November 2020

Research Review No. 41140076

Evidence for Farming Initiative Greenhouse Gas Reduction and Carbon Storage on Dairy Farms

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This review was produced as the final report of a two month project (41140076) which started in August 2020. The work was funded by a contract for £9,950 from AHDB.

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Abstract

This report provides AHDB high-level insight into the evidence landscape around transitioning to net zero in the dairy sector to feed into their Evidence for Farming Initiative (EFI). EFI aims to improve agricultural performance through providing farmers, growers and their advisers with easy access to the best available evidence on effective and cost-effective practices to carry out both emission reduction and opportunities for carbon capture and sequestration. The dairy sector is perceived as a key contributor to greenhouse gas (GHG) emissions and the aim is to provide evidence-based advice as to the effectiveness of farmer interventions.

Promar carried out primary source research and evidence gathering to support initial decision-making on the overall setting of direction for EFI in the dairy sector. An extensive list of relevant GHG reduction interventions in the dairy sector was created which was then reduced to focus on eight core areas of interventions that it was felt would make significant difference and be achievable by dairy farmers. The eight core areas, using the EFI evidence review framework, were investigated in detail to create this report. Promar were also tasked to identify key areas where supporting evidence was unavailable or lacking that could potential form AHDB research projects for the dairy sector in the future.

The initial 'long list' demonstrated the complexity of the range of GHG effecting interventions in the dairy sector and how they interacted and impacted on each other. Promar grouped the interventions into eight core areas of: organic manures, energy use and renewables, fertility and herd management, herd health and welfare, genetics and genomics, feed strategy & management, carbon capture and soil carbon. Under each core area a specific intervention was investigated in more detail. These interventions were; low emission spreading, reducing energy consumption from fossil fuels, heifer rearing, mortality rate, increase the genetic merit of the herd, homegrown feed quality, agro-forestry and increasing soil organic matter.

Each of the eight interventions was evaluated on the cost, effectiveness, strength of evidence and outcomes using the EFI framework. From the eight chosen there was variation on cost and effectiveness but all apart from feed strategy & management had a 60% or higher level of effectiveness. Key challenges will be to use the current knowledge exchange tools available to encourage and demonstrate to farmers the environmental and economic benefits of implementing these interventions. As a result of this report some specific areas requiring further research evidence have been identified and similarly the necessity to understand the issues regarding transfer value of carbon footprints when implementing these activities.

1. Introduction

Promar has worked to provide AHDB with a high-level insight of the evidence landscape around transitioning to net zero in the dairy sector. To fully consider the net zero ambition, both emission reduction and opportunities for carbon capture and sequestration will be considered. The emission sources from UK dairy farms are well understood (Figure 1).

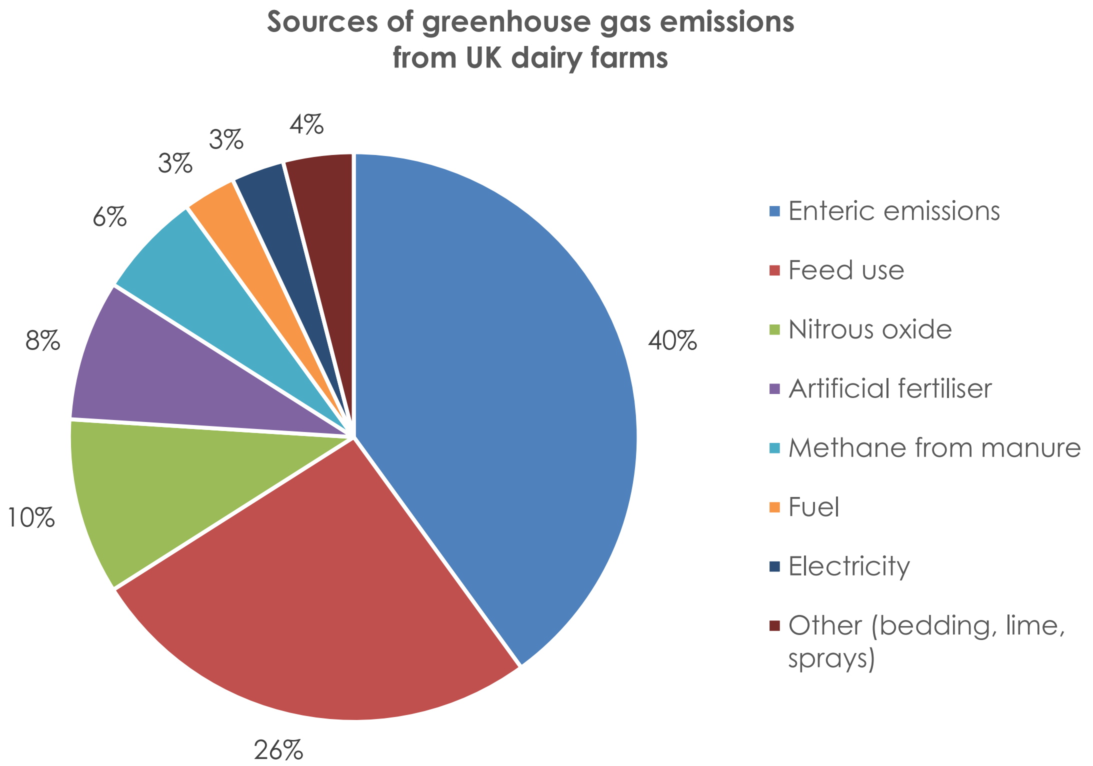


Figure 1: Sources of greenhouse gas emissions from UK dairy farms[1]

The challenge lies in implementing interventions and practice change on farm and to apply the evidence to achieve emission reduction results. Our approach is to target the key core areas that farms can focus upon that will have the largest emission reduction impact in the sector and/or are easily achievable. Broadly, these fit into two main categories of resource use efficiency and productivity efficiencies. The third category is opportunities for carbon sequestration.

The project aimed to:

- Support initial decision-making on the overall setting of direction for Evidence for Farming Initiative (EFI) for the dairy sector.
- Help EFI identify areas and topics on which it might develop evidence-translation and knowledge exchange materials for use by farmers, growers and other decision-makers.
- Support AHDB in commissioning some pieces of more focused evidence-review activity that will support the development of EFI products and services.

- Support EFI to identify areas where collaboration with relevant stakeholders, interested parties and new technology developers can leverage greater co-operation or value from datasets to drive innovation and the evidence base.

EFI aims to improve agricultural performance through providing farmers, growers and their advisers with easy access to the best available evidence on effective and cost-effective practices. EFI intends to build, over time, a repository of insight into what works in farming and growing – curating material from published research and combining this with evaluations across the sector's extensive landscape of knowledge-exchange and innovation activity.

Promar has presented the insight and evidence for net zero in dairy production using the EFI evidence standard framework outlined in Appendix One. This ensures our method aligns with other EFI projects in the arable and livestock sectors.

2. Strategies to achieve net zero

The journey to net zero emissions in the dairy sector will be determined by both emission reduction plus carbon sequestration. As a livestock based enterprise, emission reduction alone will not achieve net zero as residual emissions will always occur within the farm system. The key benefit of a net zero approach as opposed to a gross zero target is that it allows for residual emissions to be offset by carbon sequestration opportunities on farm that actively remove the same quantity of carbon from the atmosphere. Net zero aims for carbon neutrality.

As Figure 2 shows, net zero in dairy will be achieved by:

- Improved resource use efficiency and improved productivity gains and efficiencies to reduce emissions
- Increased carbon sequestration on farm

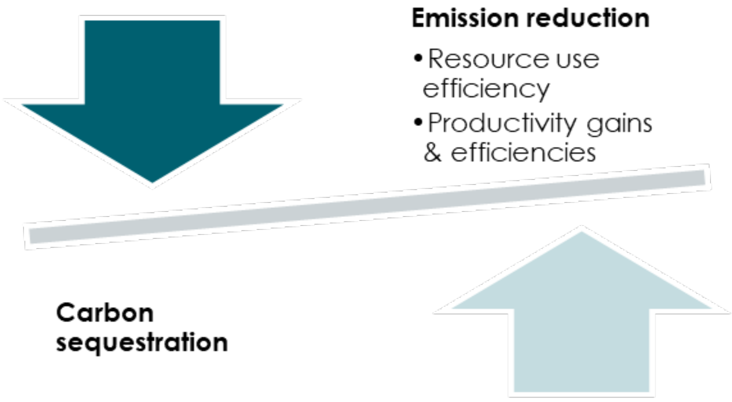


Figure 2: Journey to net zero pathways

2.1. Method scope and transfer values

Before emissions at a product level are calculated the boundaries of the assessment and scope must be agreed. This should include if the assessment is to account for Scope 1, 2 and/or 3 emissions and what segment of the supply chain is the focus (e.g. farm gate, processing, retail or consumer end product use and waste disposal).

Scope 3 emissions or value chain emissions represent all the indirect impacts upstream and downstream of an organisation's or product's footprint. Obtaining primary data for Scope 3 impacts can be very difficult and standard emission factors are usually used.

A common example of transfer value is beef calves from dairy cows entering a beef supply chain. Beef is either produced in dedicated beef herds, where beef is the only main product, or as a co-product from dairy production (i.e. bull calves from dairy herds are raised for beef and culled cows are used for meat).

The IPCC guidelines on emissions from livestock distinguish between two livestock groups only dairy cattle and other cattle[2]. When accounting for culled cows from a dairy herd, most of the rearing emissions are allocated to the dairy. When accounting for emissions from beef calves, it depends on the management system not the origin of the calf. When comparing beef from dairy herds and beef from dedicated beef units a complete Life Cycle Assessment (LCA) may provide the detail desired.

Organisations need to choose whether to adopt at Tier 1 or 2 approach to emissions reporting from livestock as it is not as simple as applying standard emission factors to different livestock categories. Methane emissions from enteric fermentation, methane emissions from manure plus nitrous oxide emissions from manure all need to be accounted for. All of these emissions are determined by feed intake estimates, methane conversion rates of feed, animal growth rates, feed digestibility, milk production, number of offspring etc.

There is also growing evidence within the scientific community that GWP* should be used to account for methane emissions as a short lived, cyclic, biogenic greenhouse gas. This is explored in more detail in Section 13.1.

2.2. Core focus areas for emission reduction and carbon sequestration

Promar has identified the following eight core areas of focus for the dairy sector to achieve net zero. These have been identified as some of the top interventions that have influence over the sources of emissions from dairy as outlined above in Figure 1. The initial long list of 23 interventions, with consultation with AHDB, was reduced to the eight example interventions outlined below. Refer to the project's associated excel sheet for full list of interventions considered. The eight core areas were identified as being either a key intervention that will make a large impact on net zero for a dairy farmer or have a high level of ease or incentive for farmers to implement such as energy use. There is opportunity for similar insight into the remaining 15 interventions to be assessed similarly by AHDB or similar in the future.

Of the eight interventions featured, each source of emissions was traced back to a particular activity on farm. Activities that contributed to the same emission source were grouped together into the eight core areas to reflect the impact of those activities on emission and the opportunities for emission reduction. The first six are focused on emission reduction with numbers 7) and 8) targeting carbon sequestration (Figure 3).

1. Organic manures to minimise the use of artificial fertilisers
2. Energy use and renewables
3. Fertility and herd management
4. Herd health and welfare
5. Genetics and genomics
6. Feed strategy and management
7. Carbon capture
8. Soil carbon

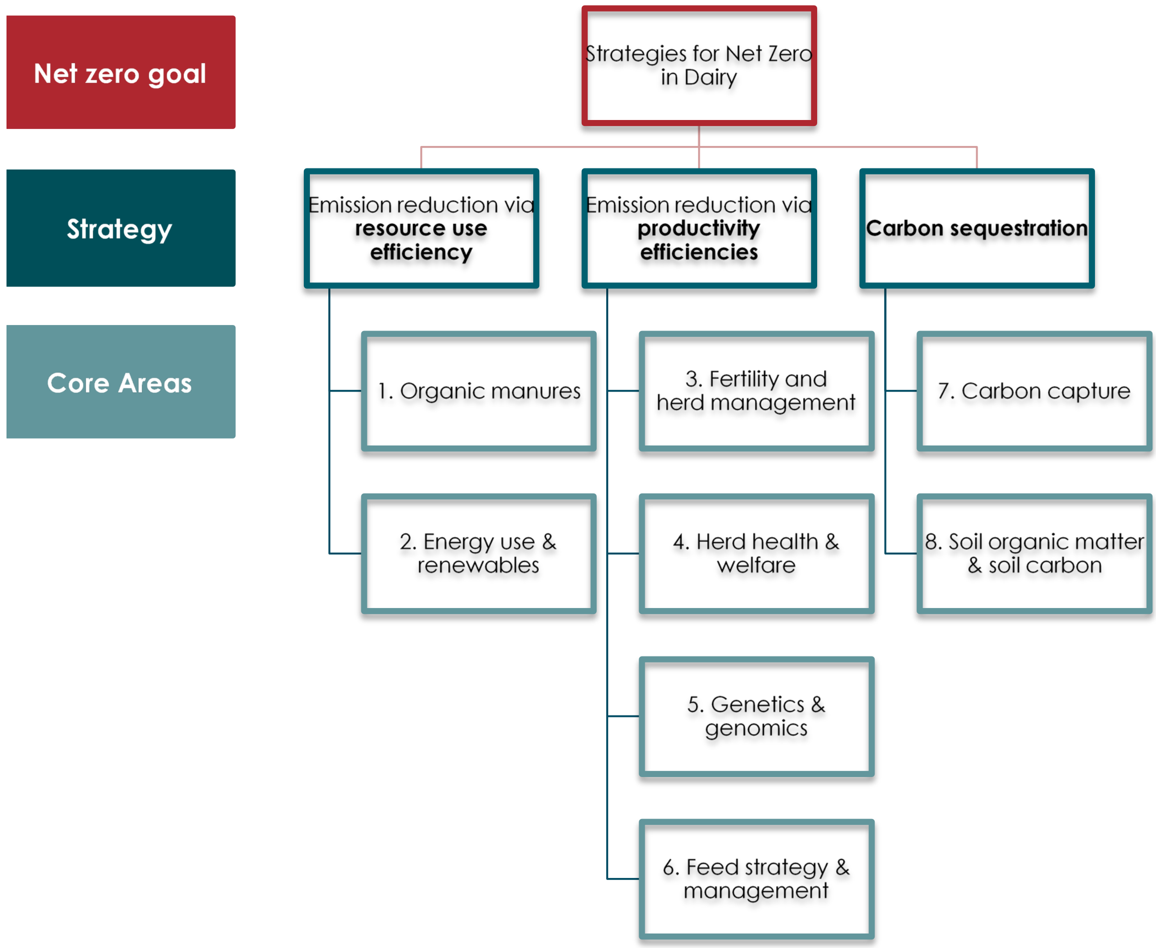


Figure 3: Key strategies and interventions to achieve net zero in the dairy sector. Source: Promar

Each core area includes several interventions or practices that farmers and land managers can implement to reduce emissions or sequester carbon. For the purposes of this project, Promar has selected one intervention for each core area that has the most potential for emission reduction or carbon sequestration. The full list of core areas and interventions is presented below (Figure 4).

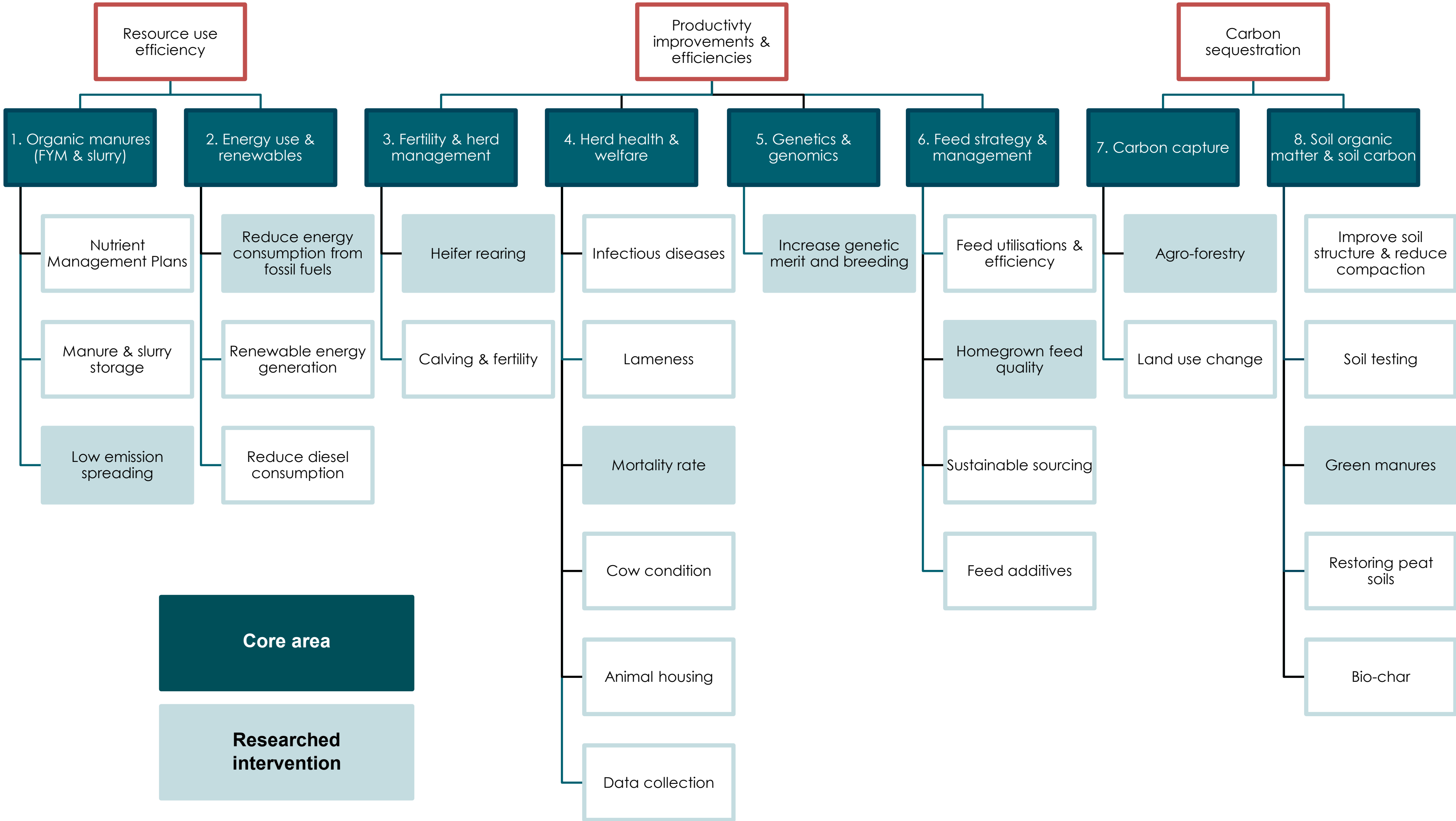


Figure 4: Summary of the eight core areas for net zero in dairy including list of interventions.

3. Summary of EFI evidence store

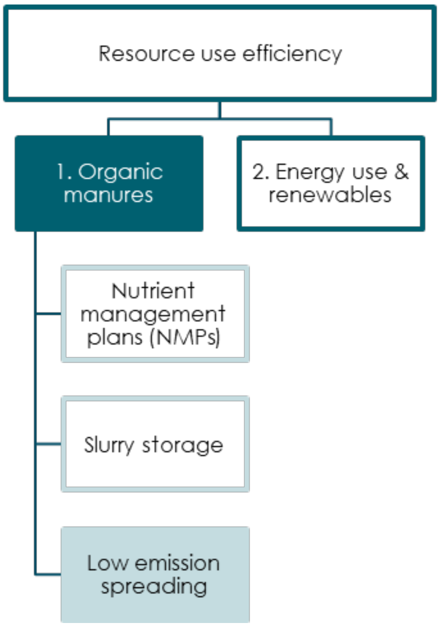
Table 1 presents the summary of each of the eight net zero core areas and main intervention against the EFI standard framework. Further detail and associated evidence to support the ratings is included in the following sections of the report.

Table 1: EFI evidence store presenting standards and ratings for each of the eight interventions

Core area *Intervention*	Outcome(s)	Cost	Effectiveness	Strength of evidence
1. Organic manures ***Use low emission spreading equipment***	Reduced nitrous oxide emissions from soil Improve nitrogen use efficiency Reduced economic costs and risks of diffuse pollution	**£ £ £** £	●●●○○	●●●○○
2. Energy use & renewables ***Reduce energy use from fossil fuels***	Reduce carbon dioxide emissions from fossil fuels Potential cost savings for the farm	**£ £** £ £	●●●●○	●●●●●
3. Fertility & herd management ***Heifer rearing to lower age of first calving***	Reduce methane emissions from digestion Reduced number of youngstock on the farm Lower economic costs of rearing youngstock	**£ £** £ £	●●●●○	●●●●●
4. Herd health & welfare ***Reduce mortality rate***	Improved herd productivity Reduced need for heifer replacements Increased slaughter value of cows sold	**£** £ £ £	●●●●○	●●●●●
5. Genetics and genomics ***Increase genetic merit & breeding traits***	Improved herd productivity and herd health Reduce methane emissions from digestion	**£ £** £ £	●●●●○	●●●○○
6. Feed strategy & management ***Improve homegrown feed quality***	Improved conversion of forage to milk Increased productivity Reduced methane emissions from digestion	**£ £** £ £	●●○○○	●●●●○
7. Carbon capture ***Consider agro-forestry (tree planting)***	Increase carbon sequestered & stored on farm Reduced soil erosion and diffuse pollution Alternative farm income	**£ £** £ £	●●●●●	●●●○○
8. Soil organic matter and soil carbon ***Incorporate green manures***	Increase carbon sequestered & stored on farm Improve soil structure Improve productivity Reduce fertiliser use if using legumes	**£ £** £ £	●●●●○	●●●○○

4. Organic manures

4.1. Intervention: Use low emission spreading equipment



Organic manures applied to agricultural land may be produced on the farm (for example: farmyard manures and slurries) or brought in from outside the farm (for example: biosolids, paper crumble, distillery effluent, pre-treated food co-products, compost and digestate). They are valuable sources of organic matter and a major provider of secondary plant nutrients. Careful application to land allows their nutrient value to be used for the benefit of crops and soils, and significant savings in the cost of purchased fertilisers can be made.

Optimising organic manures on farm involved careful nutrient management planning, effective storage and low emission field application. The use of low emission slurry spreading equipment is presented here as method to improve nitrogen use efficiency and reduce nitrous oxide emissions.

Cost	Effectiveness	Strength of evidence	Outcome(s)
£ £ £ £	●●●○○	●●●○○	Reduced nitrous oxide emissions from soil Improve nitrogen use efficiency Reduced economic costs and risks of diffuse pollution

4.1.1. What is the practice?

Nitrogen, in the form of ammonia, is lost from organic manures, such as slurry, solid manure and litter, digestate, sludge and compost, when they encounter air, particularly on warm or windy days.

Careful management of organic manures can have environmental and financial benefits by improving soil structure and reducing the need for purchased fertiliser. By reducing purchased fertiliser and improving the efficient management of organic manures produced, on farm emissions are reduced.

The timing of organic manure application can also influence emission reduction and application should only be undertaken when the crop is able to take up and make best use of the nutrients being made available. As a general principle, organic manures should be applied at the start of periods of rapid crop growth and nitrogen take up. The weather during application should not be too hot or too windy[3]. Avoiding time delays between nitrogen application and plant uptake can improve nitrogen use efficiency[4].

Low emission spreading equipment and application of slurry close to the ground reduces emissions of gases such as ammonia and nitrous oxide whilst also reducing odours. Emissions can be further reduced by incorporating surface spread manures as soon as possible after application.

Current guidance and management recommendations are found in the RB209 Organic Materials Section 2 and RB209 Section 1 Principles of nutrient management and fertiliser use[5,6].

4.1.2. How effective is it?

Low emission spreading has high emission reduction potential. Band spreaders or dribble bar systems that allow the application of slurry close to the ground can decrease ammonia emissions by 55%.[3] In addition, if liquid manure is injected directly into the soil, ammonia emissions can be reduced by 95% - 100%[3].

If solid manure is incorporated four hours after spreading, an 80 % reduction in ammonia emissions can be observed (60 % if manure is incorporated 12 hours after spreading)[3]. It has been demonstrated in a Directorate-General for Agriculture and Rural Development study that using techniques to reduce ammonia emissions leads to increased nitrogen availability during and after application, thus resulting in a lower demand for mineral fertilisers[3].

Timing of organic matter application: Recognised good agricultural practice is to apply slurry in relation to crop demand. This reduces the quantity of excess nitrogen in the soil, which is at risk of leaching or being lost as an emission[7]. However, farmers are often under pressure to empty slurry stores in the autumn / early winter period to prepare for the housing period, or during winter because of inadequate storage facilities. Such autumn / winter slurry applications result in excess soil nitrogen. Because this season is also associated with increased soil moisture, low crop nitrogen-uptake, and temperatures warm enough for nitrification / denitrification, significant emissions of nitrous oxide can occur.

Emissions are far lower if slurry is applied in the spring, when growing crops actively utilise slurry nitrogen. In the limited work that has been undertaken on free-draining grassland soils, nitrous oxide emissions from spring slurry applications were half those from late autumn / winter applications. Changing to spring slurry applications (from autumn / winter) would require investments in additional slurry storage[8].

Variable rate fertiliser spreading and lower application rates: By using precision application equipment and linking into satellite (Leaf Area Index) data farmers can manage their fertiliser and manure rates to be applied only where needed.

Just over a quarter (24%) of farms used soil nutrient software packages to help determine fertiliser applications[9]. Usage is most common on cereal and general cropping farms and on farms with at least some of their land within a Nitrate Vulnerable Zone.

4.1.3. Where does it work?

Managing manure applications can work well on all farm systems and soil types. Depending on the level of measurement and record keeping on farm managing fertiliser and organic manures can be actioned by all farms to varying levels. The main benefit for optimising organic manure application is that there is a clear environmental and cost saving benefit for farmers meaning it is more likely to be implemented. The use of band spreading, and injection can dramatically reduce ammonia emissions (and odour) and thus reduces indirect nitrous oxide emissions. However, the abatement potential is likely to be negligible, given that (a) the assumed rates of ammonia loss from slurry application is low and (b) these measures may lead to an increase in direct nitrous oxide. Injection is unsuitable for stony soils[10].

4.1.4. How much does it cost?

Some of the intervention practices have a low cost and a financial cost saving by reducing the amount of purchased fertiliser onto the farm. At the entry level there are costs of soil tests and slurry sampling to manage application rates. To invest in specialist application and precision monitoring equipment can require larger financial investment this can potentially be achieved by accessing public grants aimed at encouraging environmentally positive investment or use of an external contractor.

4.1.5. How can I do it well?

Focusing on improving manure and fertiliser application can reduce nitrous oxide and ammonia emissions and leaching losses of nitrates. It has additional benefits of reducing input costs and nitrogen fertiliser volume brought onto the farm, therefore saving farmers money. The key requirements for success are to understand the nitrogen available in organic manures on the farm by measuring and slurry sampling. By including the use of the RB209 recommendations as a management tool, regular soil testing and a nutrient management plan, farmers can tailor their manure application rates, timing and application method to fit their specific situation.

4.1.6. How strong is the evidence base?

Nitrous oxide is a large contributor to emissions from agriculture. It is widely recognised that nitrogen not utilised on the farm can have any of the following impacts:

- Inefficient use of nitrogen manures can cause excess nitrate leaching
- Excess use of nitrogen fertilisers has environmental impacts in the manufacturing process and attracts a high carbon footprint
- Poor application methods of organic manures can result in increased volatilisation of ammonia

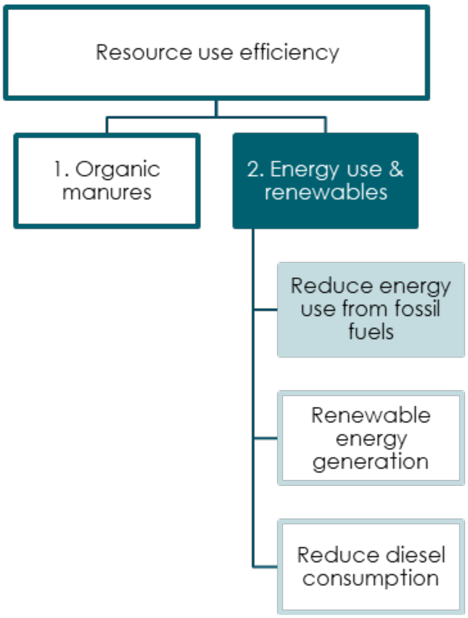
Improving precision application of organic manures can reduce amounts of mineral fertilisers required on farm. Regular Nutrient Management Plans (including soil testing and slurry sampling) are important tools for decision making.

There is a high level of academic and third party research on the application of organic manures. There is some requirement for specific advice on benefits in specific soil types, farming systems and timing of applications for crop benefit and minimising environmental impact. A scientific review of ammonia and greenhouse gas emissions from slurry storage has recently been conducted in 2020.[11]

Local research gaps may exist in determining effectiveness of low emission spreading equipment on different soil types. Some evidence suggests that band spreading, or injection may not lead to a net reduction in emissions due to increased rates of direct nitrous oxide production resulting from less ammonia emissions. Further trials may be needed to determine how reducing ammonia volatilisation may increase the available nitrogen in manures and therefore increase nitrification leading to emissions of nitrous oxide[12].

5. Energy use and renewables

5.1. Intervention: Reduce energy use from fossil fuels



Emissions from energy and fuel use typically account for 3 - 6% of a dairy farms carbon footprint. Reduced energy use from fossil fuels offers a significant emission reduction as energy emissions can potentially be reduced to zero.

Although renewable energy generation on farm is expanding, agriculture cannot claim the emission reduction from the energy exported back to the grid. This displaced energy is utilised by the energy sector where emission reduction can be accounted for. As such, reducing energy use (improving energy efficiency) on farm is the focus of this section of the report.

Cost	Effectiveness	Strength of evidence	Outcome(s)
£ £ £ £	●●●●○	●●●●●	Reduce carbon dioxide emissions from fossil fuels use Potential cost savings for the farm

5.1.1. What is the practice?

Milk cooling, water heating and vacuum pumps amount for over 70% of energy use on dairy farms[13]. Fans in shed are also becoming more mainstream for large herds that are housed to assist with ventilation which have high energy usage. By focusing on improving energy use efficiency, significant reductions in energy use can be obtained.

Variable speed vacuum pumps

Traditional vacuum pumps operate at a constant speed to provide the vacuum requirements for milking. Variable speed vacuum pumps are designed to meet capacity required when it is needed. The addition of a variable speed driver pump eliminates the need for a conventional regulator because less energy is delivered to the motor and operating speeds are reduced[14].

By maintaining a constant vacuum level and only producing necessary amounts of air flow, energy cost savings of up to 60% can be made[15]. The noise level is also greatly reduced allowing for a quieter parlour environment. There are also reduced maintenance costs and less wear, leading to an extended life compared with a conventional oil vane pump.

Milk cooling

Cooling milk accounts for the highest energy cost associated with the milking process up to 33%[13]. Milk needs to be cooled from its harvested temperature of 35 - 37 degrees, to 3.5 degrees to maintain high milk quality and low bacterial counts. There are various options to help cool the milk, including heat exchangers and variable speed milk pumps. Farms often use a 2-plate cooler, the first using water from mains/borehole and the second using water chilled by an ice bank. If using a 2-plate cooler the key to offsetting the high energy use of running of the ice bank is to access off peak electricity to build ice and save costs.

Heat exchangers

Used for pre cooling raw milk, transferring the heat from the milk to an intermediary cooling fluid (usually water). Installation of a heat exchanger to pre-cool the milk prior to entry to the bulk tank can reduce energy consumption by 60%[16].

Variable speed milk pumps

The use of a variable speed milk pump allows the milk to be pumped through the plate cooler at a more consistent speed, allowing the plate coolers to operate more efficiently and resulting in greater milk cooling. It also allows more heat to be extracted by the plate cooler and reduces the energy demand on the bulk tank. Milk can be cooled by an extra 15 - 20 degrees by installing a variable speed milk pump[16].

Heat recovery units

During the process of cooling milk, heat is rejected from the condenser coil of the refrigeration system. It is possible to recover this by passing the hot refrigeration gas through a heat exchange system which is immersed in water. A water temperature of over 50 degrees can be achieved by using this technique. The water heating system needs to be carefully configured so that the heat recovery can deliver the maximum benefit without compromising the operation of the milk cooling system. Depending on the number of cows being milked, the water storage tank should be sized to provide enough hot water for one milking[17].

Converting to LED lighting

Lighting uses between 5-15% of electricity on a dairy farm[18]. Conversion to LED enables farms to save up to 89% in lighting[19] energy costs and with energy consumption a key area of expenditure, it's the improved design and management of a dairy barn's lighting system which is essential for improved profitability and sustainability.

An additional benefit is that research into lighting installations in dairy housing, has identified the potential to increase milk yields by 6-10%[19] – indicating that milk production can be increased by regulating the dairy cow's exposure to better quality light that is closer to daylights spectrum. Additionally, energy expenses for lighting maintenance are reduced and the overall improved lighting enhances the operating and welfare conditions for both the farm workers as well as the cattle. There is the initial capital expenditure of purchasing the LED lights.

Long-day photoperiod (LDPP) research has shown that the right lighting can increase yield by 10 per cent, with milking cows exposed to 16 to 18 hours of light with a brightness of at least 160 - 200 lux followed by six to eight hours of darkness have consistently increased their milk yield[19]. There is also some evidence that by manipulating the photoperiod other traits such as reproduction, growth and lactation are also increased[20]. A study by Michigan State University suggested that there was a 50% reduction in lighting costs and an 8% increase in milk yields[21].

Purchasing green energy

Once energy usage has been reduced, purchasing energy from a Renewable Energy Guarantees of Origin Scheme (REGO) can allow dairy farmers to offset their residual energy usage[22]. This green energy obtained from renewable sources can help reduce emissions from energy use to zero.

5.1.2. How effective is it?

Energy efficiency is a very small component of a farm carbon footprint only 3-6%[23], but there are many cost-saving opportunities available to farmers that don't always need considerable capital investment.

A DairyCo survey found that the average consumption of electricity per unit of milk sold was 0.06KWH/litre, with a huge range in the data recorded[1]. Within the sample of farms assessed, milking, milk cooling and plant washing were the areas that provided the greatest potential reductions[23].

Installing variable speed milk and vacuum pumps, and heat recovery systems offer good potential for energy savings and emission reductions. Heat exchanges can save up to 60% of energy costs[16]. A variable speed milk pump will cool the liquid by an extra 15 to 20 degrees. LED energy saving lighting, installed with timers to give cows the right amount of daylight hours has been proven to reduce energy use and increase milk production by up to 5%[16].

5.1.3. Where does it work?

Interventions such as purchasing REGO renewable energy, variable speed milk pump, heat recovery systems & LED lighting work well where a farm has significant electricity costs and herd size that can justify the investment in the equipment[22]. Some of the implementations such as purchasing green energy, changing to night rate electricity have low investment costs, whereas others such as some of the technological interventions and LED lighting have a much higher capital expenditure and longer return on investment. Changing to night rate electricity has a clear cost saving benefit but there is also some research suggesting that there could be GHG emission reduction from electricity produced at off peak times[24].

5.1.4. How much does it cost?

Some interventions have a relatively low cost and short return on investment whilst others are longer term:

Table 2: Potential energy savings interventions from on Morrisons & Yougen energy report[18]

Electricity saving interventions	Return on Investment	Money Saving	Carbon Saving	% electrical saving potential from current
Milk pre-cooling (installing a plate cooler) 15C cooling = 7ppl saving vs no cooling	7 years	✓	✓	50
Move to lower tariff electricity	immediate	✓	-	-
Ensure correct amount of water being heated and on lowest electricity rate available	<1 year	✓	✓	-
Variable Speed Drive (VSD) on the vacuum pumps 50% saving = 5475 kWh = £478 cost pa to run = £955	7 years	✓	✓	60
Solar thermal heating	>10 years	✓	✓	50
Heat recovery system (15C + 40C (HRU) = 55C saving /annum =12,395kWh = £992	4-6 years	✓	✓	60
LED lighting	>10years		✓	80

Farmers need to calculate whether the investment return on LED lighting (£12 - £100 per bulb) can be justified for the environmental benefits, savings in running costs and suggested increase in milk yields.

5.1.5. How can I do it well?

To make the full impact on reducing electricity use a farm needs to implement as many interventions as possible. Measurement of electricity usage is easy to achieve regular energy usage assessment can help understand how the farm could be more energy efficient. For farms where there is a supply of renewable energy it can be useful to monitor peaks and troughs of production to match with electricity requirement where possible so electricity is always purchased/produced at the lowest price possible[25].

5.1.6. How strong is the evidence base?

Energy use represents a relatively small proportion of overall carbon footprint (3-6%). However, energy consumption is highly transparent, and any potential cost savings are immediately apparent in reduced bills.

For example, a 2,500,000-litre farm with 300 cows will use approximately 140,000 kWh of energy/year, at a financial cost of around £15,000 and emissions of 83,476kg of carbon dioxide from electricity (3.2% of the farm's footprint). If this electricity use was reduced by 10% using some of the measures outlined above in Table 2, down to 125,000 kWh/year, this would reduce the cost to £11,625 and lower the associated emissions to 74,961kg of carbon dioxide (2.8% of the farm's footprint)[23]. The areas where biggest electricity reduction potential can be made are shown in Table 2. (the financial saving in reduction in electrical usage doesn't include the cost for implementing the intervention).

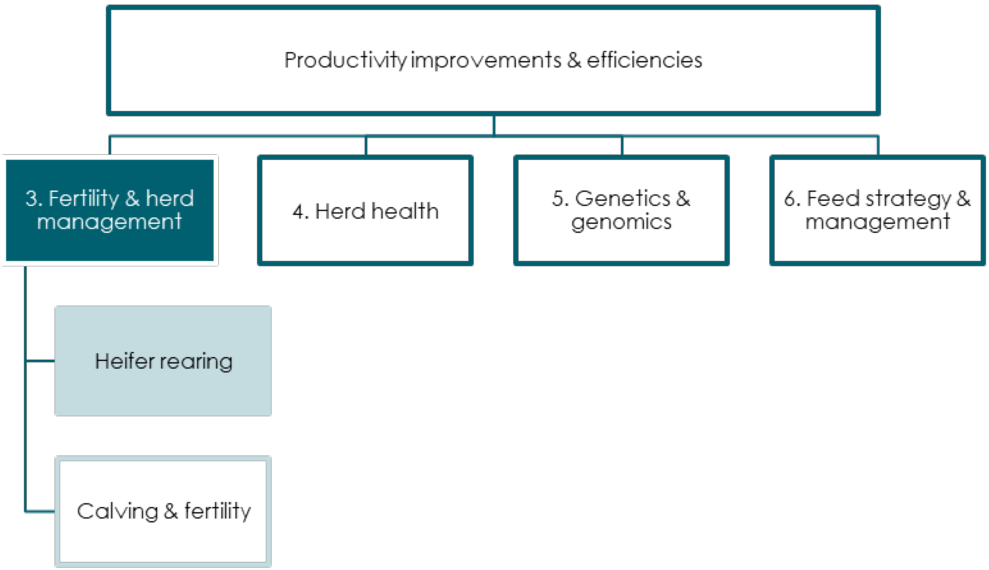
6. Fertility and herd management

6.1. Intervention: Heifer rearing to lower age at first calving

Within fertility and herd management, there are several interventions and practices that farmers can implement to reduce emissions. These include aspects of:

- Heifer rearing, covering age of first calving, calf health and disease management, colostrum management, heifer weight gain and growth rates
- Cow calving intervals and fertility, covering pregnancy rates, heat detection, replacement rates, cow longevity and number of lactations, calving percentage.

The principal focus for the purposes of this project is on heifer rearing the larger source of emissions on dairy farms.



Cost	Effectiveness	Strength of evidence	Outcome(s)
£ £ £ £	●●●●○	●●●●●	Reduce methane emissions from digestion Reduced number of youngstock on the farm Lower economic costs of rearing youngstock

6.1.1. What is the practice?

Emissions of methane from dairy farms are heavily influenced by the number of dairy replacement heifers on a farm. Lowering the age of first calving for reared heifers alongside other wider fertility improvements in the herd to lower the number of replacements required could reduce emissions from a dairy herd by up to 10%[26].

6.1.2. How effective is it?

Heifer rearing is an important enterprise on dairy farms as it accounts for approximately 20% of milk production costs and management during the rearing period can have major impacts on the lifetime performance of the dairy cow and on the carbon footprint of dairy farming[27].

On average, a heifer will need to complete two lactations before she starts to make a profit and repay her rearing costs. Heifers produce methane and nitrous oxide from manures plus consume feed that all contribute to a farms total emissions, without contributing to milk production.

Royal Veterinary College statistics show that heifers which calve at two years give on average 25,000 litres of milk throughout their first five years, while those calving two months later give just 20,400 litres[28]. The figures also show that longevity is increased; heifers calving at 24 months have a 62% chance of still being alive at five years old while those which calf at 26 months only have a 41% chance of surviving past their fifth year[28]. Another study showed that analysis of milk recording data indicates that there is a strong correlation between heifer age at first calving and lifetime yield and longevity. Heifers calving at 24 months of age produce approximately 7000 litres more milk in their lifetime than heifers calving at 36 months of age as the earlier calving heifers spend approximately 7 months longer in the milking herd than heifers calving at the greater age[27].

Animals that first calved between 22 and 26 months of age have more lactations and productive days during their life. They also had higher first and second lactation milk production and higher lifetime milk production[29].

These younger calving animals therefore achieve more days in milk over 5 years, with >44% of their days alive spent in milk production compared with only 18% - 40% in cows calving at ≥26 months[30]. Hence cows with an age of first calving below 26 months produced the most milk in their first 5 years of life. These results indicate that an age of first calving of <26 months required both a growth rate greater than 0.75 kg per day up to 15 months and good heifer fertility which resulted in the best subsequent performance[30].

The heifers replacement rate and age of first calving has a strong effect on the number of dairy cows and replacements heifers need on a farm, and consequently on total methane emissions from the herd. Reducing age of first calving has been shown to decrease methane emissions from dairy systems by up to 2.2 tonne per year[31].

6.1.3. Where does it work?

This intervention is relevant to all dairy farms that are closed herds plus any dairy farm that rears any dairy replacement youngstock.

6.1.4. How much does it cost?

Royal Veterinary College research shows that calving at 24 months rather than 26 months reduces average rearing costs by 16%. The cost of rearing a heifer increases by £2.87 per day for every day increase in age at first calving over 24 months[32].

A previous economic analysis showed that reducing age of first calving from 25 to 24 or 21 months decreased replacement costs by 4.3% or 18% respectively[30].

6.1.5. How can I do it well?

Reducing the age at first calving can have a positive effect on the carbon footprint of a dairy herd. Rearing healthy and robust heifers, who can calve down and enter the lactating herd with minimal problems will result in higher efficiency animals with the potential for better feed efficiency and milk yield. As always, heifers must be at the right body condition at breeding and calving, which in some cases may mean that daily liveweight gain for heifers may need to increase.

Set two year targets and ensure robust protocols which ensure calves are always cared for consistently, setting weight targets and monitoring progress, perform regular weighing to guide feed management.

Other practices to consider:

- Feeding 10% by body weight of colostrum within 2 hours of birth
- Colostrum quality testing
- ZST (zinc sulphate turbidity) blood sampling to check calf immunity
- Using weigh bands to assess heifer weight
- Using the AFBI Bovine growth rate calculator
- Bedding young calves in a deep straw bed
- Use of calf jackets to maintain body temperature in cold weather
- Calf housing with adequate ventilation
- Automatic calf feeders
- Weaning calves by concentrate feed intake

6.1.6. How strong is the evidence base?

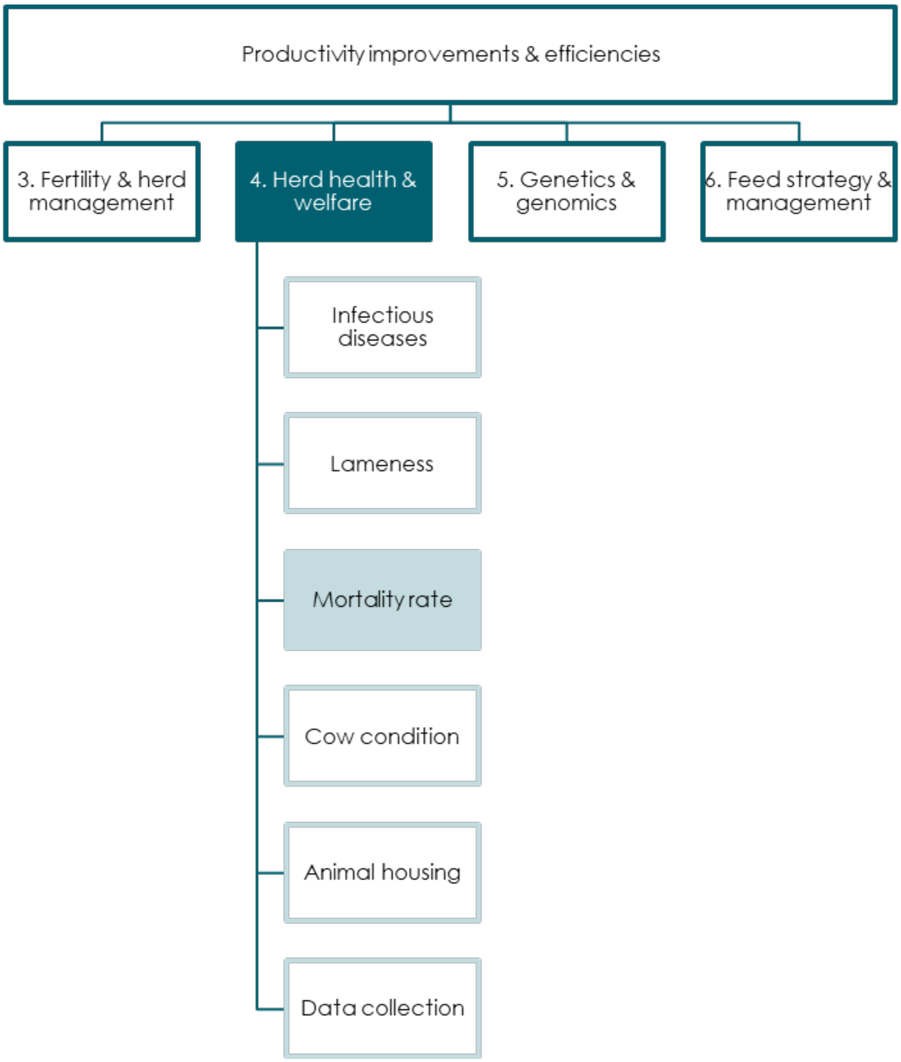
The evidence base is strong with research and industry groups all supported a lower age of first calving to achieve not only emission reduction benefits but principally economic benefits of reduced rearing costs and higher herd productivity. A trade off or research gap may exist for some breeds and for some farming systems where decision makers on farm would prefer not to lower age of first calving. Anecdotal evidence from farms suggest that there may be hesitation towards calving heifers younger due to practical implications such as concerns about increased feed requirements to reach bulling weight sooner, difficulty calving at younger ages due to narrower pelvis's, behavioural problems when young heifers enter the parlour and underdevelopment of udders and teats.

7. Herd health and welfare

7.1. Intervention: Reduce mortality rate

Within herd health and welfare there are several interventions and practices that farmers can implement to reduce emissions. These include: infectious disease management, lameness, cow condition and mobility, cow comfort and animal housing, livestock sensors and monitoring technology.

The principal focus for the purposes of this project is on reducing mortality rate (cow deaths) on farm as a key strategy to reduce emissions on dairy farms.



Cost	Effectiveness	Strength of evidence	Outcome(s)
£ £ £ £	●●●●○	●●●●○	Improved productivity Reduced need for heifer replacements Increased slaughter value of cows sold

7.1.1. What is the practice?

There are many reasons for keeping cow mortality rate low, all of which relate to emissions reduction including:

- Welfare of the cow will be increased due to reduced illness leading to an increase in milk production and reduced emissions per litre
- Increased slaughter value, however transfer value into the beef supply chain needs to be recognised
- Decreased need for replacement heifers

Impaired animal health causes both productivity and profitability losses on dairy farms, resulting in inefficient use of inputs and increase in greenhouse gas emissions produced per unit of product (i.e. emissions intensity). Endemic diseases modulate emission production through predictable means. A reduction of an animal's productive lifespan means that animals must be replaced more frequently (i.e. at a higher replacement rate), which means a greater number of replacement heifers are needed to maintain herd numbers.

A climate efficient cow has long longevity of over four or five lactations so that the emissions associated with rearing are distributed over a high lifetime milk yield. The earlier in life a cow dies, the greater the emissions impact.

7.1.2. How effective is it?

Emissions from cows deaths stay with the farm as the animal has not been transferred. There is some evidence that emissions can be reduced by up to 95g per kg FPCM for every percentage point mortality is reduced.

Cows that are culled from the herd and sold from the farm transfer emissions from milk production to another enterprise (such as slaughter) thereby lowering emissions from milk production.

7.1.3. Where does it work?

Mortality rate or cow deaths are important metrics for all UK dairy farms as an indicator of herd health.

7.1.4. How much does it cost?

There are five main components to calculating the cost of a cull: the replacement cost, the sale price of the cull, the lost margin due to replacing a cow with a heifer, the disposal cost of a dead cow and the lost margin due to emergency removal from the herd[33]. The cost of a death is high because of the loss of sale income and additional costs of disposal. If a cow can be sold as a cull cow it could save the farm between £2,700 - £3,500 depending on lactation stage[33].

7.1.5. How can I do it well?

In a study of 50 Holstein / Friesian UK dairy herds over three seasons the average total culling rate was 23.8% (including 1.7% deaths)[34]. In 2008 Kite's survey of a total of 302 herds shows that the mean culling rate was 18.9% (including 0.87% mortality) both of which appear very low[33].

Evidence from Promar's farm business accounts suggests that mortality rates on UK farms range between 0 - 6% with the top 25% of farms achieving a mortality rate of below 2% (4 cows in herd of 200)[35].

To understand what the cause of death is on the farm and to target early preventative actions, farms should:

- Record mortality rate from previous 12 months
- Register cause(s) of death
- Monitor animals closely and regularly to detect signs of illness or injury early
- Identify areas of focus with vet

Infectious diseases

Viral and bacterial infectious disease such as Bovine Viral Diarrhoea (BVD), Infectious Bovine Rhinotracheitis (IBR), Salmonellosis and Johne's disease all have direct effects on mortality, fertility and productivity. Keeping ahead of any disease outbreak via early detection and treatment of affected animals, plus up to date vaccinations in consultation with a local vet will assist reduced animal deaths from these diseases.

7.1.6. How strong is the evidence base?

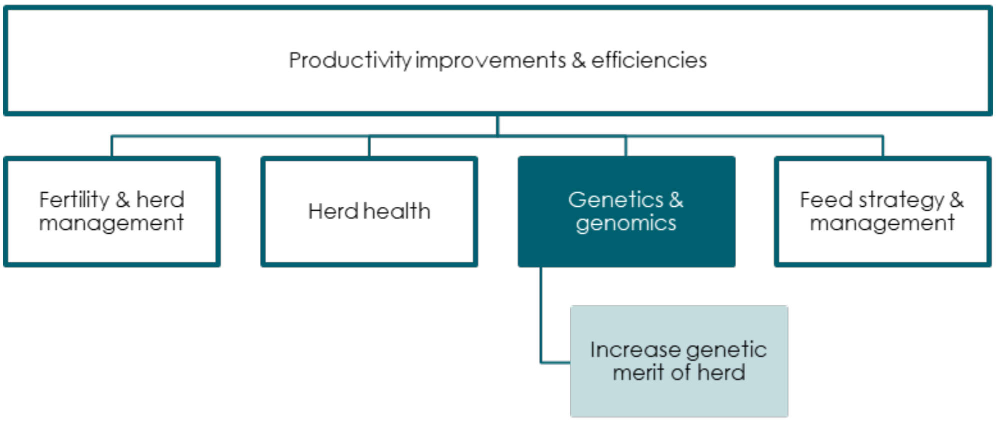
Links between herd health and welfare and productivity are clear and well known. The direct link between mortality rates and emission intensity are also well documented with increasing evidence from carbon foot-printing of UK dairy herds showing cow deaths will increase emissions per kg of milk produced. Cows that die early in their lives have a large impact on emissions because:

- Productivity will have been reduced in the lead up to the cows death
- Emissions from rearing are distributed over a lower lifetime milk yield, and
- There becomes a need for a replacement.

8. Genetics and genomics

8.1. Intervention: Improve genetic merit of herd

Genetics plays an important role in lowering emissions as greater efficiencies in milk production can be obtained. Improving the genetic merit of the dairy herd and breeding for desirable traits therefore holds a big influence over the ability of the dairy farm to improve the carbon footprint.



Cost	Effectiveness	Strength of evidence	Outcome(s)
£ £ £ £	●●●●○	●●●○○	Improved productivity and herd health Reduced methane emissions from digestion

8.1.1. What is the practice?

A solid breeding policy can contribute to a sustainable increase in milk production, increased returns for beef calves and control the number of heifers on farm.

Genetic improvement can help to reduce emissions per kg of milk via[41]:

- Improving productivity and efficiency. Selection for productivity and efficiency helps mitigate emissions in two ways:
  - Firstly, higher productivity generally leads to higher gross efficiency (converting feed into product) as a result of diluting the maintenance cost of the productive (and non-productive) animals.
  - Secondly, a given level of production can be achieved with fewer higher yielding animals and their followers.
- Reducing wastage in the farming system. Selection for improved fitness traits (e.g. lifespan, health, fertility) will help to reduce emissions by reducing wastage of animals. Improving lifespan in dairy cows and breeding higher quality beef crosses will reduce emissions of the system by reducing the number of followers required to maintain the herd at a given size.

8.1.2. How effective is it?

Methane emissions are the largest contributor of dairy's carbon footprint accounting for between 40% - 50% of total emissions[1]. Methane emissions are increased by raising surplus dairy heifers (above replacement rate requirements) and poor feed utilisation due to poor forage quality or inability to convert feed to milk due to illness/welfare results in higher methane emissions[1]. If heifers are being raised for sale into 'flying herds' or being sold as external replacements the transfer value of these cows needs to be accounted for and correctly allocated.

It is possible to decrease the methane production of a cow by selecting more-efficient cows, and the genetic variation suggests that reductions in the order of 11 to 26% in 10 years are theoretically possible, and could be even higher in a genomic selection programme[37,42]. By using sexed semen on maiden heifers and first lactation cows, you can increase the inter-generational improvement in genetic quality and make faster improvements.

Traits related to resource use efficiency such as dry matter intake (DMI), residual feed intake (RFI) and methane emission from digestion are most desired. In an experimental dataset of 588 heifers, it was shown that it is possible to decrease methane emission by selecting more efficient cows[42]. Resource use efficiency phenotypes are difficult and expensive to measure, but genomic selection is a promising tool to enable selection for resource efficient cows. Using genomic selection, a reduction in predicted methane of 15% over 10 years is theoretically possible[43].

In a UK study, reductions in the following traits all showed improved profitability and reduce emissions per cow and per kg of milk:

- Residual feed intake
- Somatic cell count
- Mastitis incidence
- Lameness incidence, and
- Calving interval.

Milk volume, milk fat and protein yield, live weight, survival and dry matter intake were estimated to increase each year. Selection on these traits estimated to result in an annual increase of 1% per year in emissions per cow, but a reduction of 0.9% per unit product per year[44].

A further reductions of methane emissions of between 15 to 30% per kilogramme of milk may even be achieved by combinations of genetic and management approaches, including improvements in heat abatement, disease and fertility management, performance-enhancing technologies, and facility design to increase feed efficiency and life-time productivity of individual animals and herds[45]. By implementing a genetic breeding programme alone a predicted methane reduction of 15% is possible[43].

8.1.3. Where does it work?

Improving the genetic merit of a dairy herd through selective breeding of desired traits or through sire semen is available to all farms in the UK.

8.1.4. How much does it cost?

£15 - £35 per straw of semen depending on breed, traits and pedigree, sex etc. Genomic testing of females would typically range between £25 - £35 per cow. At a per cow level these costs may appear relatively inexpensive but if these costs are totalled across an entire herd, then can accumulate to be quite significant. A herd of 200 cows would cost upwards of £7,000 for full genomic testing across the whole herd with semen and costs of chosen genetics additional to that.

Recent practice has focused on genetic selection criteria that include welfare traits to avoid undesirable characteristics being selected along with increased yield potential. Over time this should improve cost of production[46].

8.1.5. How can I do it well?

A focus on genetic improvement will increase cow efficiency through productivity, longevity, health and fertility, in turn lowering emissions. The use of existing genomic technologies to evaluate heifer calves will strengthen this.

Genomics can be used in dairy herds to reliably predict the top-performing animals to breed the farm's next crop of replacements. The results highlight the genetic merit of each animal, allowing farmers to select with about 70% accuracy which animals to breed from depending on their selection criteria. Farms can test all heifers as a starting point and then decide selection areas (traits) to focus on depending on breeding strategy.

Important traits to consider include[47]:

- Fat and protein levels (milk quality)
- Somatic cell count and mastitis
- Fertility
- Lameness
- Longevity (both calf survival and cow lifespan)
- Maintenance feed costs

Current breeding practices and research focuses on fitness, health, welfare, milk quality, and environmental sustainability, underlying the concentrated emphasis on a more comprehensive breeding goal. In the future, on-farm sensors, data loggers, precision measurement techniques, and other technological aids will provide even more data for use in selection, and the difficulty will lie not in measuring phenotypes but rather in choosing which traits to select for[48].

Look to develop a breeding plan which incorporates sexed semen for the highest ranked individual animals on the farm and use beef semen on the remainder to capitalise in this area. By using sexed semen on maiden heifers and first lactation cows, you can increase the inter-generational improvement in genetic quality and make faster improvements. Sexed semen can also improve the finishing quality of animals entering the beef supply chain therefore improving that animals carbon footprint. Refer to AHDB's breeding indexes for genetic evaluations, indices and analysis[49].

8.1.6. How strong is the evidence base?

Genetic evaluation – the process of predicting the genetic merit of animals from pedigree and performance data (milk yield, growth, disease incidence etc.) and, recently molecular genetic data – is a mathematically complex, internationally scarce, but key enabling tool in livestock genetic improvement[3]. New indexes have been introduced since 1995 to improve selection for the financial or economic values of animal production, longevity, fertility, health and other characteristics. Such novel selection practices have cumulatively reduced greenhouse gas emissions per breeding animal by 1.4% per annum in dairy systems[50].

Directly selecting on emissions is not yet available as direct emissions are difficult to measure. Variation has been reported between animals, between breeds and across time providing potential for improvement through genetic selection. However, measuring methane production directly from animals is currently difficult and direct selection on reduced methane emissions may prove difficult in practice. Development of new direct and/or indirect measurement techniques will help to enhance the capability for reducing emissions through genetic selection. In the meantime, we can make improvements through selection on traits that have a correlated effect on emissions as described earlier. This is particularly effective because it also improves profitability for the farmer.

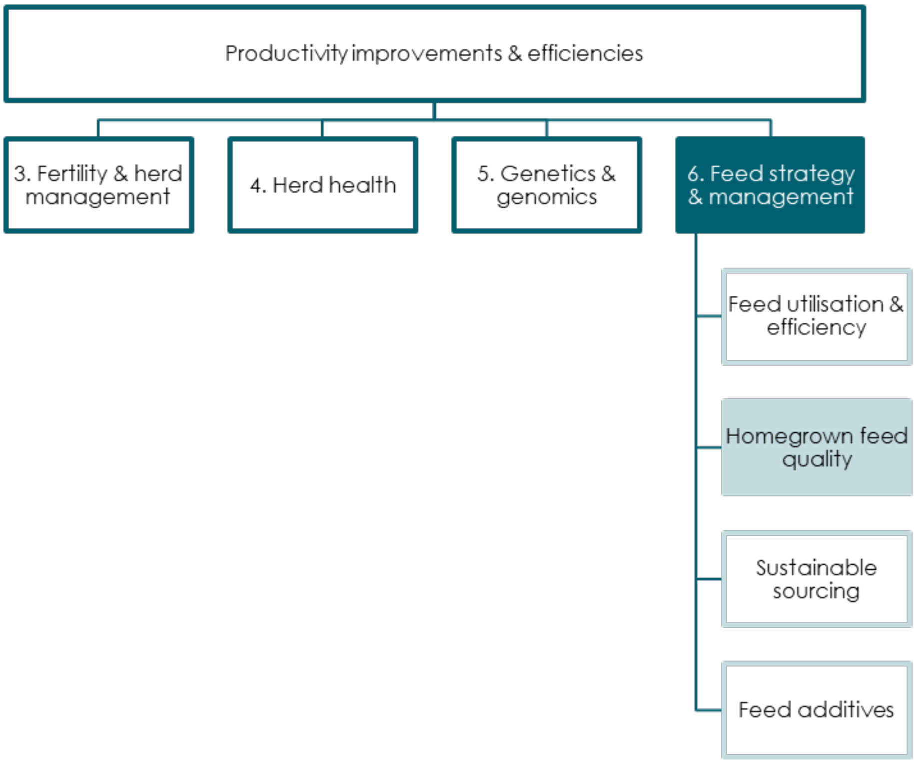
9. Feed strategy and management

9.1. Intervention: Improve homegrown feed quality

Within a feed strategy, there are many interventions and practices that farms can implement to help reduce emissions, these include:

- Feed utilisation and efficiency
- Homegrown feed quality
- Sustainable sourcing
- Feed additives to reduce methane emissions

The principal focus for the purposes of this project is on improving feed quality as a key strategy to reduce emissions on dairy farms.



Cost	Effectiveness	Strength of evidence	Outcome(s)
££££	●●○○○	●●●●○	Improved conversion of forage to milk Increased productivity Reduced methane emissions from digestion

9.1.1. What is the practice?

Feed plays a crucial role in economic and environmental performance of dairy production units because feed constitutes the highest variable cost of production and feed composition affects methane emissions at an individual cow level[51].

Feed efficiency measured as kilogrammes of dry matter (DM) consumed by the cow to produce a kilogramme of fat and protein corrected milk (kg DM/kg FPCM) is known to be an effective tool to reduce digestion emissions from livestock. Feed efficiency is not however, directly observable. It is feed intake conditional on a combination of production traits or energy sinks; for example, fat- and protein-corrected milk (FPCM) and body weight. Overall, improving forage quality and the overall efficiency of dietary nutrient use is an effective way of decreasing methane emissions.

Forage (including silage) is still the cheapest form of feed, especially with the reality of more volatile markets effecting both feed and fertiliser prices. Improving forage quality is an area that can have a big impact on reducing risk exposure and emissions on farms. Forage quality and its nutritional value will impact on feed cost and performance of the herd.

9.1.2. How effective is it?

Nutrition and feeding approaches may be able to reduce emission intensity of methane by 2.5% - 15% without compromising milk production[45]. Another study suggested a 9% - 16% reduction in emissions intensity can be achieved through changes in feeding regime plus genetic improvements although the individual contribution was not highlighted[52].

Increasing quality or digestibility of forages will increase production efficiency and this will result in decreased emissions from enteric fermentation (methane). For feeds with higher digestibility, increased dry matter intake by the cow depresses the amount of methane produced per unit of feed consumed[53]. Moreover, it decreases methane produced per unit of product by diluting maintenance energy. Therefore, the best mitigation option in this category is to increase forage digestibility to improve intake and animal productivity, thus reducing overall emissions from rumen fermentation or stored manure per unit of animal product.

9.1.3. Where does it work?

A comprehensive feed plan and ration is relevant for all dairy farms in the UK. Regions were grass and forage crops are easily grown can provide the most economic option for the farmer.

9.1.4. How much does it cost?

Feed costs vary considerable on UK dairy farms between 6 – 10 pence per litre or £200 - £250 per tonne[35]. Reducing overall dry matter intake (DMI) requirements while maintaining production has high economic value to farmers. Typically, silage is only about 50% of the total ration, but it can have a big impact on milking performance.

9.1.5. How can I do it well?

Improve forage digestibility

Increasing forage digestibility and digestible forage intake is one of the recommended methane mitigation practices[5]. Measure grass yields and focus on quality of grassland through regular forage analysis to determine crude protein and digestibility. High digestibility is an important factor impacting the conversion of feed to milk and the overall carbon footprint. Focus on producing silages with high

D values and metabolizable energy (ME)[54]. Addition of clovers and diverse sward species can provide environmental resilience in areas where high rainfall or drought is an issue.

Other strategies include decreasing the proportion of NDF in the ration or improving the digestibility of NDF to reduce the quantity of methane produced during digestion.

The digestibility of grass silages can be increased by cutting at the correct time for the crop thereby increasing the sugar content of the silage. A 2010 Defra study concluded that high sugar grass silage has the potential to decrease emissions by circa 20% be reducing methane and nitrogen excretion in manure[55]. Maize silage digestibility can be increased by choosing varieties with high digestibility traits or leaving longer maize stubble during harvest[56,57].

With all silages, effective preservation will improve silage quality and reduce emissions.

Measure forage production and intake to reduce waste

Any losses of feed produced and not consumed by the cow results in poor feed utilisation and increased feed waste, both of which contribute to higher emission intensity from milk production. Feed wastage rates should be below 10% to ensure a high percentage of forage produced is used by the animals and converted to product.

Accurate measurement of feed intake is not common practice on many farms, as this considers refusals which are not often weighed. However, monitoring and improving intakes can greatly impact on feed efficiency, reduce waste and increase milk output[58]. Technological advances and installation of feed scales, feed cameras and weighed bins can all assist in data collection and measurement of feed intake.

Diverse pasture mixes with nitrogen fixing species

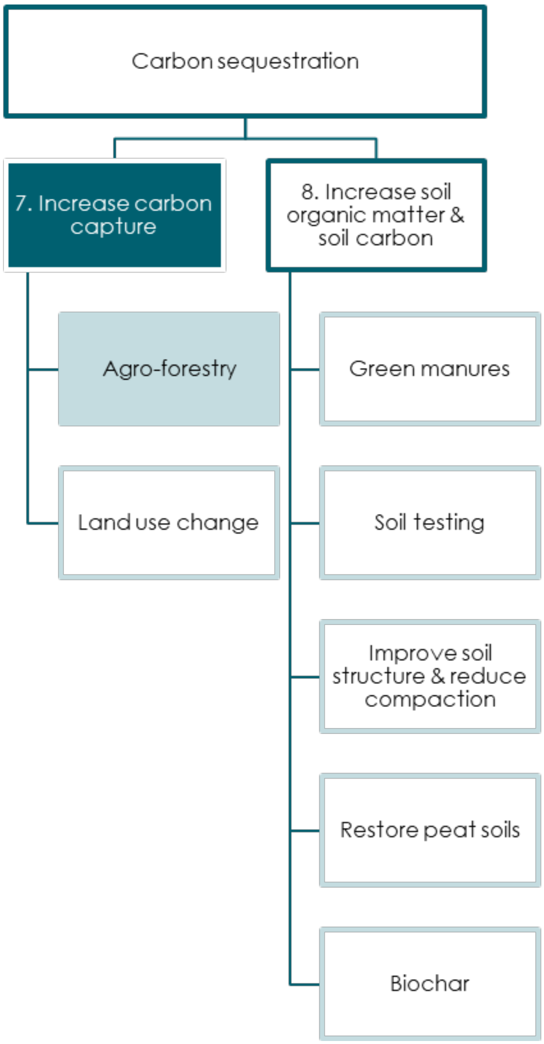
Plant communities with higher species number (richness) are a potential strategy for more sustainable production and mitigation of greenhouse gas emissions. Research has indicated the need to further understand opportunities that forage mixtures can offer sustainable ruminant production systems[59]. Compared to ryegrass based swards, one study concluded that pastures with mixed flower species produced 10% lower methane yield when measured against dry matter intake for heifers when grazed[59].

9.1.6. How strong is the evidence base?

There are many peer reviewed scientific papers available that support the link between improved forage quality, digestibility and methane emission reduction. There is also evidence to support a diet of very high concentrate feed rate that supports lower methane emissions. High concentrate feed rates do however attract other emissions due to the processing and transportation of this purchased feed. More evidence is perhaps needed to investigate concepts of self-sufficiency on farm to determine if farms that feed a high proportion roughage share in the diet from homegrown forage have a higher or lower carbon footprint.

10. Carbon capture

10.1. Intervention: Consider agro-forestry and tree planting



Cost	Effectiveness	Strength of evidence	Outcome(s)
£ £ £ £	●●●●●	●●●○○	Increase carbon sequestered & stored on farm Reduced soil erosion and diffuse pollution Alternative farm income

10.1.1. What is the practice?

Much of the biomass that commonly occurs on UK farms such as hedges, woodland and permanent pasture is already sequestering carbon at very significant levels. But with some careful management decisions this can be improved to maximise the rate at which carbon sequestration occurs. On its simplest level agroforestry means combining agriculture and trees. This could be by planting trees in blocks, within fields, on field margins or by extending hedgerows in width or length. The main types of agroforestry are:

- Silvo-pastoral: trees and livestock
- Silvo-arable: trees and crops
- Hedgerows and field boundaries

- Forest farming: cultivation within a forest environment

Agroforestry is a concept that has been around for 1000's of years but has re-gained interest in recent decades for its benefits to wildlife, soil carbon and suggested benefit to production systems. When trees and crops are combined soil erosion is reduced as the roots bind the soil reducing wash off and wind erosion. It also can reduce water pollution as the trees take up excess field water. Agroforestry can offer additional cropping opportunity for farmers through a tree crop such as top fruit and nuts or for the wood if the trees are coppiced. Trees act as Carbon Sinks removing carbon dioxide from the atmosphere and storing it in their roots.

10.1.2. How effective is it?

Approximately half of the dry mass of vegetation (biomass) is carbon. The main biomass component in trees are the stem wood. However, the harvestable stem only accounts for approximately 50% of the total tree carbon. Therefore, characterising the partitioning between components is central to the estimation of stand carbon stocks if considering tree plantations that will be harvested.

Litter from foliage, branches and roots is an important component of forest carbon stocks (typically 30–45% of the carbon stock in trees alone). Litter is therefore a much more important component than in arable land use, for example. Litter decomposition rates are highly variable because of environmental, soil and tree factors, but they are critical to understanding the effects of trees and their management on soil organic carbon stocks, and on nutrient cycling and tree growth rate[60]. Trees are both sources and sinks for carbon that is exchanged during photosynthesis, respiration and decay. Growing trees takes up carbon from the atmosphere and using timber and wood fuel can reduce emissions from fossil fuel combustion. The Woodland Carbon Guarantee Scheme (WCGS), launched by Defra in 2019, has given carbon trading a new profile in the agricultural sector[61].

It is important to understand the processes and rates of exchange (or 'flux') of the carbon in trees, and how they are affected by tree/woodland management[62]. Within the UK there are a range of carbon accounting models which use theoretical and empirically derived models of carbon flows through the forestry value chain. Flux-based carbon accounting directly measures the flow of carbon into and out of the forest. State-of-the-art sensors using a technique called eddy correlation to continuously monitor carbon exchange between all the carbon pools in a forest ecosystem and the atmosphere[63].

Capturing Carbon from the atmosphere & reduction in soil erosion and water pollution: Agroforestry systems protect soils from erosion by wind and water, as trees with long roots hold soils firm while increasing soil organic matter by adding decomposing leaf litter. Trees integrated into arable settings have been proven to reduce soil erosion by up to 65%[64]. Agriculture is a significant contributor to nitrate leaching into waterways, in a recent review of silvo-arable systems in temperate climates it was found that nitrate leaching was reduced by 46% in Canada and 30% in France[65].

Agroforestry can be a key component in efficient nutrient cycling on farms, with deeper roots bringing nutrients up from lower in the soil profile increasing the availability and fertility in the top soil layers. Trees act as a carbon store in the landscape, but wood can also be an additional, semi-permanent store when used in construction and bioenergy with carbon capture and storage.

Diverse cropping opportunities: Growing two crops from the same land such as rows of fruit trees through arable crops, or combining livestock and timber trees, can increase total yield per hectare[66]. Farm businesses can benefit from the services that agroforestry supports such as increased habitat for pollinators and shelter for livestock and crops to support improved growth, as well as diversified agricultural products such as fruits, nuts and timber.

Increase in productivity: Productivity increases under agroforestry can be significant, in some cases up to 40%[67].

10.1.3. Where does it work?

Agroforestry can work well in diverse locations and farming types. Depending on how environmental payments develop it could potentially work better in some situations.

These could be; areas of unproductive land that are difficult to crop or graze, field margins and hedgerows, particularly along watercourses – these are situations that farmers are most likely to be open to changing their practise on. Environmentally it would be suggested that converting from fields where soil is regularly ploughed (arable or grassland) to woodland would have the biggest carbon capture effect.

Growing trees in combination with grassland is another option however many farmers struggle to see how this might work practically. For tenant farmers there are additional challenges regarding environmental payments (who receives it) and potential loss of cropping or grazing land if agroforestry is implemented. The Hollies farm in Shropshire have been trailing this system since 2014 and have seen a positive change in cattle grazing behaviour but also grass in the shade of trees has gone to seed more quickly[68].

Some of the agriculture examples of increased productivity relate to reduced heat stress on the grazing cattle. Most of the research into these systems has been done in tropical climates.

10.1.4. How much does it cost?

The costs are often relatively low, and, in many cases, farmers are paid to plant trees/hedgerows as part of agri-environment schemes. Farmers need to understand the long-term cost implications of tree planting if it impacts on available cropping land, lack of land reversion options and who owns any carbon credits.

10.1.5. How can I do it well?

The challenge for dairy farmers is to understand how to plant the trees (if new schemes) so that they will thrive long term, manage current stock and integrate in with their current farming systems. They also need to understand any financial rewards they may be able to access via new schemes such as ELMS (currently Glas Tir or Countryside Stewardship) and how they are able to measure accurately the increase in carbon capture they have achieved on their farm.

10.1.6. How strong is the evidence base?

Carbon capture for new plantations

Forestry commission research has suggested that by using the estimates of total UK woodland area and tree total carbon stocks, provides an average carbon stock per hectare of approximately 57 tonnes of carbon per ha (tC/ha) or 209 tonnes of carbon dioxide per hectare (tCO_2/ha) if converting the molecular mass of carbon to carbon dioxide. Clearly, carbon stocks in trees will vary with species, age and growth rate, and with management, so the range is as wide as from 0 - 1,400 tCO_2/ha (0 - 382 tC/ha)[69].

Evidence suggests that initially there is a divide between conifers and broadleaves when it comes to carbon sequestration. Conifers are faster growing and absorb a lot of carbon quickly. An example being a forestry species, Sitka spruce has a very high yield class. A measure used in UK forestry to gauge the productivity of trees and it can also be used as an indicator of how much carbon they are absorbing. Broadleaves generally grow with a yield class of between 4-8 m^3/ha/annum[70].

Effect of woodland on soils

Data derived from the recent extensive BioSoil survey of GB forests (166 plots) show that the organic carbon stocks in the forest litter and the top organic layer averaged 56.3 and 63.1 tCO_2/ha for conifers and broadleaves, respectively (15.4 and 17.2 tC/ha). At most woodland sites, the soil contains more organic carbon than the trees, particularly sites with organic soils (e.g. deep peats and peaty gleys). Importantly, the BioSoil survey has allowed new, more reliable estimates of forest soil carbon stocks in GB across the main forest soil groups.

After afforestation it is likely that on mineral soils, particularly those with low carbon contents due to previous long-term cultivation, there will be an increase of soil carbon, from soon after planting. Rates of carbon accumulation reported are in the range 0.2–1.7 tonnes of carbon dioxide per hectare per year. On high carbon content soils there is likely to be a period of net carbon loss following planting, and the duration over which the stand (trees + soil) is a net source of CO_2 before becoming a sink will depend on the initial amount of soil carbon, the degree of soil disturbance including drainage and consequent aeration, soil nutrient status and the productivity of the trees. Stocks of carbon in the biomass of other vegetation types such as permanent grasslands and heather moorland are typically 30 and 40 tonnes of carbon dioxide per hectare (8–11 tonnes carbon per ha), respectively, although they vary substantially with management and environment. Detailed carbon balance assessment of carbon stock changes during afforestation may need to take this into account but, although substantial, such carbon stocks are typically exceeded by those in even young stands of trees[60].

Variability in carbon capture depending on tree maturity

A large body of academic work and case studies have been carried out in tropical zones particularly in regions of the work where de-forestation is prevalent such as Brazil and South America. Temperate zone research has less focus on it although there is extensive work on the benefits of planting trees on reducing carbon from the atmosphere.

Research is being carried out as to the carbon storage potential of young and mature trees and whether there is any significant difference with some indications suggesting mature forest plateaux or reduce their carbon storage over time[71]. However research in Suriname suggests that old-growth trees in tropical forests do not only contribute to carbon stocks by long carbon resistance times, but maintain high rates of carbon accumulation at later stages of their life time[72].

Available information on the fluxes of the three important greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from forests has been examined. The exchange of CO_2 with the atmosphere occurs for both the trees and the soil but CH_4 and N_2O emissions are largely from the soil alone. The aerobic production of CH_4 in plants is very small, but in flooded or waterlogged woods and forests it is likely that trees form a pathway for CH_4 produced in the soil to be emitted, although the size of this flux is not yet established[60].

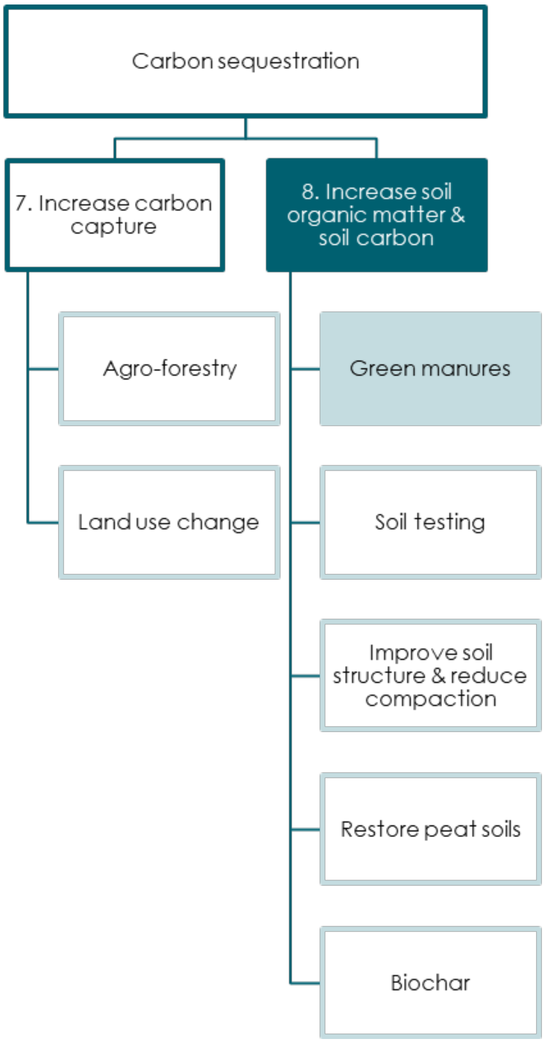
Barriers to agroforestry uptake can be technical and legislative. Farmers are unsure as to the environmental, practical and production benefits of agroforestry models. The legislative implication of planting trees and hedgerows can be long standing. Farmers are reluctant to take productive cropping land out of production to use for tree planting or environmental schemes if they are unable to revert to cropping if needed. Tenant farmers may also not perceive the benefits for tree planting if they are on short term tenancy agreements.

If agroforestry is used as a new crop opportunity, clarity is required for the end use of any by products such as wood to understand any environmental or greenhouse gas transfer value caused. It should be noted that for larger stands of tree plantations the carbon credit and benefit may be accounted for under the forestry sector not agriculture.

There can be concern from farmers on grazing efficiency under trees as grass and forage is often poorly grazed by livestock under the shadow of the tree canopy which can lead to loss of available forage in a field.

11. Soil organic matter and soil carbon

11.1. Intervention: Incorporate green manures



As micro-organisms build in healthy soils, their ability to decompose organic matter and create humus increases over time. The soil's ability to absorb organic matter also increases; whilst degraded soils that become well managed will grow at the fastest rates, all soils can continue to build organic matter.

The following are key interventions that can help build soil organic matter and increase soil carbon:

- Restoring peatlands
- Reducing cultivations and compaction
- Improving soil structure
- Planting and incorporation of green manures
- Regular soil testing to understand soil organic matter
- Incorporation of biochar

Cost	Effectiveness	Strength of evidence	Outcome(s)
£ £ £ £	●●●●○	●●●○○	Increase carbon sequestered & stored on farm Improve soil structure Improve productivity Reduces nitrate leaching

11.1.1. What is the practice?

Soil carbon is important to land-based efforts to prevent carbon emissions, remove atmospheric carbon dioxide and deliver ecosystem services in addition to climate mitigation. Organic matter provides a food source and habitat for the soil biological community, drives the cycling of nutrients within soils and is a central component of soil aggregation and the maintenance of structure and water relations. It is therefore widely recognised that soil organic matter is fundamental to the maintenance of soil fertility and function, and a key indicator of soil carbon stocks. Current soil organic matter levels in the UK are considered to be well below target levels of 3- 5%[73].

Well maintained peat soils are a large carbon sink and if they remain saturated, they conserve and accumulate more as plant material decomposes. If the peatlands become degraded and drained, they can turn into a significant source of carbon dioxide as aerobic decomposition of the peatland occurs. Every hectare of land that raises its soil organic matter levels by just 0.1% (e.g. 4.2% to 4.3%) will sequester 8.9 tonnes of carbon dioxide per year[73]. Restoring peatlands will only work on certain dairy farms in parts of the country where peatland soils have been identified. Peat soils are often found in the uplands in the UK but also large lowland regions in the East of England[74].

Farming has the potential to sequester carbon out of the atmosphere on a large scale. Plants and soils on farms have the potential to sequester vast amounts of carbon, giving farming the potential to be at the forefront of the fight against climate change.

Green manures are crops grown specifically for building and maintaining soil fertility and structure, though they may also have other functions. They are normally incorporated back into the soil, either directly, or after removal and composting. If leguminous crops are used, they can have the added benefit of fixing nitrogen which may allow farmers to reduce the amount on fertiliser they need to use on the field. Green manures prevent bare soil over winter which reduces soil erosion another cause of loss of soil carbon from soils.

Soil testing is a practise enabling farmers to measure the soil organic matter on their farm and ascertain whether interventions they make are effective. Regular and accurate soil testing allows improvement in soil structure and responsible nutrient management applications. By ensuring that pH and N,P & K are at the correct level for grasslands (refer to RB209) the soil can start to build up organic matter by careful physical and nutrient management[75].

11.1.2. How effective is it?

The UK Government has signed up to an initiative to increase soil carbon levels by 0.4% per year as part of the 25-year environment plan[76]. Increases in organic matter lead to increased soil fertility, improved structure, healthier crops and carbon sequestration. When plants photosynthesise, they absorb carbon dioxide. Some of the plant's carbon compounds are transferred into the soil via the roots. Here the carbon compounds become organic matter and build soil organic matter, another very stable form of carbon. When green manures are ploughed back into the soil the organic matter from the plant is then incorporated into the soil.

Organic matter is decomposed by the vast array of microorganisms in the soil ecosystem. About half of all organic matter is carbon, and in this form the carbon is very stable and can only turn back to carbon dioxide readily if significant oxidation occurs, such as cultivation. Eventually soil organic matter turns in to the even more stable form of humus, a highly complex, fertile and stable substance[77].

Green manures are crops grown within a rotation for the purposes of:

- Building soil organic matter and soil structure

- Supplying nitrogen and other nutrients for a following crop
- Preventing leaching of soluble nutrients from the soil
- Providing ground cover to prevent damage to soil structure
- Bringing crop nutrients up from lower soil profiles
- Smothering weeds and preventing weed seedling growth

11.1.3. Where does it work?

Green manures will work on all dairy farms but are most useful on farms where arable crops are incorporated into the rotation or an increase in nitrogen fixing legumes or brassicas as a fodder crops is seen to be beneficial to the farms rotation.

11.1.4. How much does it cost?

The cost of establishing a green manure are like any crop establishment. Cultivations, seed purchase and incorporation or mowing in the spring. There may be a cost saving on fertiliser use if a legume is used and purchased fertiliser is decreased.

11.1.5. How can I do it well?

Soil organic matter can be built with green manures such as brassicas, grasses, black medick, white or red clover and lucerne. Biologically active soils are more efficient at converting organic matter in to more stable forms of soil carbon and storing it deeper in the soil profile, ensuring it is less easily oxidised. They may be grown predominantly for varying rooting depth, nitrogen fixing potential, building of humus or forage quality.

Aggregate stability is also increased where more soil microbial life is found, therefore reducing soil erosion and improving structure. As micro-organism levels build in healthy soils, their ability to decompose organic matter and create humus increases over time. The soil's ability to absorb organic matter also increases. Biologically active soils can be enhanced by:

- **Regular supplies of organic matter (e.g. Green manures)**
- Minimal cultivations
- Minimal compaction and/or poaching
- Introduction of beneficial bacterial or fungal inoculants where necessary

11.1.6. How strong is the evidence base?

Building soil carbon is an appealing way to increase carbon sinks and reduce emissions owing to the associated benefits to agriculture. However, the practical implementation of soil carbon climate strategies lags behind the potential, partly because we lack clarity around the magnitude of opportunity and how to capitalize on it. The imperative to increase carbon levels in soils is clear, and there is widespread agreement on how organic matter and thus carbon levels can be improved. Despite this, data shows that carbon levels in arable soils have been declining.

The evidence for regular soil testing and improving soil structure is well established. It has been part of the RB209 recommendations for many years. Whilst soil testing is still not a universal practice amongst farmers there is a large body of evidence of how it has benefits environmentally, productively and can save costs due to more efficient use of fertiliser and organic manures, combined with the use of nitrogen fixing green manures could have both financial and environmental benefits to the farmer[78].

Using green manures to build soil organic matter has been widely practiced in organic systems for a number of years as synthetic fertiliser was not an option however it has only been more recently adopted by conventional farming sector as a potential for building soil organic matter to improve carbon footprints[79].

12. Knowledge gaps and future priorities

Throughout the report, several knowledge gaps and priorities for future research have been identified including:

- Effectiveness of low emission spreading equipment on different soil types.
- Identification and quantification of any transfer values of dairy farm GHG reduction interventions into other production supply chains such as arable, red meat or forestry
- Potential of increasing risk of indirect nitrous oxide emissions from organic manures if available nitrogen is not utilised by growing crops after ammonia reduction.
- Trade-offs in wider sustainability principals for many emission reduction interventions, for example:
    - Intensively housed systems may be more efficient, but animal welfare standards may be lower, or
    - Reducing heifer age of first calving to 24 months may reduce emissions but result in increased feed costs to achieve required bulling weight earlier. Any cost increases should however be outweighed by an increase in lifetime milk productivity.
- Growing maize may provide high energy feed for dairy cows but growth of crop into marginal areas could be resulting in damaging soil and water quality impacts.
- What are the benefits and challenges with under sowing maize with grass as an environmental impact minimisation exercise?
- Ability to directly select genetics based on emission factors.
- Role of feed additives to reduce methane emissions from digestion.
- Traceability and credibility of sustainable sources of soya feed products and ingredients in concentrates.
- Carbon storage potential of young and mature trees.
- Lack of clarity on best methods to quantify and capitalise on soil carbon.
- What is the carbon sequestration science evidence of different forage leys? Rye grass vs Rye grass/clovers vs mixed species swards – is there any difference?
- Use of biochar to increase organic matter of soils.
- Comparison of increased carbon sequestration of planting trees vs current soil carbon levels of permanent pasture/moorland etc over lifespan of trees.
- Green manures – what are the transfer values of cultivations and compaction of sowing and incorporating green manures vs the benefits of increased soil organic matter and nitrogen

Research around feed additives and methane inhibitors has been presented briefly below.

Feed additives and methane inhibitors

Tannins and saponins have been extensively studied and show the most mitigating potential within this category. Tannins, as feed supplements or as tanniferous plants have often, but not always, shown a potential for reducing methane emission by up to 20%[53].

Research on methane inhibitors has targeted chemical compounds with a specific inhibitory effect on rumen archaea. Among the most successful compounds tested in vivo were bromochloromethane (BCM), 2-bromo-ethane sulfonate, chloroform, and cyclodextrin. These methane inhibitors reduced methane production by up to 50% although some studies have suggested adaptation of the rumen ecosystem to this class of compounds, thus reducing their long-term efficacy, suggesting adaptation to chloroform by the rumen ecosystem. The long-term effect of methane inhibitors is uncertain, and more data are needed to establish their effects on production. In addition, public acceptance (due to perception and/or existing or future regulations or because they are known carcinogens, e.g., chloroform) could be barriers to their adoption.

Nevertheless, research groups around the world are working on developing natural or synthetic compounds that directly inhibit rumen methanogenesis. A recent example of these efforts is research with 3-nitrooxypropanol (3-NOP). The compound decreased methane production per unit of DMI in sheep in respiration chambers (a 24% reduction; and dairy cows using the SF6 technique a dramatic 60% decrease[53]. A study in the US from Penn State University found the addition of 3-NOP to the feed of dairy cows reduced their enteric methane emissions by about 25%. This feed additive compound is currently not regulated for use in the UK or European Union.

There is a large body of evidence that lipids (vegetable oil or animal fat) suppress methane production. Some studies have reported a 9% reduction in methane production in dairy cows due to lipid supplementation of the diet, but this was accompanied by a 6% reduction in DMI, which resulted in no difference in methane per unit of DMI. A more recent meta-analysis of 38 research papers reported a consistent decrease in DMI with all types of dietary fat examined (tallow, various calcium salts of fatty acids, oilseeds, and prilled fat), and milk production was increased. This combination of decreased DMI and maintained or increased milk production (assuming no decrease in milk fat) results in increased feed efficiency and, consequently, decreased methane[53].

13. Emission accounting methodologies

13.1. GWP* and methane

Ruminant livestock are associated with high levels of methane emissions which is generated from two main sources - enteric fermentation and the loss of organic material in their manures. Per molecule in the atmosphere, methane has a stronger global warming impact than carbon dioxide. However, because of their very different lifetimes, the relationship between methane emissions and the concentration of methane in the atmosphere is very different to that of carbon dioxide.

Methane has a Global Warming Potential (GWP100) 28 times higher than carbon dioxide. However, methane is short lived gas that is broken down in the atmosphere within 10 – 15 years and does not persist for 100 years like other greenhouse gases. Methane is also a biogenic gas that is cycling carbon through the biosphere (via soils plants and animals) which is very different to carbon being emitted from fossil fuels for example which is releasing long term fossil carbon into the atmosphere. Long-lived pollutants, like carbon dioxide, persist in the atmosphere, building up over centuries. The carbon dioxide created by burning coal in the 18th century is still affecting the climate today. Short-lived pollutants, like methane, disappear within a few years. Their effect on the climate is important, but very different from that of carbon dioxide, yet current policies treat them all as 'equivalent'[80].

Many in the scientific community are calling for a new Global Warming Potential (GWP*) to be used for methane. GWP* more accurately indicates the impact of emissions of both long-lived and short-lived pollutants on radiative forcing and temperatures over a wide range of timescales[81]. Expressing mitigation efforts in terms of their impact on future cumulative emissions aggregated using GWP* would relate them directly to contributions to future warming, better informing both burden-sharing discussions and long-term policies and measures in pursuit of ambitious global temperature goals[82].

GWP* has not yet been accepted nor incorporated into any greenhouse gas accounting methodology published by the IPCC or the GHG Protocol. The decision on whether to use GWP* instead of GWP_{100} values is due to be debated at the upcoming COP 26 Climate Summit, due to take place in 2021 in Glasgow.

Appendix One - Evidence standards approach

The evidence framework includes an assessment of the factors presented in Table 3 below with the corresponding ratings[83].

Table 3: EFI standards framework factors assessed and ratings

Evidence factor	Potential ratings
Effectiveness	●○○○○ Evidence tends to show negative effect. The balance of evidence (including the pooled effect size where available) suggests that the intervention has a negative effect, meaning the intervention made things worse. This takes into consideration the number of studies showing positive and negative effects, and also the levels of involvement (number and size of participating entities) in those studies.
	●●○○○ No effect. The balance of evidence (including the pooled effect size where available) suggests that the intervention has no effect overall.
	●●●○○ Evidence tends to show mixed effect. Studies show a mixture of effects and the criteria for 'tends to negative effect' or 'tends to positive effect' are not met.
	●●●●○ Evidence tends to show positive effect. The balance of evidence (including the pooled effect size where available) suggests that the intervention has a positive effect. This takes into consideration the number of studies showing positive and negative effects, and also the levels of involvement in those studies.
	●●●●● Evidence shows consistently positive effect. The evidence (including the pooled effect size where available) consistently suggests that the intervention has a positive effect. This takes into consideration the number of studies showing positive and negative effects, and also the levels of involvement in those studies.
Cost	**£** £ £ £ No equipment or timing constraints over and above existing business as usual running costs.
	£ £ £ £ May need some additional time for training or experiential learning to establish new intervention, but once implemented this rapidly transitions into business as usual running costs.
	£ £ £ £ As above plus, new equipment and capital costs for machinery and implements on farm.
	£ £ £ £ Major investment in new infrastructure on farm and/or loss of land utility/land use change that is greater than the normal rotation(s).

Evidence factor	Potential ratings
	●○○○○ (Level 1) High level observation evidence only. The body of evidence displays significant shortcomings. There are multiple reasons to think that contextual differences may unpredictably and substantially affect intervention outcome.
	●●○○○ (Level 2) Studies using quasi-experimental evidence or a least one moderate quality evidence review. We believe that the intervention may/may not have the effect anticipated. The body of evidence displays very significant shortcomings. There are reasons to think that contextual differences may substantially affect intervention outcomes.
Strength of evidence	●●●○○ (Level 3) Studies of the highest quality (RCT/equivalent) or at least one high quality evidence review. We can draw some conclusions about impact and have moderate confidence that the intervention does/does not have the effect anticipated. The design of the research allows contextual factors to be controlled.
	●●●●○ (Level 4) A developing body of high-quality evidence reviews. We can draw strong conclusions about impact and be confident that the intervention does/does not have the effect anticipated. The body of evidence is diverse and credible, with the findings convincing and stable.
	●●●●● (Level 5) An extensive body of high-quality evidence reviews. We can draw very strong conclusions about impact, and be highly confident that the intervention does/does not have the effect anticipated. The body of evidence is very diverse and highly credible, with the findings convincing and stable.

When considering individual studies of the effectiveness of interventions, the EFI standards accord greater weight to studies that use experimental studies; and when considering reviews and meta-analyses that synthesise insights from different sources, EFI will accord greater weight to syntheses prepared using rigorous methods – such as systematic reviews.

EFI is concerned to balance this commitment to rigour with an approach that allows the identification of the best available evidence within the current body of published material. The EFI standard is also designed to motivate and support practitioners and researchers to ascend the hierarchy of evidence: to progress from observational studies to the use of experimental and quasi-experimental methods, and to undertake higher quality evidence syntheses.

Mindful of these objectives, the EFI standard presents an evidence rating system with the following features (Table 4):

- Five levels, with the two highest levels awarded only to interventions for which there are agglomerations of high-quality evidence reviews
- The scope for an intervention to achieve any of the first three levels solely on the basis of individual studies, with a progression from high quality observational studies (level 1) to quasi-experimental and experimental studies (level 2 and 3)

- The scope for interventions to progress along the rating scale (from level 2 to level 5) and the quantity and quality of evidence reviews increases – so an intervention can achieve a level 2 or level 3 rating for the strength of the evidence through either individual studies or evidence reviews.
- The use of an approach similar to EMMIE-Q (developed and applied by the What Works Centre for Crime Reduction) for assessing the quality of systematic reviews
- The presence of increasingly rich contextual insight (on where interventions work, and how to implement them well) as a means of progressing from lower to higher ratings – with the highest rating reserved for interventions on which there is extensive contextual insight.
- The absence of 'level zero'. Where an intervention or practice is commonly used across the sector but there is no published evidence (or evidence of insufficient quality to allow at least a level 1 rating), the intervention will not be included in the Evidence Store – instead, it will be highlighted as a gap in the Evidence Map that EFI will develop and maintain, with a view to encouraging or commissioning research that allows the gap to be plugged.

Table 4: Levels of effectiveness from EFI standards

Level	Level 5	Level 4	Level 3	Level 2	Level 1
Features of the evidence	• An extensive body of high-quality evidence reviews	• A developing body of high-quality evidence reviews	• Studies of the highest quality (RCT/equivalent) OR at least one high-quality evidence review	• Studies using quasi-experimental methods OR at least one moderate-quality evidence review	• High quality observational studies
Benefits of the evidence	• We can draw very strong conclusions about impact, and be highly confident that the intervention does/does not have the effect anticipated • The body of evidence is *very* diverse and *highly* credible, with the findings convincing and stable	• We can draw strong conclusions about impact and be confident that the intervention does/does not have the effect anticipated • The body of evidence is diverse and credible, with the findings convincing and stable	• We can draw some conclusions about impact, and have moderate confidence that the intervention does/does not have the effect anticipated • The design of the research allows contextual factors to be controlled for	• We believe that the intervention may/may not have the effect anticipated • The body of evidence displays *very* significant shortcomings • There are *reasons* to think that contextual differences may substantially affect intervention outcomes	• The body of evidence displays significant shortcomings • There are *multiple reasons* to think that contextual differences may unpredictably and substantially affect intervention outcomes

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