Scoping Wider Impacts of Low Carbon Farming

Report to the Committee on Climate Change

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1. Introduction

For the land sector, and specifically for agriculture, a range of climate change mitigation measures have been identified and trialled (to varying levels) with the aim of reducing greenhouse gas (GHG) emissions. More recently, measures have been evaluated in the context of goals to achieve net zero GHG emissions with a target of 2050 for the UK. By interacting with farming systems, these mitigation measures will also produce wider environmental impacts, either as trade-offs or synergies, which also need to be considered in policy design. This rapid evidence appraisal has therefore been commissioned by the UK Committee on Climate Change (CCC) to provide an initial assessment of wider impacts regarding proposed measures to deliver the 2050 net zero emissions target. The appraisal comprises two parts: (i) a high-level (Tier 1) quantitative assessment of co-benefits of improved nitrogen (N) use efficiency for water quality and air quality; (ii) a broader qualitative review of expected impacts including some measures not in (i). In both cases, assessment was based upon a candidate list of mitigation measures (MM) identified by the CCC.

2. Quantitative Assessment: Water Quality and Air Quality Co-benefits (Tier 1)

2.1 Methodology

Plant growth needs N from soils therefore agriculture fertilisers containing supplemental N and other nutrients are applied to enhance crop yields (organic fertilisers such as manure or synthetic mineral compounds). Residual N in soils not taken up by plants[1] can contribute to climate change through N_2O emissions from nitrification/denitrification processes therefore mitigation measures have been designed to improved N-use efficiency. These measures also have important implications for air quality and water quality because soil N can be released to air through ammonia (NH_3) volatization and to water bodies through dissolved nitrate (NO_3) pathways (leaching and runoff). Other pathways also exist (notably NOx) but are not considered further here.

This part of the study aims to provide an indicative quantification of specific co-benefits for water quality and air quality for each target measure. This was achieved by reference to standardised GHG inventory procedures, which, in addition to providing direct N_2O emission factors, are also required to provide emissions factors for atmospheric NH_3 and aquatic NO_3 because these pathways can eventually also indirectly produce N_2O emissions. Some N from NH_3 is subsequently redeposited back to land to be emitted as N_2O, whereas some aqueous NO_3 is also converted to N_2O emissions; in both cases the N_2O fraction is small but still significant.

Emission factors used for quantification are consistent with IPCC (2006) guidance for Tier 1 GHG inventory assessments which allows a standard evaluation in the absence of more detailed monitoring or modelling data[2]. IPCC emissions factors were therefore integrated with data on agricultural fertiliser application and livestock characteristics to estimate changes in NH_3 and NO_3 to complement previous GHG assessment. For each mitigation measure (Table 1), abatement factors, applicability, and uptake rates were mainly taken from the UK GHG assessment by SRUC (2015, 2019) as used by the CCC (2019) NetZero 2050 Report. Abatement factors therefore assume either reductions in (synthetic) fertiliser application or modifications to emission factors. For a few measures currently at early stages of development and not assessed by SRUC (2015, 2019), indicative values were adopted to assess relative performance. Emissions are upscaled to country level using projected changes in livestock numbers, crop areas, and uptake, as associated with each MM by the CCC (2019) NetZero report. Fertiliser application rates and application areas are taken from SRUC (2015, 2019) but using a default average value across all arable crops. Livestock weights and excretion rates follow IPCC

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[1] N-use efficiency in plants is typically about 30-50% although it varies with different plants, soil types (texture, drainage, pH), % soil organic carbon, climate, fertilizer type/application and management (tillage, rotation system etc.). Tier 1 assessments provide default N pathway values.

[2] Recently refined by IPCC (2019) but differences are usually small and for consistency the 2006 factors were retained.

(2006) default guidance. Although more detailed modelling of air/water quality could be undertaken, the present method allows a rapid scoping assessment following the same logic and assumptions already applied for GHG (N_2O) emissions.

Dissolved NO_3 in water bodies has serious implications for human health and aquatic ecosystems hence there are strict regulatory limits. In aquatic ecosystems, excess nitrate results in eutrophication, severely impacting biodiversity, whilst consequent algal blooms cause deoxygenation also affecting aquatic life. Acidification can lead to indirect effects such as increased solubility and mobilisation of toxic aluminium and manganese, the former especially being toxic to freshwater ecosystems and fisheries.

NH_3 can have serious implications for air quality and human health due to interaction with other compounds to form particulate matter (especially $PM_{2.5}$). Atmospheric N re-deposited back to land during precipitation has detrimental effects on biodiversity at excess levels, especially in the uplands, and may also increase drought and frost risk (notably in heather) and susceptibility to pests and diseases (e.g. heather beetle).

Table 1. Selected Mitigation Measures (further details in SRUC, 2015, 2019, except *)

Manure Planning (MM2)	*Shifting Manure Application - Autumn to Spring (MM4)*	*Controlled release fertilisers (MM6)*
Crops with enhanced N use efficiency (MM7)	*Grass clover instead of N application (MM9)*	*Precision farming for crops (MM10)*
Reducing Soil Compaction (MM11)	*Slurry Acidification (MM19)*	*Anaerobic Digestion (MM20/22)*
*Triticale **	*High Sugar Grasses (MM21)*	*20% reduction in livestock (LS20) * ‡*

‡ Based upon an assumed 20% reduction in beef, lamb and dairy consumption and production per capita.

2.2 Results

Evaluation of measures is summarised in Table 2 (the full calculation is available through a supporting spreadsheet including derived abatement potential per crop area or livestock unit). When abatement factors are combined with Net Zero projected changes in cropping areas or livestock numbers then LS20 produces the greatest gains in terms of overall reduced NH_3 emissions. Other high performing measures are MM10, MM6, MM7 and MM9, although it should also be noted that the relative performance of these measures also shows some variations between UK nations due to differences in expected applicability and uptake.

Table 2. Comparison of air quality and water quality benefits of Mitigation Measures

AIR: NH_3 Abatement (tN yr^{-1})

	Eng	Scot	Wal	NI
MM2	429	86	96	39
MM4	824	132	27	9
MM6	5875	1275	243	243
MM7	4692	1005	224	197
MM9	4121	1089	937	322
MM10	5138	1100	243	215
MM11	-	-	-	-
MM19	7297	734	594	1303
MM20/22	1043	54	9	99
MM21	549	90	120	146
Triticale	372	24	3	3
LS20	17688	5444	4387	5111

WATER: NO_3 Abatement (tN yr^{-1})

	Eng	Scot	Wal	NI
MM2	1290	257	118	118
MM4	2479	397	82	27
MM6	17671	3835	730	730
MM7	14113	3022	591	591
MM9	12394	3274	2817	967
MM10	15453	3309	730	647
MM11	6493	1386	312	266
MM19	-	-	-	-
MM20/22	-	-	-	-
MM21	825	135	180	220
Triticale	1119	73	10	10
LS20	26599	8187	6597	7685

Regarding reduced NO_3 in water, when abatement factors are combined with projected changes in cropping areas or livestock numbers, the best performing measures are LS20, followed by MM6, MM10, MM7 and MM9, although there are again some differences in relative terms between the latter measures at country level due to variations in applicability and uptake.

When measures are considered at national level in terms of their combined N abatement for both air quality and water quality, then LS20 shows the largest benefits. MM10, MM6, MM9 and MM7 were also found to be have large co-benefit potential in reducing NH_3 and NO_3 pollution. It should be noted that although these were found to be the best performing measures at national level, it is very likely that other measures may be particularly important at specific locations, typically related to local factors such as soils, land use and climate. Spatial variability should therefore be recognised by policy initiatives rather than assume that relative efficacy of measures follows a universal pattern.

The estimates in Table 2 were used in a related CCC project by Vivid Economics and the Centre for Hydrology and Ecology[3], which attempted to monetise these impacts.

3. Qualitative review of wider impacts

Manure Planning (MM2); Shifting Manure Application from Autumn to Spring (MM4). Improved application of organic manures (e.g. avoiding waterlogged or hot days) can improve N-use efficiency, reduce synthetic fertiliser use, and reduce N losses to air and water. Wider benefits will depend on the type of manure (animal/diet; formation/storage), target crop, climate (precipitation, soil moisture, soil temperature), and application method (slurry injection on grassland, or direct application to crops are more efficient). Evidence suggests good manure application results in higher soil organic matter content and enhanced microfauna (e.g. Edmeades, 2003), and is associated with higher soil porosity, aeration, penetration of roots, binding of aggregates, and reduced losses of mineral N to water (Schjonning et al., 1994). In terms of risks, manure can contain pathogens (e.g. *Cryptosporidium; E. coli*), meaning application can potentially cause transmission into the food system or water supply, and it may encourage spread of anti-microbial resistant bacteria originating from animal antibiotics.

Controlled release fertilisers (CRFs) (MM6). CRFs aim to synchronise nutrient release with crop demand by providing plant-available N more slowly than conventional fertilisers. This can therefore reduce residual soil N and associated losses to air and water (Shaviv and Mikkelsen, 1993). Additional benefits may include reduction of specific plant stress or toxicity issues and induced synergistic effects between specific chemical forms of nutrients (e.g. interaction of mixed NH4/NO3 nutrition with K; rhizosphere physiological acidification and P/Fe availability). Since SRFs are intended for single applications they can reduce field traffic and hence soil compaction risk.

Crops with enhanced N use efficiency (MM7). These new crop varieties provide either the same yield as conventional crops but require less N fertiliser, or give greater yields without need for increased N inputs. Wider benefits therefore accrue through reduced residual soil N and associated reduced N losses to air and water, but evidence is currently limited. An alternative pathway to improved N use efficiency would be by enhancing abundance of plant-symbiotic fungi in root systems that act as major enablers of N uptake, such as by using direct seed drilling and mulching to reduce disruption of soil mycelium and encouraging propagule dispersion (Verzeaux et al., 2017). This would also likely be beneficial for some soil biota. There are some important uncertainties: for some crops, accumulation of nitrite-N may produce toxic effects (Hirel et al., 2011) and disease susceptibility may be increased.

Grass clover instead of N application (MM9). Clover as a legume has symbiotic root systems that can fix atmospheric N therefore grass-clover mixtures require less fertilisers, reducing soil N losses to air

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[3] Vivid Economics and CEH (2020) ‘Economic impacts of Net Zero land use scenarios’.

and water. Clover swards can promote higher forage intake and higher livestock protein content. However, limited evidence suggests N leaching risk may be similar to grass swards unless synthetic N inputs are avoided, due to the dominant role of management practices (Ledgard et al., 2009). Clover can help alleviate soil compaction due to enhanced soil biota (ADAS, 2012; De Haas et al. ,2019) while grasses enhance soil aggregate stability (Van Eekeren et al., 2009) and the combined mixtures can enhance root density. Together this can improve plant nutrient and water availability, whilst different growth patterns can suppress weeds (Finn et al., 2013). This enhances biodiversity (e.g. earthworms, pollinators, farmland birds: Van Eekeren et al., 2009; Jarvis et al., 2017; de Haas et al., 2019).

Higher minimum temperatures required for clover growth (8°C) compared to grass may limit uptake in marginal areas. Clover has peak growth late in the season and excess N when excreted by animals in patches may increase leaching losses. In addition, clover has a higher P requirement than grass and if supplied through synthetic fertiliser may increase P losses to water (Ledgard et al., 2009). Clover-specific disease can limit persistence (e.g. crown rot; root rot; stem eelworm) but can be contained with good management (rotations, soil pH etc.). Problems can occur with mildew, vein virus, and pepper spot, especially in cool damp conditions, and in some years with slugs, weevils, and leatherjackets, which may increase pesticide usage. Livestock bloat can also be an issue, caused by rapid breakdown of protein, again averted by good management (fibre/feed additives; limited grazing of wet fields). In sheep, red clover or diseased white clover has been associated with infertility and lambing issues especially when concentrated in silage, also requiring managed use (AHDB, 2016).

Precision farming for crops (MM10). Precision farming uses IT and remote sensing to implement detailed sub-field level management strategies (differential inputs, seeding, irrigation etc.) based upon soil and crop properties (nutrients, water, SOM, pests etc.). This can reduce fertiliser usage meaning less residual soil N is lost to air and water. Associated benefits may include reduced P losses to water, reduced water use, reduced pests and diseases, less pesticide use, reduced irrigation, improved soil properties (notably SOM) and biodiversity (Godwin et al., 2003; Diacono et al., 2013). Reduced trafficking by machinery can reduce soil compaction and its associated problems and improve drainage. However, these benefits will depend on the type of precision farming. Some implementations use larger machinery which may affect compaction risk and reduce soil biota.

Reducing Soil Compaction (MM11). Compaction occurs when excess loading from machinery or livestock causes soil deformation, especially on wet vulnerable soil types (eg. silty loams). Compaction affects soil biota by reducing pore size and altering soil structure and moisture, which may impact on nutrient cycling, microbial processes (notably nitrification/denitrification) and plant diseases (ADAS, 2012). Reducing compaction and prevalence of waterlogging increases oxygen available for biological activity and decreases denitrification, whilst encouraging soil fauna and root penetration increases large soil pores (macropores) that enhance water infiltration and reduce runoff and flood risk (Alaoui et al., 2018). Allowing deeper roots can also decrease plant drought risk. Reducing compaction can also benefit nutrient uptake due to: (i) N uptake by plant roots becomes more efficient (Douglas and Crawford, 1993); (ii) increased availability of mineral N but reduced denitrification losses; (iii) N losses to runoff are reduced (although leaching to groundwater may increase). In addition, plant uptake of P and K can be increased.

Improved livestock nutrition; Probiotics in livestock diets; Nitrate as feed additive (MM12,13,14) Wider implications of these measures may be most associated with excreta composition and relative likelihood of residual soil N being lost to air or water, but evidence is limited. Potential issues may also occur due to changing parasitic loads and susceptibility to specific diseases (Garg et al. 2013).

Improving cattle and sheep health (MM16,17). Wider indirect benefits are expected by improved production efficiency (less resource use per unit output) if accompanied by reduced stocking, including reduced pressures from overgrazing on biodiversity, erosion, compaction, and water quality.

Selective Beef Breeding MM18. This measure is narrowly focussed on genetic improvement in beef quality but may be expected to also improve productivity and efficient use of grassland resources. There may be implications for animal welfare and for increasing antibiotic resistance.

Slurry acidification MM19. This process lowers the content of NH_3 compared to NH_4^+ and increases the mineral fertiliser equivalent value of the manure by 39-100%, with yield benefits through improved nutrient availability (Fangueiro et al., 2015; Kai et al., 2008). Acidified slurry may also have a higher biogas production potential in anaerobic digesters. Reduced NH_3 emissions on slurry application can benefit air quality and reduce farmland odour (McCrory and Hobbs, 2001; Cocolo et al., 2016). Also reported are delayed nitrification but with a higher P content (Fangueiro et al., 2015;). Limited evidence suggests potentially reduced NO_3 leaching but increased P leaching, although this may vary with soil type. Micro-organisms are pH sensitive, therefore soil biodiversity may be affected at lower pH rates, although studies are limited. Similarly, although some studies suggest a decrease in pathogens, there is no consensus.

Anaerobic Digestion (AD) MM20/22. Manure and other farm biomass is transported to a nearby digester to produce biogas and a more enriched efficient use of N for fertiliser application. Wider benefits therefore occur through reduced soil N losses to air and water. However, the feedstock for AD may introduce new problems: increased use of maize in recent years has sometimes occurred on less-suitable land (e.g. steep slopes) with resulting negative impacts on biodiversity, nutrient runoff, and soil erosion (Mistry et al., 2011).

High Sugar Grasses (HSGs) MM21. HSGs provide more available energy soon after forage enters the rumen, allowing rumen microbes to process more grass protein which can increase livestock meat and milk production. Trials (IGER, 2005; Soteriades et al., 2018) suggest improved efficiency and a reduced N footprint when grazing animals use HSGs; particularly for sheep, an increased stocking rate may be enabled. Reduction of N in excreta can reduce soil N losses to air and water.

Triticale. This is an established wheat/rye hybrid mainly used for forage, but can be used in cereal food products, bioethanol, and anaerobic digestors. It is commonly used as a 2nd rotation crop following wheat due to its better resistance to root take-all disease (Gutteridge et al., 1993; Overthrow & Carver 2003). Triticale has a more developed rooting system than wheat which means it can be more effective in capturing soil nutrients, with reduced soil N losses to air and water (and P losses to water). Only limited research has been conducted on good quality soils, but advice suggests applying -40kgN/ha less fertiliser (e.g. Clark et al., 2016). The extensive roots have good soil binding potential, especially with lighter soils, which can reduce erosion risk. It can also enhance organic matter and improve soil structure with good management practice. Crop trials suggest it is hardier and outperforms wheat in dry conditions and on poorer soils but that it also has good yield stability appearing equally suited to wet conditions (e.g. summer of 2012) despite slightly higher lodging risk (Bassau et al., 2011; Roques et al., 2016). Compared to wheat it has higher total biomass (mainly straw) and higher N uptake but lower specific yield and protein content. Triticale can reduce weed competition through allelopathy, which may also impact on other adjacent crops (not legumes). Its softer grain requires less mechanical processing during milling, but this would require refinements to current milling technology. Yellow rust may be a problem for some varieties.

Livestock Stocking Rates. As complement to the general 20% shift in diets and livestock production (section 2), another proposal has suggested increased upland grazing (assuming a 10% increase with 80:20 ratio of sheep/cattle on the same land area). The wider implications of this measure are likely to be site-specific and would need careful planning for two main reasons (land capability and habitat type) as described below. It is also likely that there will be differences between cattle and sheep. Cattle are more restricted in their foraging habits and can provide a limited disturbance that is beneficial for biodiversity, especially for rare plants that would otherwise be outcompeted by common species such as grasses. By contrast, sheep are more indiscriminate and overgrazing in some locations has been matched by biodiversity loss, increased soil erosion, and resultant sedimentation/pollution problems in watercourses (e.g. Sansom, 1999; Meyles et al., 2006).

Land capability in the uplands is lower due to less fertile soils and colder wetter climate, which has acted against these areas being agriculturally improved. The uplands therefore typically have less of the productive and palatable vegetation (grasses etc.) that can sustain higher livestock numbers. Overstocking compared to the intrinsic land capability therefore usually results in unsustainable outcomes such as soil degradation. However, implications also vary according to local habitat characteristics (English Nature 2000) with some habitat types more resilient to additional grazing (notably when other pressures such as N deposition or climate change are more constrained).

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