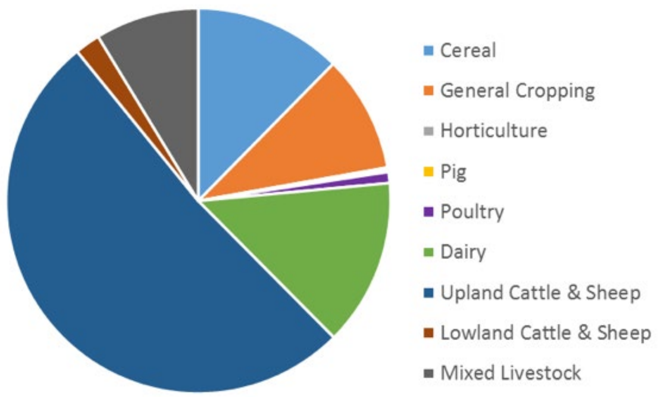


Figure 5 Apportionment by farm type of the agriculture phosphorus load delivered to watercourses in Scotland.

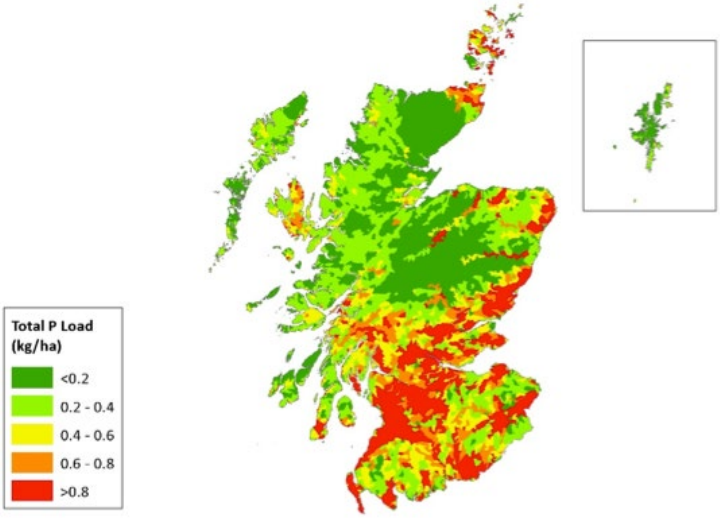


Figure 6 Total phosphorus load delivered to watercourses, summarised by waterbody.

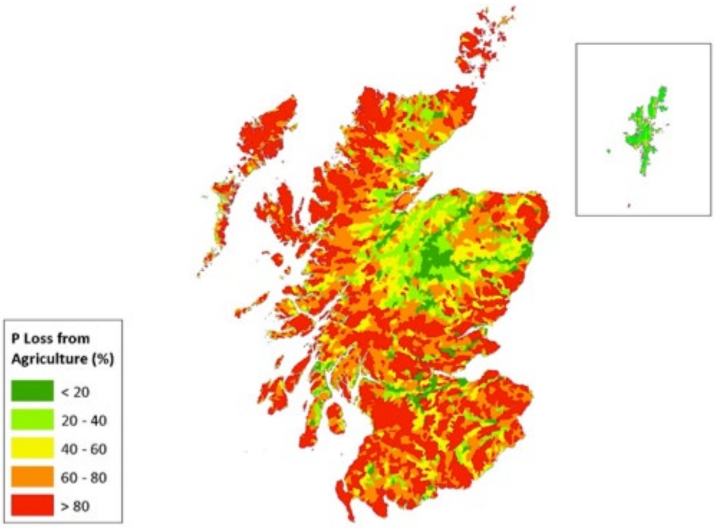


Figure 7 Agricultural contribution to the total phosphorus load delivered to watercourses, summarised by waterbody.

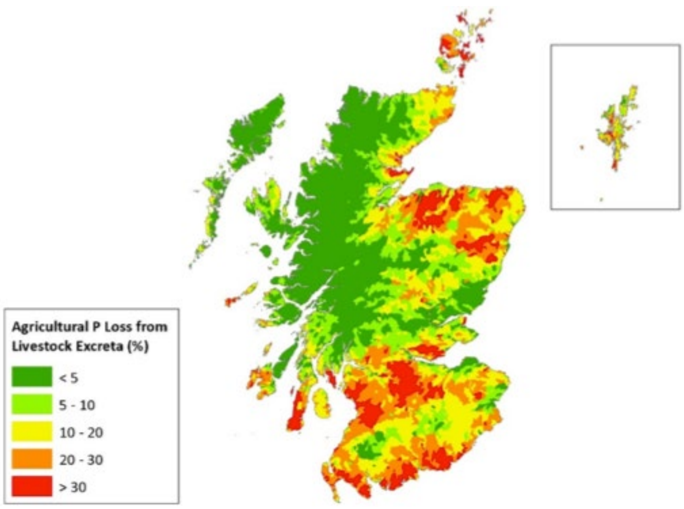


Figure 8 Livestock contribution to the agricultural phosphorus load delivered to watercourses, summarised by waterbody. This is the direct loss from excreta and manure – it does not include the contributions of these to soil phosphorus status and thus losses of phosphorus from the soil.

3.0 Ruminant Diets

3.1 Current situation

Ruminant livestock diets are based on forage with supplementary feed offered to match animal production needs. The most commonly available forages in Scotland include grazed grass, grass silage, whole-crop silage and cereal straw. The forage maize area is small but maize silage may be available in some areas. Supplementary feeds can take the form of purchased compounds, home mixed blends/straights and free access feed blocks, licks and minerals.

Historically, additional phosphorus has been included at a significant level in many supplementary feeds but the cost of phosphorus and the recognition of the levels that should actually be fed have seen a fall in phosphorus levels in ruminant diets in Scotland over the last 5-10 years. For example, target phosphorus in overall dairy diets in 2005 was 0.45 - 0.46% but from 2008 onwards has fallen to 0.40%. Technically the minimum requirement might be 0.35 - 0.36% in the total diet but a practical recommended level of 0.40% has been set to allow for variation in ingredients and a small safety margin. Ultimately the target could be 0.38 - 0.39% in the total diet. Although phosphorus levels in compound feeds have fallen, livestock may receive additional phosphorus in minerals and this is particularly the case for dairy cows where farmers are often concerned about cow fertility. Expert opinion suggests that the vast majority of lactating dairy cows in Scotland are currently offered additional phosphorus from minerals, either total mixed rations (TMR) or sprinkled on top of silage/forage, although the phosphorus content and the amounts fed vary.

Table 3 summarises the phosphorus requirements of different classes of stock. Requirements vary, with dairy cows, replacement heifers and pregnant ewes having higher requirements than finishing beef cattle and dry ewes. To allow a small safety margin, recommended levels are slightly higher at 0.39 – 0.40% for dairy cows, heifers and pregnant ewes. A review of the evidence relating to phosphorus requirements of dairy cows across a range of experiments concluded that 0.36 - 0.38 % in diet dry matter was adequate across virtually all studies and the risk of deficiency was very small (AgriSearch, 2010).

For the purposes of this study the assumption is that the on-farm forage aspect of the diets remains unchanged. Examples of current compound feed formulations for ruminant stock have been produced using least-cost principles but without inclusion of additional phosphorus mineral in the feed. Although some compounders do add mineral phosphorus into their dairy compounds it was felt that these were the minority. The nutritionists have reformulated lower phosphorus compound feeds to 0.40% as fed (0.45% in dry matter (DM)). This level was chosen as being a practical target for compound feeds that would achieve overall dietary phosphorus close to target levels in most classes of stock when taking into account lower phosphorus values found in the different forage types, which have significant variation.

Table 3 Phosphorus requirements and recommended levels for a range of livestock (% in total diet).			
Stock Type	**Level of productions**	**Minimum P Requirement (% in DM)**	**Minimum P Requirement (% in DM)**
Dairy cow (650 kg)	Lactating cow producing 40 kg milk	0.35%	0.40%
Replacement heifer (350 kg)	Daily live weight gain 0.62 kg	0.37%	0.39%
Finishing beef animal (4-500kg)	Daily live weight gain 1.30 kg	0.32%	0.32%
Pregnant ewe	Twin-bearing (4 weeks pre lambing)	0.34%	0.39%
Dry ewe	70kg ewe	0.32%	0.34%

Examples of typical diets for housed dairy cows, replacement heifers and intensively finished beef cattle are summarised in Table 4, with full details in the appendices. Dairy cow diets were based around grass silage and fermented wholecrop wheat supplemented with straight ingredients and/or compound feeds plus dairy minerals. All three of the dairy cow diets were predicted to exceed the 0.40% P (in dry weight) with oversupply of phosphorus estimated to be in the range of 11 – 23g day^{-1}.

3.1.1 Diet composition

As previously described, ruminant diets are comprised of the baseline forage plus appropriate supplements. Table 5 summarises the phosphorus levels in a range of forages, collating data from Cottrill *et al* (2008) for the UK, Northern Ireland from AgriSearch (2010) and data for Scotland obtained for this project. Grass based forages typically have phosphorus levels in the range of 0.21 - 0.41 (as % DM) with average values in the range of 0.3 - 0.4. When compared to the requirements of various types of stock, it can be seen that in many cases grass or grass silage alone can meet phosphorus requirements of the animals. Diets containing significant quantities of straw, maize silage or whole-crop silage which are naturally low in phosphorus will require supplementation however. The range in phosphorus seen for grass silage demonstrates why a small safety margin is typically built into rations. It can be difficult to formulate diets that are very low in phosphorus unless the phosphorus content of the forage is accurately known.

Ruminant compound feeds are primarily formulated to a required Metabolisable Energy (ME) level, with secondary parameters including starch, neutral detergent fibre (NDF) and digestible undegraded protein (DUP). Phosphorus levels are not used to drive compound formulations and it appears that the majority of compound feeds manufactured in Scotland for ruminants are not currently supplemented with additional phosphorus in any form and contain only the background levels found in the raw ingredients. Although bulk mineral supplements are added to the formulation these are to provide calcium, magnesium and salt. Micro elements and vitamins are added as either a single product or split into copper, Vitamin E and ‘the rest’.

The majority of compound feeds are formulated on a least-cost basis. Current compound formulations provided for this project included a range of cereal and oilseed co-products (e.g. wheatfeed, dark grains, rapeseed meal and palm kernel meal) many of which are naturally high in phosphorus. In addition, supplementary feed may be provided by proprietary compound feeds or home-mixed blends and/or straights and some classes of stock are routinely supplemented with minerals containing variable quantities of phosphorus. It should be noted that many of the raw materials used by the feed compounders are not typically available on farm e.g. palm kernel meal, wheatfeed and malt by-product. The most common feeds available on farm are likely to be cereals, rape seed meal, soya bean meal, and distillers’ products (either dried or moist). Table 6 summarises the phosphorus content of the more commonly used ingredients for compounds and on-farm use.

Table 4 Example complete diets.

Category	Diet	Milk yield (l d^{-1})	Total fresh weight (kg)	Total dry weight (kg)	Current P (g)	Current P (%)
Dairy cow (650kg)	Full TMR	43	56.9	24	113	0.47%
	Partial TMR	40	55.2	23.3	116	0.50%
	Silage + parlour feeding	30	52.5	20.3	91.7	0.45%
Heifer (350kg)	Dairy replacement	-	7.77	6.77	25.2	0.37%
Beef (450kg)	Intensive cereal beef	-	12.6	11	43.9	0.40%

Table 5 Phosphorus levels in a range of forage crops from various sources †.

Forage Type	UK average ‘Reference value’ P (% DM)	N Ireland Average P (% DM)	N Ireland Range (% DM)	Sample of 2015 forages Scotland Average P (% DM)	Sample of 2015 forages Scotland Range (% DM)
Grazed grass	0.40	0.40	0.29 - 0.52	NA	NA
Grass Silage	0.30	0.31	0.14 - 0.39	0.34	0.21 - 0.41
Wholecrop Cereal Silage	0.25	0.28	0.23 - 0.31	0.22	0.18 - 0.24
Maize Silage	0.20	0.24	0.16 - 0.32	0.22	0.21 - 0.24
Wheat straw	0.10	NA	NA	NA	NA
Barley straw	0.15	NA	NA	NA	NA

†data for the UK from Cottrill et al (2008), Northern Ireland from AgriSearch (2010) and Scotland from this project.

Table 6 Phosphorus contents of ingredients used in compound formulations.		
Feed ingredient	Typical P content (g kg-1 DM)	Comments
Wheat	3.5	Readily available – grown in Scotland and rest of the UK
Barley	4	Readily available – grown in Scotland and rest of the UK
Maize	3	Imported when price favourable
Sugar beet pulp	1.5	Grown in UK or imported. Home grown can be in short supply and competition from other sectors results in high cost. Some used in dairy TMR diets and for sheep.
Soya hulls	2	Imported product – readily available
Wheatfeed	12	By-product of flour mills, generally readily available
Barley distillers dark grains	9	By-product of whisky production
Maize distillers dark grains	10	UK produced from imported grain or imported
Wheat distillers dark grains	9	Produced either from distillery or bioethanol production, some imported
Rapeseed meal	12	UK and imported product readily available
Soya bean meal (hi pro)	7	Imported – readily available
Palm kernel meal	6.5	Imported – readily available
Beans	9	Some grown in Scotland and rest of the UK, but for human use – only those that fail to meet standards go to animal feed
Moist distillery co-products e.g. draff (barley/wheat) supergrains, vitagold	5	Grown in Scotland and rest of the UK. Demand can outstrip supply and there is an active policy of using some (supergrains, vitagold) as biofuels which diverts from animal feed.

3.2 Dairy

The following breakdown of dairy herds in Scotland provides an overview of the sector and has been used to help estimate the average concentrate feed use by dairy cows.

- 150 herds (15%) housed all year round. These tend to be the larger herds (some as high as 1200 cows) so are likely to represent around 25% of the dairy cows. These herds are predominantly fed TMR or partial TMR rations. Dairy cows that are housed all year may be fed around four tonnes of concentrate feed across the lactation.
- 25 herds (3%) are spring grazing "New Zealand style" (an extended grazing system). These are also likely to be the larger herds so may represent around 5% of the cows. The grass based herds are typically fed less than one tonne of concentrate feed over the lactation.
- 500 herds (50%) which graze for the summer period April until September (with an extra month in some years as in 2015). They are then housed for the winter (typically six months). Concentrate use is assumed to be between 2-3 tonnes per lactation.
- 325 herds (33%) which house high yielding cows (approximately 50% of the herd) at night over the grazing period April to September and housed for the winter. Concentrate use assumed to be 2-3 tonnes per lactation but on average higher than the summer grazers.

The dairy production cycle has been assumed to have a calving interval of 411 days and has been split into lactation (350 days), dry cow (40 days) and pre-calving stages (21 days). A range of dairy compound feeds for lactating cows have been produced to illustrate some of the commonly used supplements (Table 7). These have been formulated without the addition of

Table 7 Dairy Cow Compounds.									
Stock Type		High Energy 20% CP		High Energy 18% CP		Medium Energy 20% CP		Medium Energy 18% CP	
		Current	Reduced P	Current	Reduced P	Current	Reduced P	Current	Reduced P
Lactating	P Content (%)	0.46	0.40	0.49	0.40	0.59	0.40	0.57	0.40
	Amount fed (kg hd^{-1})	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
	Days Fed	350	350	350	350	350	350	350	350
	Total P intake (kg hd^{-1})	11.5	10.0	12.3	10.0	14.8	10.0	14.3	10.0
	Cost (£ t^{-1})	182.1	187.9	174.1	177.8	169.6	176.3	162.7	166.9
Drying Off	Days Fed	40	40	40	40	40	40	40	40
	P Intake	0	0	0	0	0	0	0	0
Pre-Calving	P Content (%)	0.54	0.40	0.54	0.40	0.54	0.40	0.54	0.40
	Amount fed (kg hd^{-1})	2	2	2	2	2	2	2	2
	Days Fed	21	21	21	21	21	21	21	21
	Total P intake (kg hd^{-1})	0.23	0.17	0.23	0.17	0.23	0.17	0.23	0.17
	Cost (£ t^{-1})		220.2	206.6	220.2	206.6	220.2	206.6	220.2
	Total Cost (£ hd^{-1} yr^{-1})	411.9	425.3	386.5	394.7	376.6	391.3	361.3	370.5
	Total P intake (kg hd-^{1} yr^{-1})	10.2	8.9	10.9	8.9	13.1	8.9	12.7	8.9

mineral phosphorus. Lactation feeds include high and medium energy compounds at both 18% and 20% crude protein. The range of phosphorus in these compounds varies from 0.46 - 0.59% P (as fed). The choice of compound on any farm will depend on the type of forage and the level of performance of the herd but it estimated that 40% of dairy cows receive high energy compounds and 60% medium energy compounds, with a quarter of each on the higher 20% crude protein (CP) compound. Following drying off, the majority of cows are maintained on a forage only diet before moving onto a pre-calving diet approximately 21 days pre-calving. For the purposes of the scenarios a lower phosphorus alternative has been formulated for each of the compound feeds to a constant 0.40% as fed (0.45% in DM).

Dairy heifers in their first year typically consume around 500 kg of concentrates reducing to around 300 kg in the second year. It is believed that in Scotland dairy heifers are currently calving at around 29 months of age and this reduces the need for concentrate supplementation compared to a system bringing heifers into the herd at 24 months. A typical compound feed for replacement heifers was found to contain 0.55% P (0.64% DM) and this was reformulated to 0.40% as above for use in the scenarios.

Table 8 Dairy Replacement Compounds.

Stock Type		Current	Reduced P
Dairy Replacements	P Content (%)	0.55	0.40
	Amount fed (kg hd^{-1})	300	300
	Total P intake (kg hd^{-1})	2.8	2.0
	Cost (£ t^{-1})	156.0	158.4
	Total Cost (£ hd^{-1})	78.0	79.2

Whilst compound phosphorus levels in Scotland have fallen, dairy cows also receive additional phosphorus in mineral products in either TMR rations or sprinkled on top of forage. Although expert opinion is that the majority of dairy cow minerals contain lower levels of phosphorus than in the past, it was noted that there are still minerals with 8 - 10% P on the market. It was estimated that currently around 10% of dairy cows are on these very high phosphorus minerals (typically receiving 150 g day^{-1}), a further 20% would be on a 'typical' 5% (250 g day^{-1}) (many cows on TMR rations would fall into this category) whilst the remaining 70% are fed 150 g day^{-1} of a medium phosphorus mineral. Table 10 illustrates the overall impact of combining the current range of dairy compounds and dairy minerals and the impact of moving to lower phosphorus options. Whilst there may be room to reduce mineral phosphorus in TMR (and other systems) it is unlikely that farmers will be willing to reduce them drastically without significant encouragement from vets and other advisers to provide reassurance about animal health and fertility. Uncertainty around forage intakes and phosphorus content of forage mean that a small safety margin will always be built into rations.

Mineral use for heifer replacements is less widespread; approximately 25% of heifers are thought to receive mineral either in a home mix or sprinkled on silage. The majority of these are believed to contain 2-2.5% P with typical rates of 80 g day^{-1} being fed. Mineral supplementation at grass is thought to be lower still with only 5-10% being offered feed blocks or licks.

Table 9 Dairy Minerals.

Stock Type		TMR	High P	Medium P	Reduced P	No P
Dairy Cows	P Content (%)	5.0	10.0	6.5	5.0	0.0
	Amount fed (kg day^{-1})	0.25	0.15	0.15	0.15	0.15
	Days fed	350	350	350	350	350
	Total P intake (kg hd^{-1})	4.38	5.25	3.41	2.63	0.00
	Cost (£ t^{-1})	455.0	566.0	488.3	455.0	344.0
	Total Cost (£ hd^{-1})	39.8	29.7	25.6	23.9	18.1
Dairy Replacements	P Content (%)	-	2.5	2	-	0
	Amount fed (kg day^{-1})	-	0.08	0.08	-	0.08
	Days fed	-	180	180	-	180
	Total P intake (kg hd^{-1})		0.36	0.29		0
	Cost (£ t^{-1})	-	299.1	288.0	-	243.6
	Total Cost (£hd^{-1})	-	4.3	4.1	-	3.5

Table 10 Variation in total phosphorus due to different combinations of current compound and mineral usage, and under future reduced phosphorus scenarios.

			Compounds				
			H.E. 20% CP	**H.E. 18% CP**	**M.E. 20% CP**	**M.E. 18% CP**	**All Reduced P**
	Current Usage		10%	30%	15%	45%	-
		P Intake (kg cycle^{-1})	10.2	10.9	13.1	12.7	8.9
High P	10%	5.25	15.5	16.2	18.4	18.0	
Medium P	70%	3.41	13.6	14.3	16.5	16.1	
Reduced P	20%	2.63	12.8	13.5	15.7	15.3	11.5
Zero P	-	0					8.9

3.2.1 Comparison with Agrisearch (2010) study in Northern Ireland

The Agrisearch study was conducted over a four-year period to look at the long-term impact of feeding reduced phosphorus concentrates on milk yield, feed intake, health and fertility of dairy cows. A total of 100 winter calving Holstein-Friesian cows were offered diets containing either high or low levels of dietary phosphorus. Winter rations were based on grass and maize silage with 10-12 kg concentrates cow^{-1} day^{-1} and summer rations on grazed grass (or grass and grass silage) with 3-4 kg concentrates cow^{-1} day^{-1}. The high and low phosphorus diets were met by feeding concentrates with differing phosphorus content (7.1 or 4.4 g P kg^{-1} DM in the winter and 4.9 or 3.6 g P kg^{-1} DM in the summer) resulting in overall reductions in concentrate phosphorus of 38% in winter and 46% in summer. The differential between 'high' and 'low' phosphorus concentrates was achieved by formulating a 'low' phosphorus mix and then adding dicalcium phosphate at the appropriate rate to create the 'high' phosphorus concentrate. Final phosphorus levels in the total diets were 4.8 and 3.6 g kg^{-1} DM (for high and low respectively) in the winter and 4.2 and 3.6 g kg^{-1} DM in the summer. This resulted in an overall reduction in dietary phosphorus of 25% in winter and 16% in summer. Feeding a lower phosphorus diet did not have any negative impacts on feed intake, milk yield/composition, cow health or cow fertility but reducing dietary phosphorus by 25% resulted in a 45% reduction in P excreted in manure.

The dairy cow requirement reported in Table 3 at 0.35% (3.5 g kg^{-1} DM) is closely aligned with the reduced phosphorus treatment in the Agrisearch study (0.36%). A survey prior to the Agrisearch study found that concentrates fed to dairy cows in Northern Ireland contained, on average, 0.62% P (fresh basis) (0.71% DM) and this was the level chosen for the high phosphorus concentrates in the study. Direct comparison of phosphorus levels in the Northern Ireland study with those for the current study is not easy as the Northern Ireland study included all mineral phosphorus in the concentrate feed whilst here compound phosphorus and additional mineral phosphorus have been reviewed separately. Using the information in Table 10 it can be seen that phosphorus levels in compounds can be reduced by 13 - 32% depending on the original formulation. When mineral phosphorus is included the maximum reductions range from 30 - 52%. These reductions are broadly in line with the reductions in concentrate phosphorus of 38 - 46 % in the Agrisearch study. The dairy diets assessed in this project as part of Scenario 8 (see Table 19) are closest to those used in the Northern Ireland study.

3.3 Beef

The stock categories of interest for this study were suckler cows, replacement heifers and finishing beef cattle.

Suckler cows. These have been split into predominantly spring or autumn calving cows with around 70 - 75% calving in the spring (some estimates suggest this could be as high as 80%). Spring calving cows may be out-wintered and receive less supplementation than autumn calving cows. As an estimate, spring calving cows are fed 50 - 100 kg supplement compared to 250 - 500 kg for autumn calvers. In addition to the cow supplementation, the suckled calves may get 50 -100 kg of creep feed prior to sale. A current suckler cow compound has been formulated as containing 0.56 % P with a reduced phosphorus version at 0.40% P.

Replacement heifers. These are expected to maximise growth from forage during the spring to autumn period and then be on a predominantly conserved forage diet over the winter period. Currently replacement beef heifers in Scotland are thought to calve close to 36 months of age so concentrate usage will be relatively low unless they are on straw based diets. The assumption here is that up to 100 kg compound feed is fed per annum to bulling and in-calf heifers. Where replacements for the suckler herd are offered supplementary compound feed, it is assumed to be similar to that fed to dairy heifers but at a lower rate.

Table 11 Beef Compounds.

Stock Type		Current	Reduced P
Suckler Cow (Autumn Calving)	P Content (%)	0.56	0.40
	Amount fed (kg)	275	275
	Total P intake (kg hd^{-1})	1.5	1.1
	Cost (£ t^{-1})	160.8	163.8
	Total Cost (£ hd^{-1})	44.2	45.1
Suckler Cow (Spring Calving)	P Content (%)	0.56	0.40
	Amount fed (kg)	75	75
	Total P intake (kg hd^{-1})	0.4	0.3
	Cost (£ t^{-1})	160.8	163.8
	Total Cost (£hd^{-1})	12.1	12.3
Replacements	P Content (%)	0.55	0.40
	Amount fed (kg day^{-1})	2	2
	Days fed	50	50
	Total P intake (kg hd^{-1})	0.55	0.40
	Cost (£ t^{-1})	156.0	158.4
	Total Cost (£ hd^{-1})	15.6	15.8
Finishers (Intensive)	P Content (%)	0.41	0.40
	Amount fed (kg day^{-1})	10	10
	Days fed	135	135
	Total P intake (kg hd^{-1})	5.54	5.40
	Cost (£ t^{-1})	155.3	156.0
	Total Cost (£ hd^{-1})	209.6	210.6
Finishers (Extensive)	P Content (%)	0.41	0.40
	Amount fed (kg day^{-1})	5	5
	Days fed	135	135
	Total P intake (kg hd^{-1})	2.77	2.70
	Cost (£ t^{-1})	155.3	156.0
	Total Cost (£ hd^{-1})	104.8	105.3

Finishing cattle. These can be split into cattle on very intensive systems such as bull beef and more extensive systems finishing cattle at 18 - 24 months. The intensive systems will include bulls from the dairy herd, grown and finished inside for a 12 - 14 month period on barley based diets (consuming 2 - 3 tonnes in that period) as well as cattle from the suckler herd moved onto an intensive diet post-weaning. In contrast, beef cattle at grass may be supplemented at 3 - 5 kg day^{-1} at the end of the grazing season before being housed on grass silage plus around 5 kg day^{-1} of concentrate feed. This report focusses on the feed inputs into the final finishing period (typically 4 - 5 months) of these two systems prior to slaughter. It has been estimated that 30% of cattle finish on the more extensive forage–based system with 70% finished on the more intensive system. Phosphorus requirements for finishing cattle are relatively low at 0.32% but achieving this in the total diet can be difficult. The need to achieve target liveweight gains requires supplementation by cereals and/or cereal by-products, which tend to have higher phosphorus than forage, resulting in higher phosphorus intake. A typical compound feed for finishing cattle formulated for this project contains 0.41% P (close to the target of 0.40%). An extremely low phosphorus compound was formulated (0.30% as fed) but this was approximately £12.50 a tonne more than the standard compound (£155.28). This agrees with Cottrill *et al* (2008) where reducing phosphorus to more closely match requirements might not be practical or cost-effective. Home mix rations may be fed to finishing beef animals and are generally less expensive than purchased compounds. A ration comprising approximately 82% cereals, 16% maize dark grains and 2.5% vitamins and minerals was found to have a phosphorus content of 0.43 % and cost £144.90 $tonne^{-1}$.

Mineral use in the beef sector is lower than the dairy sector. For suckler cows, minerals are often provided to cover high risk periods where extra magnesium is required. Premier Nutrition estimates that 15% of suckler cows are fed a high magnesium free access mineral and 45 % a magnesium feed block. The phosphorus content of the mineral is low (typically 2.0%) and the main feed block product on the market contains no phosphorus. Heifer replacements are typically supplemented in a similar way to the dairy heifers with approximately 25% receiving a mineral with forage and 5-10% offered feed blocks at grass. Phosphorus requirements of finishing cattle are recognised to be low and many beef finishing minerals are either very low in phosphorus or do not contain any. Around 35% of growing/finishing beef cattle are thought to be fed low phosphorus minerals.

Table 12. Beef Minerals.

Stock Type		High P	Typical	No P
Suckler Cows	P Content (%)	2.0	0.0	0.0
	Amount fed (kg day-1)	0.10	0.10	0.10
	Days fed	35	35	35
	Total P intake (kg hd-1)	0.07	0.00	0.00
	Cost (£ t-1)	288.0	243.6	243.6
	Total Cost (£ hd-1)	1.0	0.9	0.9
Suckler Replacements & Growing Cattle	P Content (%)	2.5	2	0
	Amount fed (kg day-1)	0.08	0.08	0.08
	Days fed	180	180	180
	Total P intake (kg hd-1)	0.36	0.29	0.00
	Cost (£ t-1)	299.1	288.0	243.6
	Total Cost (£ hd-1)	4.3	4.1	3.5
Finishers	P Content (%)	2.5	-	0
	Amount fed (kg day-1)	0.08	-	0.08
	Days fed	135	-	180
	Total P intake (kg hd-1)	0.27	-	0.00
	Cost (£ t-1)	299.1	-	243.6
	Total Cost (£ hd-1)	3.2	-	3.5

3.4 Sheep

The majority of sheep in Scotland are spring lambing flocks which receive compound supplement in the 6 - 8 weeks pre-lambing (typically increasing from 0.2 – 0.4 kg day^{-1} up to 1 kg day^{-1} at lambing). There is also a small number of early lambing flocks (lambing December/January) that require 1 kg day^{-1} or more of supplement from December until weaning or grass starts growing in spring (April). Many of these early flocks are likely to be pedigree flocks targeting the autumn breeding ram sales. As early lambing ewes make up a small proportion of the national flock the focus here is on spring lambing flocks.

The level of supplementation and the specification of the feed offered to ewes will depend on the availability and quality of forage and the number of lambs being carried or reared. Taking into account the range of lambing percentages across all flocks, it has been assumed that on average 46 kg of compound is fed to ewes in late pregnancy and early lactation (typically 21 kg pre-lambing and 25 kg post-lambing), although this is highly weather dependent.

In addition, it has been assumed that 10% of producers feed a top specification compound high in energy and DUP and 10% feed a medium energy low cost supplement. The remaining 80% are assumed to have fed a 'standard' 18% CP ewe compound that fits somewhere between these two. Table 13 shows how the phosphorus levels differ across the range of compounds with the top specification compound already below the target level of 0.40% largely due to higher levels of soya bean meal.

Figures from Table 3 indicate recommended phosphorus level of 0.34% for dry ewes and 0.39% for ewes in late pregnancy. Typical phosphorus levels in grass and grass silage are likely to meet the needs of ewes for the majority of the year. However, a number of sheep producers use free-access feed blocks and feed/mineral licks at certain times of the year. For this study it has been assumed that 30% ewes are offered these around tupping and a further 30% during pregnancy. Intakes of these products can be highly variable depending on the blocks themselves, forage availability and weather conditions. The vast majority of feed blocks researched for this project were found to have phosphorus in the range of 0.1 - 0.5% providing 0.1 - 1.0 g P day^{-1} assuming typical intakes provided by the manufacturers. Some of the harder 'licks' may have higher P (e.g. 1.0 %) but intakes are lower resulting in estimated phosphorus intakes of up to 1 g day^{-1}. Whilst the figures above account for the majority of products there are some specialist products with higher phosphorus percentage - e.g. feed buckets at 4% P for 'feet and fertility' providing up to 1.2 g P day^{-1} at typical intakes. Free access/in feed minerals are also available for sheep and some may have phosphorus levels as high as 6% with 30 g supplying 1.8 g P day^{-1}.

3.5 Conclusions and opportunities to reduce phosphorus levels

Many of the ruminant compound feed formulations in Scotland are not supplemented with additional phosphorus in any form (source: Premier Nutrition), thus levels reported in the various diets are driven by background levels of the raw ingredients. In particular, levels of phosphorus in individual formulations are heavily influenced by the inclusion rates of by-products, cereal/oilseed co-products etc. used by the feed compounders. In this study, moving to a lower phosphorus percentage in the compound feed was achieved by replacement of higher phosphorus ingredients. In the Northern Ireland study it was noted that moving to lower phosphorus compound feeds could be expensive with some lower cost ingredients (e.g. maize gluten) being replaced by more expensive ingredients such as soya bean meal.

This was the case in this study when compound P% was constrained to 0.40% (as fed). Across the range of diets explored there was a common theme for higher phosphorus ingredients such as maize and wheat dark grains, wheatfeed and rapeseed meal to be displaced by soya hulls and soya bean meal. As distiller's products are a commonly used ingredient in Scotland, replacement with imported soya products is not ideal. The potential to use sugar beet pulp in formulations was explored but this can be a relatively high cost ingredient and the UK product can be in short supply. Sugar beet pulp is however often included in TMR rations for dairy cows at a

Table 13 Sheep Compounds.

Stock Type	High Energy, High DUP		Standard 18% CP		Medium Energy	
	Current	Reduced P	Current	Reduced P	Current	Reduced P
P Content (%)	0.38	-	0.46	0.40	0.64	0.40
Amount fed (kg)	46	-	46	46	46	46
Total P intake (kg hd^{-1})	0.175	-	0.212	0.184	0.294	0.184
Cost (£ t^{-1})	182	-	162	166	153	157
Total Cost (£hd^{-1})	8.4		7.5	7.6	7.0	7.2

Table 14 Sheep Minerals.

	In feed or free access mineral	Higher P block / lick	Low P feed block	Hi mag feed block
P Content (%)	6.0	0.8	0.2	0.0
Amount fed (kg day^{-1})	0.03	0.09	0.10	0.09
Days fed	84	84	84	84
Total P intake (kg hd^{-1})	0.454	0.060	0.017	0.000
Cost (£ t^{-1})	450	561	495	473
Total Cost (£ hd^{-1})	8.6	4.2	4.2	3.6

modest level (around 3.0 kg day^{-1}) and also appears in some sheep feeds.

Although the amount of phosphorus fed has fallen in recent years (particularly in compound feeds) the dairy sector in particular appears to be still overfeeding phosphorus largely due to feeding additional mineral phosphorus. There appear to be opportunities to reduce the amount of mineral offered to dairy cows and this may be the area on which to focus further research and advice. Dairy farmers add mineral either in TMR or sprinkled on top of silage so even if the base diet is close to 0.40% P (and therefore adequate) producers will be overfeeding. The fear of underfeeding phosphorus means that many farmers are unwilling to rely on phosphorus in raw ingredients. Uncertainty surrounding forage intakes and knowing the phosphorus content of forages accurately compounds this problem. It is likely that farmers would need to be convinced by their vets and advisers that there would not be any negative impact on health and welfare before reducing phosphorus levels for dairy cows.

For all ruminant sectors there may be further opportunity to reduce phosphorus levels in compound feeds but this increases the cost and also, based on current least cost formulation, increases reliance on imported soya products. Opportunities to reduce phosphorus in minerals also exist in other sectors although the level of supplementation and potential over feeding is lower than for dairy.

4.0 Monogastric Diets

4.1 Introduction

Phosphorus is an essential mineral for monogastric animals. The naturally occurring quantities in cereal grains provide the majority of phosphorus in monogastric diets, but availability of phosphorus in this form to poultry and pigs is limited because it is bound up as phytate.

Phytate, also known as phytic acid and inositol hexaphosphate (IP6), is the main natural store of phosphorus in plants, particularly cereal grains. When bound in dietary phytate, it is inaccessible to monogastric animals as they cannot naturally produce the digestive enzyme phytase required to break down the phytate molecule into a useable digestible form.

Phytate is also an 'anti-nutrient' because of its ability to bind to essential nutrients needed by monogastrics. In the upper digestive system, at low pH, phytate binds to proteins and amino acids. Further down the digestive system, at higher pH levels, phytate binds to minerals such as calcium and trace elements. It interferes with digestion and stimulates the animal to increase its production of digestive secretions, which is an energy and nutrient consuming process. The net result is a reduction in animal performance.

The commercial development and use of the enzyme phytase in monogastric feeds has had an important impact on formulations, as it improves the availability of the phosphorus contained in phytate. Phytase enzymes were first used commercially in the UK in the mid-1990s. Inclusion of phytase enables supplementary levels of inorganic phosphorus to be reduced, thus lowering the risk of excretion of unwanted phosphorus.

Conversely, there is a risk that, if dietary inorganic phosphorus levels are not reduced accordingly as part of an overall dietary strategy, inclusion of phytase in the diet would actually *increase* the amount of phosphorus excreted.

The main sources of supplementary phosphorus in monogastric diets are the inorganic phosphates di-calcium phosphate (DCP) and mono-calcium phosphate (MCP). Sources of MCP are widely-used and generally considered to be 5-10% more digestible than sources of DCP. However, there is a view that MCP is detrimental to feed pellet quality and to feed mill throughput. In the context of reducing excretion of phosphorus, MCP would be favoured, but there are limited supplies available, so in practice the more available DCP may be included in some feeds. Also, DCP tends to be used more in mixed species feed mills as it is considered to be superior in providing mineral supplementation for ruminants.

An acute shortage of inorganic phosphorus around 2008 prompted both the poultry and the pig sectors to critically reassess phosphorus levels and consider reductions where possible. Once inorganic phosphorus supplies returned to normal, there was no industry-wide reversion to previous levels because lower inclusion rates had demonstrated cost savings without any adverse effects on performance.

As animal nutrition specialists continue to improve their understanding of the phytate content of raw materials, phytase is likely to play a bigger part in feed formulation for monogastrics. In turn, this is expected to lead to some further reductions in levels of phosphorus both in feeds and in excreta.

4.2 Poultry

There has been a gradual downward trend in phosphorus levels in compound feeds for both laying hens and broilers due to phytase. The laying hen sector was the first to take advantage of new phytase enzyme technology. As a result, levels of inorganic phosphate reduced substantially in compound feeds for laying hens. The broiler sector was slower to adopt phytase use. This was partly because of the need to ensure that it would not compromise leg health, a particularly important aspect of chicken welfare. There were also early concerns that the use of phytase could be associated with increased litter moisture; another important welfare concern.

Since its introduction, a number of phytase enzyme products have become available and there have been improvements in the efficiency with which plant-based phytate is broken down into phosphorus that is digestible to poultry.

The shortage of inorganic phosphorus around 2008 led to a reassessment of dietary phosphorus levels, particularly in the broiler grower and finisher stages which represent a high proportion of all poultry feeds, by tonnage. When supplies returned to normal, there was generally no reversion to previous levels because of the performance levels of stock fed the lower inclusion rates.

4.2.1 Current situation

The norm at present is for a single dose of phytase to be included in feeds for both laying hens and broilers. In Scotland, as in the rest of Great Britain, this approach is thought to account for at least 90% of all poultry feeds. The outcome is lower inclusion rates of inorganic phosphorus in compound feeds, in comparison to non-phytase containing feeds.

Single dose phytase is generally considered to provide the most cost-effective response in making phosphorus available but increasing the dose potentially enables more phosphorus to be released and made available to the stock. For this reason, a small percentage of poultry currently receive either an extra half dose (x1.5) or a double dose (x2) of phytase. This approach is likely to account for the balance in conventional production systems (up to 10%) and only in organic production is it expected that feed without phytase will be used.

A series of typical commercial poultry rations have been formulated by Premier Nutrition for this project to highlight current phosphorus levels in Scotland. Compared to other parts of the Great Britain, there is generally a greater differential between wheat and barley prices in Scotland. In practice, this means lower wheat content and more barley but this has little impact upon phosphorus levels as the content and digestibility of phosphorus is similar in both.

In total, five 'current' poultry feeds have been formulated. These are a replacement pullet grower feed, early and late lay feeds for laying hens and grower and finisher feeds for broilers. These have been selected to build up a representative picture of the current situation for poultry.

During the rearing phase, the grower feed is used for the majority of the cycle, typically 16-17 weeks. After transfer to laying premises, hens are typically fed between two and five diets to the end of the production cycle. Each stage has a different nutrient profile, designed to meet the requirements of birds as they develop. Early-lay hens with lower feed intake levels typically receive feeds with a higher percentage content of phosphorus but this is reduced as birds get older and appetite increases. Feed for laying hens in both free range and enriched colony systems are considered similar in terms of phosphorus and therefore separate formulations have not been prepared for these.

Broilers are typically fed between three and five diets between day-old and finishing weight. Early diets have higher percentage contents of phosphorus (and calcium) to support skeletal development of young chicks with low feed intakes. As before, the content decreases as birds grow and increase their feed intake levels.

4.2.2 Potential for further reductions in phosphorus in poultry feedstuffs

In theory, there is potential to increase the uptake of higher dose rates of phytase in poultry feeds, particularly in the broiler sector. In addition to 1.5x and double doses, there is current interest in 'super-dosing' phytase with a triple dose for broilers, in order to improve overall performance through improved gut health. So far, this has had limited uptake but it may lead to wider acceptance of phytase levels that exceed the single dose rate.

In the laying sector, there are concerns that further reductions in dietary phosphorus may result in insufficient substrate in the feed for phytase to act upon. Insufficient levels of phosphorus could lead to adverse welfare implications. Expert opinion therefore concludes that there is less scope to make reductions in phosphorus levels for layers than broilers. In addition, the number of feeds given to laying hens throughout the laying period is tending to decrease. This is partly due to genetic improvements which have improved persistency of lay so that high nutritional requirements must be maintained. A further consideration is the apparent correlation between the number of diet changes and an increased risk of aggressive pecking behaviour. For this reason, there is likely to be more focus in future on minimising dietary changes throughout both the rearing and the laying period.

In practice, future reductions in phosphorus excretion are possible but are likely to result not from a simple change from single to double doses but from a better understanding of the relationship between the phytate substrate in the diet and the type and level of phytase in the feed. This is likely to require a programme of research to fully evaluate responses and cost-effectiveness and to ensure that there are no adverse reactions.

It is difficult to estimate a timescale for this and to quantify the likely effects for modelling purposes in this study. It has therefore been assumed that the potential for phosphorus reduction is equivalent to what could be achieved at present if there was a move from the current situation (estimated as 90% single dose phytase and 10% double phytase) to complete use of double phytase dose levels (100%). This should be considered the maximum phosphorus reduction possible at the present time.

Table 15 Comparison of poultry diets with and without phytase.				
Diet	**Property**	**No Phytase**	**Single Phytase**	**Double Phytase**
Pullet Grower	Mono Calcium Phosphate (%)	1.39	0.90	0.77
	Total Phosphorus (%)	0.74	0.63	0.61
	Digestible Phosphorus (%)	0.45	0.45	0.45
	Relative Cost	100.0	98.8	98.8
Early Lay	Mono Calcium Phosphate (%)	0.96	0.49	0.37
	Total Phosphorus (%)	0.57	0.46	0.44
	Digestible Phosphorus (%)	0.34	0.34	0.34
	Relative Cost	100.0	98.5	98.4
Late Lay	Mono Calcium Phosphate (%)	0.82	0.35	0.23
	Total Phosphorus (%)	0.51	0.41	0.38
	Digestible Phosphorus (%)	0.30	0.30	0.30
	Relative Cost	100.0	98.3	98.1
Broiler Grower	Mono Calcium Phosphate (%)	1.19	0.67	0.58
	Total Phosphorus (%)	0.64	0.52	0.50
	Digestible Phosphorus (%)	0.40	0.40	0.40
	Relative Cost	100.0	98.7	98.6
Broiler Finisher	Mono Calcium Phosphate (%)	1.09	0.58	0.48
	Total Phosphorus (%)	0.60	0.48	0.46
	Digestible Phosphorus (%)	0.37	0.37	0.37
	Relative Cost	100.0	98.8	98.6

Table 15 provides a summary of example formulations prepared for five different poultry feeds based on no phytase (past scenario), single dose phytase (current practice for 90%) and double dose phytase (current practice for 10% but assumed to be 100% in the future scenarios). These are based on the formulations in the Appendices which set out the raw materials used and their percentage inclusion levels.

In all cases, the change from no phytase to single dose phytase provides a substantial reduction in mono calcium phosphate and thus in the total phosphorus content of the feed. Changing from single to double dose phytase results in much smaller reductions.

The percentage of digestible phosphorus is unchanged for each feed, irrespective of phytase content. In the main, the cost of feeds with double phytase is very slightly lower than those with the single dose. However, single dose feeds do represent a small but important cost saving of between 1 and 1.5%, compared to no phytase feeds.

In order to convert the unit phosphorus values for the different diets into total phosphorus intakes, it was necessary to make a series of assumptions. These were based on what is considered typical of current commercial practices. It is accepted that on some farms, the procedures followed and the feed intakes recorded will differ from the assumptions made (see Table 16).

For laying hens, the following assumptions have been made:-

- The laying cycle is 406 days or 58 weeks (16 to 74 weeks of age). Since the early lay and late lay diets would represent the two extremes of a phase-feeding approach, it is assumed that these two rations are each fed for approximately 50% of the cycle;
- Average feed consumption is 118g per bird per day (fresh weight) for the first half of the laying cycle, increasing to 123g per bird per day in the second half. Feed intake varies according to the system of egg production and account is taken of this in these figures which are based on cage and non-cage systems each representing a 50% share;
- A four week interval is allowed between successive flocks for clean-out.

For pullets, the following assumptions have been made,

- The rearing cycle is 119 days or 17 weeks. The starter is fed from day-old to five weeks (average 32g intake per bird per day) and the grower for the remainder of the cycle. The average daily feed intake is 54g per bird from 5-9 weeks and 80g from 10 to 16 weeks;
- A two week interval is allowed between successive flocks for clean-out.

For broilers, the following assumptions have been made,

- A live weight of 2.2kg is achieved in 36 days with a seven day interval allowed between successive crops;
- The grower ration is fed from 11 to 24 days, with an average consumption over this period of 1250g per bird;
- The finisher ration is fed from 25 to 36 days, with an average consumption over this period of 1830g per bird.

For breeders, the following assumptions have been made,

- A production cycle from day-old to 60 weeks (420 days), with a four week interval between successive laying flocks.
- For simplicity, it has been assumed that a grower feed is supplied up to 18 weeks of age and that an early-lay feed is supplied from then until 60 weeks.

In all cases, it is assumed that feeds contain 90% dry matter content.

Table 16 Diets used, duration each diet is used for and dry matter fed, by livestock type, used to calculate annual phosphorus intakes. Note that dry matter is 90% of fresh weight.

Stock Type	Diet	Sex	Cycle length (days)	Dry Matter Fed (kg day^{-1})	Break (days)	Cycles (yr^{-1})	Sex Weighting
Layer	Early Lay	-	203	0.106	28	0.83	-
	Late Lay	-	203	0.110	28	0.83	-
Pullet	Pullet Starter†	-	35	0.029	14	2.74	-
	Pullet Grower	-	35	0.049	14	2.74	-
	Pullet Grower	-	49	0.072	14	2.74	-
Broiler	Broiler Starter‡	-	10	0.027	7	8.49	-
	Broiler Grower	-	14	0.080	7	8.49	-
	Broiler Finisher	-	12	0.137	7	8.49	-
Breeding Bird	Pullet Grower	Male	126	0.082	28	0.81	0.1
	Pullet Grower	Female	126	0.047	28	0.81	0.9
	Early Lay	Male	294	0.126	28	0.81	0.1
	Early Lay	Female	294	0.116	28	0.81	0.9

† Pullet starter diets are the same as the pullet grower diets, but with phosphorus content increased by a factor of 1.04

‡ Broiler starter diets are the same as the broiler grower diets, but with phosphorus content increased by a factor of 1.1

4.2.3 Conclusions

Current poultry diets and feeding practices are closely-aligned to best practice. Phytase enzyme technology has been embraced and there is a strong understanding of the relative digestibility of phosphorus from the different sources of inorganic phosphorus. Phase-feeding principles (matching the feed to the requirements of the birds for growth and production) are standard practice throughout the poultry sector.

As understanding of dietary phytate from raw materials improves and phytase enzymes become more efficient, there are likely to be further small incremental reductions in the total phosphorus content, particularly in broiler feeds. However, it is important that any further changes made do not compromise the welfare of the birds. Further research studies may be needed to verify this and to provide confidence to producers and feed manufacturers alike.

4.3 Pig Diets

A review of phosphorus use in the UK pig industry (Kyriazakis, 2008) suggested that prior to 2008, phosphorus levels in the diets of all classes of pig were formulated at 20-35% above the recommended Nutrient Requirement Standards (BSAS, 2003). Several reasons for this oversupply were identified, including the requirement for safety margins, a degree of uncertainty over the digestible phosphorus content of feedstuffs, but also advice offered by veterinarians to maintain leg soundness of the breeding stock. An additional factor may have been availability of cheap supplies of inorganic phosphorus pre-2008, providing an added incentive to bolster inclusion levels as an insurance policy for bone strength. This particularly applies in an industry with a significant breeding sow population kept outdoors where robust genotypes are required that can withstand extreme climatic and ground conditions.

As for poultry, the shortage of inorganic phosphorus around 2008 prompted the pig industry to critically reassess phosphorus levels and consider reductions, particularly in grower and finisher diets which represent the highest proportion of all pig feeds, by tonnage. New commercially available phytase enzyme products, claiming to have enhanced digestibility through more efficient breakdown of the phytate molecule, also created the opportunity to reduce levels of supplementary inorganic phosphate in pig diets, without affecting performance.

Use of apparent phosphorus digestibility, as a method of formulating pig diets, has now been accepted in the pig industry as the most efficient method to minimise excretion of surplus undigested phosphorus since this takes into account total phytate content and quantifiable phytase levels within the chosen feed ingredients.

Phosphorus requirements for pigs through various growth stages is based on precise assumptions for growth and performance parameters, e.g. growth rate, and feed conversion ratio, both of which derive from predicted feed intakes. However, in the practical situation, for pigs kept in larger group sizes, an increasing trend in the UK pig industry, not only are these parameters difficult to obtain at an individual level but, in the group situation, studies have confirmed feed intake to be variable, leading to size and weight variation within the group. Feed intake variability is due to a number of contributory factors, such as genotype, housing system, bedding type, health status, feeder design and provision, group size and social hierarchy. For these reasons, it is common to advise the use of average recommendations to satisfy pigs' requirements for phosphorus within the group situation, in the absence of precise defined feed intake levels for each individual pig.

4.3.1 Current situation

The norm for most pig diets produced in specialist monogastric feed mills is for a single dose of Phytase in combination with inorganic phosphorus as MCP.

In Scotland, as in the rest of Great Britain, this approach is thought to account for at least 90% of all pig feeds. The outcome is lower inclusion rates of inorganic phosphorus in compound manufactured feeds, in comparison to those diets produced without supplementary phytase.

A series of typical commercial pig rations have been formulated by Premier Nutrition for this project to highlight current phosphorus levels in Scotland. Compared to other parts of Great Britain, there is generally a greater differential between wheat and barley prices in Scotland due to the higher quantities of barley grown in comparison to wheat. In practice, this means lower wheat and higher barley content in pig diets, however this has little impact upon dietary levels of phosphorus as the content and digestibility of phosphorus is similar for both cereals.

In total, five different 'current' pig feeds have been formulated. These are a rearer feed, grower feed, finishing feed, lactating and dry sow feeds. These have been selected in order to build up a representative picture of the current situation for pigs.

During the post-weaning phase, the rearer feed is provided in bulk to feed the pig over the majority of the early growth stage up to 35kg. Due to limited feed intake and high requirement of phosphorus for bone development, younger pigs receive a higher percentage inclusion rate of phosphorus which diminishes as their appetite increases and phosphorus requirement reduces as they become more physiologically mature. Ideally, there should be a precise matching of supply of phosphorous with the pig's requirements incrementally throughout the growth phase. However this is mitigated in practice with practical considerations such as all in all out housing systems, which commonly features automatic pelleted feed delivery systems connected to bulk bins positioned at the end of each house, inevitably limiting the number of diets that can be fed. There remains the risk, therefore, of either under or over-supply of phosphorous whilst attempting to match the precise needs of a population through use of a limited number of diets that span the entire growth phase, recently extended through increased slaughter weights demanded by the modern processing industry.

4.3.2 Potential for further reductions in phosphorus in pig feedstuffs

Defra (2013) attempted to demonstrate on-farm that dietary phosphorus can be reduced without negative effects on pig performance and health. In particular, the dry sow phase and finisher phases were targeted as areas where phosphorus could be reduced.

Dry sow phase

The dry sow has tended to be oversupplied with phosphorus for most of gestation (Kyriazakis, 2008), hence there may be scope for reducing the phosphorus content of dry sow diets below current British Society of Animal Science (BSAS) standards without adversely affecting reproductive performance and bone strength. In contrast, the requirement for phosphorus during lactation is mainly dependent upon level of milk production therefore a lower level of food intake in the early stages of lactation as the sow builds up appetite, would require a higher concentration (g/kg) of digestible phosphorus to be included in the diet. In conclusion, therefore, the possibilities for reducing phosphorus excretion during lactation are limited compared to those during pregnancy, if detrimental impact on sow and piglet welfare is to be avoided.

Finisher phase

Finisher diets represent the highest proportion of pig feeds by tonnage, also, as pigs tend to be slaughtered at increasingly heavier weights, there is an increasing tendency for three diets to be fed throughout this extended period. This means that potentially the final stage finisher diet could be formulated with lower levels of phosphorus, since the pig's phosphorus requirement reduces as it becomes more physiologically mature. Significantly, this growth stage covers up to 25% of all total phosphorus currently excreted (Table 2).

In Defra (2013) neither the low phosphorus dry sow diet nor the low phosphorus finisher diet had any additional inorganic phosphorus added, with no adverse effects on pig performance recorded. This indicates that in most situations, there is no need for the inclusion of additional inorganic phosphorus, which can be costly given the decreased availability of suitable inorganic phosphorus sources. However, further research will be needed to look at possible long term effects on sow performance and longevity, especially when levels are reduced below the recommended standard. The research also needs to take into account differences in requirements for indoor and outdoor sows where ingestion of soil will be a factor, and the translation of the findings from pigs on straw based systems compared to those on slats.

In this project, the six specimen formulations for the five specific pig diets are designed to provide decreasing amounts of total phosphorus as supplied through inorganic sources, yet still match the pigs' requirement for digestible phosphorus (Table 17). However, the sixth option, where reformulation leads to exclusion of particular ingredients, could lead to undesirable consequences, such as the substitution of domestically produced rapeseed with imported soya, irrespective of cost. Table 17 highlights that total phosphorus can be reduced by approximately 40% in each of the specimen diets, whilst matching the requirement for digestible phosphorus within each of the different classes of pig's diet and adding between 1 and 2% to overall diet cost. Inorganic sources of phosphorus, as supplied through MCP, can be potentially removed altogether from all but rearer and lactation diets.

Table 17 Comparison of pig diets with gradually descending levels of Phosphate.							
Stock Type	**Property**	**Diet 1**	**Diet 2**	**Diet 3**	**Diet 4**	**Diet 5**	**Diet 6**
Rearer 13 to 35 kg	Dicalcium Phosphate (%)	1.56	-	-	-	-	-
	Mono Calcium Phosphate (%)	-	1.00	0.54	0.23	0.13	0.13
	Total Phosphorus (%)	0.64	0.57	0.47	0.41	0.38	0.38
	Digestible Phosphorus (%)	0.32	0.32	0.32	0.32	0.30	0.30
	Relative Cost	100.0	99.3	100.7	100.9	101.1	101.2
Grower 35 to 65 kg	Dicalcium Phosphate (%)	1.32	-	-	-	-	-
	Mono Calcium Phosphate (%)	-	0.89	0.38	0.06	0.00	0.00
	Total Phosphorus (%)	0.59	0.56	0.44	0.38	0.36	0.33
	Digestible Phosphorus (%)	0.28	0.29	0.28	0.28	0.27	0.26
	Relative Cost	100.0	99.8	101.0	101.3	101.2	102.7
Finisher 65 to 110 kg	Dicalcium Phosphate (%)	1.14	-	-	-	-	-
	Mono Calcium Phosphate (%)	-	0.72	0.27	0.00	0.00	0.00
	Total Phosphorus (%)	0.53	0.48	0.38	0.33	0.33	0.30
	Digestible Phosphorus (%)	0.24	0.24	0.24	0.25	0.25	0.24
	Relative Cost	100.0	99.4	101.4	102.1	102.7	104.5
Lactating sow	Dicalcium Phosphate (%)	1.70	-	-	-	-	-
	Mono Calcium Phosphate (%)	-	1.08	0.63	0.32	0.22	0.27
	Total Phosphorus (%)	0.64	0.56	0.47	0.41	0.39	0.35
	Digestible Phosphorus (%)	0.32	0.32	0.32	0.32	0.30	0.30
	Relative Cost	100.0	99.2	101.0	101.5	102.0	104.3
Dry Sow	Dicalcium Phosphate (%)	1.28	-	-	-	-	-
	Mono Calcium Phosphate (%)	-	0.81	0.36	0.04	0.00	0.00
	Total Phosphorus (%)	0.52	0.47	0.37	0.31	0.30	0.25
	Digestible Phosphorus (%)	0.24	0.24	0.24	0.24	0.23	0.22
	Relative Cost	100.0	99.4	101.3	102.0	102.4	103.3

1. Dicalcium phosphate (DCP), no phytase
2. Monocalcium phosphate (MCP), no phytase
3. Monocalcium phosphate (MCP) and 500 FTU of Phyzyme (early phytase)
4. Monocalcium phosphate (MCP) and 750 FTU of Quantum Blue (latest generation phytase)
5. As per 4, but also reducing digestible phosphorous (DP) specification by 0.02%
6. As per 5, but also forcing the total phosphorus down as low as possible before ingredient costs become prohibitive or formulation infeasible, the example chosen eliminates rapeseed meal and wheatfeed.

Finally, in order to convert the unit phosphorus values for each diet into annual total phosphorus intakes for each of the various categories of pig, it was necessary to make assumptions around pig management systems chosen to be representative of the pig industry in Scotland. These include the following:

- All in all out housing systems based around three week batch farrowing, enabling a period of downtime (e.g. 3-5 days) between batches for depopulation immediately followed by cleaning and disinfection before the next incoming batch of pigs;
- Closed herd systems utilising home grown gilts as replacement parent females;
- Weighting taken of outdoor production and outdoor-specific genotypes in overall estimated dry matter intake values given for sows and gilts;
- In-pig gilts fed on lactating diet. In practice, however, larger herds may well use a specialist gilt rearer diet so this assumption can be quite variable;
- Single rearer diet chosen to represent the early grower phase from 13-35kg. In practice, on larger herds where larger quantities can be purchased and utilised, as many as three separate diets may be used within this growth period;
- A single finisher diet chosen for the final growth period >65kg live weight. Typically, two separate diets (65-85kg, 85-110kg) may be fed to pigs particularly on larger scale farms where larger quantities can be purchased and utilised.

The assumptions for which diets are appropriate for the different census categories are listed in Table 18.

4.3.3 Conclusions

In conclusion, therefore, there is scope to reduce total phosphorus levels through progressively reduced levels of inorganic phosphorus and incorporation of phytase in diet formulation, particularly new commercially available phytase enzyme products, claimed to have enhanced digestibility through more efficient breakdown of the phytate molecule. However, when setting allowance levels, there is a need to take into account the population factor where, within large pen group sizes containing sometimes as many as 200 pigs, there can be considerable variation in individual feed intake and therefore growth rate leading to size and body weight variation within the group. Practicalities also need to be considered, such as occurrence of inadequate levels of mixing and separation of minerals, especially within liquid feeding systems, leading to uneven distribution of phosphate allocation along the feed line. Perhaps the first step is to promote awareness of current best practice utilising the latest generation versions of phytase, enabling lower phosphorus input and output levels to be achieved. This has not yet been widely adopted by all parts of the industry. Also, making use of a third finisher diet to cope for the needs of pigs with an extended growth period when slaughtered at heavier weights provides further scope for lower dietary phosphorus levels. This latter phase of finishing (>80kg live weight) currently contributes 25% to phosphorus output levels (Table 2), hence any dietary reductions in phosphorus will have significant benefits in lowering phosphorus outputs in slurry overall.

Table 18 Diets used, duration each diet is used for and dry matter fed, by livestock type, used to calculate annual phosphorus intakes.

Stock Type	Diet	Cycle length (days)	Dry Matter Fed (kg day^{-1})	Break (days)	Cycles (yr^{-1})	Weighting
Sows in Pig and Other Sows	Dry sow	134	3.2	4	2.3	1.00
	Lactating sow	35	6.5	4	2.3	1.00
Gilts in Pig	Dry sow	133	3.0	4	2.8	0.85
	Lactating sow	12	3.2	4	17.0	0.15
Gilts Not Yet in Pig	Dry sow	42	2.8	4	8.6	-
Boars	Dry sow	365	3.0	0	1.0	-
Other Pigs > 110kg	Finisher	42	3.0	4	8.6	-
Other Pigs 80 - 110kg	Finisher	42	2.6	4	8.6	-
Other Pigs 50 - 80kg	Grower	42	2.2	4	8.6	0.50
	Finisher	42	2.2	4	8.6	0.50
Other Pigs 20 - 50kg	Rearer	42	1.7	4	8.6	0.50
	Grower	42	1.7	4	8.6	0.50
Other Pigs < 20kg	Rearer	42	0.5	4	8.6	-

5.0 Scenario Modelling

The aim of this project is to quantify the impacts of changes in dietary phosphorus amounts on phosphorus loads delivered to watercourses. Based upon the potential changes to current feed practices, a number of scenarios were agreed with the project steering group. These scenarios are listed in Table 19.

Scenario 6 is the combined result of modifying the diets for all livestock types to a level which could in principle be achieved without significant outside drivers and thus may be considered as showing the greatest realistic potential impact. Scenario 7 would result in greater feed costs for the pig industry and so may not be financially viable. Scenarios 8 and 9 may require significant input from vets and advisors to convince the ruminant sector, and dairy farmers in particular, that phosphorus levels can be reduced from current levels without any negative health impacts (as demonstrated in the N Ireland study). The difficulty of accounting accurately for the phosphorus content of forage in ruminant diets may also make this more difficult to achieve.

5.1 Calculation of new excretal phosphorus values

The excretal phosphorus values per head or per livestock place listed in Table 2 represent the excess phosphorus in livestock diets for scenario 1. Assuming that there is no change in the phosphorus utilised by the livestock (e.g. for growth or milk and egg production) and that the proposed dietary modifications would have no impact on livestock health, then it is possible to assume that any difference in phosphorus intake from scenario 1 (expressed as kg P per head or place) can be directly applied as an adjustment to the livestock excretal phosphorus amount.

5.2 Additional impacts of reduced excretal phosphorus

Modifying livestock diets to reduce the absolute load of excretal phosphorus may have additional impacts on diffuse agricultural phosphorus loads, due to changes in the properties of the livestock excreta and changes to the amount of phosphorus being applied to land as excreta and manure. These additional impacts are discussed below.

5.2.1 Solubility

Phosphorus in excreta (and manure) consists of soluble and non-soluble fractions. The non-soluble fraction include water-insoluble feed matter, sloughed gut tissue and digestive secretions, whilst the soluble fraction is the phosphorus consumed in excess of the animal's needs but re-entered the digestive tract in saliva from the circulation (Dou *et al* 2002). Reducing phosphorus intakes so there is less excess phosphorus in the diets should thus not only reduce the total excretal phosphorus but also the solubility of this phosphorus. It is the soluble fraction that is transported by surface runoff and drain flow away from the fields to water courses, so there is an additional benefit from reduced dietary phosphorus in terms of diffuse phosphorus losses to water.

Two relationships between total manure / excretal phosphorus and the soluble fraction are shown in Figure 9 (from Chapuis-Lardy *et al* 2004) and Figure 10 (from Bremer *et al* 2008). Based on these relationships, it was assumed that a 25% drop in manure phosphorus content would results in a 10% drop in the soluble fraction. This adjustment was applied to all livestock types in all scenarios.

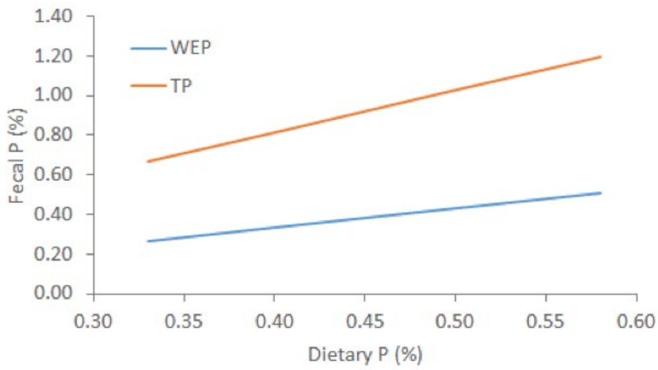


Figure 9 Changes in total phosphorus and soluble phosphorus in faecal matter with dietary phosphorus (taken from Chapuis-Lardy et al 2004).

Table 19 Changes to diets for different livestock types used in the scenarios, and whether changes were also included for soil P.

Scenario	Pig Diet†	Poultry Die‡	Ruminant Diet		Soil P & Fertiliser Use
			Compounds	Minerals	
1	No phytase	No phytase	Current	Current	No change
2	Current phytase	Current phytase	Current	Current	No change
3	Max. phytase	Max. phytase	Current	Current	Modified
4	Current phytase	Current phytase	Reduced P	Current	Modified
5	Current phytase	Current phytase	Reduced P	Reduced	Modified
6	Max. phytase	Max. phytase	Reduced P	Reduced	Modified
7	Max. phytase + soya	Max. phytase	Current	Current	Modified
8	Current phytase	Current phytase	Reduced P	Zero P	Modified
9	Current phytase	Current phytase	Current	Zero P	Modified

† No phytase for pig diets is diet 1 in Table 17. Current phytase use is 10% of pigs on diet 1 and 90% of pigs on diet 3. Maximum phytase is 100% of pigs on diet 5. Maximum phytase + soya is 100% of pigs on diet 6.

‡ Current phytase use is assumed to be 5% of poultry without phytase, 90% single phytase, 5% double phytase. Maximum phytase is 100% of poultry on double phytase.

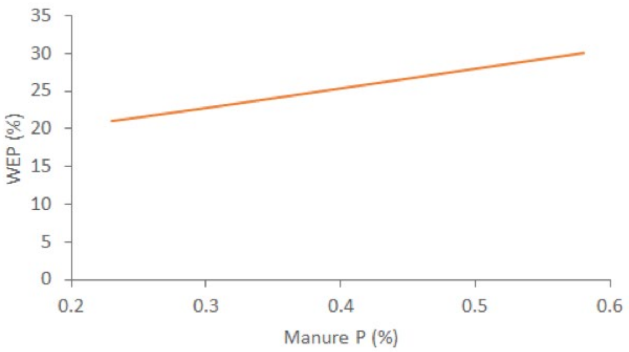


Figure 10 Reductions in soluble phosphorus as total manure phosphorus decreases (taken from Bremer et al 2008).

5.2.2 Changes to soil phosphorus status

Soil phosphorus status specifies the amount of available phosphorus in the soil. Ideally, soils should be maintained such that there is an adequate soil phosphorus supply to allow sufficient phosphorus to be extracted for crop growth. If there is too much soil phosphorus then losses of phosphorus to water can increase substantially. At an appropriate phosphorus status, phosphorus fertiliser applications should balance phosphorus removed in plant offtake. Six soil status values are used in Scotland (ranging from Very Low to Very High), with the two Moderate values appropriate depending upon crop type or rotation. SRUC Technical Note TN668 specifies how fertiliser rates should be adjusted in order to build up or run down phosphorus status to the Moderate values (Table 20). The average adjustment to change soil phosphorus status by one class is approximately 25 kg P_2O_5 ha^{-1} yr^{-1}. It should be noted that any response in soil phosphorus status to reduced inputs would occur over a period of 10 - 20 years. Table 21 shows how the extractable soil phosphorus concentration varies with soil phosphorus status – a change of one class results in an approximate doubling (or halving) of the concentration. Based upon this, it was assumed that every reduction in phosphorus applied of 25 kg P_2O_5 ha^{-1} yr^{-1} would result in a halving of soil phosphorus concentration.

The relationship derived between phosphorus status changes and concentration changes means that the net effect of reducing the phosphorus applied on losses of soil phosphorus is independent of the distribution of soil phosphorus status in an area and the spatial distribution of fertiliser (and/or manure) applied.

For each WFD catchment, the change in excretal phosphorus from dairy, beef, pigs and poultry was expressed per hectare of arable and grass land. The default modelled soil phosphorus losses from arable and grassland were adjusted such that a reduction in excreta of 25 kg P_2O_5 ha^{-1} yr^{-1} would reduce soil phosphorus losses by 50%. As the calculated impacts of changes in sheep diets for the different scenarios were very small, the impacts of any changes on soil phosphorus status, which would partly occur on rough grazing land as well as managed land, were ignored.

It was assumed that the data on current soil phosphorus status used in the original modelling work could already account for some of the reductions in pig and poultry excreta from current phytase use. Therefore, to err on the side of caution, changes in soil phosphorus due to reduced phosphorus in pig and poultry excreta were based upon the difference between each scenario and the value for scenario 2 (and thus there is no change in soil phosphorus losses associated with scenario 2 itself).

Table 20 Adjustments to build-up or run-down soil phosphorus status (kg P_2O_5 ha^{-1} yr^{-1}; taken from SRUC Technical Note TN668).

P Sorption Capacity	Very Low	Low	Moderate (M-)	Moderate (M+)	High
1	+40	+20	0	-10	-20
2	+60	+30	0	-20	-30
3	+80	+40	+20	0	-40

Table 21 Classification of extractable soil phosphorus (mg l^{-1}) by soil phosphorus status.

Very Low	Low	Moderate (M-)	Moderate (M+)	High	Very High
< 1.8	1.8 to 4.4	4.5 to 9.4	9.5 to 13.4	13.5 to 30	> 30

5.2.3 Increased fertiliser use due to reduced soil phosphorus status

If soil phosphorus status were to be reduced due to reduced livestock excretal phosphorus, there is the potential that some soils would drop to below moderate status and additional fertiliser phosphorus would be required in order to maintain soils at an appropriate level. In this situation, there is the possibility that losses from livestock would be reduced, but incidental losses resulting from phosphorus fertiliser applications would be increased. Analysis of the model outputs suggests that, averaged across the results for the whole of Scotland, the loss due to a kilogram of beef excretal phosphorus and a kilogram of fertiliser phosphorus are comparable, whilst they are greater for a kilogram of dairy excretal phosphorus and lower for a kilogram of pig or poultry excretal phosphorus. These summarised results are crude and very sensitive to the environment where manure / fertiliser is applied and the management practices therein. The differences would also vary spatially, but are not reported here.

Available national phosphorus balances data suggest however, there is currently a surplus of phosphorus. Defra figures (Defra 2014) for the UK soil phosphorus balance show a phosphorus surplus ranging between 87 and 79 thousand tonnes on commercial farms during 2010 to 2013, which is approximately 7 kg P ha^{-1} of agricultural land. Data are presented separately for England (where the phosphorus surplus per hectare is lower than the average) and subtraction of the England data from the total suggests that the surplus for the rest of the UK is approximately 10 kg p ha^{-1}. This surplus is greater than any of the changes in excretal phosphorus resulting from the scenarios (see Table 23; a reduction of 2,000 t yr^{-1} spread across just under 2m ha of managed land is a change of only 1 kg ha^{-1}), so it should be possible to maintain current soil phosphorus status through improved management and distribution of manures to areas with lower phosphorus status. Therefore the potential requirement for any increased fertiliser use was assumed to be negligible and thus ignored as part of scenario 6. Note that although the reductions in excreta will be localised to catchments where livestock are present, these are also likely to be catchments with a phosphorus surplus, so the assumption should remain valid at catchment level although the phosphorus budgets stated are only for the whole of Scotland.

The fact that there is a surplus of phosphorus in Scotland suggests that the calculated reductions in the soil phosphorus status and associated soil phosphorus losses may be an over-estimate.

5.3 National results – excreta and pollution

Excretal phosphorus values for the different livestock types for the reduced phosphorus diets are shown in Table 22. Current practice for pig diets (scenario 2) results in a reduction of around 30% from the diets with no phytase assumed for scenario 1, reductions in poultry excretal phosphorus values are around 20%. If pigs and poultry are on the lowest phosphorus diets currently used (scenario 3), then there is a further 30% reduction in pig excreta values and reductions of up to 10% for poultry. The pig diets with the absolute lowest financially viable phosphorus contents (scenario 7) result in a further reduction of around 20%, such that values are up to 75% lower than the initial no-phytase values. The reductions in excretal phosphorus for the ruminants are significantly lower except for 'dairy cows and heifers' as these receive the most supplementary phosphorus. Lower phosphorus contents in compounds and minerals (scenarios 4 and 5) reduce excretal phosphorus for 'dairy cows and heifers' by 15% and 20% for scenarios 4 and 5 respectively, but values for other ruminants are a few percent. Complete removal of mineral phosphorus for ruminants (scenarios 8 and 9) only results in marginally greater excretal phosphorus reductions, again except for 'dairy cows and heifers' where reductions under scenario 8 are 35%.

Table 23 shows the total excretal phosphorus by livestock category resulting from integrating the excretal phosphorus values in Table 22 with the national livestock numbers. The percentage reductions in total excretal phosphorus from scenario 1 are shown in Table 24. Note that there are slight differences in the total excretal phosphorus values from those shown in Table 2 (a 3% difference overall) due to differences in the methodology of calculation (Table 2 is calculated directly from livestock numbers, Table 23 is calculated from the outputs of Gooday *et al* (2015) after scaling the results at county level to account for differences in livestock totals in 2010 and 2014). Updating the baseline outputs to account for current use of phytase in the pig and poultry sectors, results in 34 and 18% reductions respectively, although this is only a 2% reduction in the national total for excretal phosphorus. Reductions in the pig and poultry sector can reach over 50 and 20% respectively if further improvements are made to diets, which may be significant locally but limited for the whole of Scotland. Reductions in total sheep excreta are minor (2%) because they consume a small amount of mineral and compound feeds and so the dietary phosphorus has not been significantly affected by the changes investigated in this project. Because they produce a much larger proportion of the national excreta budget, changes in cattle excreta - particularly for dairy animals - can have a significant impact, with national loads dropping by 12-15% where compound and mineral phosphorus intake is reduced (scenarios 4 and 5) and 15-27% where mineral phosphorus intake is removed entirely (scenarios 8 and 9).

Table 22 Excreta phosphorus values (kg hd^{-1} yr^{-1} or kg $place^{-1}$ yr^{-1}) for the different livestock types under the different scenarios. A dash indicates no change from the baseline value (scenario 1).

	Stock Type	1	2	3	4	5	6	7	8	9
Dairy	Dairy Cows and Heifers	19.4	-	-	16.3	15.5	15.5	-	12.5	15.6
	Dairy Heifers in Calf 2 Years +	12.2	-	-	11.8	11.7	11.7	-	11.6	12.1
	Dairy Heifers in Calf < 2 Years	12.2	-	-	11.6	11.6	11.6	-	11.5	12.1
Beef	Bulls	9.1	-	-	9.1	9.1	9.1	-	9.1	9.1
	Beef Cows and Heifers	13.5	-	-	13.1	13.0	13.0	-	13.0	13.5
	Beef Heifers in Calf 2 Years +	12.2	-	-	12.1	12.0	12.0	-	11.9	12.1
	Beef Heifers in Calf < 2 Years	12.2	-	-	12.1	12.0	12.0	-	11.9	12.1
	Other Cattle 2 Years +	8.0	-	-	7.9	7.8	7.8	-	7.8	7.9
	Other Cattle < 2 Years	8.0	-	-	7.9	7.8	7.8	-	7.8	7.9
	Other Cattle < 1 Year	5.0	-	-	-	-	-	-	-	-
Sheep	Sheep	1.8	-	-	1.8	1.8	1.8	-	1.8	1.8
	Lambs Less than 1 Year	0.2	-	-	-	-	-	-	-	-
Pigs	Sows in Pig and Other Sows	7.1	5.1	3.7	5.1	5.1	3.7	3.0	5.1	5.1
	Gilts in Pig and Barren Sows	4.4	3.0	2.2	3.0	3.0	2.2	1.6	3.0	3.0
	Gilts Not Yet in Pig	4.4	4.0	3.1	4.0	4.0	3.1	2.7	4.0	4.0
	Boars	5.2	3.8	2.8	3.8	3.8	2.8	2.2	3.8	3.8
	Other Pigs > 110kg	3.7	2.3	1.6	2.3	2.3	1.6	1.3	2.3	2.3
	Other Pigs 80 - 110kg	3.7	2.5	1.9	2.5	2.5	1.9	1.6	2.5	2.5
	Other Pigs 50 - 80kg	2.6	1.6	1.0	1.6	1.6	1.0	0.7	1.6	1.6
	Other Pigs 20 - 50kg	2.6	1.7	1.1	1.7	1.7	1.1	1.0	1.7	1.7
	Other Pigs < 20kg	0.4	0.1	0.1	0.1	0.1	0.1	0.5	0.1	0.1
Poultry	Layers	0.20	0.16	0.15	0.16	0.16	0.15	0.15	0.16	0.16
	Pullet	0.11	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	Broilers	0.14	0.11	0.10	0.11	0.11	0.10	0.10	0.11	0.11
	Breeding Birds	0.29	0.26	0.25	0.26	0.26	0.25	0.25	0.26	0.26
	Other Poultry	0.35	-	-	-	-	-	-	-	-

Table 23 Total phosphorus excreted (t yr-1) by livestock category under the different scenarios.						
Scenario	**Dairy**	**Beef**	**Sheep**	**Pigs**	**Poultry**	**Total**
1	5,146	14,503	6,799	846	2,245	29,539
2	5,146	14,503	6,798	557	1,847	28,851
3	5,146	14,503	6,798	389	1,741	28,577
4	4,497	14,350	6,685	557	1,847	27,936
5	4,340	14,321	6,684	557	1,847	27,749
6	4,340	14,321	6,684	389	1,741	27,475
7	5,146	14,503	6,799	360	1,741	28,549
8	3,760	14,292	6,683	557	1,847	27,139
9	4,408	14,445	6,797	557	1,847	28,054

Table 24 Reduction in total phosphorus excreted (%) by livestock category under the different scenarios.						
Scenario	**Dairy**	**Beef**	**Sheep**	**Pigs**	**Poultry**	**Total**
1	-	-	-	-	-	-
2	0.0	0.0	0.0	34.1	17.7	2.3
3	0.0	0.0	0.0	54.0	22.4	3.3
4	12.6	1.1	1.7	34.1	17.7	5.4
5	15.7	1.3	1.7	34.1	17.7	6.1
6	15.7	1.3	1.7	54.0	22.4	7.0
7	0.0	0.0	0.0	57.5	22.4	3.4
8	26.9	1.5	1.7	34.1	17.7	8.1
9	14.3	0.4	0.0	34.1	17.7	5.0

The impacts of changes in excretal phosphorus on actual losses of diffuse agricultural phosphorus are shown in Table 25. The percentage reduction in the agricultural phosphorus loss resulting from each livestock sector is typically 20-30% greater than the reduction in excretal phosphorus due to the additional benefit of the reduced solubility of the excretal phosphorus (Section 5.2.1). However, as losses of phosphorus from the soil (in both dissolved and particulate forms) and fertiliser contribute 74% and 10% of the national phosphorus loss budget respectively, the reductions in the national pollutant load due to any change in losses directly from livestock are small (between 2% for scenario 8 and almost zero for scenarios 2 and 3). The potential consequences of reduced excretal phosphorus on soil phosphorus status (and thus losses of phosphorus from the soil) are slightly more important than the changes directly due to the excreta, being 3% for scenario 8 (for a total reduction of 5.1%). As the biggest changes in total excreta are in the diary sector (up to 1,400 t P in excreta yr^{-1} in scenario 8, compared to up to 210 t P in excreta yr^{-1} for the other livestock classes[1]), the majority of the change in the soil losses is attributable to the feed changes in the dairy sector.

The results in Table 25 show the reduction in the national phosphorus load by scenario. There are significant spatial variations in these reductions due to differing livestock intensities across Scotland. Figure 11 shows the variations in the reduction in the agricultural phosphorus load due to scenario 6 by WFD waterbody – reductions can be over 8% in some catchments, and these tend to be those catchments with higher initial loads (Figure 6), particularly those associated with intensive dairy farming in the south-west (Figure 1).

Table 25. Contribution (t yr^{-1}) to the national phosphorus load from the different agricultural sources under the different scenarios.								
Scenario	**Dairy**	**Beef**	**Sheep**	**Pigs**	**Poultry**	**Soil**	**Fertiliser**	**Total**
1	137	204	83	3.7	17	2,091	301	**2,837**
2	137	204	83	2.1	13	2,091	301	**2,832**
3	137	204	83	1.3	12	2,080	301	**2,819**
4	114	202	81	2.1	13	2,045	301	**2,757**
5	109	201	81	2.1	13	2,035	301	**2,741**
6	109	201	81	1.3	12	2,025	301	**2,730**
7	137	204	83	1.2	12	2,086	301	**2,825**
8	90	200	81	2.1	13	2,004	301	**2,691**
9	111	203	83	2.1	13	2,047	301	**2,760**

[1] Note that changes to soil phosphorus due to reduced phosphorus in pig and poultry excreta are calculated relative to the excreta amounts in Scenario 2 (see Section 5.2.2).

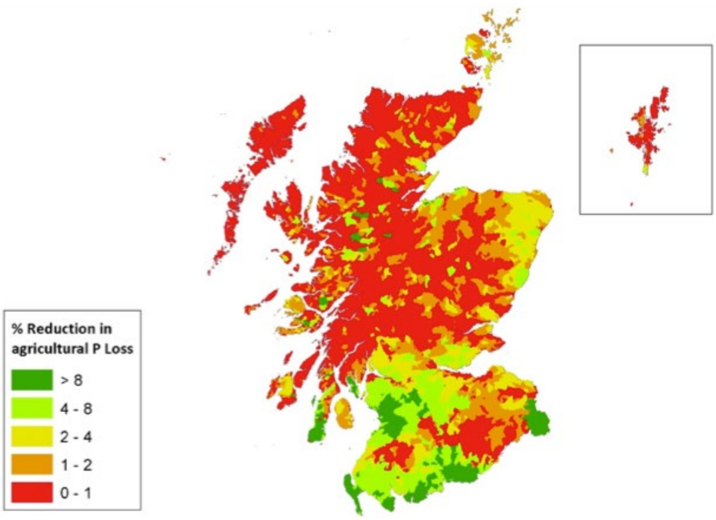


Figure 11 Reductions in the agricultural phosphorus load due to scenario 6, summarised by WFD waterbody.

5.4 National results – costs and other impacts

This project has estimated that the total cost of feed for pig and poultry (excluding ducks, geese and other poultry), and for minerals and compounds for ruminants (excluding calves, growing cattle and lambs) is £393m (Table 26). Scottish Government (2015) estimate that the total income for the whole farming sector is £824m in 2014, with the output of finished livestock and livestock products for all livestock types being £1,619m and the total cost of feedstuffs being £644m. The difference in feed costs is partly due to the difference in livestock covered by this project, but also because this project has not calculated costs of forage or silage.

For the ruminant sector, the bulk of the cost is associated with compound feeds, with minerals making a smaller contribution to the total cost (7% for dairy, 1% for beef and 17% for sheep). The national data in Table 26 for the different scenarios shows that the poultry diets save £1 - 2m annually, whereas the pig diets cost up to £1m more annually and the dairy and beef diets £2 - 4m. These changes in feed costs are relatively small in comparison to national feedstuff budgets and national outputs, although the consequences for any individual farm enterprise could be significant. Integration of the national feed cost data (Table 26) and national livestock excreta phosphorus totals (Table 23) reveals a cost of up to £0.80 kg^{-1} excretal phosphorus reduced for pigs, £0.10 kg^{-1} for beef and £0.40 kg^{-1} for dairy. Thus, excluding poultry diet changes (which are at a lower cost than the baseline), it is most economical to reduce excretal phosphorus in beef diets, then dairy diets and followed by pig diets (although reducing dairy diets has the biggest impact on phosphorus losses).

All of the diets within each scenario have been constructed to ensure that there is sufficient phosphorus for livestock health even allowing for the uncertainty in the phosphorus provided from silage and forage. For ruminant livestock, reductions in phosphorus in compound feeds for the scenarios have been driven by the replacement of higher phosphorus ingredients with lower phosphorus alternatives. In Scotland, dried distillers dark grains are readily available and may have low transport costs. Switching to lower phosphorus ingredients produced in the UK may not be a cost-effective option due to competition from other sectors, and the potential for higher prices if the demand from the agricultural sector increased. Sugar beet pulp is low in phosphorus but is not produced in Scotland, can be in short supply and is relatively expensive. Other home produced products e.g. beans, may only be available if they do not meet the specification for human food use and some of the moist distillery co-products e.g. supergrains and Vitagold are reported to be going for biofuel production. Importing more soya products would increase transport costs and concerns over global sustainability mean this is not the ideal option.

Table 26 Feed cost implications due to the different scenarios. Note that the feed costs for dairy beef and sheep refer to mineral and compound feeds only and do not include any costs for forage or silage.

Scenario	Value	Dairy	Beef	Sheep	Pigs	Poultry
1	Cost (£m)	74.7	145.5	30.8	35.7	105.9
2		-	-	-	1.01	-1.31
3		-	-	-	1.92	-1.52
4		2.43	1.46	2.34	1.01	-1.31
5	Cost Increase (%)	4.91	1.41	-0.25	1.01	-1.31
6		4.91	1.41	-0.25	1.92	-1.52
7		-	-	-	3.16	-1.52
8		4.88	1.37	-2.19	1.01	1.01
9		-0.45	-0.09	-4.53	1.01	1.01

5.5 Comparison with other scenarios for reducing diffuse agricultural phosphorus

This project has used the source and sector apportioned phosphorus results of Gooday et al (2015) as the basis for modifying the agricultural phosphorus load and determining the impacts of changes in excretal phosphorus. Gooday *et al* (2015) also estimated the impacts of future scenarios of compliance with GBRs and the NVZ AP on phosphorus losses, with maximum compliance assumed to reduce the national phosphorus load by 14% and a '2027' scenario resulting in a 6% reduction. The reductions in this project due to changes in dietary phosphorus are thus comparable to those achieved through compliance with regulation.

The costs calculated for the dietary changes in this project are a few million pounds, approximately £1 ha^{-1} of managed agricultural land in Scotland. Although there are diffuse agricultural pollution mitigation methods that result in a cost-saving to the farmer (typically due to reduced fertiliser use), those that require expenditure by the farmer typically require more than £1 ha^{-1} to be spent (Newell-Price *et al* 2011) and may not achieve reductions (at national scale) as great as those calculated within this project. Thus it may be sensible to encourage the livestock industry to reduce dietary phosphorus levels rather than encourage the implementation of mitigation measures where these measures may be less cost-effective.

5.6 Results summarised for 2015 RBMP Cycle Priority Catchments

Diffuse pollution priority catchments have been identified by SEPA as catchments failing to meet environmental standards and which require a catchment-wide approach to reduce the diffuse pollution risk. Fourteen priority catchments (Figure 12), containing some of Scotland's most important waters (for conservation, drinking water, bathing and fishing), were selected using a risk-based approach for action in the first (2015) river basin management plan cycle. These catchments have been targeted for the provision of on-farm advice to help mitigation of diffuse pollution. There is also work on the mitigation of other water environment impacts, such as morphological change, abstractions, flooding and alien species, where these are causing waterbody downgrades. Because of the importance of these catchments, and the focus of agricultural advice within them to improve water quality, the results of this project have been summarised for these 14 catchments.

The priority catchments range in size from under 100 km^2 of agricultural land to over 1,700 km^2 (Table 27). The annual agricultural phosphorus loads in the catchments vary between 2.8 and 0.24 kg P ha^{-1}. Figure 13 shows the apportionment of the phosphorus losses, and thus the different livestock types present in the catchments. With the exception of the Tay and South Esk (where stocking densities averaged across the whole catchment are much lower), the contribution from livestock is between 15 and 40% of the agricultural phosphorus load. Contributions from pigs and poultry are generally very small (<2% of the total load), whilst dairying is important (12-20% of the load) for half of the catchments.

The reductions in the agricultural phosphorus load for the priority catchments, due to changes in pig and poultry diets are, like the national picture, relatively small (<1%). Reductions due to changes in ruminant diets (scenarios 4, 5, 6, 8 and 9) are only a few percent except for those catchments with significant dairy animals, where reductions are between 5% (due to changing phosphorus in compounds) and 15% (changing compounds and also removing all mineral phosphorus). A significant proportion of these changes would be due to the potential impacts of reduced excreta and manure on soil phosphorus status, and so if these reductions did occur, they would occur over the next 10 to 20 years.

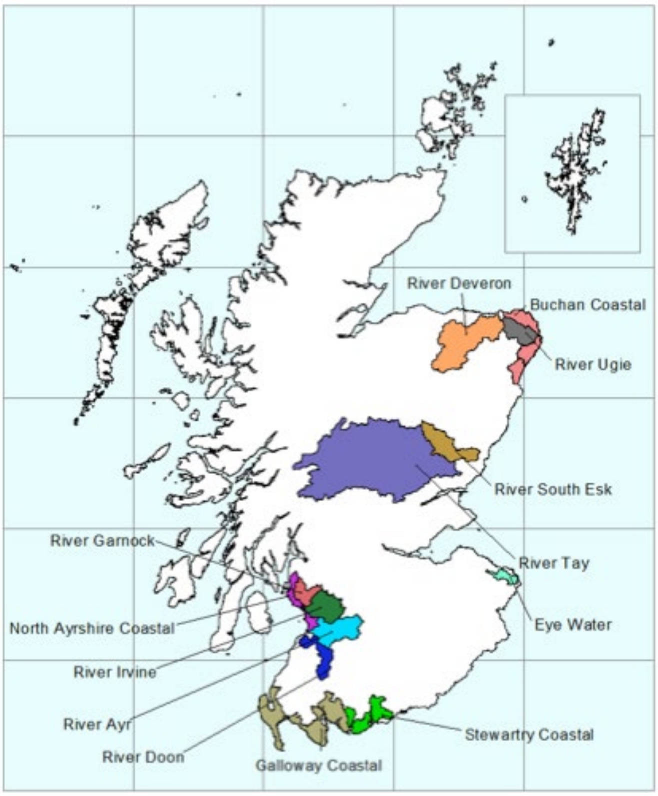


Figure 12 2015 RBMP cycle priority catchments.

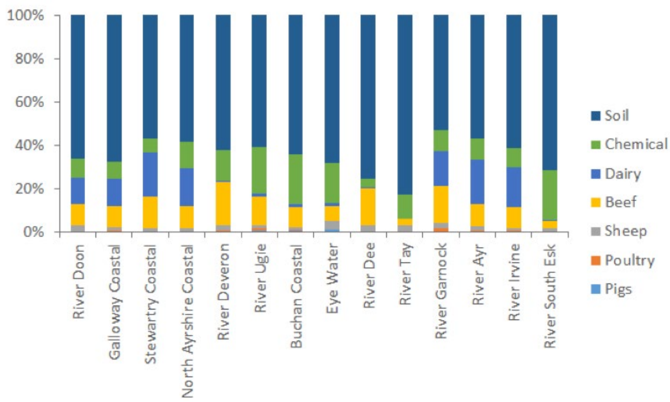


Figure 13 Apportionment of the agricultural phosphorus load for the 2015 RBMP cycle Priority Catchments.

Table 27 Current agricultural phosphorus loads per hectare of agricultural land for the 2015 river basin management plan cycle priority catchments, and the load reductions achieved by the different scenarios.

Priority Catchment	Ag. Area (km²)	P Loss (kg ha⁻¹)	Reductions (%) in P Loss under the Scenarios							
			2	3	4	5	6	7	8	9
River Doon	161	1.59	0.0	0.0	5.0	6.1	6.1	0.0	9.9	5.3
Galloway Coastal	721	1.74	0.2	0.6	7.3	8.9	9.3	0.2	14.3	7.9
Stewartry Coastal	243	0.66	0.0	0.0	7.8	9.5	9.6	0.0	15.5	8.3
N. Ayrshire Coastal	133	1.07	0.1	0.1	6.6	8.1	8.1	0.1	13.2	7.1
River Deveron	718	0.41	0.3	0.7	1.1	1.3	1.7	0.7	1.5	0.7
River Ugie	253	0.57	0.7	1.8	1.6	1.9	3.0	1.7	2.4	1.5
Buchan Coastal	431	0.88	0.5	1.6	1.6	1.9	2.9	1.7	2.5	1.5
Eye Water	96	0.41	0.6	1.5	1.4	1.6	2.6	1.1	2.1	1.3
River Dee	481	0.24	0.1	0.3	1.0	1.2	1.5	0.3	1.6	0.6
River Tay	1,752	0.66	0.1	0.5	0.5	0.6	1.0	0.3	0.7	0.3
River Garnock	152	1.83	0.3	0.5	5.6	6.9	7.1	0.3	10.9	6.0
River Ayr	328	2.09	0.2	0.4	7.9	9.7	9.9	0.2	15.7	8.6
River Irvine	269	2.83	0.1	0.3	7.7	9.4	9.6	0.1	15.4	8.4
River South Esk	273	0.76	0.2	0.7	1.0	1.1	1.7	0.7	1.6	0.8

5.7 Implications for water quality

Figure 14 shows the current phosphorus status for those WFD waterbodies where there is either measured water quality data or the measurements of a neighbouring catchment can be used as a proxy, using the 2014 phosphorus standards. For the 133 waterbodies currently failing to achieve good status for phosphorus, it is possible to determine the reduction in concentration required to achieve good status. Using the sector apportionment data from Gooday *et al* (2015), it is possible to determine the reduction required from the agricultural sector alone to achieve the overall reduction required for these waterbodies to achieve good status. Of the 133 waterbodies, 27 require a reduction greater than could be achieved even through removal of the entire agricultural load. The calculated reductions required can then be compared with the reductions in the agricultural pollutant load due to the dietary changes under the scenarios. Figure 15 and Figure 16 show the required reductions in the total load and the agricultural load, and how these compare to the reductions in the load due to the dietary changes under scenario 6. Of the 133 waterbodies currently failing to achieve good status, scenario 6 would result in six achieving good status. However, the majority of the reduced phosphorus load under scenario 6 is due to reduced soil phosphorus. The reduction in soil phosphorus status due to reduced inputs would be a gradual process typically over 10 – 20 years.

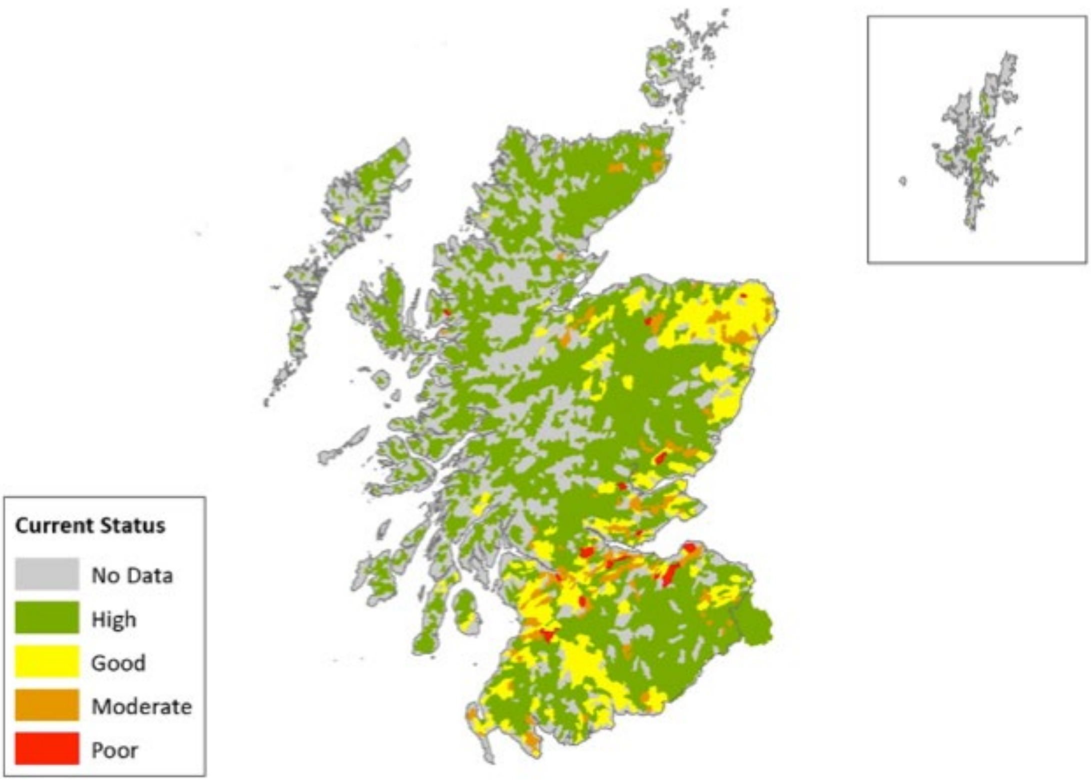


Figure 14 Current WFD phosphorus status for each catchment.

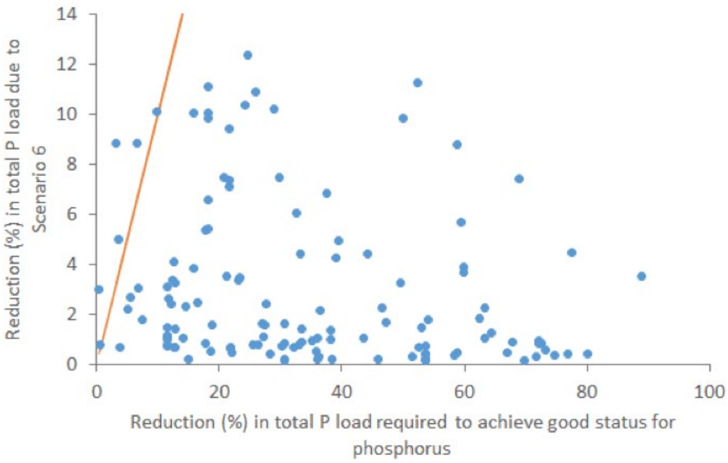


Figure 15 Comparison of the reduction in the agricultural load required for a catchment to achieve good status for phosphorus, and the reductions in load predicted for scenario 6. Points to the left of the one-one line would achieve good status due to scenario 6.

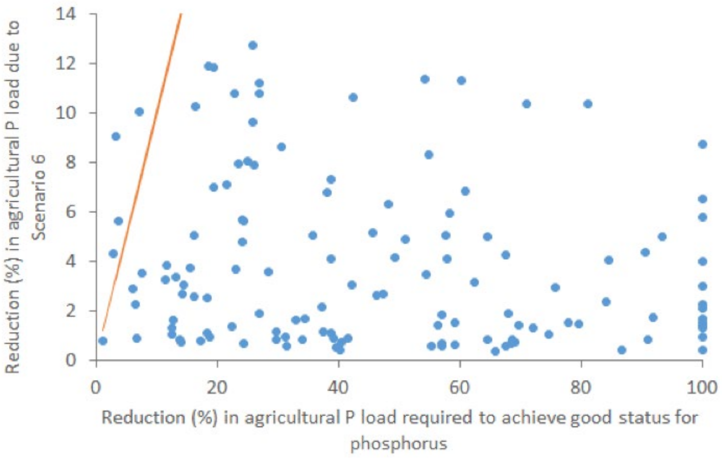


Figure 16 Comparison of the reduction in the agricultural load required for a catchment to achieve good status for phosphorus, and the reductions in load predicted for scenario 6. Points to the left of the one-one line would achieve good status due to scenario 6. Many catchments could not achieve good status solely through mitigation of the agricultural load (i.e. the agricultural load reduction required is greater than 100%).

6.0 Conclusions

The objective of this project was to estimate the potential for reducing the amount of phosphorus in livestock diets and the consequences of this for diffuse pollution and, ultimately, water quality.

For both ruminants and monogastrics, this project has estimated the amount of phosphorus in current diets and the potential to reduce this in future, based on feed ingredient substitution, a reduction in the use of mineral phosphorus and further increased use of phytase. For different feed change scenarios, the impacts of reduced dietary phosphorus on excretal phosphorus were calculated and these results were integrated with an existing dataset of phosphorus losses for Scotland (Gooday *et al* 2015). The agricultural phosphorus load delivered to water from each of the livestock sectors was modified to account for the changes in excretal phosphorus, and from this potential changes in water quality status could be estimated.

6.1 Ruminants

Ruminant livestock diets in Scotland are based on a combination of forages and supplementary feeds, provided to match animal maintenance and production needs. Supplementary feeds include purchased compounds, home-mixed blends / straights and free access feed blocks, licks and minerals. Phosphorus requirements are higher in dairy cows, replacement heifers and pregnant ewes and lower in beef finishing cattle and dry ewes.

Historically, significant levels of mineral phosphorus were included in supplementary feeds, but, in recent years, quantities in compound feeds have reduced, partly due to cost but also because of improved understanding of nutritional requirements. However, there still appear to be opportunities to reduce phosphorus levels in ruminant feeds, particularly in the dairy sector. Dairy cows continue to receive additional phosphorus in minerals and a key motivation for this is improved fertility. Mineral phosphorus for dairy cows is supplied either in total mixed rations or as a supplement to silage or forage and the content and the amounts fed both vary. The fear of under-supplying means that many farmers add supplementary phosphorus, particularly where there are concerns or uncertainties over the phosphorus content of the other ingredients used. It is difficult to formulate diets that are very low in phosphorus unless the phosphorus content of the forage is known accurately, and a cheap and reliable way of measuring the content of forage is not currently available. It is also important to note that some forages are naturally low in phosphorus and will require supplementation.

Many ruminant compound feeds are not supplemented with additional phosphorus and the phosphorus requirements of some ruminants can be met by forages alone (e.g. the requirements of dry ewes would generally be met by grass or grass silage). Requirements for finishing beef cattle are also low but the vast majority of cattle will be supplemented in the finishing phase with cereal blends/compounds which exceed their requirements. In these instances, the scope for making reductions is based on replacing ingredients such as maize and wheat dark grains (which are comparatively high in phosphorus) with lower phosphorus alternatives such as soya hulls, soya bean meal and sugar beet pulp. However the use of imported soya – rather than home-produced ingredients – would not be ideal, whilst UK produced sugar beet pulp is relatively high-cost and can be in short supply.

Complete removal of mineral phosphorus in dairy diets could reduce national phosphorus losses by 20 t yr^{1} (which is just under 1% of the national total of 2,800 t). The reductions in excreta and manure may result in an additional reduction of 40 t yr^{1} due to reductions in soil phosphorus status and associated losses, although this would take 10 to 20 years to be realised. Using compounds with lower phosphorus contents could also reduce losses from dairy animals by about 20 t yr^{1}, again with an associated saving in soil phosphorus. These dietary changes should have no impact on animal health or fertility. Dietary changes in the beef and sheep sector result in marginal reductions in losses (1 to 2 t yr^{1}).

Limited feedback from industry experts working with dairy farmers suggests that they would be receptive to reducing phosphorus in dairy cow diets as the reduction or removal of mineral phosphorus would probably result in cost savings for their business. In contrast, further reductions in phosphorus in compound feeds are likely to increase the cost per tonne as cheaper higher phosphorus ingredients are replaced by more expensive lower phosphorus alternatives. Overall it appears that reduction or removal of mineral phosphorus over and above the animal requirements is a win-win situation.

6.2 Monogastrics

In the monogastrics sector, dietary phosphorus levels have reduced in recent years for poultry and pigs. A key reason for this is the introduction and now widespread use of phytase enzyme in compound feeds. Phytase enzyme allows both poultry and pigs to digest phosphorus which is in the form of phytate and as a result, dietary supplies of inorganic phosphorus can be reduced.

Current dietary phosphorus reductions for monogastrics can also be traced back to the time of phosphorus shortages and increased prices in and around 2008. Lower dietary inclusion rates at that time demonstrated cost savings without adverse effects on performance and thus there was no need to return to increased levels when availability returned.

Calculated reductions in national phosphorus losses relative to current practice are only 1 to 2 t yr^{1}. These changes may be more important locally, as the pig and particularly the poultry industry is concentrated in a relatively small area.

As animal nutrition specialists continue to improve their understanding of the phytate content of raw materials, phytase is likely to play a larger part in feed formulation for monogastrics in future. In turn, this is expected to lead to some further small reductions in dietary phosphorus levels.

6.3 Overall

The overall conclusion to this project is that there appear to be opportunities to reduce the amount of phosphorus offered to dairy cows, particularly in minerals, as livestock are typically overfed phosphorus to provide certainty that there is no under-feeding. Opportunities for other livestock are limited as changes have already been made due to historical drivers and because there is limited supplementary phosphorus added to feed.

National reductions in phosphorus losses of 5% are possible (although some of this change will occur over the next 10-20 years as soils respond to reduced phosphorus inputs), meaning that the impacts of changes in dietary phosphorus are comparable to those achieved through compliance with regulation. The overall total cost of these changes to diets are estimated to be around £5m per annum, with the dairy and beef sector costs rising by £3.6m and £2m respectively, and small savings being made in the sheep and poultry sectors. These costs do not account for any distortion of market prices due to demand for different feed ingredients or the impacts of importing ingredients such as soya versus using home-grown materials or local by-products. For both the dairy and beef sectors, reduced mineral inputs alone results in a cost saving (and a reduction in phosphorus losses) and it is only the increased ingredient costs for lower phosphorus compounds that results in the overall cost increases for these sectors.

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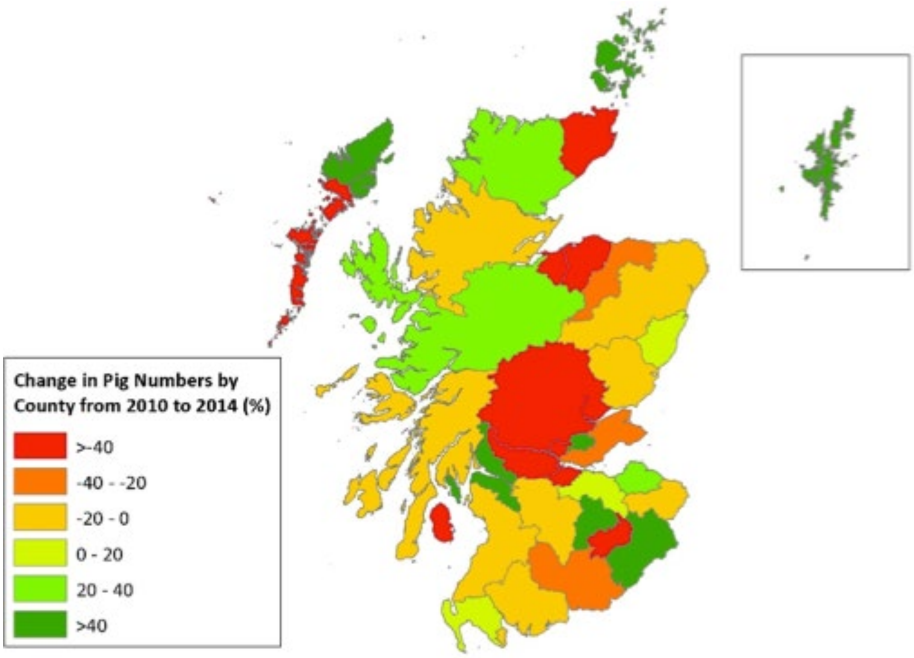
Appendix 1: County Level Changes in Livestock 2010-2014

Note that although there are significant percentage changes for some counties, these are generally where the actual number of livestock is fairly small and so probably represent changes on only one or two farms.



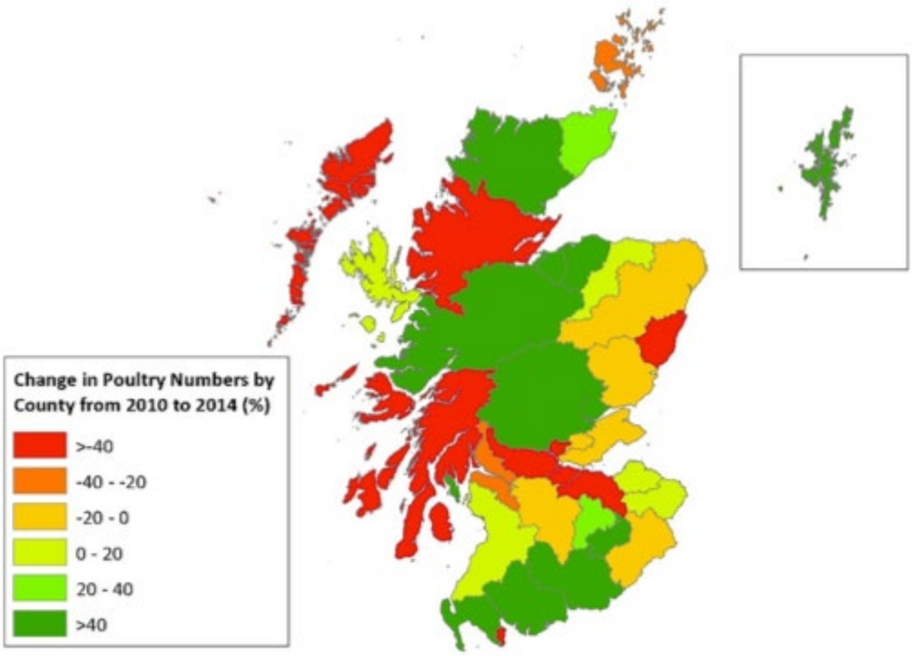


Figure 17 Percentage changes in pigs and poultry at county level between 2010 and 2014. Data for livestock types were aggregated by converting livestock counts to excretal phosphorus values.

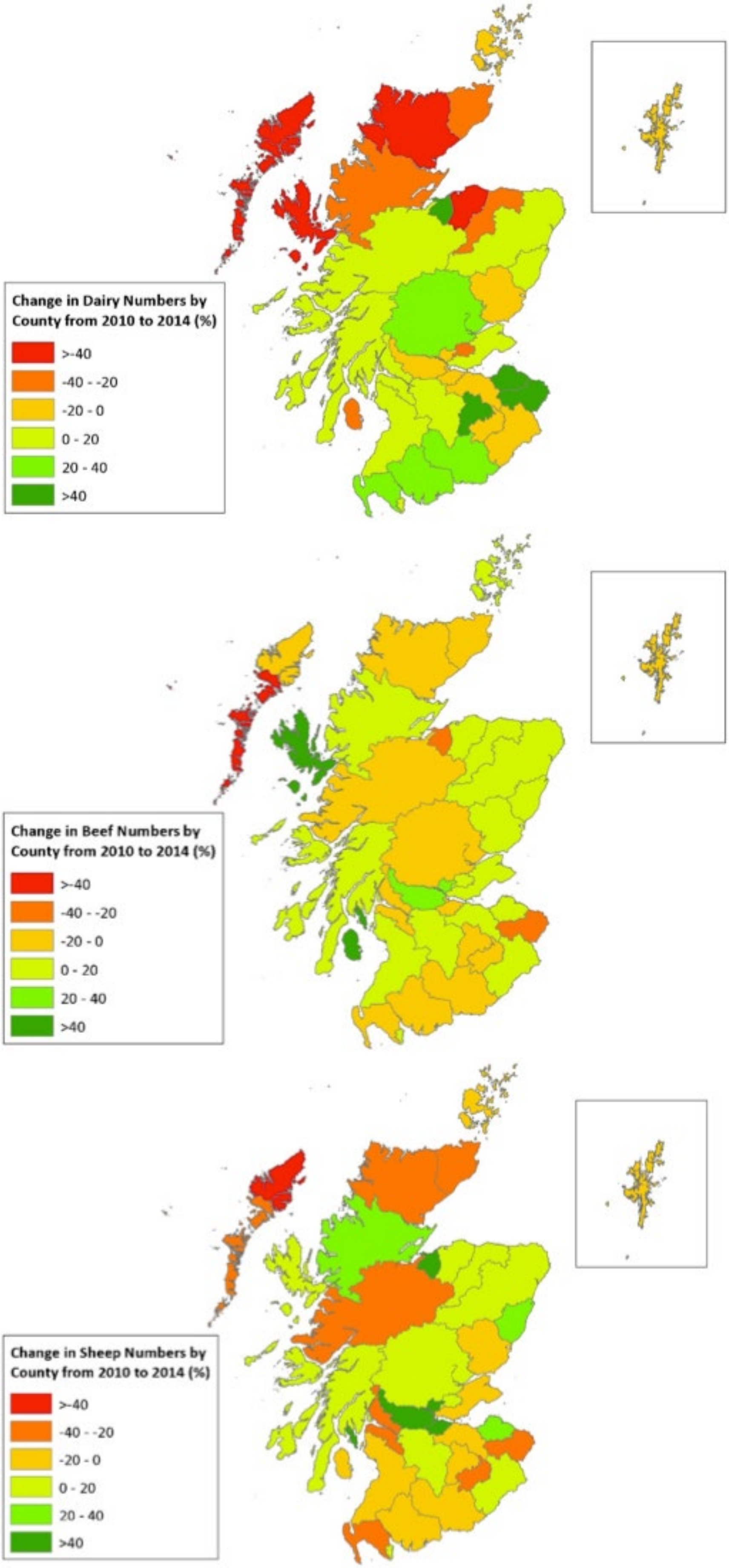


Figure 18 Percentage changes in ruminants at county level between 2010 and 2014. Data for livestock types were aggregated by converting livestock counts to excretal phosphorus values.

Appendix 2: Detailed Dietary Information

Lactating Dairy Cow Compounds – High Energy	High energy 20%CP Current	High energy 20%CP 0.4% P	High energy 18%CP Current	High energy 18%CP 0.4% P
Cost	£182.07	£187.88	£174.08	£177.79
Feedstuffs				
Maize	38.9	27.5	20.3	40.1
Wheat	150.0	150.0	150.0	150.0
Barley	150.0	150.0	150.0	150.0
Wheatfeed	0.0	0.0	67.1	0.0
Maize Dark Grains	100.0	0.0	100.0	24.5
Wheat Dark Grains	100.0	46.4	100.0	100.0
Rapeseed, ext 00	3.3	0.0	24.5	0.0
Soya hulls	0.0	83.2	0.0	85.3
Soya bean meal extr, 48%	171.7	244.5	93.2	152.7
Palm kernel meal Exp	150.0	150.0	150.0	150.0
Megalac	21.6	33.9	30.3	32.9
Molasses	60.0	60.0	60.0	60.0
Vitamin E	0.5	0.5	0.5	0.5
Limestone	10.0	10.0	10.0	10.0
Calcined magnesite	4.0	4.0	4.0	4.0
Salt	10.0	10.0	10.0	10.0
Cattle Copper	5.0	5.0	5.0	5.0
Ruminant Premix	25.0	25.0	25.0	25.0
Nutrients				
Dry Matter (%)	87.70	88.17	87.77	88.10
ME (MJ/kg)	11.60	11.60	11.60	11.60
Crude protein (%)	20.00	20.00	18.00	18.00
ERDP (g/kg)	125.79	123.66	114.56	114.50
DUP (g/kg)	49.09	29.11	40.00	46.77
Starch (%)	20.56	20.10	20.76	20.81
Sugar (%)	5.44	5.90	5.24	5.19
Starch + sugar (%)	26.00	26.00	26.00	26.00
NDF (%)	20.51	21.05	22.55	23.42
Oil (%)	6.43	6.22	7.29	6.69
Phosphorus (%)	0.46	0.40	0.49	0.40
Phosphorus (% DM)	0.53	0.45	0.56	0.45

Lactating Dairy Cow Compounds – Medium Energy	Med. energy 20%CP Current	Med. energy 20%CP 0.4% P	Med. energy 18%CP Current	Med. energy 18%CP 0.4% P
Cost	£169.61	£176.26	£162.73	£166.89
Feedstuffs				
Maize	0.0	0.0	0.0	0.0
Wheat	150.0	150.0	150.0	150.0
Barley	126.8	22.5	150.0	74.9
Wheatfeed	0.0	0.0	69.5	0.0
Maize Dark Grains	100.0	58.2	100.0	100.0
Wheat Dark Grains	100.0	100.0	100.0	100.0
Rapeseed, ext 00	242.6	0.0	149.7	0.0
Soya hulls	0.0	208.2	0.0	186.7
Soya bean meal extr, 48%	0.0	181.0	0.0	109.4
Palm kernel meal Exp	150.0	150.0	150.0	150.0
Megalac	16.2	15.5	16.3	14.6
Molasses	60.0	60.0	60.0	60.0
Vitamin E	0.5	0.5	0.5	0.5
Limestone	10.0	10.0	10.0	10.0
Calcined magnesite	4.0	4.0	4.0	4.0
Salt	10.0	10.0	10.0	10.0
Cattle Copper	5.0	5.0	5.0	5.0
Ruminant Premix	25.0	25.0	25.0	25.0
Nutrients				
Dry Matter (%)	88.38	88.34	88.01	88.12
ME (MJ/kg)	11.10	11.10	11.10	11.10
Crude protein (%)	20.00	20.00	18.00	18.00
ERDP (g/kg)	129.16	123.81	116.57	112.26
DUP (g/kg)	36.14	53.79	32.93	43.43
Starch (%)	17.79	12.73	19.98	15.18
Sugar (%)	5.84	5.27	5.46	4.76
Starch + sugar (%)	23.64	18.00	25.44	19.94
NDF (%)	23.85	29.17	24.55	29.28
Oil (%)	6.51	5.49	6.43	5.77
Phosphorus (%)	0.59	0.40	0.57	0.40
Phosphorus (% DM)	0.67	0.45	0.64	0.45

Dry Dairy Cow Compounds	26%CP Current	26%CP 0.4% P
Cost	£220.21	£206.58
Feedstuffs		
Wheat	160.0	160.0
Barley	29.3	6.5
Maize Dark Grains	100.0	0.0
Wheat Dark Grains	100.0	0.0
Rapeseed, ext 00	55.1	0.0
Soya hulls	0.0	195.7
Soya bean meal extr, 48%	289.9	434.2
Palm kernel meal Exp	150.0	69.9
Megalac	13.3	31.0
Molasses	60.0	60.0
Vitamin E premix	1.5	1.5
Calcined magnesite	10.9	11.3
Cattle Copper	5.0	5.0
Ruminant Premix	25.0	25.0
Nutrients		
Dry Matter (%)	87.88	88.30
ME (MJ/kg)	11.60	11.60
Crude protein (%)	26.00	26.00
ERDP (g/kg)	161.03	156.46
DUP (g/kg)	68.90	84.74
Starch (%)	13.30	12.74
Sugar (%)	6.70	7.26
Starch + sugar (%)	20.00	20.00
NDF (%)	20.29	19.90
Oil (%)	5.85	5.21
Phosphorus (%)	0.54	0.40
Phosphorus (% DM)	0.62	0.45

Heifer Rearing Compounds	Current	0.4% P
Cost	£156.02	£158.37
Feedstuffs		
Wheat	150.0	150.0
Barley	150.0	150.0
Wheatfeed	167.1	0.0
Maize Dark Grains	100.0	100.0
Wheat Dark Grains	100.0	100.0
Rapeseed, ext 00	50.7	16.1
Soya hulls	0.0	157.8
Soya bean meal extr, 48%	0.0	45.5
Palm kernel meal Exp	150.0	150.0
Megalac	17.7	16.2
Molasses	60.0	60.0
Vitamin E	0.5	0.5
Limestone	10.0	10.0
Calcined magnesite	4.0	4.0
Salt	10.0	10.0
Cattle Copper	5.0	5.0
Ruminant Premix	25.0	25.0
Nutrients		
Dry Matter (%)	87.63	88.02
ME (MJ/kg)	11.10	11.10
Crude protein (%)	16.00	16.00
ERDP (g/kg)	103.54	101.99
DUP (g/kg)	30.12	34.19
Starch (%)	21.57	18.74
Sugar (%)	5.12	4.45
Starch + sugar (%)	26.69	23.19
NDF (%)	25.69	28.71
Oil (%)	6.49	5.95
Phosphorus (%)	0.55	0.40
Phosphorus (% DM)	0.63	0.45

Suckler Cow Compounds		
	Current	0.4% P
Cost	£160.80	£163.82
Feedstuffs		
Wheat	60.7	160.0
Barley	150.0	3.6
Wheatfeed	168.3	0.0
Maize Dark Grains	100.0	100.0
Wheat Dark Grains	100.0	100.0
Rapeseed, ext 00	43.9	28.8
Soya hulls	0.0	199.3
Soya bean meal extr, 48%	0.0	31.0
Palm kernel meal Exp	220.0	220.0
Megalac	2.5	2.5
Molasses	60.0	60.0
Vitamin E premix	0.5	0.5
Limestone	15.0	15.0
Calcined magnesite	39.1	39.1
Salt	10.0	10.0
Cattle Copper	5.0	5.0
Ruminant Premix	25.0	25.0
Nutrients		
Dry Matter (%)	88.11	88.69
ME (MJ/kg)	10.30	10.30
Crude protein (%)	16.00	16.00
ERDP (g/kg)	100.06	97.41
DUP (g/kg)	32.17	37.32
Starch (%)	16.27	12.15
Sugar (%)	4.91	4.25
Starch + sugar (%)	21.17	16.40
NDF (%)	28.88	33.10
Oil (%)	5.57	5.16
Phosphorus (%)	0.56	0.40
Phosphorus (% DM)	0.63	0.45

Beef Finishing Compounds				
	Home mix*	Current	Reduced P	Very low P
Cost	£144.90	£155.28	£156.03	£167.87
Feedstuffs				
Maize		4.5	4.1	0.0
Wheat	418.6	250.0	250.0	250.0
Barley	396.7	250.0	250.0	242.6
Maize Dark Grains	159.8	100.0	76.6	0.0
Wheat Dark Grains		100.0	100.0	0.0
Soya hulls		0.0	10.8	169.7
Soya bean meal extr, 48%		10.3	20.3	117.7
Palm kernel meal Exp		148.8	150.0	63.9
Megalac		25.9	27.7	45.5
Molasses		60.0	60.0	60.0
Vitamin E		0.5	0.5	0.5
Limestone		10.0	10.0	10.0
Salt		10.0	10.0	10.0
Cattle Copper		5.0	5.0	5.0
Ruminant Premix		25.0	25.0	25.0
Vitalmin Beef	25.0			
Nutrients				
Dry Matter (%)	87.78	87.47	87.56	87.99
ME (MJ/kg)	11.60	11.60	11.60	11.60
Crude protein (%)	14.00	14.00	14.00	14.00
ERDP (g/kg)	87.16	93.78	94.05	90.54
DUP (g/kg)	27.59	25.55	26.93	37.99
Starch (%)	15.81	29.00	29.00	29.00
Sugar (%)	2.48	4.36	4.43	5.06
Starch + sugar (%)	48.29	33.36	33.43	34.06
NDF (%)	15.10	21.38	21.57	20.38
Oil (%)	3.62	6.69	6.65	6.31
Phosphorus (%)	0.43	0.41	0.40	0.30
Phosphorus (% DM)	0.49	0.47	0.46	0.34

* This will incur additional labour and machinery cost

Ewe Compounds	High energy Current	High energy 0.4% P	Med. energy Current	Med. energy 0.4% P
Cost	£182.16	£182.16	£153.23	£157.33
Feedstuffs				
Maize	150.0	150.0	0.0	0.0
Wheat	150.0	150.0	72.5	80.9
Barley	0.0	0.0	63.2	150.0
Wheatfeed	0.0	0.0	250.0	0.0
Maize Dark Grains	0.0	0.0	44.4	0.0
Wheat Dark Grains	0.0	0.0	100.0	98.3
Malt byproduct	100.0	100.0	100.0	0.0
Rapeseed, ext 00	0.0	0.0	74.4	0.0
Sunflower meal, ext	0.0	0.0	0.0	51.2
Soya hulls	49.3	49.3	0.0	246.4
Soya bean meal extr, 48%	207.1	207.1	30.0	107.6
Palm kernel meal Exp	150.0	150.0	150.0	150.0
Sugar beet pulp	50.9	50.9	0.0	0.0
Megalac	32.6	32.6	5.5	5.5
Molasses	60.0	60.0	60.0	6.0
Vitamin E premix	1.0	1.0	1.0	1.0
Limestone	10.0	10.0	10.0	10.0
Calcined magnesite	4.0	4.0	4.0	4.0
Salt	10.0	10.0	10.0	10.0
Ruminant Premix	25.0	25.0	25.0	25.0
Nutrients				
Dry Matter (%)	88.08	88.08	87.95	88.35
ME (MJ/kg)	11.60	11.60	10.60	10.60
Crude protein (%)	18.00	18.00	18.00	18.00
ERDP (g/kg)	102.43	102.43	113.58	114.85
DUP (g/kg)	60.00	60.00	40.00	44.58
Starch (%)	20.27	20.27	15.16	15.11
Sugar (%)	6.33	6.33	6.26	4.89
Starch + sugar (%)	26.59	26.59	21.42	20.00
NDF (%)	21.99	21.99	30.20	32.22
Oil (%)	5.88	5.88	5.22	4.20
Phosphorus (%)	0.38	0.38	0.64	0.40
Phosphorus (% DM)	0.43	0.43	0.73	0.45

Complete Diet – Full TMR 650 kg cow 50 days in milk yielding 43kg (3.75% fat and 3.20% protein)			
Raw material	**As fed (kg)**	**DM (kg)**	
Grass silage	35.00	8.75	
WCW fermented	7.00	2.45	
Wheat	3.25	2.83	
Sugar beet pulp, molassed	3.00	2.67	
Barley dark grains	2.50	2.23	
Rapeseed meal	1.75	1.59	
Soya bean meal, ext	1.75	1.55	
Pot ale syrup	1.00	0.45	
Maize	1.00	0.87	
Calcium soap product	0.40	0.38	
Dairy mineral	0.25	0.247	
Total	56.90	24.02	
Nutrients		**Target**	
	Actual	**Min**	**Max**
Dry matter (kg)	24.02	22.40	25.40
Forage (% DM)	46.60	40.00	60.00
ME (MJ)	290.00	289.00	
M/D (MJ/kgDM)	12.10	12.00	13.00
Crude Protein (% DM)	18.00	16.00	19.00
Phosphorus (g)	113.00	96.00	
Phosphorus % (DM)	0.47		

Complete Diet – Partial TMR 650 kg cow 50 days in milk yielding 40kg (3.75% fat and 3.20% protein)			
Raw material	**As fed (kg)**	**DM (kg)**	
Grass silage	34.00	8.50	
WCW fermented	7.00	2.45	
18% dairy cake	6.50	5.80	
Wheat	3.00	2.61	
Sugar beet pulp, molassed	1.50	1.33	
Barley dark grains	1.50	1.33	
Soya bean meal, ext	1.00	0.89	
Pot ale syrup	0.50	0.23	
Dairy mineral	0.15	0.15	
Total	55.15	23.29	
Nutrients		**Target**	
	Actual	**Min**	**Max**
Dry matter (kg)	23.30	21.50	24.50
Forage (% DM)	47.00	40.00	60.00
ME (MJ)	276.00	273.00	
M/D (MJ/kgDM)	11.90	12.00	13.00
Crude Protein (% DM)	16.90		
Phosphorus (g)	116.00	93.00	
Phosphorus % (DM)	0.50		

Complete Diet – Silage plus parlour feed 650 kg cow 100 days in milk yielding 30kg (3.60% fat and 3.25% protein)			
Raw material	**As fed (kg)**	**DM (kg)**	
Grass silage	35.00	8.75	
WCW fermented	7.50	2.62	
20% dairy cake	10.00	8.91	
Total	52.50	20.29	
Nutrients		**Target**	
	Actual	**Min**	**Max**
Dry matter (kg)	20.30	19.60	22.60
Forage (% DM)	56.10	40.00	60.00
ME (MJ)	236.00	234.00	
M/D (MJ/kgDM)	11.60	11.80	
Crude Protein (% DM)	16.80	16.00	18.50
Phosphorus (g)	91.70	81.00	
Phosphorus % (DM)	0.45		

Complete Diet – Suckler weighing 400 – 500 kg			
Raw material	**As fed (kg)**	**DM (kg)**	
Barley	8.50	7.39	
Protein concentrate	3.00	2.66	
Straw - wheat	1.00	0.86	
Beef mineral	0.08	0.07	
Total	12.58	10.99	
Nutrients		**Target**	
	Actual	**Min**	**Max**
Dry matter (kg)	11.00		10.80
Forage (% DM)	7.82	40.00	
ME (MJ)	137.00	145.00	
M/D (MJ/kgDM)	12.50		
Crude Protein (% DM)	13.70		
Predicted LWG (kg)	1.33		
Phosphorus (g)	43.90	33.70	
Phosphorus % (DM)	0.40		

Complete Diet – Heifer replacement weighing 350 kg gaining 0.75 kg/day			
Raw material	**As fed (kg)**	**DM (kg)**	
Youngstock blend	4.20	3.69	
Straw - wheat	3.50	3.01	
Youngstock mineral	0.08	0.07	
Total	7.77	6.77	
Nutrients		**Target**	
	Actual	**Min**	**Max**
Dry matter (kg)	6.77		6.75
Forage (% DM)	44.50	40.00	
ME (MJ)	68.10	73.10	
M/D (MJ/kgDM)	10.10		
Crude Protein (% DM)	13.10		
Predicted LWG (kg)	0.62		
Phosphorus (g)	25.20		
Phosphorus % (DM)	0.37		

Lactating Sow Diets						
Phytase	None	None	Phyzyme	Quantum Blue	Quantum Blue	Quantum Blue
Phytase Amount	-	-	500 FTU	750 FTU	750 FTU	750 FTU
	DCP	MCP	MCP	MCP	MCP Red. DP	MCP Red. DP Low P ingred
Cost	£160.16	£158.85	£161.77	£162.60	£161.99	£165.75
Feedstuffs						
Barley	26.06	26.19	30.00	30.00	30.00	29.52
Wheat	48.91	48.79	45.42	45.52	45.53	50.00
Wheat Feed	0.00	0.00	0.00	0.00	0.00	0.00
Rape seed extraction	5.00	5.00	5.00	5.00	5.00	0.00
Extracted Soya Bean Meal (GM)	12.92	12.92	12.60	11.47	11.31	13.35
Monocalcium Phosphate		1.08	0.63	0.32	0.22	0.27
(Sugar) Cane Molasses	2.00	2.00	2.00	2.00	2.00	2.15
	0.51	0.51	0.50	0.50	0.50	
Soya oil (GM)	1.18	1.18	1.15	1.14	1.14	1.78
Methionine	0.03	0.03	0.03	0.02	0.02	0.05
Lysine	0.26	0.26	0.26	0.28	0.28	0.31
Threonine	0.07	0.07	0.07	0.07	0.07	0.10
Sodium Chloride	0.48	0.48	0.48	0.48	0.48	0.53
Phytase			0.10	0.10	0.10	0.10
Calcium Carbonate	0.64	1.25	1.20	1.07	1.11	1.56
Min/vit PMx	0.25	0.25	0.25	0.25	0.25	0.25
Valine						0.04
Ext Sun 36			0.31	1.78	1.98	
Dical	1.70					
Nutrients						
DM	87.52	87.52	87.37	87.33	87.32	87.19
PROTEIN	15.75	15.75	15.74	15.78	15.78	14.85
OIL B	4.00	4.00	4.00	4.00	4.00	4.00
FIBRE	3.96	3.97	4.10	4.32	4.35	3.51
ASH	5.11	5.30	4.90	4.54	4.50	4.78
CALCIUM	0.85	0.85	0.76	0.66	0.66	0.81
PHOSPHORUS	0.64	0.56	0.47	0.41	0.39	0.35
PI DPHOSH	0.32	0.32	0.32	0.32	0.30	0.30
PI DPHOSPP	0.32					
SODIUM	0.20	0.20	0.20	0.20	0.20	0.22
SALT	0.77	0.77	0.77	0.78	0.78	0.84
MAGNESIUM	0.17	0.17	0.17	0.17	0.17	0.14
AME ADULT	11.92					
PI DEGR MJ	13.59	13.59	13.60	13.60	13.60	13.74
PI NEGR MJ	9.79	9.79	9.79	9.78	9.78	10.00
PI NESW MJ	10.00	10.00	10.00	10.00	10.00	10.20
LYSINE	0.89	0.89	0.90	0.90	0.90	0.88
METHIONINE	0.26	0.26	0.26	0.26	0.26	0.26

Dry Sow Diets						
Phytase	None	None	Phyzyme	Quantum Blue	Quantum Blue	Quantum Blue
Phytase Amount	-	-	500 FTU	750 FTU	750 FTU	750 FTU
	DCP	MCP	MCP	MCP	MCP Red. DP	MCP Red. DP Low P ingred
Cost	£174.95	£173.96	£177.20	£178.41	£178.18	£179.67
Feedstuffs						
Barley	35.00	35.00	35.00	35.00	35.00	35.00
Wheat	47.09	47.03	45.93	45.18	45.12	55.00
Wheat Feed	9.87	9.98	11.85	12.97	13.05	2.19
Rape seed extraction	0.37	0.35	0.02	0.00	0.00	0.00
Extracted Soya Bean Meal (GM)	0.00	0.00	0.00	0.00	0.00	0.36
Monocalcium Phosphate		0.81	0.36	0.04	0.00	0.00
(Sugar) Cane Molasses	2.00	2.00	2.00	2.00	2.00	2.40
	0.00	0.00	0.00	0.00	0.00	
Soya oil (GM)	1.07	1.07	1.04	1.01	1.01	1.21
Methionine	0.00	0.00	0.00	0.00	0.00	0.00
Lysine	0.25	0.25	0.25	0.25	0.25	0.27
Threonine	0.07	0.07	0.07	0.07	0.07	0.07
Sodium Chloride	0.49	0.49	0.49	0.48	0.48	0.48
Phytase			0.10	0.10	0.10	0.10
Calcium Carbonate	0.00	0.44	0.40	0.40	0.42	0.42
Min/vit PMx	2.50	2.50	2.50	2.50	2.50	2.50
Valine						0.00
Ext Sun 36			0.00	0.00	0.00	
Dical	1.28					
Nutrients						
DM	84.98	84.97	84.81	84.77	84.76	84.75
PROTEIN	10.44	10.44	10.50	10.58	10.58	10.17
OIL B	3.50	3.50	3.50	3.50	3.50	3.50
FIBRE	4.05	4.06	4.14	4.21	4.21	3.60
ASH	3.64	3.77	3.39	3.16	3.15	2.85
CALCIUM	0.86	0.85	0.76	0.71	0.71	0.71
PHOSPHORUS	0.52	0.47	0.37	0.31	0.30	0.25
PI DPHOSH	0.24	0.24	0.24	0.24	0.23	0.22
PI DPHOSPP	0.24					
SODIUM	0.20	0.20	0.20	0.20	0.20	0.20
SALT	0.78	0.78	0.78	0.78	0.78	0.79
MAGNESIUM	0.14	0.14	0.15	0.15	0.15	0.13
AME ADULT	11.69					
PI DEGR MJ	12.86	12.86	12.87	12.88	12.88	13.20
PI NEGR MJ	9.62	9.62	9.61	9.61	9.61	9.94
PI NESW MJ	9.80	9.80	9.80	9.80	9.80	10.10
LYSINE	0.53	0.53	0.53	0.53	0.53	0.52
METHIONINE	0.16	0.16	0.16	0.16	0.16	0.15

Rearer (15 – 35 kg) Diets						
Phytase	None	None	Phyzyme	Quantum Blue	Quantum Blue	Quantum Blue
Phytase Amount	-	-	500 FTU	750 FTU	750 FTU	750 FTU
	DCP	MCP	MCP	MCP	MCP Red. DP	MCP Red. DP Low P ingred
Cost	£190.56	£189.35	£191.89	£192.24	£191.56	£191.56
Feedstuffs						
Barley	20.00	20.00	20.00	20.00	20.00	20.00
Wheat	44.99	45.00	45.77	46.59	46.70	46.70
Wheat Feed	0.00	0.00	0.00	0.00	0.00	0.00
Rape seed extraction	0.00	0.00	0.00	0.00	0.00	0.00
Extracted Soya Bean Meal (GM)	29.20	29.19	29.03	28.86	28.84	28.84
Monocalcium Phosphate		0.99	0.54	0.23	0.13	0.13
(Sugar) Cane Molasses	0.00	0.00	0.00	0.00	0.00	0.00
Soya oil(GM)- Spray	0.00	0.00	0.00	0.00	0.00	
Soya oil (GM)	2.79	2.78	2.58	2.36	2.33	2.33
Methionine	0.12	0.11	0.11	0.11	0.11	0.11
Lysine	0.35	0.35	0.36	0.36	0.36	0.36
Threonine	0.14	0.14	0.14	0.14	0.14	0.14
Sodium Chloride	0.48	0.48	0.48	0.48	0.48	0.48
Phytase			0.10	0.10	0.10	0.10
Calcium Carbonate	0.13	0.69	0.64	0.52	0.56	0.56
Min/vit PMx	0.25	0.25	0.25	0.25	0.25	0.25
Valine						0.00
Ext Sun 36			0.00	0.00	0.00	
Dical	1.56					
Nutrients						
DM	87.91	87.90	87.73	87.65	87.64	87.64
PROTEIN	20.66	20.66	20.67	20.68	20.68	20.68
OIL B	4.96	4.96	4.77	4.57	4.55	4.55
FIBRE	3.52	3.52	3.53	3.55	3.55	3.55
ASH	4.88	5.06	4.62	4.24	4.19	4.19
CALCIUM	0.60	0.60	0.51	0.41	0.41	0.41
PHOSPHORUS	0.64	0.57	0.47	0.41	0.38	0.38
PI DPHOSH	0.32	0.32	0.32	0.32	0.30	0.30
PI DPHOSPP	0.32					
SODIUM	0.20	0.20	0.20	0.20	0.20	0.20
SALT	0.75	0.75	0.75	0.75	0.75	0.75
MAGNESIUM	0.16	0.16	0.17	0.17	0.17	0.17
AME ADULT	12.33					
PI DEGR MJ	14.40	14.40	14.40	14.41	14.41	14.41
PI NEGR MJ	10.10	10.10	10.10	10.10	10.10	10.10
PI NESW MJ	10.35	10.35	10.35	10.35	10.35	10.35
LYSINE	1.31	1.31	1.31	1.31	1.31	1.31
METHIONINE	0.40	0.40	0.40	0.40	0.40	0.40

Grower (35 – 65 kg) Diets						
Phytase	None	None	Phyzyme	Quantum Blue	Quantum Blue	Quantum Blue
Phytase Amount	-	-	500 FTU	750 FTU	750 FTU	750 FTU
	DCP	MCP	MCP	MCP	MCP Red. DP	MCP Red. DP Low P ingred
Cost	£173.62	£173.42	£175.37	£175.93	£175.54	£178.08
Feedstuffs						
Barley	18.59	16.78	18.57	18.62	18.62	25.00
Wheat	50.00	50.00	50.00	50.00	50.00	46.27
Wheat Feed	0.00	0.00	0.00	0.00	0.00	0.00
Rape seed extraction	4.20	7.50	5.65	7.01	7.13	0.15
Extracted Soya Bean Meal (GM)	20.30	18.49	19.35	18.44	18.36	22.44
Monocalcium Phosphate		0.89	0.38	0.06	0.00	0.00
(Sugar) Cane Molasses	2.00	2.00	2.00	2.00	2.00	2.00
	0.00	0.00	0.00	0.00	0.00	
Soya oil (GM)	1.73	2.08	1.70	1.65	1.64	1.78
Methionine	0.07	0.06	0.06	0.06	0.06	0.08
Lysine	0.37	0.38	0.38	0.39	0.39	0.36
Threonine	0.14	0.14	0.14	0.14	0.14	0.14
Sodium Chloride	0.42	0.42	0.42	0.42	0.42	0.42
Phytase			0.10	0.10	0.10	0.10
Calcium Carbonate	0.60	1.00	1.00	0.86	0.88	1.00
Min/vit PMx	0.25	0.25	0.25	0.25	0.25	0.25
Valine						0.00
Ext Sun 36			0.00	0.00	0.00	
Dical	1.31					
Nutrients						
DM	87.57	87.72	87.46	87.44	87.44	87.25
PROTEIN	18.43	18.53	18.48	18.52	18.53	18.30
OIL B	4.00	4.40	4.01	4.00	4.00	4.00
FIBRE	3.81	4.09	3.96	4.12	4.13	3.56
ASH	4.99	5.18	4.71	4.33	4.31	4.32
CALCIUM	0.75	0.75	0.66	0.56	0.56	0.56
PHOSPHORUS	0.59	0.56	0.44	0.38	0.36	0.33
PI DPHOSH	0.28	0.29	0.28	0.28	0.27	0.26
PI DPHOSPP	0.28					
SODIUM	0.18	0.18	0.18	0.18	0.18	0.18
SALT	0.74	0.75	0.75	0.75	0.75	0.75
MAGNESIUM	0.18	0.19	0.18	0.19	0.19	0.16
AME ADULT	11.94					
PI DEGR MJ	13.86	13.87	13.88	13.89	13.89	14.04
PI NEGR MJ	9.80	9.80	9.80	9.80	9.80	9.96
PI NESW MJ	10.03	10.04	10.04	10.04	10.04	10.19
LYSINE	1.15	1.16	1.16	1.16	1.16	1.15
METHIONINE	0.33	0.32	0.33	0.32	0.32	0.34

Finisher (65 – 110 kg) Diets						
Phytase	None	None	Phyzyme	Quantum Blue	Quantum Blue	Quantum Blue
Phytase Amount	-	-	500 FTU	750 FTU	750 FTU	750 FTU
	DCP	MCP	MCP	MCP	MCP Red. DP	MCP Red. DP Low P ingred
Cost	£151.71	£150.83	£153.77	£154.98	£154.98	£157.63
Feedstuffs						
Barley	29.41	29.41	29.38	30.00	30.00	30.00
Wheat	50.00	50.00	50.00	49.36	49.36	50.00
Wheat Feed	0.00	0.00	0.00	0.00	0.00	2.79
Rape seed extraction	6.35	6.37	7.63	8.66	8.66	0.41
Extracted Soya Bean Meal (GM)	7.76	7.75	6.99	6.45	6.45	10.80
Monocalcium Phosphate		0.72	0.26	0.00	0.00	0.00
(Sugar) Cane Molasses	2.00	2.00	2.00	2.00	2.00	2.00
	0.00	0.00	0.00	0.00	0.00	
Soya oil (GM)	1.36	1.36	1.32	1.27	1.27	1.47
Methionine	0.04	0.04	0.03	0.03	0.03	0.05
Lysine	0.39	0.39	0.39	0.40	0.40	0.37
Threonine	0.13	0.13	0.13	0.13	0.13	0.13
Sodium Chloride	0.43	0.43	0.43	0.43	0.43	0.45
Phytase			0.10	0.10	0.10	0.10
Calcium Carbonate	0.74	1.15	1.08	0.92	0.92	1.17
Min/vit PMx	0.25	0.25	0.25	0.25	0.25	0.25
Valine						0.00
Ext Sun 36			0.00	0.00	0.00	
Dical	1.14					
Nutrients						
DM	87.42	87.42	87.30	87.28	87.28	87.07
PROTEIN	14.45	14.45	14.52	14.61	14.61	14.33
OIL B	3.75	3.75	3.74	3.74	3.74	3.78
FIBRE	4.14	4.14	4.28	4.41	4.41	3.72
ASH	4.56	4.69	4.27	3.92	3.92	4.08
CALCIUM	0.75	0.75	0.66	0.56	0.56	0.61
PHOSPHORUS	0.53	0.48	0.38	0.33	0.33	0.30
PI DPHOSH	0.24	0.24	0.24	0.25	0.25	0.24
PI DPHOSPP	0.24					
SODIUM	0.18	0.18	0.18	0.18	0.18	0.19
SALT	0.76	0.76	0.77	0.77	0.77	0.79
MAGNESIUM	0.16	0.16	0.17	0.17	0.17	0.15
AME ADULT	11.92					
PI DEGR MJ	13.48	13.48	13.49	13.51	13.51	13.66
PI NEGR MJ	9.80	9.80	9.80	9.80	9.80	9.97
PI NESW MJ	10.00	10.00	10.00	10.01	10.01	10.17
LYSINE	0.89	0.89	0.89	0.90	0.90	0.88
METHIONINE	0.25	0.25	0.25	0.25	0.25	0.25

Pullet Grower Diets			
Phytase	None MCP	Single MCP	Double MCP
Relative cost	100.000	98.790	98.800
Feedstuffs			
Wheat	52.12	51.28	51.08
Barley	20.00	20.00	20.00
Wheatfeed	6.42	8.19	8.60
Sunflower Ext	10.00	10.00	10.00
Soya Ext	7.12	6.71	6.61
Vegetable Fatblend	0.50	0.50	0.50
Limestone	1.62	1.57	1.56
Salt	0.20	0.20	0.20
Sodium Bicarbonate	0.15	0.15	0.15
MCP	1.39	0.90	0.77
Lysine HCl	0.14	0.15	0.15
Liquid Methionine	0.10	0.10	0.10
Supplement	0.25	0.25	0.25
Phytase 1st dose		0.01	0.01
Phytase 2nd dose			0.01
Nutrients			
Protein	15.00	15.00	15.00
Oil	1.95	1.96	1.97
Fibre	5.57	5.67	5.70
Ash	6.02	5.60	5.50
Calcium	1.00	1.00	1.00
Total phosphorus	0.74	0.63	0.61
Digestible phosphorus	0.45	0.45	0.45

Early Lay Diets			
Phytase	None MCP	Single MCP	Double MCP
Relative cost	100.000	98.530	98.430
Feedstuffs			
Wheat	37.88	38.82	39.04
Barley	15.00	15.00	15.00
Bisuitmeal	7.50	7.50	7.50
Sunflower Ext	2.50	2.50	2.50
Soya Ext	22.75	22.61	22.58
Soya Oil	3.46	3.18	3.11
Limestone	9.13	9.08	9.07
Salt	0.18	0.18	0.18
Sodium Bicarbonate	0.12	0.12	0.12
MCP	0.96	0.49	0.37
Lysine HCl	0.05	0.05	0.05
Liquid Methionine	0.22	0.22	0.22
Supplement	0.25	0.25	0.25
Phytase 1st dose		0.01	0.01
Phytase 2nd dose			0.01
Nutrients			
Protein	17.39	17.42	17.43
Oil	5.36	5.09	5.03
Fibre	3.80	3.82	3.83
Ash	13.26	12.81	12.70
Calcium	3.80	3.80	3.80
Total phosphorus	0.57	0.46	0.44
Digestible phosphorus	0.34	0.34	0.34

Late Lay Diets			
Phytase	None MCP	Single MCP	Double MCP
Relative cost	100.000	98.300	98.100
Feedstuffs			
Wheat	45.34	46.38	46.62
Barley	15.00	15.00	15.00
Bisuitmeal	7.50	7.50	7.50
Sunflower Ext	2.50	2.50	2.50
Soya Ext	15.87	15.63	15.57
Soya Oil	2.12	1.83	1.76
Limestone	10.02	9.97	9.96
Salt	0.16	0.16	0.16
Sodium Bicarbonate	0.14	0.14	0.14
MCP	0.82	0.35	0.23
Lysine HCl	0.10	0.10	0.10
Liquid Methionine	0.18	0.18	0.18
Supplement	0.25	0.25	0.25
Phytase 1st dose		0.01	0.01
Phytase 2nd dose			0.01
Nutrients			
Protein	15.00	15.00	15.00
Oil	4.02	3.74	3.67
Fibre	3.81	3.84	3.84
Ash	13.74	13.30	13.19
Calcium	4.10	4.10	4.10
Total phosphorus	0.51	0.41	0.38
Digestible phosphorus	0.30	0.30	0.30

Broiler Grower Diets			
Phytase	None MCP	Single MCP	Double MCP
Relative cost	100.00	98.70	98.60
Feedstuffs			
Wheat	44.92	46.10	46.36
Barley	10.00	10.00	10.00
Whole rapeseed	6.50	6.50	6.50
Soya Ext	30.14	29.92	29.87
Vegetable Fatblend	2.95	2.55	2.43
Soya oil	1.50	1.50	1.50
Limestone	1.13	1.08	1.07
Salt	0.10	0.10	0.10
Sodium Bicarbonate	0.22	0.22	0.22
MCP	1.19	0.67	0.58
Liquid Lysine	0.35	0.36	0.36
Liquid Methionine	0.41	0.41	0.41
Threonine	0.10	0.10	0.10
Supplement	0.50	0.50	0.50
Phytase 1st dose		0.01	0.01
Phytase 2nd dose			0.01
Nutrients			
Protein	20.70	20.71	20.71
Oil	8.50	8.11	7.99
Fibre	3.55	3.57	3.58
Ash	5.38	4.91	4.82
Calcium	0.80	0.80	0.80
Total phosphorus	0.64	0.52	0.50
Digestible phosphorus	0.40	0.40	0.40

Broiler Finisher Diets			
Phytase	None MCP	Single MCP	Double MCP
Relative cost	100.00	98.80	98.55
Feedstuffs			
Wheat	49.73	50.83	51.08
Barley	10.00	10.00	10.00
Whole rapeseed	7.50	7.50	7.50
Soya Ext	24.26	24.11	24.07
Vegetable Fatblend	3.24	2.85	2.73
Soya oil	1.50	1.50	1.50
Limestone	1.05	1.00	0.99
Salt	0.10	0.10	0.10
Sodium Bicarbonate	0.24	0.24	0.24
MCP	1.09	0.58	0.48
Liquid Lysine	0.38	0.38	0.38
Liquid Methionine	0.32	0.32	0.32
Threonine	0.10	0.10	0.10
Supplement	0.50	0.50	0.50
Phytase 1st dose		0.01	0.01
Phytase 2nd dose	_	_	0.01
Nutrients			
Protein	18.60	18.64	18.64
Oil	9.20	8.83	8.71
Fibre	3.60	3.63	3.63
Ash	4.96	4.49	4.40
Calcium	0.74	0.74	0.74
Total phosphorus	0.60	0.48	0.46
Digestible phosphorus	0.37	0.37	0.37

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CREW is a Scottish Government funded partnership between the James Hutton Institute and Scottish Universities.