**Farming and Food Analysis**
RESAS
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# Evidence for the Farmer-Led Arable Climate Change Group

**Briefing**

This report highlights evidence on Scotland's arable sectors for the Arable farmer-led climate change group, covering the context and structure of the industry, greenhouse gas emissions, biodiversity, performance and productivity.

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## Executive Summary

This report highlights evidence on the Scottish arable sector and its contribution to Green House Gas (GHG) emissions. For the purposes of this report, the 'arable sector' includes cereals, other crops, horticulture, and vegetables (incl. for human consumption, stock feed and seeds).

The main findings from this report are:

**Context and structure:**

- In 2019, the combined output of arable produce in Scotland (cereals, cereals, crops, fruit and vegetables) accounted for a third of agricultural output with a value of £1.1 billion.
- Around 550,000 hectares were used to grow cereals, crops, fruit and vegetables, accounting for around 10% of Scotland's total agricultural area. This is also equivalent to 12% of the total arable land in the UK
- In 2018-19, the average Scottish farm had a farm business income (incl. support payments) of around £38,700. On average, General Cropping and Cereal farms show significantly higher profitability at £132,000 and £64,000 respectively.
- When support payments are excluded, over 60% of cereal farms and just under 80% of General cropping farms remain profitable, compared to 28% of farms across the agricultural sector as a whole.
- Production and destinations of arable produce vary with supply and demand. The area, yield and quality of crops can vary due to land suitability, environmental conditions, pests and diseases. Not all arable produce is intended for or fit for human consumption. Around 35% of cereal production went to animal feed in 2019.

**Greenhouse gas emissions and biodiversity:**

- Large reductions in emissions are required from all sectors of the Scottish economy to meet Scotland's legally binding 2045 Net Zero target, and the target of a 75% reduction from 1990 levels by 2030.
- Agriculture represented 18% of Scotland's emissions, or 7.5 MtCO2e[1], in 2018. The Scottish Government's Climate Change Plan update requires the equivalent of a 31% reduction in agricultural emissions by 2032 from 2018 levels, a pace around four times faster than historic declines.
- Emissions from arable farms account for around 1.6 MtCO2e, or 21% of total agricultural emissions, the majority of which are from farm vehicles and soil management.
- Evidence on technically feasible mitigation specific to arable and tillaging covers (amongst other things) grain/legume rotations, pH management, and variable rate nitrogen & lime application.

[1] Million tonnes of carbon dioxide equivalent

- Evidence suggests these measures could deliver reductions around 0.24 to 0.3 MtCO2e, if applied to their maximum technical capacity based on current levels of arable land. This equates to a 15-19% reduction of arable emissions and, if matched with equivalent reductions across all agricultural sector, would not be sufficient to meet agriculture's envelopes by 2032, falling short by around half.
- The Climate Change Committee states changes in farming practices, woodland planting and reductions in livestock numbers are all required to achieve net zero. Their advice also highlights three key changes required to reduce agricultural emissions:

  1 - Diet change with their main pathway to net-zero assuming a 20% reduction in UK consumption of red meat by 2030, rising to 35% by 2050
  2 – Low-carbon farming practices, similar to those outlined above
  3 – Productivity measures to improve crop yields and reduce stocking rates

- The Climate Change Committee have also stressed that not only are the changes outlined critical for agriculture to reduce its emissions but also critical to free up the land required for other sectors to achieve the emissions reductions needed.
- Scotland has recognised loss of biodiversity as a twin challenge alongside the climate emergency. Overall, biodiversity benefits from a mix of habitats and is influenced by land use intensities. Declines in biodiversity can be directly linked to agricultural intensification and pesticide use. However there are proven ways to improve biodiversity on arable farms including through management of hedgerows, field margins, crop rotation, retaining winter stubble and use of green manure.

**Performance and productivity:**

- Evidence suggests that Scotland is mid-table in international comparisons when it comes to agricultural productivity growth. This report sets out some potential options for increasing agricultural productivity in Scotland.
- As with other farms types in Scotland, the performance of Cereals and General Cropping farms varies, both between and within farm types.
- Cereal farms' efficiency in particular is volatile, potentially due to their specialisation and vulnerability to global market prices, weather and supply – more so than many other farm types in Scotland.

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# 1 Context and Structure

## 1.1 Composition of the Arable Sector

### 1.1.1 Definition

Data on farms that specialise in cropping, and data on the total arable land in Scotland, are both important to understanding the overall Scottish arable sector. Arable land is defined here as land used for crops, fallow and set aside land. Around 10% of Scotland's total agricultural area in 2019 was arable land.

Unless otherwise stated, data in this chapter are from the June Agricultural Census, Total Income from Farming (TIFF), and Farm Business Survey (FBS), further detail in Annex B.

Farms where more than two-thirds of output comes from arable are categorised as 'specialist cereal', 'general cropping' and 'horticulture' farms. Specialist cereal farms make more than two-thirds of their output from cereals and oilseeds. General cropping farms make more than two thirds of output from crops. Horticulture farms make more than two-thirds of their output from fruit, vegetables, flowers, nursery stock and mushrooms. A glossary and definitions of these categories and other terms can be found in Annex A.

### 1.1.2 Composition of the Arable Sector

In 2019, around 550,000 hectares were used to grow cereals, crops, fruit and vegetables[2] in Scotland, accounting for around 12%[3] of the total arable land in the UK and around 10% of Scotland's total agricultural area. Large areas of Scotland have limited arable growing conditions. These are usually hilly or rocky lands that are more suitable for livestock. In 2019, 86% of the total agricultural land area in Scotland was designated as Less Favourable Areas (LFA)[4]. Most of Scotland's arable land, 80% in 2019, was on non-LFA land.

Further details on the distribution of arable land use by crop in 2019 in both Scotland and the UK as a whole, are included in Table B1 in Annex B.

Collectively, Scottish farmers produced around 4.7 million tonnes of arable produce. Barley varieties accounted for the majority (nearly 2 million tonnes or 41%), with wheat and potato varieties accounting for much of the rest – 20% and 25% respectively.

In terms of value, the combined output was around £1.1 billion, accounting for a third of Scotland's total agricultural output by value. Around £250 million of the output was attributable to potatoes, and barley accounted for an additional £250 million.

Production and destinations of arable produce vary with demand and supply. The area, yield and quality of crops can vary due to land suitability, environmental conditions, pests and diseases. Not all arable produce is intended for or fit for human consumption.

[2] Excluding around 30,000 hectares fallow and set aside land
[3] Agriculture in the UK 2019 (publishing.service.gov.uk)
[4] Including common grazing. Figure based on Scottish Agricultural Census: June 2019 https://www.gov.scot/publications/final-results-june-2019-agricultural-census/pages/1/ and UK Standard Area Measurements (SAM)

### 1.1.3 Outputs and Value – Cereals and oilseed rape

In 2019, Scottish farmers produced around 3.2 million tonnes of cereals and oilseed rape, a 22% increase on 2018 and the highest year for cereal production since 2015.

The rise in production was due to an increase in average yields, largely due to improved weather conditions in 2019, with 2018 being a poor year for both yield and production. The total area of cereals and oilseed rape sown remain fairly stable, increasing by 2%. Around 462,000 hectares in total were used to grow cereals and oilseeds in 2019.

As shown in Table 1, barley is the main cereal crop grown in Scotland, most of which is spring barley. Around 291,000 hectares of barley were planted in 2019, making up 63% of the total area used to grow cereals and oilseeds.

**Table 1: Area, yield and production estimates for the 2018 and 2019 Scottish harvest**

| | **2018** | | | **2019** | | |
|---|---|---|---|---|---|---|
| **Crop** | **Area** (000 ha) | **Yield** (t/ha) | **Production** (000 t) | **Area** 000 ha) | **Yield** (t/ha) | **Production** (000 t) |
| Wheat | 100 | 6.8 | 681 | 107 | 8.7 | 937 |
| Oats | 32 | 5.5 | 176 | 32 | 5.9 | 189 |
| Total Barley | 288 | 5.7 | 1,656 | 291 | 6.7 | 1,943 |
| *of which:* | | | | | | |
| *Winter Barley* | 38 | 7.1 | 268 | 49 | 8.2 | 399 |
| *Spring Barley* | 250 | 5.5 | 1,388 | 242 | 6.4 | 1,544 |
| **Total Cereals** | **420** | **6.0** | **2,512** | **430** | **7.1** | **3,069** |
| Oilseed Rape | 33 | 3.9 | 126 | 32 | 3.9 | 124 |

*Source: Cereal and oilseed rape harvest: final estimates - 2019 - gov.scot (www.gov.scot)*

Cereals have a strong association with the whisky industry. The major markets for Scottish cereals are malting (44% of all cereals in 2019), animal feed (35%) and milling (8%). Around 53% of barley production in 2019 was sold for use in the malting industry. 33% of Scottish wheat production was also sold for malting.

In 2019, the combined output of Scottish cereals was around £409 million, the equivalent to 12% of Scottish agriculture's total output by value. Barley varieties accounted for the lion's share (£250 million or 61%) with wheat accounting for a further third (£107 million). The output from oilseed rape in the same year was around £39 million.

In 2019 the market value of cereals produced for feed and other purposes (including sales to animal feed manufacturers, feed and seed retained on farm of origin or sold farm-to-farm) was estimated at £142 million, around 35% of the combined value of output above.

### 1.1.4 Outputs and Value – Potatoes and other crops

In 2019, around 28,500 hectares were used to grow potato varieties – both seed (planting) and ware (eating). This increased 4% on 2018, but was 2% below the ten-year average. Both seed and ware potatoes increased in area.

In 2019, total output from Scottish potatoes was around £250 million, 22% of arable and 7% of Scottish agricultural output by value. Seed potatoes accounted for £155 million of this.

Other crops, grown in smaller quantities, include triticale, rye, peas and beans for combining and crops for stock feeding. They account for a further 26,000 hectares of which around

19,000 were to grow vegetables for stock-feeding. These crops, which also include oilseed rape, contributed around £76 million, 7% of arable or 2% of total Scottish agricultural output.

### 1.1.5 Outputs and Value – Horticulture

In 2019, the area used to grow vegetables intended for human consumption (excluding potatoes) remained fairly steady at around 19,000 hectares, a 1% decrease from the previous year but remaining above the ten-year average.

From 2018 to 2019, the total soft fruit growing areas decreased by 1% to around 2,000 hectares. However, it remains higher than the average over the past 10 years. Strawberries are the most popular grown fruit, followed by blackcurrants and raspberries. Most fruit (around 73%) is grown under cover in either glasshouses or walk-in plastic structures (Poly-tunnels), allowing for a much longer growing season.

In 2019, the total output from Scottish horticulture was around £346 million, the equivalent to 31% of arable output and 10% of Scottish agriculture's total output by value. Most of this came from vegetables (£164 million or 48%) and fruit (£144 million or 42%). Flowers and nursery stock accounted for a further £37 million (11% of horticulture output).

### 1.1.6 Scottish Arable Farms

**11,500**

Number of holdings with arable land

**22%**

Percentage of all Scottish holdings with arable land

**550,000**

Area of Arable Land

Of Scotland's 51,000 holdings, 22% had arable land in 2019. The majority of arable land is accounted for by specialist cereal (5% of holdings and 30% of arable land) and general cropping holdings (3% of holdings and 30% of arable land). Of all holdings, a further 1% were specialist horticulture (2% of arable land).

Most of the arable land and arable holdings in Scotland are in the South East and North East. Table 2 below provides the figures for specialist cropping and specialist cereal farms. Full details are included in Tables B2 & B3 in Annex B.

**Table 2. Number of specialist cropping, cereal or arable holdings by region, 2019**

| NUTS2 | Specialist General Cropping Holdings | | Specialist Cereal Holdings | | All Holdings with Arable Land | |
|---|---|---|---|---|---|---|
| | *Holdings* | *Arable Area (ha)* | *Holdings* | *Arable Area (ha)* | *Holdings* | *Arable Area (ha)* |
| North East Scotland | 260 | 24,900 | 900 | 55,200 | 2,720 | 148,600 |
| Eastern Scotland | 910 | 107,000 | 790 | 59,100 | 2,880 | 227,300 |
| Southern Scotland | 120 | 17,900 | 310 | 32,500 | 2,220 | 101,000 |
| Highlands & Islands | 350 | 16,200 | 340 | 17,000 | 3,570 | 68,700 |
| West Central Scotland | 10 | 400 | 20 | 1,200 | 150 | 3,300 |
| **Scotland** | 1,650 | 166,300 | 2,360 | 165,000 | 11,520 | 548,900 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

### 1.1.7 Holding Size

In 2019, 61% of arable farms were between 10 and 200 hectares. Smaller or larger holdings are less common. Of specialist cereal holdings, 12% were larger than 200 hectares and covered around 73,000 hectares, or 44% of total cereal area. In general cropping, 23% of holdings were larger than 200 hectares and covered around 92,000 hectares, or 55% of the general cropping area. In contrast, the majority of horticulture (78%) farms were under 10 hectares in size. Full details are in Table B4-6 in Annex B.

### 1.1.8 Workforce

Different crops have different labour requirements. Specialist cereal holdings rely on a mix of occupiers and spouses, accounting for 53% of the workforce, and employees, for 39%. On general cropping holdings 44% of labour is from occupiers and spouses and 45% from hired employees. Horticulture is more reliant on hired labour, which makes up 21% of the workforce while 67% are casual or seasonal staff. Full details are in Annex B in Table B7-9.

## 1.2 Profitability and Turnover

### 1.2.1 Estimated Farm Business Incomes and Profit

Farm Business Income (FBI) statistics are estimated from a sample of nearly 500 farms with a standard output (the average monetary value of the agricultural output at farm-gate price) over €25,000. The FBS does not collect information on non-supported sectors, which include farms predominantly engaged in horticulture, pigs, poultry and some fruit production. A large number of part-time and small Scottish farms with low output are also not included[5].

Farms with more than two thirds of output from crops are categorised by the FBS as Cereals or General Cropping. A glossary and definitions of these and other terms is in Annex A.

Table 3 shows FBI by upper and lower performance bands, with and without support payments. FBI is used to show the profit a farm makes. FBI figures measure profitability from agricultural activity and includes income from non-agricultural activities using farm resources. For example, tourism, renewables or processing and sale of farm products. There are wide variations in performance across farm types.

In 2018-19, the average FBI in Scotland was around £38,700. Excluding support payments, this falls to around -£4,700, suggesting support plays an important role for many farms.

On average, General Cropping and Cereal farms show higher profitability. General Cropping farms are most profitable with average FBI of around £132,100, falling to £91,800 excluding support. Cereal farms had an average FBI of around £64,100 or £30,900 excluding support.

**Table 3. Farm business income by performance band – arable farms**

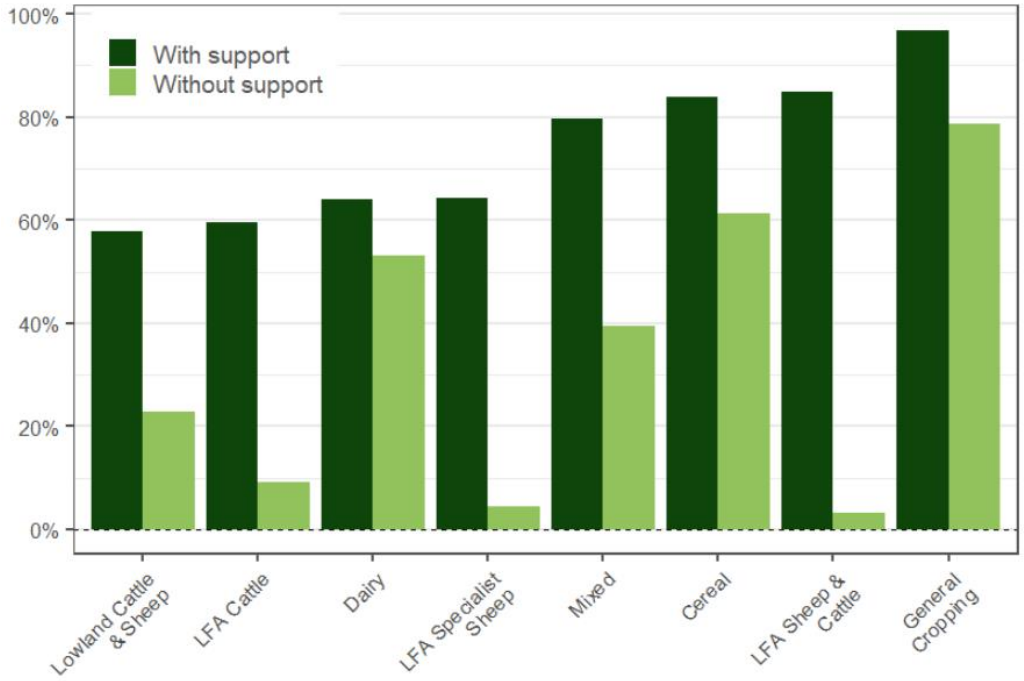
| | **Lower 25%** | | **Average** | | **Upper 25%** | |
|---|---|---|---|---|---|---|
| | Including Support | Excluding Support | Including Support | Excluding Support | Including Support | Excluding Support |
| Cereals | -£800 | -£26,900 | £64,100 | £30,900 | £188,600 | £134,800 |
| General Cropping | £27,800 | -£3,200 | £132,100 | £91,800 | £294,300 | £245,000 |
| **All Farms** | **-£15,500** | **-£53,800** | **£38,700** | **-£4,700** | **£159,800** | **£100,800** |

[5] Farms with Standard Labour Requirements (SLR) more than 0.5. Standard Labour Requirements represent the approximate average labour requirement for a livestock or crop enterprise. The annual hours of a full-time worker is 1,900 hours.

*Source: Farm Business Survey 2018/2019*

The figure below shows profitability by farm type, represented by the proportion of farms with income from farming greater than zero (i.e. agricultural output is greater than input). Around 80% or more of Cereal, General Cropping or Mixed farms were profitable with support payments and in comparison to farming sectors engaged primarily in cattle and sheep this drops relatively little when support payments are removed.

**Proportion of farms with agricultural output greater than input, 2018-19**




Scottish Government analysis shows that across all farm types, 28% of farm businesses turn a profit without support, and 72% turn a profit when support is included.

Table 4 shows the average total input, amount received from support payments and grants and output for arable farm types. Economic efficiency is calculated as a ratio of outputs to inputs. The average General Cropping farm had the highest economic efficiency in 2018-19, of around 144%. Cereal farms were on average more economically efficient than the average farm, with efficiency around 136%.

**Table 4. Farm output and input – arable farms**

| | Output | Input | Support payments and grants | Diversification Margin | Economic efficiency* |
|---|---|---|---|---|---|
| Cereals | £208,600 | £188,300 | £33,200 | £10,700 | 136% |
| General Cropping | £429,000 | £346,200 | £40,200 | £9,000 | 144% |
| **All Farms** | **£190,000** | **£199,300** | **£43,400** | **£4,600** | **124%** |

** Including support payments and diversification. Source: Farm Business Survey 2018/2019*

### 1.2.2 Diversification

Data on diversification and investment in renewable energies on arable farms in Scotland is scarce. The Farm Structure Survey 2016 found that across all farming around 9% of farms

made more than 50% of their turnover from diversified activities and 16% made more than 10%. As shown in Table 5, more cereal (12%) and general cropping (14%) farms were making 10-50% of their turnover from diversified activities, although fewer were making more than 50%.

**Table 5: Proportion of turnover from other gainful activities, by farm type, 2016**

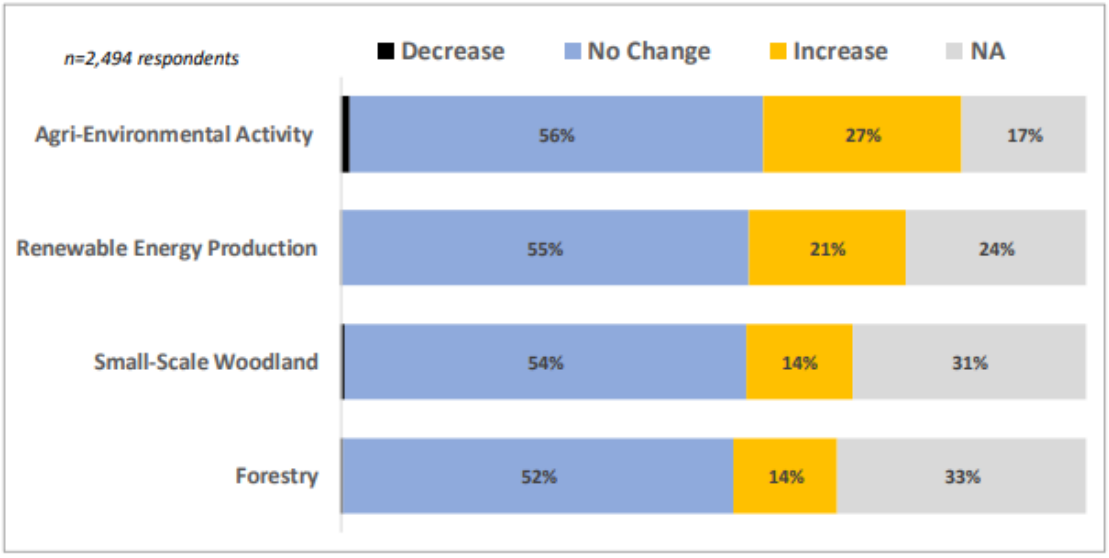
| Farm Type | Proportion of turnover from other gainful activities | | |
|---|---|---|---|
| | **0-10%** | **>10-50%** | **More than 50%** |
| | % of holdings | % of holdings | % of holdings |
| Cereals | 82% | 12% | 6% |
| General Cropping | 80% | 14% | 6% |
| Horticulture | 70% | 11% | 19% |
| **All Farms** | **84%** | **7%** | **9%** |

** Including support payments and diversification. Source: Farm Business Survey 2018/2019*

The Farmers' Intention Survey 2018, summarised by SRUC in their October 2019 briefing, revealed that over 50% of (Scottish) farmers (from all sectors) plan no changes to the levels of agri-environmental provision on their holding in the succeeding five years, while between approximately 14% and 27% of farmers plan to increase provision of "public goods" through increased agri-environmental, forestry, small-scale woodland and renewable energy production.

Of those who did signal intentions to increase these activities, identification of a successor, status as a new entrant, tenure, gender and land type were the most significant characteristics of those intending to increase public good activities. Lower productivity of land appears to be a factor which positively influences the decision of farmers to increase the level of forestry and small-scale woodland on their farm or holding.

The figure below shows the overall intentions of the farmers, crofters and smallholders surveyed to change the level of activities on their farm or holding that may enhance 'public good' provision in the next five years (2018-2023). Over 50% of respondents planned no changes to the level of each of the activities and for many the question was not applicable as they currently don't engage in that activity. The type of public good provision that most respondents planned to increase is agri-environmental activity, at 27%.



## 1.3 Future Trends

### 1.3.1 Impacts of Brexit

In late 2020, the Anderson Centre produced a report for Scottish Government, assessing the impacts on Scottish agriculture of a UK-EU Free-Trade Agreement (FTA) and a No-Deal Brexit.

Overall, the modelled impacts of an FTA were projected to result in relatively small changes in Scottish agricultural output over the longer term. This is becausemost agricultural trade, with the exception of seed potatoes, can continue effectively tariff-free and quota-free. Indeed, the modelling suggests that increased demand from the rest of the UK could actually increase Scottish agricultural output in some cases.

Specifically for wheat and barley (the cereals covered within the model), output by value were projected to remain unchanged overall but with a larger shared consumed domestically and less exported overseas. It should be noted that this modelling is not suitable for capturing the initial disruption being experienced by individual businesses in the early stages of the deal.

Trade between the UK and EU, however, is no longer frictionless with new non-tariff measures (NTM) – additional certifications, enhanced border checks, etc. – now in place. As a result, the costs of such trade are set to increase. For wheat and barley these costs are projected to be minimal (around 0.1% ad-valorem equivalent (AVE) on average) owing to the channels used (Bulk shipments rather than Ro-Ro) and the industry being largely accustomed to trading across non-EU markets already. Where problems could arise are on shipments of inputs and time delays when disease pressure is at its peak.

### 1.3.2 Changing Dietary Demands

According to a 2018 report by Food Standards Scotland[6], Scottish households generally eat too many calorie-dense foods, and do not eat enough fruit, vegetables, oil-rich fish, and fibre. For example, the average intake of fruit and vegetables between 2001 and 2015 was 3.2 portions on average (257g per day) – this should increase to 5 portions a day (402g). Inequalities exist as well: 'most deprived' areas consumed on average 2.5 portions, while 'least deprived' consumed 3.9 portions.[7]

**Table 6. Average expenditure on veg, fruit, potatoes, and bread per person per week, 2018-19**

| Category | Scotland | | UK | |
|---|---|---|---|---|
| | Purchase | Expenditure | Purchase | Expenditure |
| Bread | 672g | £1.36 | 521g | £1.18 |
| Potatoes* | 621g | £1.41 | 620g | £1.27 |
| Fruit and vegetables* | 2,030g | £4.62 | 2,245g | £5.29 |
| *of which:* | | | | |
| *Vegetables** | *1,045g* | *£2.32* | *1,139g* | *£2.60* |
| *Fruit** | *985g* | *£2.30* | *1,106g* | *£2.69* |
| **Food and Non-Alcoholic Drinks** | **..** | **£28.85** | **..** | **£28.32** |

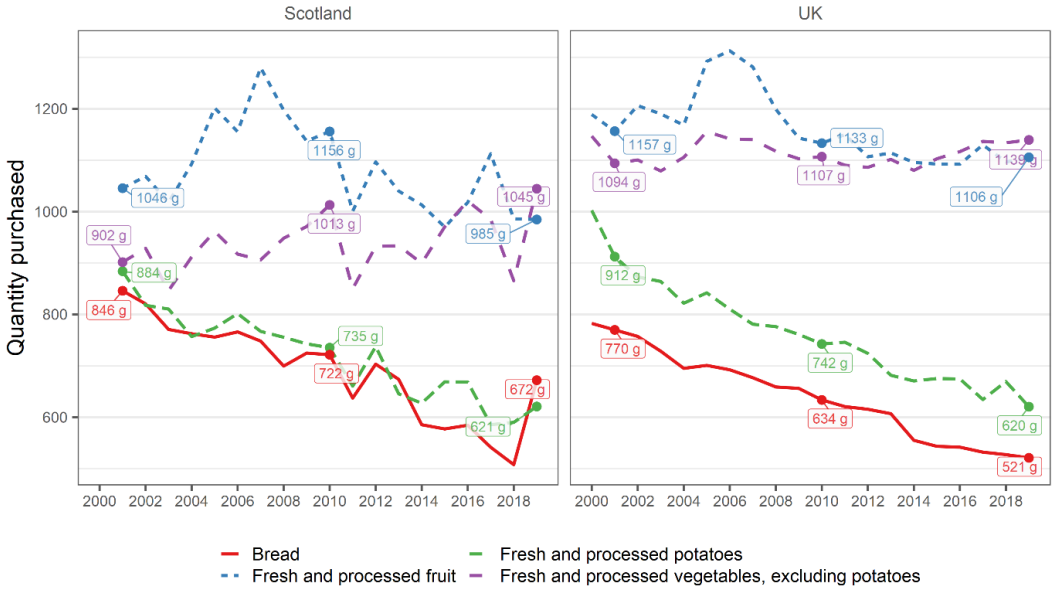
** Fresh and/or processed. Source: Family Food, DEFRA, October 2020*

[6] Food Standards Scotland, 2018. Available at: https://www.foodstandards.gov.scot/downloads/Situation_report_-_the_Scottish_diet_-_it_needs_to_change_-_2018_update_FINAL.pdf
[7] Using SIMD classifications.

DEFRA's Family Food datasets, based partly on ONS' Living Costs and Food Survey, show UK and Scottish household purchases and expenditure on food and drink. The latest release, with data up to 2018/2019, shows the average volume of fresh and processed fruit and vegetables purchased has remained fairly stable, though below UK levels. In 2018/19, Scottish households purchased 2,030g of fresh/processed fruit and vegetables per person per week (290g/day) compared to 2,245g for UK households (321g/day).

**Quantity of vegetables, fruit, potatoes, and bread purchased, 2000-2019**

Per person per week

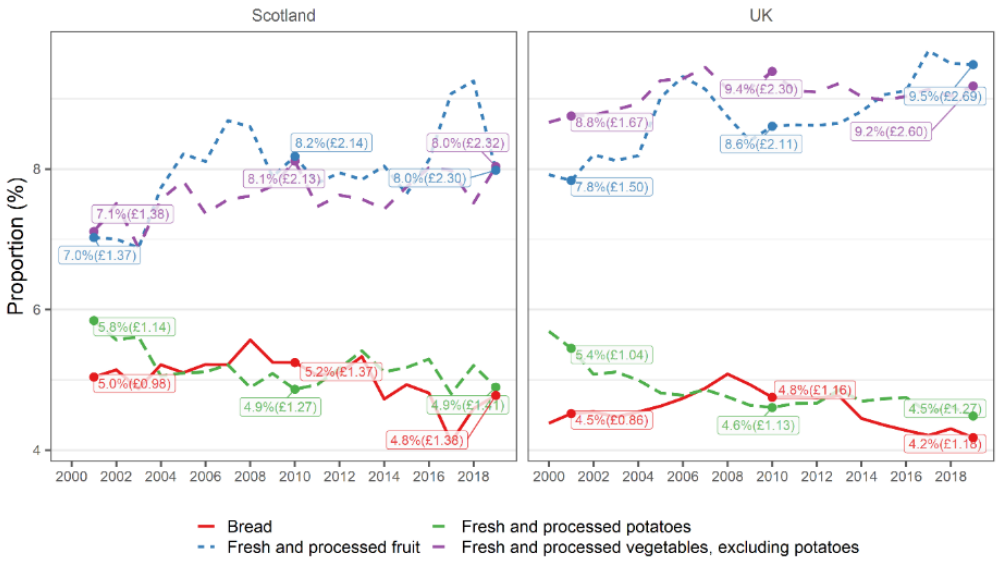



Source: Family Food Datasets, DEFRA, October 2020

The proportion of total food and drink expenditure spent on bread and potatoes has seen a similar broad downward trend since 2001. In 2018/2019, 9.7% of total UK food and drink expenditure was spent on bread and potatoes, a similar proportion to that seen in since 2001 (8.7% for Scottish households). Fruit and vegetable expenditure as a proportion of total food and drink expenditure has increased for both UK and Scottish households.

**Expenditure on vegetables, fruit, potatoes, and bread, 2000-2019**

Proportion of total spending on food and non-alcoholic drinks, per person per week




Source: Family Food Datasets, DEFRA, October 2020

A number of key reports have discussed changes to red meat consumption. The UK Climate Assembly[8] – a citizens' assembly on climate change – discussed their preferred future for food, farming and land use on the path to net zero in the UK. This included 20-40% voluntary and education driven reductions in red meat and dairy consumption.

The Climate Change Committee[9] have also formally modelled these reductions in their 6th Carbon Budget report in order to determine their pathways for the UK, including Scotland, to reach net-zero by 2050.

Their advice also highlights three key changes required to reduce agricultural emissions:

i. diet change with their main pathway to net-zero assuming a 20% reduction in UK consumption of red meat by 2030, rising to 35% by 2050;
ii. low-carbon farming practices;
iii. productivity measures to improve crop yields and reduce stocking rates.

The sectoral pathway for Scottish agriculture in the CCC report requires an emissions reduction of 23% by 2030 and the CCC state changes in farming practices, woodland planting and reductions in livestock numbers are all required to achieve net zero.

Such changes in Scottish diets may not directly impact cereal production, but could indirectly affect the arable sector via reduced demand for animal feed: a large proportion of Scottish-produced feed grains are destined for the Scottish red meat sector, of which the majority of outputs are destined for the rest of the UK.[10]

[8] https://www.climateassembly.uk/report/read/final-report-exec-summary.pdf
[9] Sixth Carbon Budget - Climate Change Committee (theccc.org.uk)
[10] Anderson Centre, Dec 2020. Summary Report: Analysis of Brexit Scenario Impacts on Scottish Agricultural Sectors.

# 2 Greenhouse Gas Emissions and Biodiversity

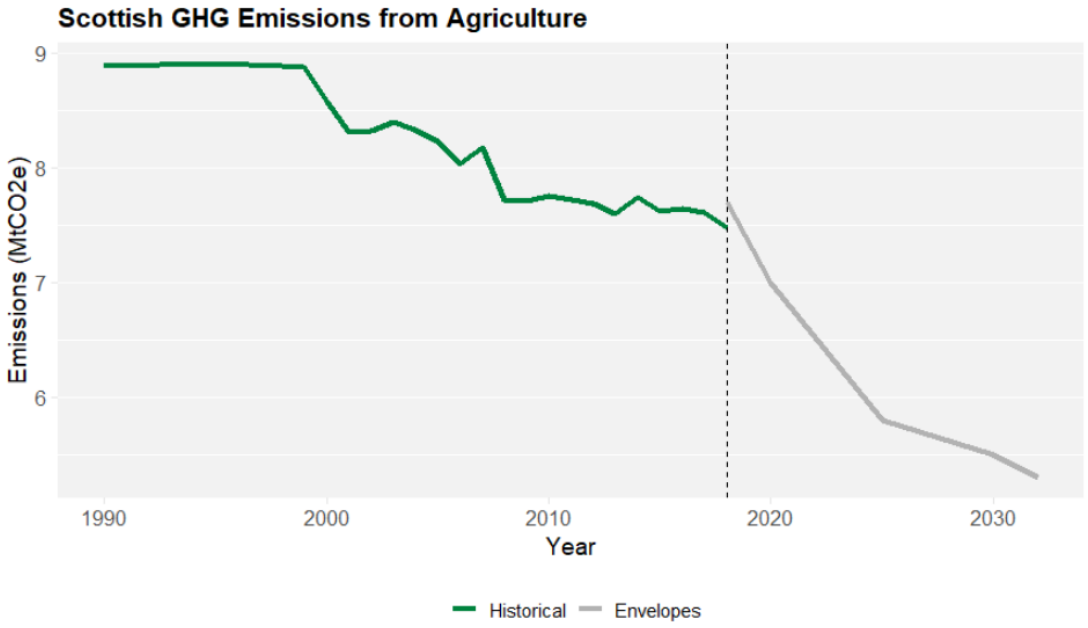
## 2.1 Sector Emissions

The Scottish Government has committed to reaching net zero emissions by 2045, including a reduction of 75% by 2030. Whilst a number of countries have adopted net zero targets by on or around 2045, Scotland's 2030 target is particularly ambitious and requires quick action.

Scotland has a legal requirement to meet these goals, and every industry must adjust to contribute to reducing emissions. The Greenhouse Gas (GHG) inventory measures the domestic emissions, i.e. those produced in Scotland. It is the key data source against which Scottish Government measures its progress against its net zero targets. Emissions arising from goods produced in Scotland and exported overseas for consumption are counted in the Scottish GHG inventory. Emissions arising from goods produced overseas and imported into Scotland for consumption are not counted in the Scottish GHG inventory.

In 2018 total Scottish emissions were 41.6 million tonnes of carbon dioxide equivalent (MtCO2e). The 2019 figures are scheduled to be published in summer 2021.

In 2018 emissions from agriculture were 7.5 MtCO2e, or 18% of Scottish emissions. The sectoral envelope as set out in the Climate Change Plan update requires agricultural emissions reduce by 2.4 MtCO2e to 5.3 MtCO2e[11] in 2032, the equivalent of a 31% reduction from 2018 levels. As shown below this requires agriculture to reduce emissions at a pace nearly four times faster than historic reductions. Progress towards delivering the plan will be part of statutory annual reporting at a sector-by-sector level to the Scottish Parliament from May 2021 onwards.



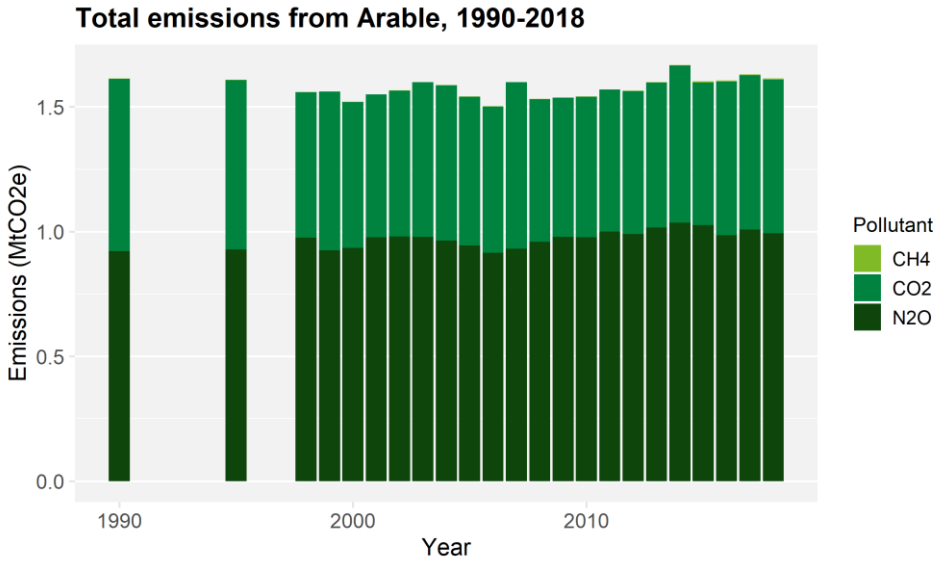

Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot), Securing a green recovery on a path to net zero: climate change plan 2018–2032 - update - gov.scot (www.gov.scot)

Note: there is a small break in the series due to a slight mismatch in the historic data and the forecast envelopes

[11] The Climate Change Plan update incorporates some likely methodological changes not yet included in GHG inventory figures resulting in 7.7 MtCO2e in 2018 rather than 7.5.

### 2.1.1 Emissions from Arable Farms

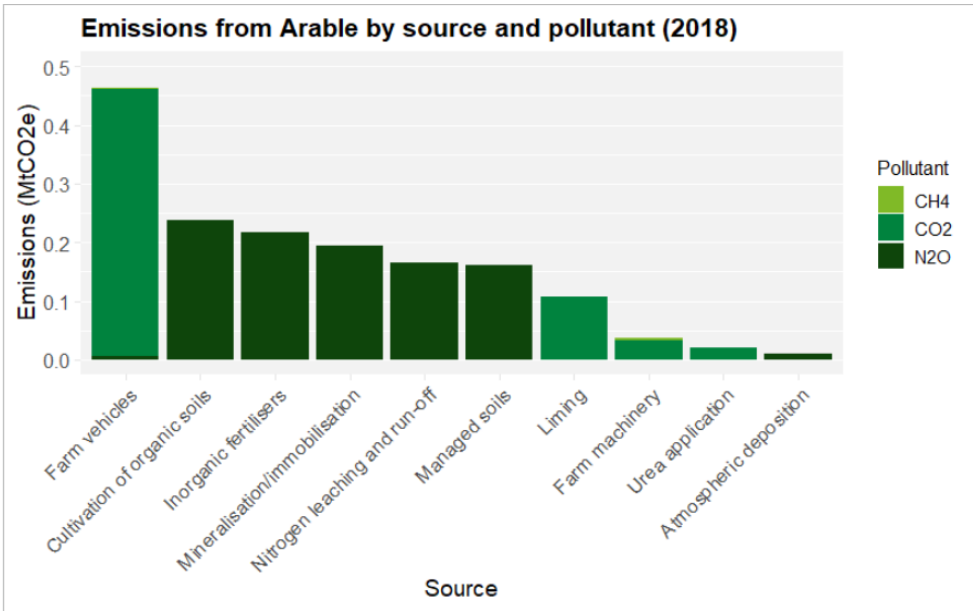
The GHG Inventory for agriculture includes emissions from fertilisers, crop residues, and managed soils. It does not explicitly break down all relevant emissions by sub-sector. Therefore, we have estimated emissions from arable of 1.61 MtCO2e, 21% of agricultural emissions. More detail on how we have done this is in Annex C. Unlike other sectors, emissions from arable are mainly from carbon dioxide and nitrous oxide, with less than 1% from methane. Between 1990 and 2018, emissions from arable have risen by 1%.




Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot)

### 2.1.2 Sources

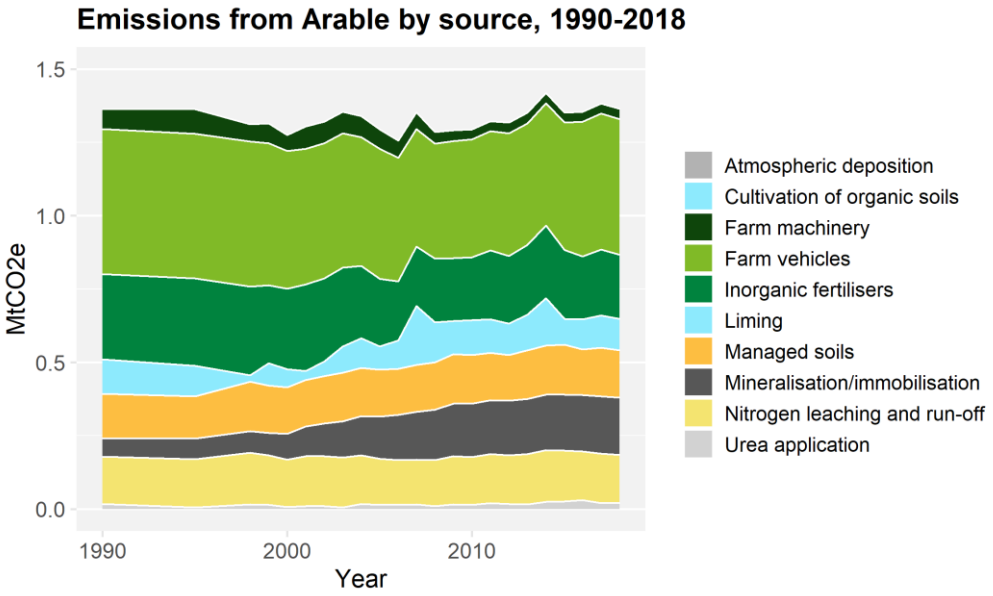
The chart below shows how the 2018 emissions from arable break down by source and pollutant.[12] Farm vehicles are the largest source, contributing 29% of emissions from arable. The next largest source is cultivation of organic soils, contributing 15%.




Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot), RESAS classification based on ADAS data

[12] It is not possible to split the GHG Inventory data by product type.

Over time, the largest reductions in emissions by source have come from inorganic fertilisers. However, emissions from mineralisation/immobilisation have more than doubled in the same period. This increase is larger than the decrease from inorganic fertilisers.




Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot), RESAS classification based on ADAS data

## 2.2 Options for Reducing Emissions

### 2.2.1 Potential Savings

Research undertaken by CXC and SRUC on behalf of Scottish Government assessed potential savings from mitigation measures that could be applied in Scotland and the likely maximum uptake that could be achieved. The maximum uptake figures below are shown as a percentage of arable and grassland.[13] The report did not assess timescales for uptake of measures, which will be influenced heavily by factors like behaviour change and policies. Table 7 summarises measures that could be applied in the arable sector. Estimates of aggregate emissions savings have been added based on the 2019 areas.

**Table 7. Sources of climate change mitigation in crops and grassland by 2050**

| Area 2019 | Mitigation measure | Maximum Uptake 2050 | Per ha mitigation (kg CO2e) | Aggregate Mitigation (MtCO2e) |
|---|---|---|---|---|
| 1,863,000 ha | Grain legume rotations | 5% | 553 | 0.05 |
| | Improved crops | 24% | 13 | 0.006 |
| | Intercropping | 6% | 89 | 0.001 |
| | Nitrification and urease inhibitors | 81% | 71 | 0.11 |
| | pH management | 33% | 112 | 0.07 |
| | Slurry injection | 17% | 26 | 0.01 |
| | Slurry trailing hose | 17% | 7 | 0.002 |
| | Variable rate nitrogen & lime application | 17% | 151 | 0.05 |
| | **Additive Total** | **..** | | **0.3** |

*Source: Marginal abatement cost curve for Scottish agriculture (climatexchange.org.uk)*

[13] It has not been possible to provide specific figures for only arable in the timeframe

Strictly speaking the ‘additive total’ overstates the savings as some measures may interact and reduce the impact of other measures. Whilst overall for agriculture in the CXC report, these interactions were assessed to be relatively low they mainly occur in the measures relevant to the arable sector and therefore may overestimate the total reduction.

This is because some measures cannot be carried out on the same land in certain combinations, or may be less effective if they are. For example, soil pH management can be applied to a maximum of 33% of agricultural land, and variable rate nitrogen and lime application can be applied to a maximum of 17% of agricultural land – however, they cannot be applied together, meaning the true maximum for both measures is 33%. As a result, constraints may slightly overestimate the mitigation potential overall. Mainly this is related to the combined uptake of slurry measures, pH management, variable liming, nitrification inhibitors and legumes on the same land. Further explanation is available on page 14 of the CXC report.

If each of these measures were applied to their maximum potential as identified in the report, estimated reductions from emissions based on current levels of arable land would be up to around 0.3 MtCO2e. However, the potential interactions outlined above may reduce this by around a fifth, to 0.24 MtCO2e.

This would be up to a 15-19% reduction in terms of 2018 emissions from the arable sector or 10-12% of the 2.4 MtCO2e reductions required by agriculture by 2032 with the remaining 88-90% needed to come from elsewhere in the sector. This would not be sufficient to meet the equivalent of the arable sector’s share of the necessary reductions. A reduction of 2.4 MtCO2e is equivalent to a 31% reduction from 2018 levels. Therefore, even if all agricultural sectors were to achieve an equivalent 15-19% reduction in their emissions this would not be sufficient, by around a half, for the agriculture sector to meet its envelope by 2032.

The Climate Change Committee states changes in farming practices, woodland planting and reductions in livestock numbers are all required to achieve net zero. Their advice also highlights three key changes required to reduce agricultural emissions:

1 - Diet change with their main pathway to net-zero assuming a 20% reduction in UK consumption of red meat by 2030, rising to 35% by 2050
2 – Low-carbon farming practices, similar to those outlined above
3 – Productivity measures to improve crop yields and reduce stocking rates

It is important to note that the figures above are average estimates that were provided for Scotland as a whole. On an individual farm basis, both the mitigation and the net costs (below) can be very different and some measures above cover a wide range of possible actions which would be demanding to assess individually. Therefore the GHG benefits achieved and costs could vary widely.

Further details on each of these measures, such as costs, underpinning assumptions, constraints and potential uptake can be found on pages 12-13 of the CXC report and in the Annexes on pages 43-53. They have also been collated into Annex D for ease.

As set out within the CXC report, there is scope for all sectors in agriculture to mitigate their operational GHG emissions through other practices and alternative land use such as those to encourage carbon sequestration.

### 2.2.2 Costs

Some of these measures would involve the purchase of capital equipment with upfront costs. The table below shows the net costs to farmers including capital costs on an average annual basis. These do not include any wider costs such as those to Government or Research and Development from developing measures. Negative figures below show a net saving to the farmer, i.e. if implemented they would provide a financial saving to the farmer as well as a reduction in emissions. Based on current levels the average potential net cost to the arable sector is around £9m which is equivalent to 2% of the value of cereal output, where the majority of emissions are associated.

**Table 8. Sources of climate change mitigation in the crop/arable sector by 2050**

| Area 2019 | Mitigation measure | Maximum Uptake 2050 | Per unit annualised cost (£) | Aggregate Cost (£m) |
|---|---|---|---|---|
| 1,863,000 ha | Grain legume rotations | 5% | 406.00 | 35 |
| | Improved crops | 24% | -10.17 | -5 |
| | Intercropping | 6% | -45.18 | -5 |
| | Nitrification and urease inhibitors | 81% | 20.67 | 31 |
| | pH management | 33% | -45.00 | -27 |
| | Slurry injection | 17% | 21.35 | 7 |
| | Slurry trailing hose | 17% | 8.16 | 3 |
| | Variable rate nitrogen & lime application | 17% | -93.57 | -30 |
| | **Additive Total** | **..** | | **9** |

*Source: Marginal abatement cost curve for Scottish agriculture (climatexchange.org.uk)*

### 2.2.3 Current Uptake & Implementation Constraints

This section contains a brief summary of some of the key issues relating to each of the measures outlined in Tables 7 & 8 above drawing heavily on the CXC report.

#### 2.2.3.1 Grain legume rotations

Legumes source nitrogen directly from the atmosphere, meaning very little (or no) nitrogen fertilisers are needed. They also provide some of this nitrogen to crops grown alongside and after them, reducing the need for nitrogen fertilisers.

Frequency of rotation depends on different factors according to the legume. Some legumes can only be grown once every few years to reduce risk of disease, and others may delay yields. Different types of soils may also mean legumes are unsuitable for some areas.

In 2016, legumes for human consumption were grown on 1.7% of the arable crop area in Scotland. It is assumed that this could increase to 5% of the arable area.

#### 2.2.3.2 Improved crops

Nitrogen fertilisation is vital to achieve current yields for most crops, but a significant proportion (nearly half) is lost to the environment, causing multiple environmental problems.

Using crops which are more efficient in utilising the nitrogen fertiliser reduces GHG emissions and pollution, and reduce economic loss due to fertiliser lost to the environment.

Nitrogen-use efficiency varies between individual plants of the same species, and some can be selected for further breeding. New cultivars such as perennial wheat or disease resistant varieties can help to retain more carbon in the soil as well as reduce fertiliser, pesticide and fuel use. Currently, main research streams are being carried out for nitrogen-fixing cereals which could substantially reduce the need for nitrogen fertilisation in these plans.

There is assumed to be a seed price premium of around 10% for improved crops, but beyond that there are no further costs and this measure is applicable to all crops. Currently, uptake is assumed to be zero, but could be implemented widely on arable areas.

#### 2.2.3.3 Intercropping

Growing a legume crop alongside a cereal crop reduces the need for fertiliser, as the legume crop sources nitrogen directly from the atmosphere and provides some of this to plants grown in the same area. In the UK, intercropping is typically pea or fava bean grown alongside spring oats, spring barley, or spring wheat. Currently, intercrops are usually used as feed for livestock.

Costs may be a constraining factor as pea seed is around 50% more expensive than barley seed. While there are no reported figures on current uptake, there is growing interest in intercropping, and it possible that in future grain will be separated and used for human consumption, increasing incentive to adopt intercropping. Future uptake can be expected to be high, as intercropping is applicable to 43% of winter and spring oat, and 100% of spring non-malting barley.

#### 2.2.3.4 Nitrification and urease inhibitors

Chemical inhibitors improve the availability of nitrogen fertilisers for plants and reduce both GHG emissions and nitrate leaching. Urea in combination with inhibitors can further reduce emissions. These can be injected into the soil, applied as a coating, mixed into slurry, or spread after grazing.

There is little data available on current use of nitrification and urease inhibitors in Scotland, and in the MACC model uptake was assumed to be 0%. However, costs are relatively low for implementation.

#### 2.2.3.5 pH management

Soil pH plays an important role in crop productivity and regulating and modifying emissions, including improving fertiliser efficiency. Costs include the purchase of lime, spreading and soil analysis, and provide a benefit from additional income due to increased yield.

Currently, 64% and 30% of farms carried out pH testing on arable and grazing land respectively. A survey showed that of the sample, 57% of grassland soils and 34% of arable soils had low or very low pH values. This suggests that uptake can be expected to be fairly high, at around 50% on grasslands and 30% on croplands.

#### 2.2.3.6 Slurry injection and trailing hose

Livestock slurry can be applied to soil using a range of techniques, with the most common in Scotland currently being a low trajectory splash plate. Implementation of bandspreading and injection techniques involve installing pipes and/or machinery to apply slurry directly to the surface of the soil, and can reduce crop contamination and ammonia emissions.

There is a requirement for capital investment to implement this measure, which may be a constraining factor for some farm businesses. However, this measure is already being used in many farms across Scotland, with 28% of slurry bandspread and 3.5% injected in 2016. The CXC report assumes that this measure can be applicable to around half of all organic manure applications in Scotland and indicates at a UK level such applications comprise just over 40% of the total. The main method in Scotland at present is with a low-level splash plate, so there is room for significant increase in uptake.

#### 2.2.3.7 Variable rate nitrogen & lime application

Where soil pH and other crop-growing conditions are highly variable, tailoring nitrogen and lime application can save resources and enhance yield, as well as reducing GHG emissions. Precision farming technologies can tailor the rate of inputs to soils within one square metre.

Current adoption is around 8% across the UK, likely lower in Scotland due to smaller arable farms. There are capital costs associated with implementing and maintaining this measure.

## 2.3 Biodiversity

### 2.3.1 What do we know about biodiversity?

The Convention on Biological Diversity defines biodiversity as the variability among living organisms from all sources including within and between species and of ecosystems. It is vital to supporting humans by contributing to food production, manufacturing supplies, recreation, soil quality, and climate stabilisation. In December 2020 the Scottish Government published a Biodiversity Statement of Intent which includes proposals in relation to land use.

The Dasgupta Review of the Economics of Biodiversity commissioned by HM Treasury highlights that we are demanding more goods and services than nature can sustainably supply. This means global stocks of natural assets have been depleted. The review makes clear that increased biodiversity helps mitigate risks to economic prosperity and climate change. Acting immediately on biodiversity loss is significantly more cost effective than delaying action. We can respond by reducing our use of natural resources, increasing the efficiency with which we use them or increasing them through conservation and rebuilding.

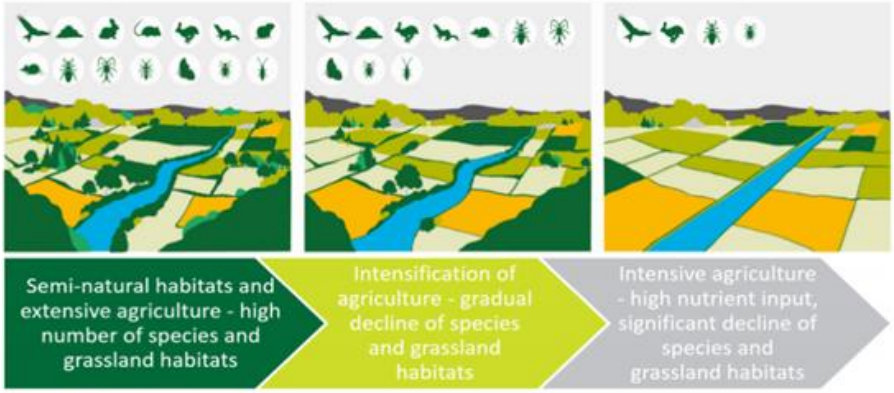
#### 2.3.1.1 What is the relationship between farming and biodiversity?

Agricultural intensification has negatively impacted biodiversity, particularly due to a trend towards homogeneity leading to fragmentation and loss of habitats. Overall biodiversity benefits from a mix of land use intensities as well as a mix of habitats[14] as shown below.[15] Land management practices can contribute to maintaining biodiversity, and have a negative impact where practices are intensive.

[14] James Hutton Institute. Briefing for RESAS.
[15] https://www.eca.europa.eu/Lists/ECADocuments/SR20_13/SR_Biodiversity_on_farmland_EN.pdf

The UKG review states the relationship between farming and biodiversity is complex. Biodiversity can benefit farmers by improving productivity including soil health, and farming approaches can be tailored to benefit wildlife and biodiversity[16]. However, this is not always true: for example, an area of farmland may have high biomass, but low biodiversity[17].

**Figure 1 – Decline in farmland biodiversity due to intensification of land use**




*Source:* ECA.

A change of land use can result in various impacts on biodiversity: for example, conversion from semi-natural grazing to forestry may be detrimental, as the diversity and richness of wildlife associated with the former can be considerable, whereas conversion from improved grassland (which can be poor for wildlife) to forestry is likely to make little difference[18].

Farmland is particularly able to deliver services such as energy sources, food production and recreation. However, the Natural Capital Asset Index shows that the natural capital[19] asset value of agricultural and cultivated land has been reducing over recent years. The Index is made up of quality (38) x quantity indicators (ie area) and the recent agriculture decline seems to be driven by a reduction in land designated arable land and market gardens[20].

Biodiversity varies across regions, land uses and species. A commonly used indicator for biodiversity is bird populations. Research by Nature.Scot shows that most wader species have seen significant declines while seed-eaters show stable or increasing long-term trends. Overall there has been an increase in the species that contribute to the farmland bird indicator since 1994, however losses have been found for some species including greenfinch, kestrel, lapwing, oystercatcher grey partridge and corn bunting.

[16] The importance of biodiversity and wildlife on farmland | Business Wales (gov.wales)
[17] Final Report - The Economics of Biodiversity: The Dasgupta Review - GOV.UK (www.gov.uk)
[18] Does plantation forestry restore biodiversity or create green deserts? - Bremer, L., Farley, K.
[19] "Natural capital is the part of nature which directly or indirectly underpins value to people including ecosystems, species, freshwater, soils, minerals, the air and oceans, as well as natural processes and functions. … In combination with other types of capital, natural capital forms part of our wealth; that is, our ability to produce actual or potential goods and services into the future to support our wellbeing." Natural Capital Terminology (publishing.service.gov.uk)
[20] Scotland's Natural Capital Asset Index - 2019 Update summary.pdf (nature.scot)

**Summary of long and short term trends for bird species on farmland in Scotland.**

| Species | Long-term trend | Short-term trend |
|---|---|---|
| Common snipe | Increase | Increase |
| Curlew | Decrease | Decrease |
| Lapwing | Decrease | Decrease |
| Oystercatcher | Decrease | Decrease (slowing) |
| Redshank | Decrease | Decrease (slowing) |
| Linnet | Increase | Stable |
| Skylark | Stable | Decrease (accelerating) |
| Tree sparrow | Increase | Increase |
| Yellowhammer | Stable | Increase |
| Corn bunting | Decrease | Increase |

Long-term changes in Scottish and UK farmland bird populations have been driven by many factors including intensification, reduced crop type diversity within farms and reduced spring-sown crops[21]. Pesticide use removes weed and insect food sources for birds, either directly or through the food chain and has also contributed to decline.[22] Agri-environment schemes have been in Scotland for around two decades, helping reverse impacts with results varying between species.

There are also concerns on declining populations of formerly widespread plants like cornflower and corn marigold and insects like butterflies and bumblebees on arable land.

Pollinators play an essential role in plant reproduction and ecosystem functions, and there are currently large worrying declines in their populations. The value of insect pollinators for crops has been estimated at £400 million p.a. in the UK[23]. The European Court of Auditors have found that EU measures did not ensure protection of wild pollinators, and key EU policies, including the CAP, do not include specific requirement to protect wild pollinators.

2.3.1.2 What is the relationship between arable farming and biodiversity?

State of Nature in Scotland 2019 shows changes in farmland management in the past 50 years to have the greatest impact on nature include increased pesticides and fertilizer use, continuous cropping, changed sowing seasons and non-cropped habitat loss. Changes in food production patterns can cause invertebrate declines. Conversion to more intensive agriculture and agrochemical pollutants are key drivers.

Arable farming can support wildlife and agri-environment schemes aim to encourage this. Birds require winter food and shelter, sites for nesting and food supply through the summer[24]. Approaches can be particularly successful when management interventions at a field level target specific species e.g. corn buntings in Eastern Scotland[25].

Some of the options that appear to be most successful in terms of uptake include:

- Retention of winter stubbles for wildlife and water quality – which is supporting seed-eating birds helping maintain a stable trend for these birds[26]
- Stubbles followed by green manure – supporting birds and pollinators
- Wader grazed and mown grassland options – supporting waders, and other wildlife.

[21] https://www.nature.scot/official-statistics-terrestrial-breeding-birds-1994-2019
[22] *A review of evidence Is reported in* Wilson, J.D., Evans, A.D. & Grice, P.V. (2009) *Bird conservation and agriculture*.
[23] POST (2010) Insect Pollination, London
[24] Managing Arable Farmland for Wildlife
[25] Adaptive management and targeting of agri-environment schemes does benefit biodiversity: a case study of the corn bunting Emberiza calandra - Perkins - 2011 - Journal of Applied Ecology - Wiley Online Library
[26] Hancock, M.H. & Wilson, J.D. (2003) 'Winter habitat associations of seed-eating passerines', *Bird Study*, Vol 50, 116-130

Arable fields can host thousands of species of insects and spiders. Some will be pests but others are natural predators of these pests, pollinators or can assist in the breakdown of organic matter. They are also a food source of some birds, bats, other mammals and amphibians. The balance between all these arthropods species is out of kilter in lots of our farmland, with knock on effects higher up the food chain, and for the farm business.

Hedgerows provide habitat for birds, butterflies, insects and small mammals, with 130 priority Biodiversity Action Plan species known to be associated with hedgerows[27] [28].

Field margins are strips of land, such as a hedge, between the field boundary and the crop. There is a body of evidence identifying their multiple benefits[29]. They can provide semi-natural habitat, areas for wild plants, for feeding, shelter and nesting for wildlife. Flower-rich field margins can encourage pollinators for crops and predators of pests. Buffers also help reduce the effects of runoff and soil erosion from farming operations. They can provide corridors across the landscape, linking other areas of wildlife habitat. Field margins can be left to naturally regenerate, as crop edges without herbicide or insecticide application, or cultivated and managed as margins to deliver particular benefits. Mowing or cutting at the end of the growing season can help maintain diversity of flowers[30].

Water Margins are essential to prevent soil erosion and the transfer of pollutants to watercourses. Direct run-off, leaching and spray drift can lead to pollutants, sediment, pesticides entering water courses and negatively impact water quality. Vegetation at the water margin can contribute to water quality and biodiversity[31] [32].

NatureScot has a project working with clusters of farmers and crofters to test outcome based innovative approaches to supporting biodiversity for environmental outcomes. Two of the pilots are in East Lothian (focused on hedgerow restoration) and in Strathspey (waders)[33].

Other good examples can be seen at:

- **Strategic Cereal Farm Scotland**, a research project with Balbirnie Home Farm on reducing synthetic inputs on-farm and improving soil guided by regenerative principles - cover crops, min till and livestock integration. It uses soil and plant health metrics to direct inputs via diverse rotations, including field veg, potatoes and cattle.
- **Farming and Nature –** Whitmuir Estate case study
- **Sustainable Cropping Systems**: Both JHI and SRUC have undertaken significant research, e.g. JHI is running a project on the use of legumes with cereals[34]
- The Burren (Ireland) was the first to test payments by results. This is an agri-environmental programme that aims to conserve and support heritage, environment and its communities. The Burren focusses on management of species rich grassland and key indicator species/habitats.
- **Corn Bunting Recovery** - collaborative efforts by local farmers and estates in Angus and Fife using targeted greening and agri-environmental measures has helped the recovery of a threatened species with record breaking increases and expansion of

[27] See for example http://www.hedgelink.org.uk/wildlife-and-hedgerows.htm
[28] R. Wolton (2009) *UK Biodiversity Action Plan: Priority species linked to hedgerows, A report to Hedgelink*
[29] *Multifunctional Role of Field Margins in Arable Farming (2014) Hackett M, Lawrence A – ADAS UK*
[30] Field margins – Wildlife and Farming
[31] WAT-SG-44 (sepa.org.uk)
[32] Cole L et al; *(2015) Riparian buffer strips: their role in the conservation of insect pollinators in intensive grassland systems*
[33] For more information see https://www.nature.scot/piloting-outcomes-based-approach-scotland-pobas-project
[34] Agroecology | Ecological Sciences | Research | The James Hutton Institute

the range. Management practices have included delayed mowing and fallows to protect nests and use of a corn bunting mix (including clover, legumes and cereal). [35]

- **SEAMs** (Sustainability in Education and Agriculture using Mixtures) project is developing a network of field sites across the main arable food production areas of Scotland. These sites are trialling crop mixtures, providing information on how to tailor the use of crop mixtures to different locations in Scotland. They provide a platform for knowledge exchange and learning. The sites are working farms spread across Scotland and the project is taking a participatory approach. More info here
- Durie Farm – Leven, Fife; an example of a farm's agroecological transition[36].

[35] https://www.rspb.org.uk/about-the-rspb/about-us/media-centre/press-releases/prophesies-proven-correct-after-great-year-for-one-of-scotlands-fastest-declining-birds/
[36] Agroecological Transitions - Durie Farms.pdf (nature.scot)

# 3 Performance and Productivity

## 3.1 Key Metrics for Performance and Productivity

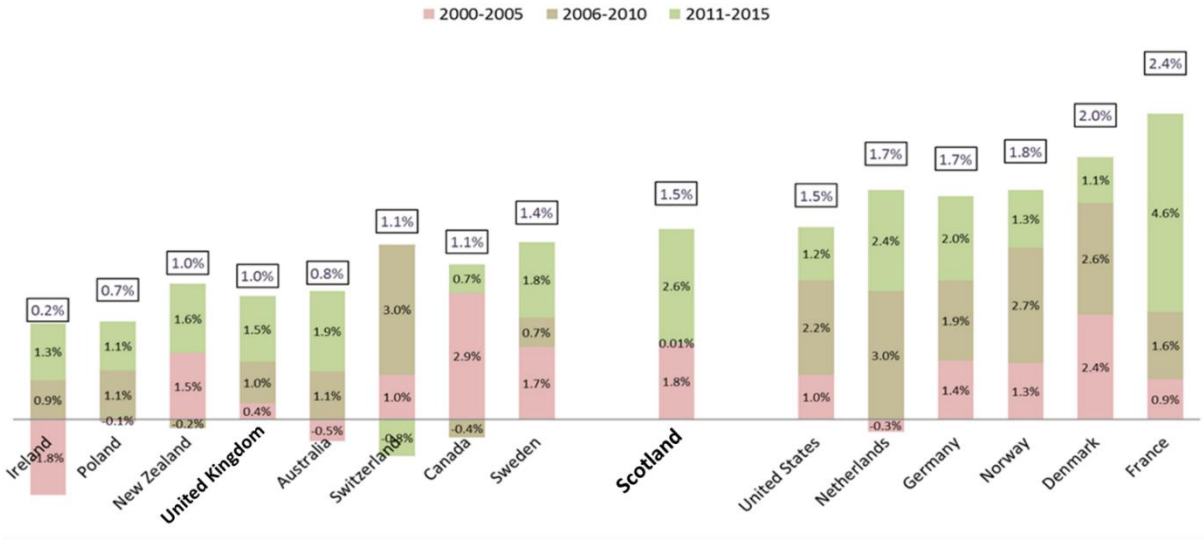
### 3.1.1 Total Factor Productivity

Productivity refers to the efficiency of production. One method of quantifying productivity commonly used is Total Factor Productivity (TFP). This looks at an industry's overall efficiency in converting all of its inputs into all of its outputs, and is usually presented in terms of TFP growth over time.

Productivity is a key measure of sustainable growth, and growth in productivity is usually assumed to be related to the increase and adoption of new technology. In the case of agriculture, low productivity means more inputs per unit of output, which may lead to higher pollution, lower wages and lower farm incomes.

SRUC's Boosting Productivity Growth in Scottish Agriculture report assesses productivity of agriculture in Scotland and elsewhere. Since 2000, agricultural productivity has been growing, with average annual growth of 1.5%. Scottish agricultural productivity appears to have had stronger growth than UK agricultural productivity overall. However, it is important to note that this is from a fairly low base.

Average annual growth in agricultural productivity by selected countries, 2000 to 2015




Source: Boosting Productivity Growth in Scottish Agriculture

The chart above shows international estimates of agricultural productivity growth, with variation over time. Scotland appears to sit around the middle of international rankings of agricultural productivity growth. It is important to note that the Scottish Government uses data from the census to calculate agricultural TFP internally, whereas TFP growth for the other countries is based on data published by the United States Department of Agriculture (USDA). Therefore, this comparison should be viewed with some caution.

In the case of agriculture, productivity can be heavily impacted by factors such as land quality, weather conditions and outbreaks of crop and livestock diseases. There are

challenges to supporting agricultural productivity in Scotland, particularly around land and weather disadvantages, and lack of adoption of new and existing technologies.

There is wide variation in performance between farm types and within farms types in Scotland, as shown below. There are clear differences in TFP between farm type and between time periods, with cereals showing the strongest TFP growth in recent years.

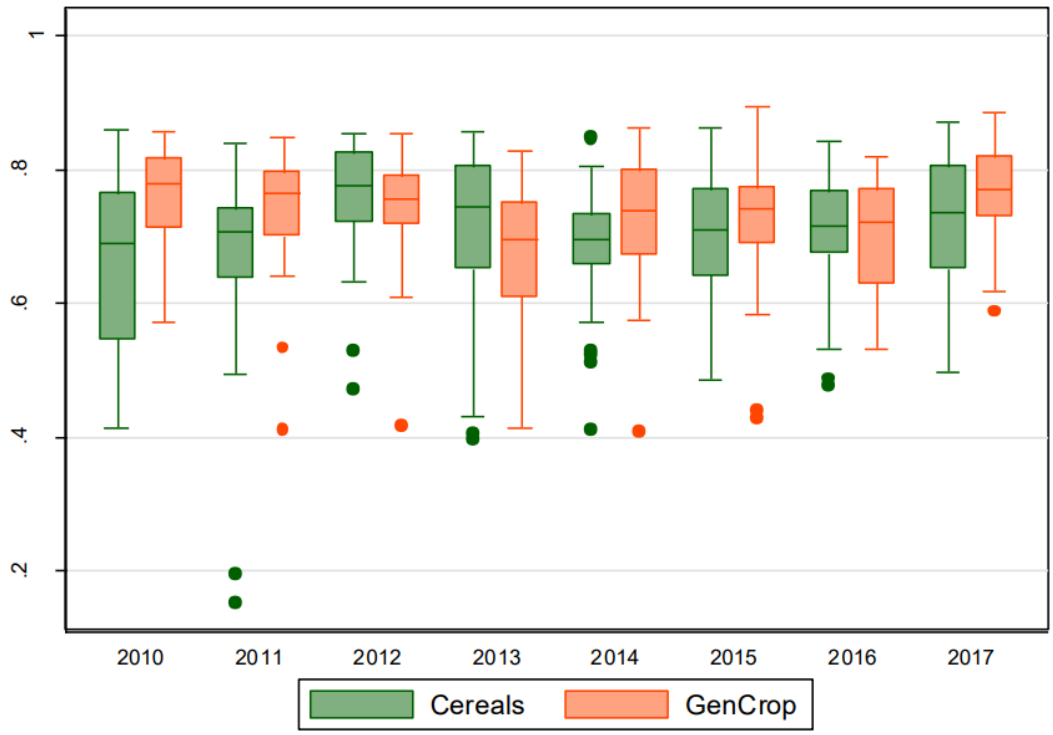
**Table 9. Total Factor Productivity Growth by Sector**

| | Cereals | General Cropping | LFA Cattle and Sheep | LFA Sheep | LFA Cattle | Dairy |
|---|---|---|---|---|---|---|
| 2000-05 | -0.2% | -0.7% | -0.2% | +0.4% | +0.1% | -0.1% |
| 2006-10 | -1.4% | +1.0% | +0.9% | +0.6% | +0.1% | +1.3% |
| 2011-17 | +1.2% | +0.7% | -0.3% | -0.1% | -0.8% | -2.1% |

*Source: SRUC, Boosting Productivity Growth in Scottish Agriculture, April 2020*

Performance within the Cereals and General Cropping farm types also fluctuates over the years, with Cereals showing the highest volatility and range in economic efficiency (a farm-level measure of productivity[37]). This is potentially due to their specialisation within specific crops and vulnerability to global market prices and weather variances.

**Economic Efficiency of Cropping Farm Types, 2010-2017**




*Adapted from SRUC, Boosting Productivity Growth in Scottish Agriculture, April 2020, p. 5.*

[37] A measure which combines technical efficiency (the rate of physical output to physical input) and allocative efficiency (the rate at which costs are minimised). This provides an analogue to TFP at a sectoral level.

## 3.2 Options for Improving Performance

SRUC's Boosting Productivity Growth in Scottish Agriculture report provides a high level summary of a long list of measures which would potentially increase productivity in Scottish farming broadly covering approaches to information sharing, financial schemes and management changes. Information sharing covers, for example, knowledge exchange, education and implementation. Financial schemes covers positive and negative effects of support and grant schemes. Further details on these can be found in Annex E. It should be noted that there are limits and caveats to both uptake and effectiveness of these measures and the report was not specifically targeted at the arable sector.

The SRUC report highlights that in Scotland there is generally a low uptake of current, mainstream technologies and techniques. One of the main technologies to have potential to affect agricultural production in developed countries is the concept of SMART farming and interconnectivity of machinery with data gathering and analysis for decision making. Precision Agricultural Technologies (PATs) represent a suite of technologies and approaches that reduce variability at the field or herd level. This provides a holistic system approach to managing spatial and temporal variability to increase profitability, optimize yield and quality, and reduce costs and environmental impact.

### 3.2.1 Current Uptake

SRUC highlighted, in the same report, that the bulk of adoption among the surveyed Scottish cereal and potato producers is on machine guidance and variable rate systems. Both have been found, in multiple farm studies, to reduce fuel use and management time if used optimally. However, issues have been identified around the appropriate level of training of farmers to operate PATs needed to raise returns and productivity to noticeable levels. Further options, such as nutrient management, soil nutrient mapping, improved soil management, changing cereal yields, and varietal uptake, have also been shown to improve yields. These are covered in Annex E.

The Scottish Survey of Farm Structure and Methods (2016) collected information on, for example, tillage methods, soil conservation, manure application, manure storage, and irrigation. While not all of the below measures directly increase yield, they may improve efficiency, decrease GHG emissions, and/or improve biodiversity, which will result in indirect increases in yields. Many of the measures below, including tillage methods, nutrient management and slurry methods are also covered across many of the GHG mitigation measures listed in Section 2.2 confirming that many of the GHG measures could also result in financial gains.

#### 3.2.1.1 Tillage methods

More intensive tillage systems, such as conventional ploughing, leave low levels of crop residue cover, whereas reduced tillage methods leave about 30% or more residue cover. These residues reduce the amount of soil erosion, soil compaction and fuel consumption. Reduced tillage or no-till systems will also increase levels of soil organic carbon, and may result in lower direct carbon emissions from the soil (see e.g. Table 7 on page 15).

In 2015/16, conventional inversion tillage was used on the majority of land (90%), with reduced, conservation tillage on 6% of land.

#### 3.2.1.2 Winter soil cover

Maintaining soil cover over the winter is a practice aimed at reducing soil erosion and the loss of particulate pollutants (e.g. plant protection products and faecal microbes), in addition to contributing to the amount of organic matter in the soil. The survey asked about coverage of land sown/cultivated over the preceding winter (i.e. winter 2015/16), including if the soil had been left bare.

In 2015/16, 42% of respondents said that they had sown or cultivated autumn or winter crops over the winter, while a further 42% said they had sown or cultivated plant residues or stubble. A small proportion (3%) said that they had sown or cultivated cover or immediate crop, while 13% had left their soil bare over winter.

#### 3.2.1.3 Crop rotation

Crop rotation is the practice of alternating crops grown on a specific field each year in a planned pattern or sequence. The proportion of arable land not included in a holding's crop rotation is intended to give an indication of the degree to which monoculture is undertaken. The use of monoculture is also linked to environmental disadvantages and can have adverse effects on the productive capacity of the land. Crop rotation can also result in potential emission savings, as shown in Table 7.

In 2015/16, over half (54%) of holdings with arable land included all their land in general crop rotation, and a further 19% left out only 0-25% of their arable land.

#### 3.2.1.4 Irrigation

Finding suitable sources of water for irrigation is a major problem in many countries in Europe, and is becoming more of an issue in Scotland in some eastern areas. Additionally, inefficient and unplanned use of irrigation can lead to over-wet soils which can affect yields and lead to leaching of nutrients. The use of monoculture is also linked to environmental disadvantages and can have adverse effects on the productive capacity of the land.

It was reported that a total of 94,000 hectares of land (2% of the crops and grass in the survey) could be irrigated using the equipment and the quantity of water normally available at the location.

Just under 2,000 holdings with crops (just under a fifth of all holdings with crops) had undertaken irrigation in the twelve months up to March 2016, over an area of 26,000 hectares (just under 5% of crop area).

#### 3.2.1.5 Nutrient Management

In 2015/16, 17% of holdings with grassland had carried out a nutrient management plan on their grassland, and 42% of holdings had carried out a nutrient management plan on their other land. Nearly a third of holdings with grassland had carried out pH testing on their grassland, while 64% of holdings had carried out pH testing on their other land.

Of those with temporary grassland, 16% of holdings reported that some of it was sown with a 'low n variety mix', such as red clover. The area sown accounted for 21% of grassland on surveyed holdings.

Much like reduced tillage and crop rotation, improved soil management can also result in potential emission savings (again, shown in Table 7).

#### 3.2.1.6 Manure and Slurry

Immediate incorporation of manure and slurry, following application onto fields, can reduce environmentally harmful ammonia emissions, and preserves nitrogen in the soil. A threshold of four hours from the time of application to manure and slurry being ploughed in, along with immediate injection of slurry, is used to define immediate incorporation. In 2015/16, 29% of holdings reported applying manure of slurry on their land. There were 12 million tonnes broadcast, of which 3% was ploughed in within four hours. There was a further 5 million tonnes applied with a bandspread, and a further 0.6 million 600,000 tonnes injected.

### 3.2.2 Farm Advisory Service

Initiatives like the Farm Advisory Service (FAS) can provide a link between national policy and individual farmers, which can then translate the goals of policy into concrete actions. The FAS 'One to Many' service was procured by Scottish Government as part of the broader Scottish Rural Development Programme (SRDP) 2014-2020, and sought to improve the business and environmental performance of Scottish Agriculture through the provision of advice. There is clear evidence that the FAS One to Many service delivered a wide-ranging programme, which appears to be well regarded by those who use it, as outlined in the recent Farm Advisory Service - One to Many: evaluation. However, this evaluation also demonstrated that FAS impacts are hard to measure. At present there is limited data about the extent of engagement with the programme, and limited monitoring of on-farm improvements resulting from that engagement. To ensure that the FAS can support policy delivery in the ways envisaged in this report, this gap will need to be addressed.

# Annex A – Definitions and Classifications of Farms

## Definitions

| | |
|---|---|
| **Farm Business Income (FBI)** | The total income available to all unpaid labour (farmers and spouses, non-principal partners and directors and their spouses and family workers) and on their capital invested in the farm business, including land and buildings. Income from diversified activities are included in overall FBI. |
| **Farm types** | Farms are classified based on the how much of their standard output is from the crop and livestock enterprises on each farm. |
| **Less Favoured Area (LFA)** | Land where farming is more difficult due to natural constraints, such as hills and soil quality. |
| **Standard Output** | The standard output of an enterprise is an estimate of the average output value for every unit of production. It is defined as the estimated worth of crops and livestock without taking into account the costs incurred in the process. |

### Classification of Farms

The classification is based on detailed sub-types as defined in the European Commission (EC) farm typology 2, which have been grouped together where required to give the types shown below. The classification is based on the relative importance of the various crop and livestock enterprises on each farm assessed in terms of standard output. The method of classifying each farm is to multiply the area of each crop (other than forage) and the average number of each category of livestock by the appropriate standard output, with the largest source of output determining the type of farm. The list below defines the main types that are reported in the Farm Business Survey.

- **Specialist Sheep (LFA)** – Farms in the less-favoured areas with more than two thirds of the total standard output coming from sheep.
- **Specialist Beef (LFA)** – Farms in the less-favoured areas with more than two thirds of the total standard output coming from cattle.
- **Cattle and Sheep (LFA)** – Farms in the less-favoured areas with more than two thirds of the total standard output coming from sheep and beef cattle together.
- **Cereals** – Farms where more than two-thirds of the total standard output comes from cereals and oilseeds.
- **General Cropping** – Other farms where more than two-thirds of the total standard output comes from all crops.
- **Dairy** – Farms where more than two-thirds of the total standard output comes from dairy cows.
- **Lowground Cattle and Sheep** – Farms NOT in the less-favoured areas with more than two-thirds of the total standard output coming from sheep and beef cattle.
- **Mixed** – Farms where no enterprise contributes more than two-thirds of the total standard output.

# Annex B – Tables

**Table B1: Crops, fallow, and set-aside land in Scotland and the United Kingdom, 2019**

| Category | Scotland | | United Kingdom | |
|---|---|---|---|---|
| | *Hectares* | *Proportion* | *Hectares* | *Proportion* |
| Wheat | 107,480 | 18.5% | 1,815,769 | 36.8% |
| Triticale | 533 | 0.1% | 13,036 | 0.3% |
| Barley: Winter | 48,802 | 8.4% | 452,713 | 9.2% |
| Spring | 242,090 | 41.8% | 709,513 | 14.4% |
| Oats (including mixed grain)(1) | 31,938 | 5.5% | 189,380 | 3.8% |
| Rye | 6,415 | 1.1% | : | : |
| Rape for oilseed (including linseed)(2) | 31,855 | 5.5% | 544,919 | 11.0% |
| Potatoes | 28,491 | 4.9% | 144,065 | 2.9% |
| Peas and beans for combining | 2,320 | 0.4% | : | : |
| Maize | 879 | 0.2% | 228,252 | 4.6% |
| Turnips, swedes and beet for stockfeeding | 4,794 | 0.8% | : | : |
| Other crops for stockfeeding(3) | 11,368 | 2.0% | 93,387 | 1.9% |
| Vegetables for human consumption | 18,635 | 3.2% | 114,548 | 2.3% |
| Orchard and soft fruit(4) | 2,165 | 0.4% | 2,165 | 0.0% |
| Bulbs, other flowers and nursery stock | 1,018 | 0.2% | 11,419 | 0.2% |
| All other crops(5) | 10,126 | 1.7% | 10,126 | 0.2% |
| Fallow land | 30,752 | 5.3% | 224,261 | 4.5% |
| **Total Crops, Fallow and Set-Aside:** | **579,661** | **100%** | **4,938,120** | **100%** |

(1) Includes rye for England and Wales and triticale for Wales.
(2) Figure for Scotland includes linseed.
(3) Includes lupins. England, Wales and Northern Ireland figures included turnips, swede and beet for stock feeding.
(4) Soft fruit includes fruit grown in greenhouses and plastic structures as well as fruit grown in the open
(5) Includes crops grown under cover for England, Wales and Northern Ireland. England figure includes sugar beet, flax and borage
: Information not available.

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

**Table B2. Number of specialist cropping, cereal or arable holdings by region, 2019**

| NUTS2 | Specialist General Cropping Farms | | Specialist Cereal Farms | | All Holdings with Arable Land | |
|---|---|---|---|---|---|---|
| | *Holdings* | *Arable Area (ha)* | *Holdings* | *Arable Area (ha)* | *Holdings* | *Arable Area (ha)* |
| North East Scotland | 257 | 24,859 | 896 | 55,182 | 2,716 | 148,594 |
| Eastern Scotland | 914 | 106,989 | 789 | 59,135 | 2,877 | 227,308 |
| Southern Scotland | 122 | 17,893 | 313 | 32,448 | 2,219 | 101,027 |
| Highlands & Islands | 345 | 16,209 | 342 | 17,053 | 3,565 | 68,728 |
| West Central Scotland | 9 | 362 | 23 | 1,160 | 146 | 3,251 |
| **Scotland** | 1,647 | 166,313 | 2,363 | 164,979 | 11,523 | 548,909 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

**Table B3. Number of specialist horticulture holdings and total arable area, by region, 2019**

| NUTS2 | Specialist Horticulture | | All Holdings with Arable Land | |
|---|---|---|---|---|
| | *Holdings* | *Arable Area (ha)* | *Holdings* | *Arable Area (ha)* |
| North East Scotland | 75 | 1,900 | 2,716 | 148,594 |
| Eastern Scotland | 182 | 10,295 | 2,877 | 227,308 |
| Southern Scotland | 96 | 178 | 2,219 | 101,027 |
| Highlands & Islands | 350 | 162 | 3,565 | 68,728 |
| West Central Scotland | 10 | 10 | 146 | 3,251 |
| **Scotland** | 713 | 12,546 | 11,523 | 548,909 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

**Table B4. Number of specialist cereal holdings by size and farm type, 2019**

| Farm Size (hectares) | Specialist Cereal Farms | | All Holdings with Arable Land | |
|---|---|---|---|---|
| | *Holdings* | *Area (hectares)* | *Holdings* | *Area (hectares)* |
| 0-<2 | 45 | 52 | 801 | 196 |
| 2-<5 | 155 | 454 | 791 | 793 |
| 5-<10 | 189 | 1,073 | 600 | 1,615 |
| 10-<20 | 223 | 2,335 | 671 | 3,858 |
| 20-<50 | 488 | 11,545 | 1,618 | 23,109 |
| 50-<100 | 501 | 26,462 | 2,199 | 70,477 |
| 100-<200 | 474 | 49,682 | 2,538 | 161,536 |
| 200 & over | 288 | 73,375 | 2,305 | 287,327 |
| **Total** | 2,363 | 164,979 | 11,523 | 548,909 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

**Table B5. Number of general cropping and area by farm size, 2019**

| Farm Size (hectares) | General Cropping Farms | | All Holdings with Arable Land | |
|---|---|---|---|---|
| | *Holdings* | *Area (hectares)* | *Holdings* | *Area (hectares)* |
| 0-<2 | 124 | 33 | 801 | 196 |
| 2-<5 | 81 | 76 | 791 | 793 |
| 5-<10 | 42 | 115 | 600 | 1,615 |
| 10-<20 | 45 | 467 | 671 | 3,858 |
| 20-<50 | 181 | 4,826 | 1,618 | 23,109 |
| 50-<100 | 364 | 19,909 | 2,199 | 70,477 |
| 100-<200 | 435 | 48,637 | 2,538 | 161,536 |
| 200 & over | 375 | 92,249 | 2,305 | 287,327 |
| **Total** | 1,647 | 166,313 | 11,523 | 548,909 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

**Table B6. Number of specialist horticulture and area by farm size, 2019**

| Farm Size (hectares) | Specialist horticulture Farms | | All Holdings with Arable Land | |
|---|---|---|---|---|
| | *Holdings* | *Area (hectares)* | *Holdings* | *Area (hectares)* |
| 0-<2 | 285 | 67 | 801 | 196 |
| 2-<5 | 198 | 111 | 791 | 793 |
| 5-<10 | 70 | 80 | 600 | 1,615 |
| 10-<20 | 43 | 176 | 671 | 3,858 |
| 20-<50 | 28 | 352 | 1,618 | 23,109 |
| 50-<100 | 27 | 1,255 | 2,199 | 70,477 |
| 100-<200 | 35 | 4,301 | 2,538 | 161,536 |
| 200 & over | 27 | 6,204 | 2,305 | 287,327 |
| **Total** | 713 | 12,546 | 11,523 | 548,909 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

**Table B7. Agricultural workforce on specialist cereal farms 2019**

| Category | Specialist Cereal Farms | | All Holdings with Arable Land | |
|---|---|---|---|---|
| | *Holdings* | *Workforce* | *Holdings* | *Workforce* |
| Occupiers and spouses working more than half time | 839 | 987 | 6,260 | 7,780 |
| Occupiers and spouses working less than half time | 728 | 857 | 4,342 | 5,286 |
| Full-time employees | 460 | 879 | 3,542 | 8,452 |
| Part-time employees | 321 | 491 | 2,271 | 3,646 |
| Casual and seasonal workers | 135 | 255 | 1,138 | 6,375 |
| **Total workforce** | 1,481 | 3,469 | 9,217 | 31,539 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

**Table B8. Agricultural workforce on general cropping farms 2019**

| Category | General Cropping Farms | | All Holdings with Arable Land | |
|---|---|---|---|---|
| | *Holdings* | *Workforce* | *Holdings* | *Workforce* |
| Occupiers and spouses working more than half time | 820 | 980 | 6,260 | 7,780 |
| Occupiers and spouses working less than half time | 612 | 718 | 4,342 | 5,286 |
| Full-time employees | 522 | 1,222 | 3,542 | 8,452 |
| Part-time employees | 313 | 481 | 2,271 | 3,646 |
| Casual and seasonal workers | 165 | 415 | 1,138 | 6,375 |
| **Total workforce** | 1,267 | 3,816 | 9,217 | 31,539 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

**Table B9. Agricultural workforce on horticulture farms 2019**

| Category | Specialist horticulture farms | All Holdings with Arable Land |
|---|---|---|

| | *Holdings* | *Workforce* | *Holdings* | *Workforce* |
|---|---|---|---|---|
| Occupiers and spouses working more than half time | 266 | 379 | 6,260 | 7,780 |
| Occupiers and spouses working less than half time | 280 | 395 | 4,342 | 5,286 |
| Full-time employees | 126 | 1,012 | 3,542 | 8,452 |
| Part-time employees | 91 | 264 | 2,271 | 3,646 |
| Casual and seasonal workers | 79 | 4,090 | 1,138 | 6,375 |
| **Total workforce** | 513 | 6,140 | 9,217 | 31,539 |

*Source: June Agricultural Census 2020, via RESAS Agricultural Analysis Unit*

# Annex C – GHG Inventory Assumptions

Sources in the inventory have been attributed based on the following percentages:

**Table C1. Emission source attribution**

| IPCC | SourceName | Crops | Dairy | Deer | Goats | Horses | Beef | Pigs | Sheep |
|---|---|---|---|---|---|---|---|---|---|
| 3H_Urea_application | Fertiliser Application | 80% | 10% | | | | 10% | | |
| 1A4cii_Agriculture/ Forestry/Fishing:Off-road | Agriculture - mobile machinery | 60% | 20% | | | | 20% | | |
| 3A4_Enteric_Fermentati on _other_livestock | Enteric | | | 7% | 1% | 67% | | 25% | |
| 3D11_Inorganic_nitrogen _fertilizers | Grass - Direct | | 30% | | | | 60% | | 10% |
| 3D14_Crop_residues | Grass - Direct | | 30% | | | | 60% | | 10% |
| 3G1_Liming - limestone | Liming | 50% | 15% | | | | 30% | | 5% |
| 3G2_Liming - dolomite | Liming | 50% | 15% | | | | 30% | | 5% |

*Michael MacLeod, Ilkka Leinonen and Vera Eory (2018) Biotic material flows in Scottish cattle supply chains SRUC 10/4/18*

This results in the following estimates of GHG emissions for agriculture in 2018:

**Table C2. Estimates of GHG emissions for agriculture, 2018**

| Agricultural Sector | Emissions in Inventory | Attributed based on expert input | Proportion attributed |
|---|---|---|---|
| | $MtCO_2e$ | $MtCO_2e$ | % |
| Beef | 2.97 | 0.47 | 16 |
| Arable/Crops | 1.02 | 0.59 | 58 |
| Dairy | 0.86 | 0.31 | 36 |
| Sheep | 0.99 | 0.05 | 5 |
| Other livestock | 0.20 | .. | .. |
| Uncategorised | 0.02 | .. | .. |

**Table C3. Further Breakdown of GHG emissions from the arable sector in the Inventory, 2018**

| IPCC | Sector | Attribution | MtCO2e |
|---|---|---|---|
| **3D11 Inorganic N Fertilizers** | **Arable** | **Direct** | **0.218** |
| **3D14 Crop Residues** | **Arable** | **Direct** | **0.161** |
| **3D21 Atmospheric Deposition** | **Arable** | **Direct** | **0.009** |
| **3D22 Nitrogen Leaching and Run-off** | **Arable** | **Direct** | **0.105** |
| **3D22 Nitrogen Leaching and Run-off** | **Crops** | **Direct** | **0.060** |
| **1A4ci_Agriculture/Forestry/Fishing:Stationary** | **Crops** | **Direct** | **0.036** |
| **1A4cii_Agriculture/Forestry/Fishing:Off-road** | **Crops** | **Attributed** | **0.462** |
| **2D1_Lubricant_Use** | **Crops** | **Direct** | **0.000** |
| **3D15 Mineralisation/immobilisation associated with loss/gain of soil organic matter** | **Crops** | **Direct** | **0.195** |
| **3D16 Cultivation of Organic soils** | **Crops** | **Direct** | **0.239** |
| **3G1_Liming - limestone** | **Crops** | **Attributed** | **0.059** |
| **3G2_Liming - dolomite** | **Crops** | **Attributed** | **0.049** |
| **3H Urea Application** | **Crops** | **Attributed** | **0.020** |

# Annex D – CXC Measures for the Arable Sector

This annex contains an extract of mitigation measures from the CXC (2020) report that are specific to the arable sector(s).

## Growing more grain legumes in rotations

Legumes (e.g. peas, beans, clover) have the special ability to source nitrogen straight from the dinitrogen gas found in the atmosphere, requiring very low (or no) additional nitrogen fertilisers. This is possible due to their symbiotic relationships with bacteria in the soil. They also provide some of this nitrogen to crops which are cultivated with them and also to those which follow them in a rotation (as the above ground residues and roots of the leguminous crops increase the nitrogen content of the soil), reducing the fertiliser requirement for those crops. This measure is about increasing the area of grain legumes in rotations in Scotland.

The description, assumptions and results in the UK MACC report of 2015 (Eory et al. 2015) was used for this measure.

### Overview

N fixing crops (legumes) form symbiotic relationships with bacteria in the soil that allows them to fix atmospheric N and use this in place of N provided by synthetic fertilisers. This measure is about increasing the area of grain legumes in arable rotations, thereby reducing N fertiliser use in two ways: by requiring no N fertiliser (so there will be a reduction per ha equivalent to the N fertiliser which would have been applied to the non-leguminous crop that would otherwise have been grown); and by having a residual N fertilising effect so that the crops grown after legumes require less N than when grown after non-legumes (Defra 2011).

### Greenhouse gas mitigation summary

Grain legumes are able to fix in excess of 300 kg N $ha^{-1}$ $y^{-1}$; can supply N to subsequent crops; are valuable as a break crops in arable rotations; and can provide biodiversity benefits (Rees et al. 2014). The abatement achievable is due to the change in crop areas (i.e. replacement of other arable crops with grain legumes in the rotation and applying no fertiliser on them) and a reduction in N fertiliser use of 30 kg $ha^{-1}$ on the subsequent crop (Defra 2011).

**Table D1. Data from literature on abatement**

| Abatement | Value | Country | Reference |
|---|---|---|---|
| **N use** | -0.5 t $CO_2e$ $ha^{-1}$ of soil nitrous oxide emissions | UK | (Moran et al. 2008) |
| **N use** | -0.5 t $CO_2e$ $ha^{-1}$ of soil nitrous oxide emissions | UK | (MacLeod et al. 2010) |
| **N use** | No fertiliser on the legume, -33 kg N $ha^{-1}$ on the following crop; i.e. -0.64 t $CO_2e$ $ha^{-1}$ where legumes introduced (not rotation average) | France | (Pellerin et al. 2013) |

### Costs

We estimated the cost of this measure from the difference of the gross margin in grain legumes (field beans and peas £380 $ha^{-1}$, (SAC 2013)) and other crops (weighted average:

£809 ha-1, (SAC 2013). The fertiliser savings from the reduced fertilisation of the following crop is accounted for as benefit ( £23.55 ha 1). The net cost is in high contrast with the only data found in the literature, which estimates the net costs as £13.6 ha-1 for the area where legumes are introduced (Pellerin et al. 2013). This estimate consists of savings in fertilisers and their applications, elimination of tillage operation for the following crop, and changes in the gross margins of the rotations.

### Current uptake and maximum additional future uptake

The frequency of legumes in the rotation depends on different factors according to the nature of the legume. For example, peas are grown only one year in five due to the need to reduce the risk of disease. This is less of a concern for field beans but these are harvested late and delay sowing, and hence yield, of any subsequent cereal crop. Therefore, in practice, beans are also only likely to be grown once in every 5 years. The inclusion of peas and beans in rotations including oilseed rape is limited to once in every six years, due to disease risk. Peas are unsuitable for 'heavy' soils (effectively clay loam and heavier), while beans are unsuited to light soils (sandy loam and equivalents). Therefore, we limited the applicability of the grain legumes to 1/6 of the total arable crop area in any given year.
In 2016, field beans and peas and peas and beans for human consumption were grown on 3,100 ha and 9,300 ha (0.7% and 1.7% of the arable crop area, respectively) in Scotland. Although we assumed the introduction of Greening measures in the Common Agricultural Policy increases the area where field beans and peas are cultivated to 5% of the arable area, this increase is not included in the future reference scenario, but included in the abatement of this measure.

### Assumptions used in the MACC

**Table D2. Assumptions used in the modelling**

| Parameter | Change in value |
|---|---|
| **N fertiliser use on subsequent crop** | -30 kg N $ha^{-1}$ |
| **Cost (difference in gross margin between field beans and peas and other crops)** | £429 $ha^{-1}$ |

## Crop varieties with higher nitrogen-use efficiency

Nitrogen fertilisation is essential to achieve current yields of most crops. However, only 49% of the nitrogen applied to and biologically fixed by crops (including grass) is recovered as food and feed in Europe (Westhoek et al. 2015), most of the remaining being lost to the environment as ammonia, nitrate and nitrous oxide, causing multiple environmental problems. Crops need nitrogen for their growth, but due to the nature of biophysical processes they can utilise only part of the nitrogen which is in the soil. Improving the efficiency of crops to utilise the nitrogen fertiliser is therefore key in mitigating emissions as well as reducing the economic loss as unrecovered nitrogen. Plant breeding can contribute to improving the nitrogen-use efficiency. Nitrogen-use efficiency varies between individual plants of the same species, and some of this variation is heritable. Therefore, plants with increased nitrogen-use efficiency can be selected for further breeding. Additionally, radically new cultivars can improve nitrogen-use efficiency and thus reduce GHG emissions or at least the emission intensity of production. For example, perennial wheat can help retain

more carbon in the soil as well as reduce fertiliser, pesticide, and fuel use. Nitrogen-fixing cereals, for which three main research streams are ongoing, could, when realised, bring substantial reduction in the nitrogen-fertilisation needs of plants. However, due to data limitations, these mitigation measures only look at possible improvements in existing cultivars.

### Overview

Nitrogen fertilisation is essential to achieve current yields of most crops. However, only 49% of the nitrogen applied to and biologically fixed by crops (including grass) is recovered as food and feed in Europe (Westhoek et al. 2015), most of the remaining being lost to the environment as ammonia, nitrate and nitrous oxide, causing multiple environmental problems.

Improving the efficiency of crops to utilise the nitrogen fertiliser is therefore key in mitigating emissions as well as reducing the economic loss of unrecovered nitrogen. Nitrogen-use efficiency (NUE) is defined as yield per unit of nitrogen available to the crop (Moll et al. 1982). Barraclough et al. (2010) demonstrated that season and nitrogen input had a significant effect on NUE, but crop variety choice also contributed to NUE variation. It has been proposed that NUE can be improved both via adopting crop, soil and fertiliser management practices and through plant breeding (Barraclough et al. 2010; Hawkesford 2014; Hawkesford 2017; Sylvester-Bradley & Kindred 2009). The latter is possible as NUE varies between plants and some of this variation is linked to phenotypic traits and genotypic markers (Bingham et al. 2012). This variation can be as much as threefold (from 27 to 77 kg DM (kg N)-1), as Barraclough et al. (Barraclough et al. 2010) found in wheat varieties from four different European countries.

Additionally, radically new cultivars can improve NUE and reduce GHG emissions. For example, perennial wheat can help retain more C in the soil as well as reduce fertiliser, pesticide and fuel use (Bell et al. 2008). Nitrogen-fixing cereals (for which three main research streams are ongoing, targeting nodule development, identification of nitrogen-fixing biofertilisers and the introduction of nitrogenase enzyme and pathway into the plant (Beatty & Good 2011)) could, when realised, bring substantial reduction in the nitrogen fertilisation needs of plants.

Breeding for improved NUE can target both the efficiency of nitrogen uptake and nitrogen utilisation in the plant; as these are different physiological processes they are genetically independent, raising the potential for parallel gains (Hawkesford 2014). However, such breeding needs to consider potential trade-offs with other desirable traits; for example, the root system can be modified to increase the uptake of subsoil nitrate, but this adversely affects the uptake of phosphate from the topsoil (Bingham et al. 2012; Ho et al. 2005). Despite the yield plateau of the last two decades (Knight et al. 2012), most of the experimental studies which have looked at the improvements in NUE of different varieties of the same crop concluded that there has been a continuous improvement in NUE in the past decades. The economics of grain price and fertiliser costs are two potential causes of the yield plateau, resulting in stagnating nitrogen applications in the past two decades for newer varieties which require higher nitrogen rates to manifest their full yield improvement (Knight et al. 2012). This suggests that the improvement might continue as a baseline in the future, and there is scope to accelerate these gains. The assumption in this report is that these

improvements can be achieved faster and adopted on larger growing areas, given increased incentives to breeding companies to research and develop and to farmers to adopt such cultivars.

This mitigation measure examines using traditional breeding to improve NUE and considers three major crops in Scotland: wheat, barley and oilseed rape. The measure means cultivating varieties of already common crops in Scotland that have higher NUE than the currently common varieties.

### Greenhouse gas mitigation summary

The abatement rate is approximated from an estimate of the NUE or yield improvement, assuming that yields are kept constant and nitrogen application decreases to achieve the same yield. As the genetic gain in breeding is cumulative, the mitigation measure is assumed to have an annually increasing nitrogen-reduction effect (even though new cultivars with improved yields tend to require increasing nitrogen inputs (Foulkes et al. 1998; Knight et al. 2012)).

For wheat and oilseed rape, the gap between the improvements in new cultivars and the realisation of that on farms is 0.013 and 0.012 t ha-1 y-1, respectively, equivalent to 0.2% and 0.4% yield increase annually. The assumed annual nitrogen reduction is therefore 0.2% and 0.4% for these two crops, respectively. The barley annual NUE gain is 1.2%. If we assume that 80% of this gain is realised on farms, there is an additional potential improvement of 0.24% in the NUE. Thus, we assume an annual nitrogen reduction of 0.24%.

**Table D3. Data from literature on abatement**

| Abatement | Value | Country | Reference |
|---|---|---|---|
| **Wheat** | | | |
| **Yield** | +0.063 t $ha^{-1}$ $y^{-1}$ (cumulative) of new cultivars (~1%) | UK | (Knight et al. 2012) |
| **Yield** | +0.05 t $ha^{-1}$ $y^{-1}$ (cumulative) realised on farms | UK | (Knight et al. 2012) |
| **Yield** | +0.096 t $ha^{-1}$ $y^{-1}$ (cumulative) historically over 20 years (1969-1988) | UK | (Foulkes et al. 1998) |
| **NUE (kg grain N (kg N) $^{-1}$)** | +0.9% $y^{-1}$ historically over 20 years (1969-1988) | UK | (Foulkes et al. 1998) |
| | | | |
| **Yield** | +1% $y^{-1}$ (cumulative) historically over 75 years (1931-2005) | W Europe | (Bingham et al. 2012) |
| **NUE (kg yield DM (kg N) $^{-1}$)** | +1.2% $y^{-1}$ (cumulative) historically over 75 years (1931-2005) | W Europe | (Bingham et al. 2012) |
| | | | |
| **Yield** | +0.06 t $ha^{-1}$ $y^{-1}$ (cumulative) of new cultivars (~2%) | UK | (Knight et al. 2012) |
| **Yield** | +0.048 t $ha^{-1}$ (cumulative) realised on farms | UK | (Knight et al. 2012) |

### Costs

A price premium might have to be paid for varieties with improved NUE. We assume that other traits of the crops are not going to be adversely affected with the level of improvement set out above; therefore, no costs or benefits beyond the seed price premium and the nitrogen savings are included in the calculations. The seed price premium is estimated to be 10% of the price.

### Current uptake and maximum additional future uptake

The measure is in theory applicable to all crops, although here we considered only three major crops: wheat, barley, and oilseed rape. The current NUE of the common cultivars is regarded as the baseline, and thus the current uptake of this measure is assumed to be zero.

### Summary of assumptions used in the MACC

**Table D4. Assumptions used in the modelling**

| Parameter | Change in value |
|---|---|
| **N application** | -0.13% annually (cumulative) |
| **Crop yield** | No change |
| **Seed cost** | +10% |

## Intercropping

Intercropping is the spatially and temporally coexistence of two or more arable crops. Typically, one of the crops is a grain legume, and therefore biologically fixes nitrogen. Hence, there will be a reduction in the quantity of fertiliser applied per hectare. In addition, there is the potential for some of the fixed nitrogen to be transferred to the other crop, further reducing the requirement for inorganic nitrogen. However, the nitrogen concentration of legumes is higher than non-legume crops, thus the emissions from the residues will be increased. In the UK, the grain legume is typically pea or faba bean and the cereal is spring oats, spring barley or spring wheat. Although the technology is being developed to separate the cereal from the grain legume, intercrops are usually used as feed for ruminants or monogastrics. However, there will be the need to adjust the ration depending on the protein content of the actual harvested crop. It is assumed that the yield of the intercrop is similar to that of the sole cereal crop.

### Overview

Intercropping is the spatially and temporally coexistence of two or more arable crops. Typically, one of the crops is a grain legume, and therefore biologically fixes nitrogen. Hence, there will be a reduction in the quantity of fertiliser applied per hectare. In addition, there is the potential for some of the fixed nitrogen to be transferred to the other crop, further reducing the requirement for inorganic nitrogen. However, the nitrogen concentration of legumes is higher than non-legume crops; thus the emissions from the residues will be increased. In the UK, the grain legume is typically pea or faba bean and the cereal is spring oats, spring barley or spring wheat. Although the technology is being developed to separate the cereal from the grain legume, intercrops are usually used as feed for ruminants or

monogastrics. However, there will be the need to adjust the ration depending on the protein content of the actual harvested crop. It is assumed that the yield of the intercrop is similar to that of the sole cereal crop.

### Greenhouse gas mitigation summary

The mitigation arises due to the reduction in inorganic fertiliser applications. In addition, there is the potential for a reduction in fuel use as there will be a reduction in the number of tractor passes due to a reduction in the number of fertiliser applications. There will be an increase in the nitrous oxide emissions from the residues due to the higher nitrogen concentration of the legume relative to the cereal.

As a result of the legume component of the intercrop, it is assumed that the inorganic fertiliser input is approximately halved (SAC 2018). It is assumed that this measure is only applicable to the spring barley and oat area that is used for feed. Based on spring barley and spring oat area, and IPCC (2006), it is assumed that the N contained in the residue will increase by 40%.

### Costs

Pea seed is approximately 50% more expensive than barley seed (SAC 2018). Assuming a replacement rate seed mixture, the costs of the seeds will be three times higher than for a pure barley crop.

### Current uptake and maximum additional future uptake

The measure is applicable to the area sown for feed production. The crop can be harvested as either whole crop silage or grain. Based on reported figures (Scottish Government 2018b), the tonnage used for feed is 50% of the barley crop, which equates to 43% of the spring barley area. In the case of oats, 30% was used for feed. Therefore, the applicability is 43% of winter and spring oat, and 100% of spring non-malting barley.

There is increasing interest in growing intercrops. However, there are no reported figures on current uptake. It has been assumed that this measure is applicable to intercrops that are grown for feed. As the technology improves, there is the potential for the grain to be separated and therefore used for human consumption. However, for this to be common practice, there is the need for the market to accept products that have been grown as intercrops as opposed to pure stands.

### Assumptions used in the MACC

**Table D5. Assumptions used in the modelling**

| Parameter | Change in value |
|---|---|
| **N application rate** | -50% |
| **Residue returns (N)** | +40% |
| **Energy $CO_2$** | Reduction in 1 tractor pass: -1.57 l $ha^{-1}$ (@2.594 kg $CO_2e$ $l^{-1}$) |
| **Seed costs** | +200% (+£150 $ha^{-1}$) |

## Nitrification and urease inhibitors

Nitrous oxide emissions from soils are a result of bacteria transforming nitrogen compounds (such as those applied as fertilisers) and in the meantime releasing some of the nitrogen as nitrous oxide. One of these processes, nitrification, can be slowed down by certain chemical compounds (like dicyandiamide (DCD), 3,4-dimethyl pyrazole phosphate (DMPP) and nitrapyrin), which depress the activity of nitrifying bacteria. This, in turn, improves the availability of the nitrogen fertiliser for the plants and reduces both nitrous oxide emissions and nitrate leaching (however, in some cases it can increase ammonia and hence indirect nitrous oxide emissions). Furthermore, a large proportion of the nitrogen in urea-based fertilisers gets transformed into ammonia and, due to the urease enzyme, released by soil bacteria. This leads not only to ammonia (and indirect nitrous oxide) emissions but reduces the nitrogen plants can utilise. Urease inhibitors delay urea hydrolysis to ammonia, reducing ammonia emissions. Using urea in combination with urease inhibitors and nitrification inhibitors can further reduce nitrous oxide emissions. Nitrification and urease inhibitors can be injected into the soil together with liquid fertilisers; applied as a coating on granular fertilisers; and mixed into slurry before application. They can also be spread after grazing to reduce emissions from urine.

### Overview

Nitrification inhibitors depress the activity of nitrifying bacteria, improving the nitrogen fertiliser's plant availability and reducing nitrous oxide emissions and also nitrate leaching in high rainfall circumstances (Akiyama et al. 2010), although in some cases they can increase ammonia (and hence indirect nitrous oxide) emissions (Lam et al. 2017). Various compounds have been identified as nitrification inhibitors; probably the most widely studied are dicyandiamide (DCD), 3,4-dimethyl pyrazole phosphate (DMPP) and nitrapyrin.

Furthermore, urea-based fertilisers have a high rate of ammonia volatilisation when applied to soils, due to the urease enzyme released by soil bacteria. This leads not only to ammonia (and indirect nitrous oxide) emissions, but reduces the N plants can utilise. Urease inhibitors delay urea hydrolysis to ammonia, reducing ammonia emissions (Harty et al. 2016). Using urea in combination with urease inhibitors and nitrification inhibitors can therefore further reduce nitrous oxide emissions.

Nitrification and urease inhibitors can be injected into the soil together with liquid fertilisers, applied as a coating on granular fertilisers and mixed into slurry before application. They can also be spread after grazing to reduce emissions from urine.
In our analysis, we considered the application of nitrification inhibitors with ammonium nitrate fertiliser, and nitrification and urease inhibitors with urea applications. We expressed the effect as a change in the soil nitrous oxide emission factor.

### Greenhouse gas mitigation summary

The effectiveness of nitrification inhibitors in reducing nitrous oxide emissions and nitrogen leaching depend on a variety of factors. In a meta-analysis of 113 datasets of field experiments Akiyama et al. (2010) found that the nitrous oxide reduction effect depended on the type of nitrification inhibitor and land use type. The effect also depends on the type of

fertiliser used (Misselbrook et al. 2014) and on environmental conditions at the site (Cardenas et al. 2019).

UK experiments showed variable results. In fertiliser experiments by Misselbrook et al. (2014) across six sites (including arable and grassland fields), nitrous oxide emissions from ammonium nitrate were significantly reduced at two sites (average effect -43%), while nitrous oxide emissions from urea treatment were significantly reduced at four sites (average effect -54%). The mean nitrous oxide emission reduction across the six experiments was 38% and 64% for DCD applied with ammonium nitrate and urea, respectively. There was no significant effect of DCD on ammonia emissions, apart from at one site. Nor was yield significantly affected either in all but one case (where it was reduced by 20%).

Cattle urine experiments by the same authors showed significant reduction in three out of four cases, with a mean effect of -70%. Ammonia emissions and grass yields were not significantly affected. Slurry experiments did not reveal any significant effect, as variability amongst the replicates was very high (Misselbrook et al. 2014).

Grassland experiments in the UK with ammonium nitrate and urea fertiliser showed mixed results too. Cardenas et al. (2019) found that DCD increased the nitrous oxide emission factor at one site significantly (by 20%), decreased it at another site significantly (by 52%), and had no significant effect at a further three sites. When DCD was applied with urea the nitrous oxide emission factor changed significantly at only one site (-94%). However, applying urea instead of ammonium fertiliser reduced the nitrous oxide emission factor by 49%, and using urea combined with DCD resulted in a 85% reduction in the nitrous oxide emission factor compared to using ammonium nitrate only. Yield changes were not significant in any case.

Experiments at two permanent grassland sites in Ireland showed that urea applied with a combination of urease and nitrification inhibitor reduced nitrous oxide emissions by 56% (Harty et al. 2016).

**Table D6. Data from literature on abatement**

| Abatement | Value | Country | Reference |
|---|---|---|---|
| **Nitrous oxide emissions** | Average: -38% (95% confidence interval: -44% to -31%)<br>DCD: -30% (95% confidence interval: -36% to -26%)<br>nitrapyrin: -50% (95% confidence interval: -55% to -30%)<br>DMPP: -50% (95% confidence interval: -55% to -42%) | Across the world | (Akiyama et al. 2010) meta-analysis |
| **Nitrous oxide emission factor** | DCD with ammonium nitrate: -38%<br>DCD with urea: -64%<br>DCD with cattle urine: -70% | UK, grass and arable | (Misselbrook et al. 2014) - experiments |
| **Nitrous oxide emission factor** | DCD with ammonium nitrate: -19%<br>DCD with urea: -66% | UK, grass | (Cardenas et al. 2019) - experiments |

| Abatement | Value | Country | Reference |
|---|---|---|---|
| **Nitrous oxide emission factor** | DCD and NBPT with urea: -56% | Ireland, grass | (Harty et al. 2016) - experiments |

### Costs

Agrotain® Plus, which is a combined urease and nitrification inhibitor, costs around £0.1 (kg N)$^{-1}$, derived from information posted on agricultural forums (precise price information was not publicly available). This value was used for both the nitrification and urease inhibitor application.

### Current uptake and maximum additional future uptake

The current uptake is assumed to be 0%.

### Assumptions used in the MACC

**Table D7. Assumptions used in the modelling**

| Parameter | Change in value |
|---|---|
| **Ammonium nitrate $EF_1$ change** | -25% |
| **Ammonium nitrate $EF_1$ change** | -50% |
| **Fertiliser cost change** | £0.1 kg $N^{-1}$ |

## Soil pH management

One of the important properties of agricultural soils is their pH, in other words their acidity level. The optimal soil pH is between pH 5.6 and pH 6.2, depending on the soil type. Soil surveys in Scotland show that many areas have soils that are too acidic. The acidity of these soils compromises crop growth, reducing the yield, and increases the proportion of nitrogen fertiliser which is converted to nitrous oxide and emitted from the soil. Soil pH control is, therefore, a practice which can increase the yield and reduce nitrous oxide emissions at the same time. It involves applying lime to the soil, when and where needed, and usually testing the soils every four to five years.

### Overview

The acidity of soils (soil pH) plays a major role in regulating the chemistry and fertility of soils and depends upon the net balance of a wide range of chemical and biological processes. Good management of soil acidity is essential to optimise crop productivity. Most crop plants are more productive in a range of pH between 5.5 to 7.0. Outside of this range productivity decreases and the utilisation of nutrients added – including nitrogen fertilisers – becomes less efficient. There is a range of indirect ways in which pH influences GHG emissions, making pH management an important tool in GHG mitigation.

Soil pH plays an important role in regulating and modifying nitrous oxide emissions. In more acid soils, there is a higher ratio of $N_2O$:dinitrogen[38] emission because the $N_2O$ reductase

[38] Dinitrgoen ($N_2$) is the for of nitrgoen making up 78% of the Earth's atmosphere; it has a very low reactivity and is not a greenhouse gas or nitrogen pollutant

enzyme which converts $N_2O$ to dinitrogen is inhibited (Liu *et al.* 2014). Thus, in soils that have a tendency to produce $N_2O$ by denitrification, more acid conditions are likely to lead to a higher $N_2O$ emission rates (Simek *et al.* 1999; Goulding 2016; Zhu *et al.* 2019). Because soil acidity can also reduce crop growth, maintaining soil pH at an appropriate level is considered important for both the optimisation of crop production and efficient use of fertiliser inputs (Goulding 2016). Lower crop biomass and higher nitrous oxide emissions in acid conditions can lead to a large increase in the quantity of Nitrous Oxide produced per unit of crop product) (nitrous oxide emission intensity).

Evidence suggests that lime application may modify soil microbial communities (Goulding 2016) and increase organic matter inputs (Fornara *et al.* 2011; Jokubauskaite *et al.* 2016) with the effect of increasing soil carbon stocks (SOC) (Li *et al.* 2018, Fornara *et al.* 2011). Managing soil pH involves gathering information on the current status of the soil (e.g. via soil sampling and analysis) and the application of lime on land which is below the optimal pH for crop or grass growth. Optimal pH varies depending on the land use, type of crop grown, and soil type. Required lime application rates to optimise pH vary depending on soil type and on the difference between the existing soil pH and the target pH. Usually it is sufficient to repeat this process in every four years.

### Greenhouse gas mitigation summary

Changes in nitrous oxide emissions following lime application result from changes to the nitrification and denitrification processes. These effects are context specific, with variable relationships between pH and the proportion of applied nitrogen emitted as nitrous oxide (Skiba *et al.* 1998; Russenes *et al.* 2016). However, since liming increases soil nutrient availability (ALA 2011; Goulding 2016), requirement for nitrogen application is likely to decrease, or the same nitrogen fertilisation rate would result in increased yield, i.e. a net reduction in nitrous oxide emission intensity.

SOC content is likely to increase where pH is raised – again, a complex and context specific response (Li *et al.* 2018). In grassland, Fornara *et al.* (2011) reported substantial increases in grassland SOC for limed treatments, both in fertilised and unfertilised swards. For cropland, Tu *et al.* (2018) reported a positive correlation between pH and SOC. Based on the aforementioned papers and work in SRUC here we assume that an increase of 1 pH unit in the range pH 4-7 corresponds to an increase in SOC concentration of 0.82-1.97 g $kg^{-1}$. At a typical soil bulk density of 1.1 g $cm^{-3}$, and assuming pH impact to 20 cm depth (Goulding 2016) this roughly equates to an increase of 1.8-4.3 t C $ha^{-1}$. Assuming a 20-year stabilisation period (de Klein *et al.* 2006), this equates to a sequestration rate of 330-788 kg $CO_2$e $ha^{-1}$ $year^{-1}$. Note that this is a broad extrapolation based on site-specific data and should be taken as an indication only. To provide a conservative estimate we assume 300 kg $CO_2$e $ha^{-1}$ $year^{-1}$ C sequestration in this work.

Direct $CO_2$ emissions from lime application means that lime can be (though is not necessarily) a net source of $CO_2$ (Hamilton *et al.*, 2007). The relevant IPCC Guidelines for National greenhouse gas Reporting (de Klein *et al.*, 2006) assume lime to be a $CO_2$ source, with an estimate of 0.0625—0.125 kg $CO_2$ kg $lime^{-1}$. This emission factor is directly related to the mass fraction of C in lime ($CaCO_3$), with the maximum emission assuming release of all molecular C to the atmosphere as $CO_2$ (de Klein *et al.*, 2006; Fornara *et al.*, 2011). This contrasts with the findings of Hamilton *et al.* (2007), who show that whilst lime can be a

source of $CO_2$, it is more often a net sink. Fornara *et al.* (2011) also show that lime can be a C sink; the authors identify two pathways by which this can be the case. Lime may either a) increase carbonic acid ($HCO_3^-$) concentrations in soil water, sequestering 25-50% of lime C, or b) contribute to the movement of existing soil C from labile to humified pools, increasing its net storage time in the soil.

Emissions associated with lime extraction (embedded emissions) have been estimated at 0.074 kg $CO_2$e kg lime$^{-1}$ (range 0.054—0.089 kg $CO_2$e kg lime$^{-1}$) (Kool *et al.* 2012).

### Costs

The costs of lime application include purchase of lime, spreading and soil analysis. It is recommended that farms apply lime at three to six year intervals depending on results of soil analyses (SRUC 2014). The financial benefits of soil pH management consist of the additional income from yield increase.

### Applicability and uptake

The Scottish Government (2018a) reports that 64% and 30% of farms carried out pH testing on arable and grazing land respectively in 2016. A recent survey of over 1,000 fields of grassland (Ayrshire, Water of Coyle) and arable land (Perth, East Pow), showed that 57% of grassland soils and 34% of arable soils had low or very low pH values (SRUC 2018). This is consistent with UK data indicating that between 31% and 49% of arable and grassland soils have suboptimal pH (PAAG 2016). The applicability of the measure is assumed to be 50% on fertilised grasslands and 30% on croplands.

#### Summary of assumptions used in the MACC

**Table D8. Assumptions used in the modelling**

| Parameter | Change in value |
|---|---|
| **Yield change** | +6.22% (crops and grass) |
| **$EF_1$ change** | -3% |
| **C sequestration** | 300 kg $CO_2$e ha$^{-1}$ y$^{-1}$ |
| **Lime cost** | £111 ha$^{-1}$ (3.7 t ha$^{-1}$ lime @ £30 t$^{-1}$) in every 4 years |
| **Lime spreading cost** | £10.16 ha$^{-1}$ in every 4 years |
| **Soil analysis cost** | £20 ha$^{-1}$ in every 4 years |

## Slurry injection and bandspreading of slurry

Livestock slurry can be applied to the soil using a range of techniques. The most common approach in Scotland is to use a low trajectory splash plate (broadcast). Bandspreading and injection are practical alternative methods that can be used for spreading slurry to cropland and grassland. In bandspreading, a series of parallel pipes connected to a slurry tank apply the slurry in discreet bands directly on the surface (trailing shoe / trailing hose), while in injection the slurry is placed into slits cut by machinery. These techniques reduce odour and crop contamination. They also mitigate ammonia emissions and subsequent nitrous oxide emissions (from the transformation of ammonia into nitrous oxide). However, due to the

increased pool of ammonium nitrogen in the soil and the changes in the soil conditions, direct emissions of nitrous oxide can increase.

### Overview

Livestock slurry can be applied to the soil using a range of techniques. The most common approach in Scotland is to use a low-trajectory splash plate (broadcast), which accounts for over 68% of applications (Scottish Government 2016). Bandspreading and injection are practical alternative methods that can be used for spreading slurry to cropland and grassland.

Compared to broadcast, these techniques spread the slurry more evenly, reducing odour and crop contamination (Thorman 2011). Bandspreading and injection have also been shown to reduce ammonia emissions (Hafner *et al.* 2019), and therefore the associated indirect GHG emissions. However, due to the increased pool of ammonium-nitrogen in the soil and the changes in the soil conditions, emissions of nitrous oxide can increase (Thorman 2011).

The measure entails switching from applying slurry via a splash plate (broadcast) to: (a) band spreading in which a series of parallel pipes connected to a slurry tank applies the slurry in discreet bands on the grass surface (trailing shoe / trailing hose) or (b) injection of slurry below the soil surface.

### Greenhouse gas mitigation summary

Trailing shoe and injection technology can dramatically reduce ammonia emissions (Defra 2007, Hafner *et al.* 2019). The semi-empirical model of Hafner *et al.* (2019) using European data predicted a reduction relative to broadcast of 63% by injection; this compares with a reduction of 48% observed in a UK study (Defra 2007). The model predictions for trailing shoe were 33% lower than for broadcast (Hafner *et al.* 2019). However, in a UK study, trailing shoe / hose only had a significant impact on ammonia emissions in three of fourteen experiments with a mean reduction of 12% (Defra 2007).

The lack of effect was explained by the fact that the slurry did not stay in the band and therefore did not rapidly infiltrate the soil. The results of the Defra Greenhouse Gas Platform Project[39] revealed that trailing hose resulted in a reduction in emissions in spring, but not in autumn. The leaching losses associated with autumn applications of slurry were higher for trailing shoes than for broadcast. In terms of direct nitrous oxide emissions, the effect of application method was variable with either no effect or increases in emissions being reported (Bourdin *et al.* 2014, Chadwick *et al.* 2011, Defra 2007). The results of the Defra study (2007) showed no consistent impact on N use efficiency of the slurry, and thus there is no consistent effect on reducing the requirement for the associated inorganic fertiliser inputs.

Compared to broadcast, the energy cost of trailing hose and injection are higher. The Farmscoper tool (ADAS 2017) assumes that the significant reductions on ammonia volatilisation will be offset by increases in energy required to power the equipment for both band spreading and injection, along with mixed effects on nitrate leaching and direct nitrous oxide (Table D9 and D10).

[39] http://www.ghgplatform.org.uk/

**Table D9. Effect on pollutant flows of Farmscoper measure 70: Using slurry *trailing hose / trailing* shoe application techniques (ADAS 2017)**

| | Ammonia | Energy use | Nitrate | Nitrous oxide |
|---|---|---|---|---|
| | | | | |
| **Pathway(s)** | Gaseous | Gaseous | | All flows |
| **Effect** | -50% | -25% | +50% | +10% |

**Table D10. Effect on pollutant flows of Farmscoper measure 71: Use slurry injection application techniques (ADAS 2017)**

| | Ammonia | Energy use | Nitrate | Nitrate | Nitrous oxide | Nitrous oxide |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Pathway(s)** | Gaseous | | Runoff/ Preferential | Leaching | Runoff/ Preferential | Leaching |
| **Effect** | -80% | +100% | -50% | +25% | -50% | +25% |

From the evidence detailed above, it is assumed in this work that the volatilisation (FRACgas) is reduced by 48% and 12% for injection and trailing hose, respectively. Thus, the revised FracGas values are 0.1 for injection and 0.18 for trailing hose. It is assumed that the increase in fuel use offsets the reduction in nitrous oxide emissions and thus neither is changed in the model.

**Table D11: Data from literature on abatement**

| Abatement | Value | Country | Reference |
|---|---|---|---|
| **FracGas** | Injection: 0.1<br>Trailing shoe / hose: 0.18 | UK | (Defra 2007) |
| **Energy $CO_2$** | No change (reduction in nitrous oxide is offset increase in $CO_2$) | UK | (ADAS 2017) |

## Costs

This measure involves the purchase of equipment for band spreading or injection and higher operating costs associated with increased fuel use, particularly for injection systems. Cost estimates are given in Table D12.

**Table D12. Financial costs and benefits of the measure**

| Costs/savings | Value ('-' sign for savings) | Reference |
|---|---|---|
| **Trailing shoe / trailing hose** | £0.91/$m^3$ slurry | (ADAS 2017) |
| **Slurry injection** | £2.38/$m^3$ slurry | (ADAS 2017) |

## Applicability

In the UK, 43% of the organic manures applied is cattle or pig farm-yard manure (FYM), and 44% is cattle or pig slurry (Defra 2019). Therefore, it is assumed that the measure is applicable to 50% of organic manure applications. Slurry is applied to 2.2 % of the winter sown crops, 5.6% of the spring sown crops and 25.6% of grassland (Defra 2019). It has

been assumed that the slurry applied to cropland is incorporated at the time of application. Therefore, this measure is regarded as only being applicable to grassland.

### Current uptake and maximum additional future uptake

In Scotland in 2016, 17.2 million tonnes of FYM or slurry was applied (Scottish Government 2016). In 2016, 4.8 million tonnes (28%) was bandspread, and 0.6 million tonnes (3.5%) was injected. In addition, 0.4 million tonnes were broadcast and ploughed in within 4 hours (2.3%). These technologies reduce ammonia emissions; therefore, the reduction in indirect emissions will not apply to this (we assume that these technologies are used on cropland). Based on UK figures, we estimated that 50% of the 17.2 million tonnes is slurry and the remainder FYM (Defra 2019). Thus, as ammonia emission mitigation technologies are already applied to 5.8 million tonnes (bandspread, injected and ploughed in within 4 hours), the potential for uptake is 2.8 million tonnes.

### Assumptions used in the MACC

**Table D13. Assumptions used in the modelling**

| Parameter | Change in value |
|---|---|
| **FracGas** | Injection – 0.1<br>Trailing shoe / hose 0.18 |
| **Energy** $CO_2$ | Reduction in nitrous oxide is offset by increase in $CO_2$ |
| **Cost of trailing shoe / trailing hose application** | £0.91 $m^{-3}$ slurry |
| **Cost slurry injection** | £2.38 $m^{-3}$ slurry |

## Variable rate nitrogen and lime application

Crop-growing conditions are not uniform within a field; while some parts of the field give high yields, in other parts the crops do not perform well. Differences in soil structure, acidity (pH), nutrient content, among other things, can cause such variation. If the variation is considerable, tailored field operations can save resources and enhance the yield. High-resolution sensors, mapping, and decision-making computer systems and variable-rate spreading technologies applied together (in other words precision farming technologies) are capable of varying the rate of inputs applied to soils within one square metre. Variable-rate nitrogen fertiliser application can reduce GHG emissions and GHG emission intensity as these types of fertiliser result in high or equal yield while using the same or less input.

The five main ways they can affect GHG emissions are: increasing yield, reducing nitrogen fertiliser application, reducing tillage and thus increasing soil carbon sequestration, reducing fuel consumption, and reducing other inputs to field operations (impacting off-farm emissions). Maintaining soil pH at an appropriate level is considered important for both maximising crop production and efficient use of fertiliser. Lower crop biomass and higher nitrous oxide emissions in acid conditions can lead to a large increase in emission intensity nitrous oxide (the quantity of nitrous oxide produced per amount of crop produced). Precision lime application takes account of the often large gradients in pH within fields,

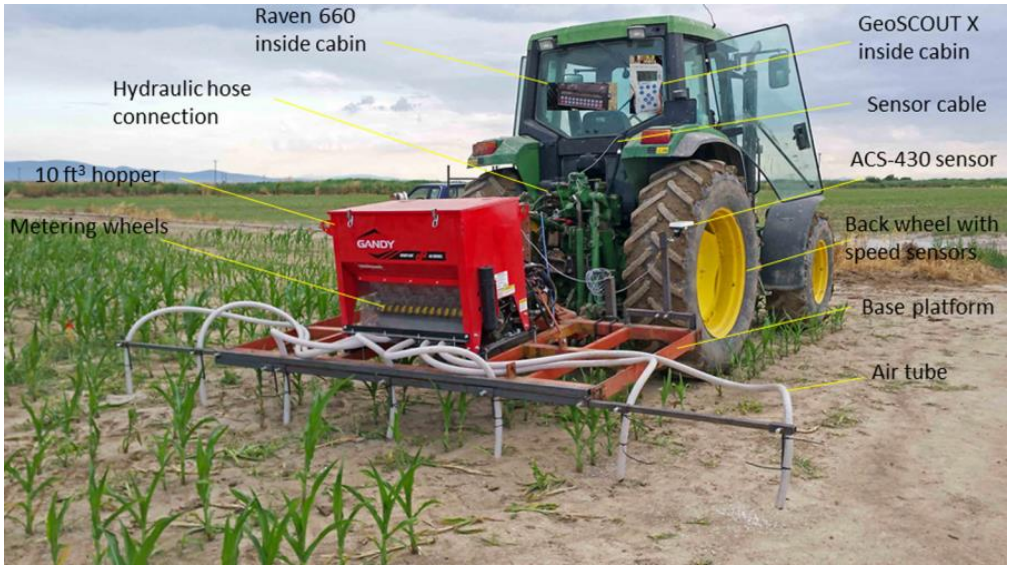
applying lime with variable rate applicators on a spatial basis according to the lime required to bring soil up to a target pH.

**Overview**

Nitrous oxide emissions arising from the use of synthetic nitrogen fertilisers can be reduced by more targeted use, supported by a better understanding of spatial heterogeneity in field conditions, linked to technology capable of delivering variable rate fertiliser applications. Precision agriculture technologies (PATs) allow the farmers to consider the field as a heterogeneous entity and apply selective management, potentially increasing efficiency (Aubert et al. 2012). Schwartz et al. (2010) categorised PATs into guidance, recording and reacting technologies.

Guidance technologies (e.g. controlled traffic farming, machine guidance) help to make machinery movement more precise within and between the fields. Recording technologies (e.g. soil mapping, canopy sensing) collect information from the field (including the soil and crops) before, during or after the growing period. Recorded data, in turn, can be integrated to support the use of variable rate nitrogen applications. This can take into account not only in-field variation, but the temporal aspect if in-season information is collected (Diacono et al. 2013). The technology is rapidly developing, and under the H2020 EU research funding scheme there have been more than a dozen projects in recent years working on technological and infrastructure development for precision solutions across farming systems.

Machine guidance technologies are systems that pilot machinery using GPS in order to reduce overlaps of and avoid gaps between passes. At the entry level a GPS receiver mounted on the machinery and a lightbar or an on-board display providing driving direction is needed; with such systems ±40 cm accuracy can be achieved. More advanced solutions, with accuracy up to ±2 cm, use auto-guidance systems (auto-steering) integrated in the tractor's hydraulics and directly control steering. Machine guidance is a prerequisite for VRNT, but could be used in itself (Barnes et al. 2017a).




**Example of a VRNT system (Stamatiadis et al. 2018)**

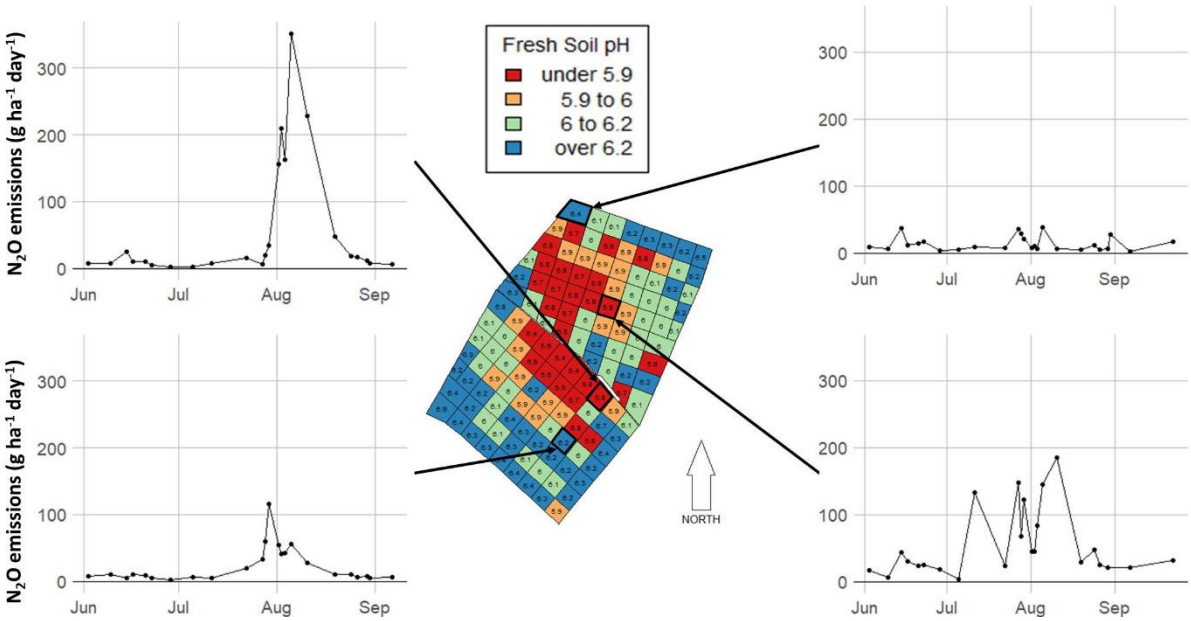
Variable rate nitrogen technology (VRNT) makes it possible to adjust the application rate to match fertiliser need better in that precise location within the field. Using a digital map or real-time sensors, a decision tool calculates the N needs of the plants and transfers that

information to a controller, which adjusts the spreading rate (Barnes et al. 2017a). VRNT applications in crop and grass production can reduce GHG emissions and their intensity as they result in high or equal yield while using the same or less input. The five main ways they can affect GHG emissions are summarised by Balafoutis et al. (2017): increasing yield with while reducing N fertiliser application; reducing tillage and thus increasing soil C sequestration; reducing fuel consumption; and reducing other inputs to field operations (impacting off-farm emissions).

Current commercially available VRNTs adjust N rates on the basis of canopy reflectance measurements using software to model the link to crop N requirement. However, new research is being undertaken on the underlying causes of variable reflectance (and N recovery), which is likely to be soil related. The outcome of this research is likely to lead to new approaches to precision management within the next 5-10 years.

Nitrous oxide accounts for a significant share of the GHG emissions from arable and grassland systems. Soil pH plays an important role in regulating and modifying these nitrous oxide emissions. In more acid soils, there is a higher ratio of nitrous oxide: $N_2$ emission from denitrification because the nitrous oxide reductase enzyme which converts nitrous oxide to $N_2$ is inhibited (Liu et al. 2014; Zhu et al. 2019).

Thus, in soils that have a tendency to produce nitrous oxide by denitrification, more acid conditions are likely to lead to higher nitrous oxide emission rates. Because soil acidity can also reduce crop growth, maintaining soil pH at an appropriate level is considered important for both the optimisation of crop production and efficient use of fertiliser inputs (Goulding 2016). Lower crop biomass and higher nitrous oxide emissions in acid conditions can lead to a large increase in emission intensity nitrous oxide (the quantity of nitrous oxide produced per unit of crop). New precision approaches to lime application take account of the often large gradients in pH within fields, applying lime with variable rate applicators on a spatial basis according to the lime required to bring soil up to a target pH. Although this management approach is specifically designed to optimise crop growth through pH management, it is likely that there will be co-benefits in terms of nitrous oxide emission given the sensitivity of emissions to pH. Preliminary measurements highlight the increased emissions of nitrous oxide in the more acidic areas of grassland (figure below). Work is currently underway at SRUC in the UK in partnership with other European countries and AgResearch in NZ to test this hypothesis using conventional and variable rate lime applications on grassland soils, followed by subsequent measurements of nitrous oxide emission during the growing season (http://eragas.eu/research-projects/magge-ph).




**Spatial heterogeneity of pH and associated nitrous oxide emissions from a Scottish grassland soil to a depth of 20 cm measured on a 10 by 10 m grid (each square on this map) at the Easter Bush field site in SE Scotland. Measurements of pH provided by Soil Essentials.**

Variable-rate lime applications may therefore provide an opportunity to optimise productivity while reducing GHG emissions. The technology is becoming widely available, and although uptake is currently low, it is likely there will be increased adoption of precision liming over the next 10 years.

The measure would require farmers to use machine guidance systems as well as VRNT and variable rate lime application for their arable and temporary grassland field operations, either buying the system, or using contractors for fieldwork who use these technologies. In line with our previous estimates (Eory et al. 2015), we assumed the implementation of a medium accuracy system, capable of 10 cm-accuracy auto-steering and including yield mapping and variable-rate nitrogen application.

## Greenhouse gas mitigation summary

As the variety of possible VRNT system specifications is large, and measurements of environmental effects are relatively sparse, currently it is not possible to derive robust quantitative information on the GHG effects of this technology. Eory et al. (2015) derived a central estimate from international studies of 20% N reduction in application, assuming no effect on the yield. Experimental evidence on the N fertiliser use and yield effect shows a large variation, between -57% and +1% and -2% to 10%, respectively. However, from a commercial perspective, it is most likely that a grower would choose to use the same amount of fertiliser N and obtain a high yield when using this technology. Barnes et al. (2017b) found that most potato and wheat farmers in the UK reported a -5% - +5% effect of the technology on N fertiliser and fuel use, and a 5-10% increase in wheat yield. From this information, the abatement here is assumed to consist of a 5% decrease in N use and a 7.5% increase in yield.

Experimental evidence suggests modest yield responses and emission reductions in response to lime. The magnitude of the response depends on the baseline. Liming on acid soils is considered to be a part of good agricultural practice; However recent surveys in Scotland have indicated that 63% of soils have a pH of 6.25 or below and 13% of soils have a pH of 5.5 or below (Edwards et al. 2015). These values lie below the optimum for many crops and are likely to require lime addition to ensure improved crop production.

### Costs

We derived the net costs for an average size (120 ha) farm, considering: capital investment in equipment (auto-steer: £5,000 every 5 years; yield monitor: £5,000 every 15 years); maintenance of the equipment (5% of capital cost); signal costs (annual £250); training (£500 every 5 years); and changes in fuel and fertiliser costs and income. We assumed that the costs, calculated at an area basis, would be the same on smaller farms as it is possible to hire contractors to apply VRNT.

The additional cost of the variable rate liming was estimated by adding the cost of soil mapping; £120 $ha^{-1}$ (Soil Essentials *pers. comm.*).

### Current uptake and maximum additional future uptake

The measure is applicable on all conventional (fertilised) arable and improved grasslands (i.e. grassland which is fertilised) which needs pH management. To reflect constraints we assumed that it is applicable on 30% of cropland and 20% of grassland. Current adoption of VRNT is around 8% across the UK (Barnes et al. 2017b). However, uptake is probably rather smaller in Scotland (~5%), given the smaller arable farm size. The current uptake of variable rate nitrogen and lime application is estimated to be negligible (0%).

### Assumptions used in the MACC

**Table D14. Assumptions used in the modelling**

| Parameter | Change in value |
|---|---|
| **Yield** | +7.5% |
| **Synthetic N application rate** | -5% |
| **C sequestration** | 300 kg $CO_2e$ $ha^{-1}$ $y^{-1}$ |
| **Fuel $CO_2$** | -3% |
| **Emissions from the use of lime** | 215.70 kg $CO_2e$ $ha^{-1}$ $y^{-1}$ |
| **$EF_1$ change** | -3% |
| **Lime cost** | £111 $ha^{-1}$ (3.7 t $ha^{-1}$ lime @ £30 $t^{-1}$) in every 4 years |
| **Lime spreading cost** | £10.16 $ha^{-1}$ in every 4 years |
| **Soil analysis and map cost** | £120 $ha^{1}$ in every 4 years |
| **Training** | £500 in every 5 years |
| **Auto-steer** | £5,000 in every 5 years |
| **Yield monitor** | £5,000 in every 15 years |
| **Signal cost** | £250 $y^{-1}$ |
| **Maintenance** | 5% of capital cost |
| **Change in field operation costs from reduced overlaps** | -3% |

# Annex E – Productivity Measures – long list

**Measures for Improving Performance – Information Sharing**

| Measure | Logic behind intervention | Potential barriers | Feasibility in Scotland |
|---|---|---|---|
| Farm advisory service | Studies have found high rates of return on public investment in applied advice. | | Existing in the SRDP - could be extended |
| Farmer discussion groups | Studies have found high rates of return on public investment in applied advice. | Lack of strong evidence; depends on method and context. | Can be encouraged |
| Support for farmer learning | Support for new entrants and for continued professional development likely to increase adoption of new technologies and management practices. | Low turnover in farming. | Can be implemented |
| Agriculture education | Apprenticeships, college and university courses have improved the level of specialist knowledge among farmers in other countries. | Low turnover in farming. | Can be implemented |
| Required qualifications | Some countries have created "license to farm" to ensure continuous improvement of current farming systems, including environmental goals. | May be politically unpopular. | Can be implemented |
| Support for Research and Development | Research suggests that reduction of government support for R&D in the 1980s had a negative impact on productivity. | Must be strategic, targeted, and adopted by farmers. | Can be implemented |
| Demonstration farms | Some evidence to support that farmers who attend improve practice on their own farms. | Unclear how it would impact farmers at scale. | Relatively untested |
| Smart farms | Have been used in Australia to implement cutting edge technologies. | Potential high costs. | None existing in Scotland |
| Monitor farms | Evaluation suggests the model has been effective in improving farming performance and enterprise among active participants. | Potential high costs. | Existing - could be extended |

**Measures for Improving Performance – Financial Schemes**

| Measure | Logic behind intervention | Potential barriers | Feasibility in Scotland |
|---|---|---|---|
| Reduction in direct support | Most studies find a negative relationship between subsidies and productivity.<br>May lead to significant restructuring in agriculture, particularly for smaller/more vulnerable farms. | Likely to have negative political impacts; may lead to further "middling out". | Can be implemented; may not be feasible due to Scottish agricultural context |

| | | | |
|---|---|---|---|
| Capital grants or loans | Studies find both positive and negative impacts on productivity: increased ability to innovate/develop business; low risk and potential crowding out. Loans may be more effective due to requirement to pay back. | May not be WTO eligible; may lead to overcapitalisation. | Can be implemented; limited by WTO rules |
| Support for new entrants | Younger entrants may have more innovative approaches to business, and may have stronger ICT and business planning skills. | Lack of retirement housing; lack of long leases for farmland. | Existing in the SRDP - could be extended |
| Support for exit | There are barriers to succession, meaning less productive management can continue longer than in other industries. | Lack of retirement housing; lack of business planning and succession. | Can be implemented |
| Changing tax incentives | Evidence from Ireland suggests that tax incentives for longer tenancies on agricultural land may increase productivity. | Potential high costs, both financial and administrative. | Can be implemented |

**Measures for Improving Performance – Established Technologies**

| Measure | Logic behind intervention | Potential barriers | Feasibility in Scotland |
|---|---|---|---|
| Precision Agricultural Techniques | Evidence suggests some PATs can reduce fuel use and management time; there is a training requirement for farmers. | High initial costs; high training requirement; lack of take-up by farmers. | Needs wider adoption |
| Nutrient management and soil nutrient mapping | Promising in increasing yield and additional benefits in managing GHG emissions | Lack of take-up by farmers. | Needs wider adoption |
| Improved soil management | For example, nutrient management and mapping; reduced cultivations to increase soil quality. | Lack of take-up by farmers. | Needs wider adoption |
| Robotic Milkers | More effective for larger herds and potential for growth; there is a training requirement. | Lack of take-up by farmers. | Can be encouraged |
| EID | Appears to give significant savings in labour use. | High initial costs; lack of take-up by farmers. | Needs wider adoption |
| EBVs; pedigree recording | Studies suggest EBVs can increase profitability of livestock farms. | High initial costs; lack of take-up by farmers. | Needs wider adoption |
| Changing cereal yields and varietal uptake | Improved crop yields have not been consistent across Scottish farms; it is not clear why this is so. | Lack of take-up by farmers. | Further research required |

**Measures for Improving Performance – Management Changes**

| Measure | Logic behind intervention | Potential barriers | Feasibility in Scotland |
|---|---|---|---|
| Precision livestock farming | Targeted precision livestock farming has potential to increase net margins per animal. | High initial costs; lack of take-up by farmers. | Needs wider adoption |
| Changing business size | Large farms tend to be more efficient and better adopters of new technology. | Politically unpopular "middling out" | Can be encouraged |
| Collaborative farming agreements | May be of particular benefit to new entrants, through increased availability of land. | | Existing - could be extended |
| Disease control and eradication | Reduces loss and improves productivity. | | Existing - could be extended |
| Risk management | Investment in productivity should be accompanied by steps to manage and reduce risk. | Could reduce incentive to innovate. | Can be implemented |
| Changing the input-output mix | Switching from specialised farms to more mixed operations may offer opportunities for recycling of inputs, and best use of land. | High training requirement for farmers. | Can be encouraged |
| Widen the range of planted crops | A wider range of crops could diffuse the intensity of work and machinery requirements over the course of the year. | High training requirement for farmers. | Further research required |