MM16: Improving or Renovating Land Drainage on Mineral Soils

Measure category
Cropland management: water and soil management

Overview
Drainage acts to prevent soil waterlogging, and reduces the likelihood of structural damage and poaching occurring on mineral soils (Dobbie & Smith, 2006; Lilly et al., 2012). These factors act to control the rates of nitrification and denitrification processes, with the majority of studies suggesting a net reduction in N_2O emissions (Bouwman et al., 2002; Dobbie & Smith, 2006; Krol et al., 2016). A reduction in soil waterlogging is also likely to increase crop yields, either directly (through reduced necessity for anaerobic respiration), or indirectly, through prevention of crop losses during periods where areas of the soil are unworkable (Macleod et al., 2010). In order to ensure soils are adequately drained, drainage systems must be implemented, if they are not present in the agricultural area, or renovated and maintained if they have deteriorated since their implementation.

Mitigation summary

Effect on GHG categories*	**Rating**	**Notes**
Enteric CH_4		
Manure CH_4		
Manure N_2O		
Soil N_2O: residue N	-	
Soil N_2O: applied N	-	
Soil N_2O: grazing	-	
Energy CO_2: fieldwork		
Energy CO_2: other		
CO_2 liming and urea		
CO_2 sequestration below ground		
CO_2 sequestration above ground		
Pre-farm emissions		
Post-farm emissions		
Substitution of higher C products		
Production increases by more than the emissions		
Confidence in mitigation effect	Moderate	Likely to represent net abatement, but abatement magnitude is less certain
Cost-effectiveness**	Moderate	
Confidence in cost-effectiveness	Moderate	Costs and abatement variable

* ”-“ GHG reduction, “+”: GHG increase, “ ”: no significant effect
** low: =< £0/tCO_2e, moderate: £0/tCO_2e< >SCC, high: >SCC

Related measures and potential interaction

Measure	Impact on other measures
10. Precision farming	Elements of this measure (e.g. yield mapping) may be used to identify areas in need of drainage remediation. Precision farming also implies good agricultural practice, which may reduce the requirement for drains as a risk mitigation strategy.
2. Cover cropping	Cover cropping is only applicable on free draining soils; this measure may reduce this baseline.
17. Reduced soil compaction	Preventative soil compaction strategies will be less effective if land is not adequately drained. Requirement for remediation of compaction may be lower if land is drained.
18. Move stock off wet land	The baseline applicability of this measure is likely to be affected by implementation of drainage.

It is also worth noting that any measures which impact fieldwork requirements (spreading of fertilisers, lime, etc.) are likely to be impacted by the implementation of drainage; the most likely effect is that the fieldwork element of these measures will become less complex, with lower risk of soil waterlogging complicating or precluding the application of these measures.

Inclusion in other marginal abatement cost curves

UK 2008	UK 2010	UK 2015	Ireland 2012	France 2013	France 2019
Yes	Yes	Yes*	No	No	?

*Measure was reported on in 2015 UK MACC, but was not reassessed since the 2008/2010 MACCs.

What does the measure entail?

Drainage systems act to lower the water table of the drained area, and reduce the likelihood that soils will become waterlogged in drained areas. Implementing this measure requires the construction of drains in areas where drains have not been previously implemented, and the maintenance or renovation of existing deteriorated systems. The exact construction of these systems is likely to depend on locally specific requirements (Lilly et al., 2012), with variables such as drain type and spacing varying according to topographical and management considerations.

Abatement potential

In areas of water scarcity, drainage can improve soil absorption capacity; in areas of waterlogging, drainage improves soil structure (Frelih-Larsen et al., 2014). The latter is likely to reduce N_2O emissions. There are also likely to be indirect effects; Macleod et al. (2010) report that this measure can reduce greenhouse gas emissions via three pathways:

1. Via reduction of denitrification, reducing direct N_2O emissions.
2. Indirectly, by improving crop yields.
3. By reducing anaerobic conditions which favour methanogenesis, reducing CH_4 emissions.

The abatement rate (AR) assumed by Moran et al. (2008) was 1 tonne CO_2-eq ha^{-1} $year^{-1}$. This abatement rate was based on expert opinion and assumed a reduction in denitrification rates, reducing N_2O emissions (pathway 1 above). Variations in emission factors (EFs) for N_2O in waterlogged soils have been recorded between 0.4—7.0% (Macleod et al., 2010); the default, assuming no waterlogging, is 1% (de Klein et al., 2006). This AR was later critiqued internally as arbitrary (Macleod et al., 2010), and based on further feedback, the authors suggested a revision of the original 2008 estimate to a range of 0.2—1 tonne CO_2-eq ha^{-1} $year^{-1}$.

In a study which influenced the original MACC abatement estimate, Dobbie & Smith (2006) found a consistent linear relationship between soil water table depth and emissions of N_2O-N in a Scottish grassland. Lilly et al. (2012) assert that this is likely to be the main pathway through which drainage impacts N_2O emissions, with drainage implementation likely to reduce the water table height by an average of 18cm, and potentially up to 60cm. In practical terms, Dobbie & Smith (2006) suggest that maintaining the water table below 35cm is likely to reduce N_2O emissions by 50%. Further adding to the complexity, there may exist interactions between tillage regimes and soil drainage status (Rochette, 2008; MacDonald et al., 2011). Poorly aerated soils (i.e. those with poor drainage) may show a reduction in N_2O emissions resulting from ploughing, which aerates the soil. Heavier, clay-rich soils (e.g. gleysols) are also unlikely to benefit greatly from drainage, with no great effect of this measure on waterlogging, and hence a reduced potential impact on N_2O emissions. Drainage is likely to primarily impact direct N_2O emissions; simulated changes in drainage of grassland using the DNDC model suggested minimal changes to nitrate leaching resulting from drainage (Lilly et al., 2012).

More recently, the Farmscoper tool (Gooday et al., 2014, 2015) estimated a net increase in emissions, stemming largely from direct N_2O emissions, where field drainage systems are allowed to deteriorate. This was equated to an estimated net emission of 515 kt CO_2-eq nationally (Defra, 2012). CO_2-eq Krol et al. (2016) also found that drainage influences emissions of N_2O stemming from manure application, especially in the autumn season. Soil moisture deficit, a variable influenced by rainfall, soil texture, and soil drainage status, was a significant predictive variable for N_2O emissions. The authors found that the mean EF for imperfectly drained soils, as compared to well drained soils, was 4.1—4.5 fold higher in spring and summer, and 17.3 fold higher in autumn. Soils with moderate drainage, as compared to well drained soils had an EF 1.5—2.2 fold higher in spring and summer, and 3.5 fold higher in autumn as compared to well drained soils.

There is also consistent theme in discussions of drainage effects on N_2O (Macleod et al., 2010; S. Anthony, pers. comm.) which suggests that drainage is a risk-minimisation strategy rather than a mitigation strategy; mitigation results from good soil practice (e.g. not working waterlogged soils) rather than drainage *per say*. It is probable that the non-significance of a soil-texture related explanatory variable in the derivation of the new UK Tier 3 EFs for N_2O (Chadwick et al., 2016) stems, at least in part, from the good agricultural practice observed in the field trials which provided data for this model; more mixed practice may have exacerbated the importance of this variable in modulating the magnitude of N_2O fluxes.

Implementation costs

Implementation costs of drainage (on land without drainage previously established) can be split into an implementation cost (for the installation of drains) and a more regular maintenance cost to ensure drains remain working at optimum capacity.

Moran et al. (2008) assumed an implementation cost of £1850 ha^{-1} for drainage on arable or grassland, and a 20-year lifetime before re-implementation is required. The authors also assumed a regular cost of £250 ha^{-1} every five years for drain cleaning and maintenance. Posthumus et al. (2015) made similar estimates (£2000 ha^{-1} to implement and 25 year lifetime), but assumed a zero or negligible maintenance cost. However, the authors did suggest that measures which act to control erosion may reduce the sediment load to drains, reducing the cost of (or requirement for) maintenance (Posthumus et al., 2015). Following critique of the 2008 UK MACC, the MACC update (Macleod et al., 2010) suggested a revised implementation cost range of £2000—5000 ha^{-1}. The majority of this variation stemmed from differences in drain construction and spacing, which would in turn vary depending on local environmental factors (e.g. soil type, topography).

Moran et al. (2008) estimated a crop yield increase of 10% for land where drainage was implemented. This was characterised as an indirect yield increase in the updated MACC (Macleod et al., 2010), on the basis that half of a poorly drained field may be unworkable one year in five, translating to a 10% decrease in five-year average yields. Posthumus et al. (2015) suggested that drainage may increase yields, but did not quantify this increase physically or financially.

Applicability, current uptake and potential additional maximum uptake

Moran et al. (2008) estimated maximum potential additional uptake of 40% of grassland, 30% arable land, and 20% of land used to grow root crops and others, equating to a total area of 4 million hectares. Critique of the 2008 UK MACC resulted in an expert workshop approach to updating these figures (reported in Macleod et al., 2010); collation of expert opinion from this exercise suggests the following:

- <5% of arable land is believed to require new drains
- 6—20% of arable land is believed to require drainage renovation
- <5—20% of grassland is believed to require new drains
- 6— >30% of grassland is believed to require drainage renovation

Based on these responses, Macleod et al. (2010) suggest that a range of 5—40% of grassland be estimated to require implementation of drainage, and 5—30% of arable land be estimated to require implementation of drainage.

Other sources find estimates in similar magnitudes. A 2012 survey of English systems found 17% of respondents reported drainage issues (Hallett et al., 2012). This is unlikely to imply that 17% of land has drainage issues, but does form an upper bound for estimates of this variable. In the 2015 MACC update, Eory et al. (2015) suggested that drainage systems are likely to continue deteriorating, but found that there is no robust evidence for this. Lilly et al. (2012) found that drainage systems in Scotland, while having seen historical investment over the past two centuries, are deteriorating and have little current investment. An approximate estimate based on survey results suggests that around half of cultivated land (arable or improved grassland) in Scotland has some degree of seasonal waterlogging and would benefit from drainage. This result is indicative of a more general observation that cultural and historical factors is likely to make for substantial spatial heterogeneity in the baseline uptake for this measure. Many areas of land were historically drained, some of which are still effective to some degree; as such, these areas will have a higher baseline ‘uptake’ of this measure. The rate of drain degradation is also highly variable; soil erosion rate is one factor which strongly affects the ongoing viability of drains (Posthumus et al., 2015). Some drainage may require renovation in as little as 20—25 years (Moran et al., 2008; Posthumus et al., 2015), while anecdotal accounts suggest that drains from Victorian and even Roman periods may still be effective to some degree (Macleod et al., 2010; S. Anthony, pers. comm.). Discussions reported in Moran et al. (2008) suggest that potential for additional uptake may be lowest in England, where land has been historically drained, and higher in Scotland. Anecdotal evidence suggests there may also be greater uptake potential in Wales, which has seen little historical investment in drainage.

Assumptions used in MAC

The impact of drainage on N_2O EF_1 was assessed using ranges estimated by a variety of literature sources (Dobbie & Smith, 2006; Macleod et al., 2010; Krol et al., 2016). These ranges were collated and, with equal weighting, used to estimate a range of impacts to the EF_1 emission factor caused by soil waterlogging/inadequate drainage (Fig. #IRD.1). This was assumed to be the only emissions impact of the measure (Moran et al., 2008; Macleod et al., 2010; Eory et al., 2015).

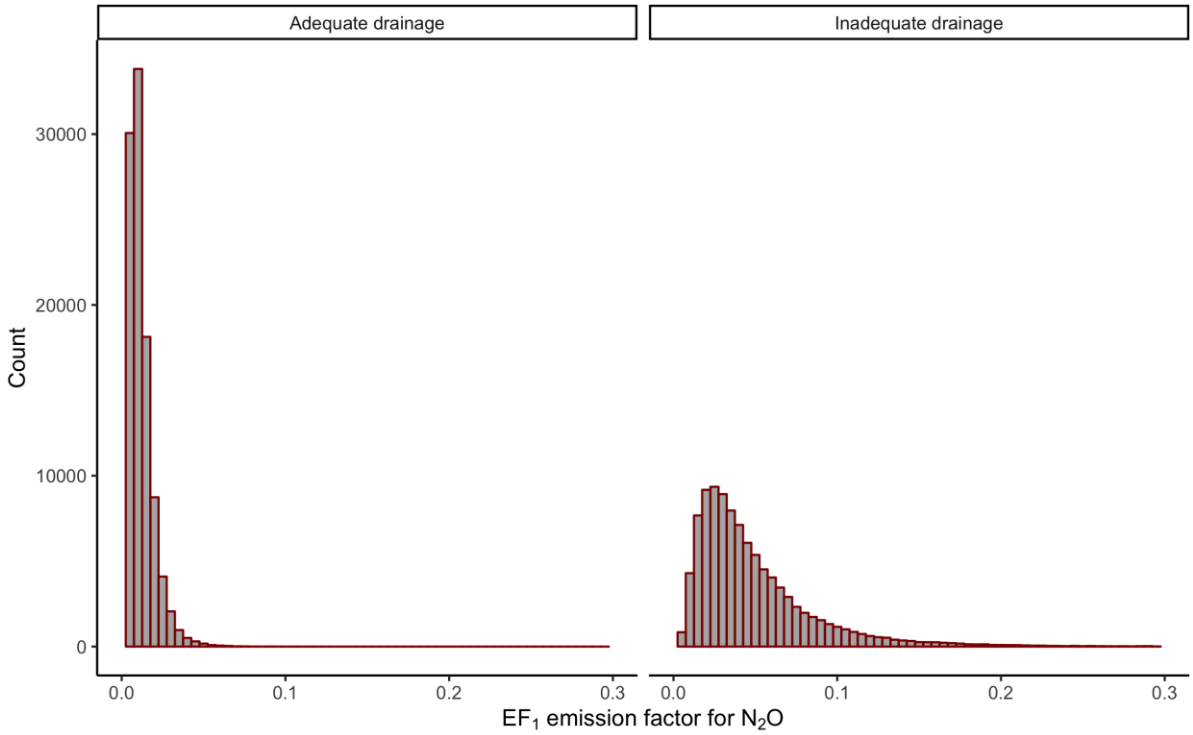

Fig.1. Assumed impact of drainage on the magnitude of the EF_1 emission factor for N_2O emissions from applied nitrogen. The adequate drainage scenario uses the stock EF_1 emission factor from de Klein et al. (2006).

Nitrogen application rates (from both synthetic fertiliser and manure) were collated by crop type from the British Survey of Fertiliser Practice (Defra, 2018b), with uncertainties characterised by variability in per-hectare application rates for the past five years.

Crop value per hectare was collated from data presented by SAC (2017), using the range estimated in this data source to characterise uncertainty.

Maximum potential additional uptake was set using the ranges defined by Macleod et al. (2010), following expert consultation on this parameter. These ranges were 5—30% for arable land, and 5—40% for grassland, with a feasible potential at 45% of this figure. Total areas of each type of land were calculated based on 2018 data from Defra (2018a). These areas were adjusted to remove areas with peat soils (not suitable for drainage) using data from Graves et al. (2011).

The assumed cost of soil drainage stemmed from indirect yield loss, using the logic and values described by (Macleod et al., 2010). In this scenario, half of an undrained field is assumed to be unworkable due to waterlogging for one year in five, resulting deterministically in a 10% yield loss ($1/5 \times 0.5 = 0.1$). This scenario was implemented stochastically in the MAC model, with the annual probability of a 50% yield loss being 20% (1 in 5). This scenario was run over 20 years (the assumed lifetime of a drainage system) and the value of yield losses in years where waterlogging occurred was calculated and annualised (assuming a 3.5% discount rate for future losses).

The cost of implementing drainage was assumed using the updated ranges suggested by Macleod et al. (2010) following expert consultation (£2000—5000 ha^{-1}) at a 20-year lifetime. The cost of drainage maintenance was estimated to lie between £0 (Posthumus et al., 2015) and £250 (Moran et al., 2008), and to be required at a 5-year interval (Moran et al., 2008). Both costs were annualised using a discount rate of 3.5%.

A Monte Carlo simulation (Mersenne seed = 2605, samples = 10^5) was conducted to assess the effects of these parameters and uncertainties on the estimated marginal abatement cost, abatement rate and abatement potential for drainage in agricultural soils.

The mean marginal abatement cost for this measure across crop types (unweighted by area) was estimated to be £20 tonne CO_2-eq; this is within the range reported by Moran et al. (2008) and Macleod et al. (2010). There was some variability in this estimate both within and between crop and land use types (Fig.2).

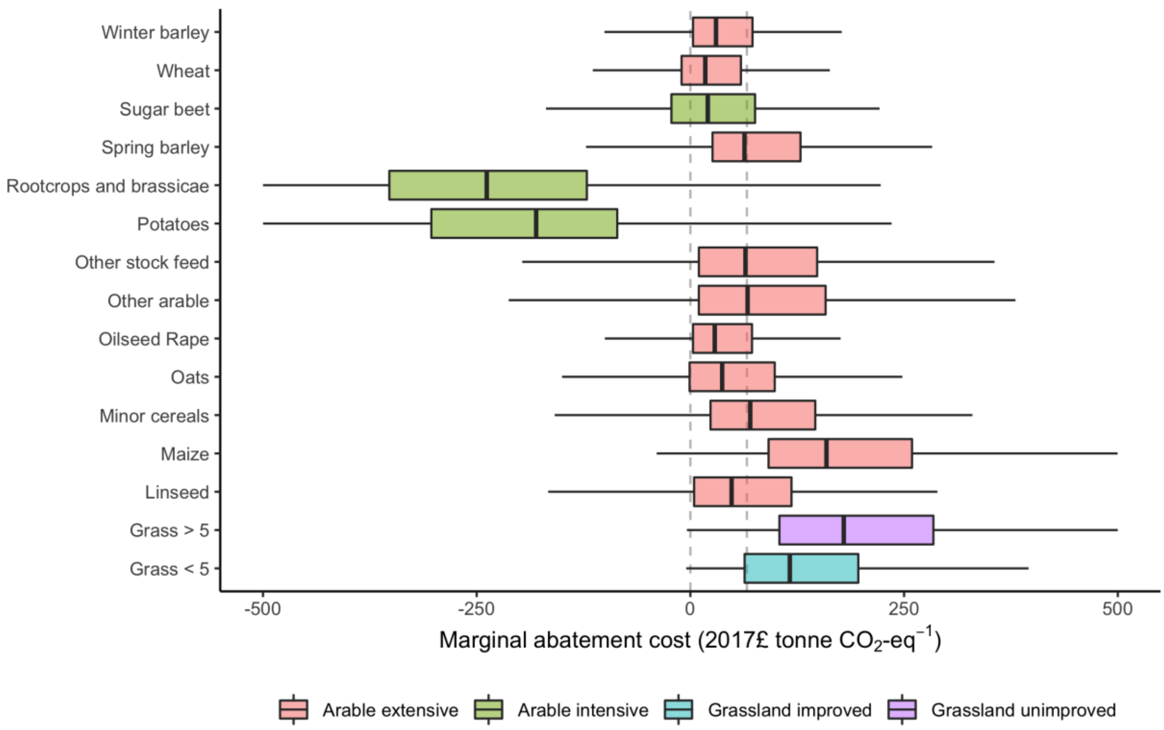

Fig.2. Estimated marginal abatement cost for installing and maintaining drainage across different crops and land uses. Vertical dashed lines indicate MACs of £0 and £66.10 (the social cost of carbon; Department for Business Energy & Industrial Strategy, 2018). The <5 and >5 categories for grass refer to time, in years, since last renovation.

The defined model did not allow disaggregation of drainage impacts on EF_1 by crop or soil types; as such the variability/uncertainty shown in Fig. #IRD.2 stems from a) differences in N application rates, and b) differences in the relative value of different crops (and hence the magnitude of savings resulting from avoided yield loss). The majority of arable crops had a median MAC between zero and the social cost of carbon (SCC), whilst some more valuable produce (e.g. potatoes and brassicas) had a strongly negative estimated cost. Implementation on grassland appeared to be rarely cost-effective.

The total abatement potential was calculated based on the estimated total areas for each crop type (Defra, 2018a), scaled to remove any area estimated to comprise peatland soil. Abatement was calculated both as a maximum technical potential, and scaled to reflect estimated abatement achievable below the SCC for each crop category (Fig.3). Over all crop categories, the maximum technically possible abatement was estimated at 1161 kt CO_2-eq year^{-1}, and cost effective abatement, achievable below the SCC, was estimated at 786 kt CO_2-eq year^{-1}. The estimate reported by Moran et al. (2008) (1 Mt CO_2-eq year^{-1}) falls within this range.

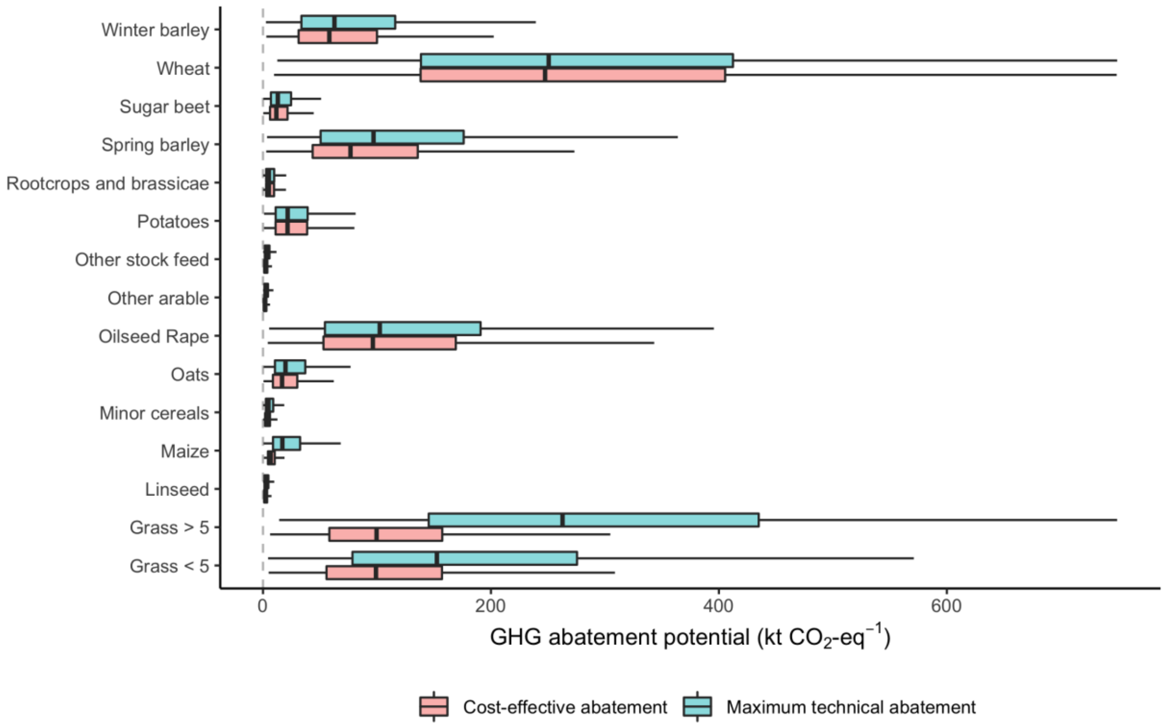

Fig.3. Abatement potential of improving drainage in agricultural soils, disaggregated by crop and measure. Cost effective abatement indicates estimated abatement achievable below the SCC; maximum technical abatement indicates estimated total abatement achievable.

The majority of the abatement realisable below the SCC comes from commonly grown cereals and oilseed (primarily wheat, barley and oilseed rape). There is also a substantial amount of abatement available from grasslands (both younger, improved grasslands, and older grasslands), though fractionally, this is a smaller amount of the total available (the majority of which is not cost effective).

Ancillary effects

Posthumus et al. (2015) estimated 2% reduction in run-off and soil loss and a 25% reduction in P loss resulting from implementation of drainage. This estimate was based on broad ‘effectiveness categories’, so could be further refined, but indicates that there may be some nutrient loss mitigation resulting from implementation of this measure. This, in turn, would positively impact eutrophication, acidification, and biodiversity, as well as indirectly reducing GHG emissions via reduced nutrient application rates.

Identified implementation challenges and barriers

Identifying land upon which drainage would positively impact yields and reduce N_2O emissions is a challenge which must be overcome in order to implement this measure. In addition, this measure involves a great deal of capital expenditure in years where drains are implemented, and even maintenance is not likely to be annual; as such, cash flow-related limitations may be one of the main challenges to land managers seeking to implement this measure.

References

Bouwman, A.F., Boumans, L.J.M. & Batjes, N.H. (2002) Modeling global annual N2O and NO emissions from fertilized fields. *Global Biogeochemical Cycles* 16(4), pp. 28-1-28–9. Available at: http://doi.wiley.com/10.1029/2001GB001812 [Accessed: 29 August 2014].

Chadwick, D., Rees, B., Bell, M., Cardenas, L., Williams, J., Nicholson, F., Watson, C., McGeough, K., Hiscock, K., Smith, P., Top, K., Fitton, N., Skiba, U., Cowan, N., Manning, A. & Misselbrook, T. (2016) *Final Report - AC0116: Improvements to the national agricultural inventory - Nitrous oxide. The InveN2Ory Project (2010-2016). Report to Defra, DARDNI, Scottish Government and Welsh Government.*

Defra (2012) *2012 review of progress in reducing greenhouse gas emissions from English agriculture*. Department for Environment, Food & Rural Affairs.

Defra (2018a) Farming Statistics: Provisional crop areas, yields and livestock populations. (October), p. 23. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/747210/structure-jun2018prov-UK-11oct18.pdf.

Defra (2018b) *The British Survey of Fertiliser Practice: Fertiliser use on farm crops for crop year 2017*. York, England.

Department for Business Energy & Industrial Strategy (2018) *Data tables 1 to 19: supporting the toolkit and the guidance. Table 3.*

Dobbie, K.E. & Smith, K.A. (2006) The effect of water table depth on emissions of N2O from a grassland soil. *Soil Use and Management* 22(1), pp. 22–28.

Eory, V., Macleod, M., Topp, C.F.E., Rees, R.M., Webb, J., McVittie, A., Wall, E., Borthwick, F., Watson, C., Waterhouse, A., Wiltshire, J., Bell, H., Moran, D. & Dewhurst, R. (2015) Review and update the UK Agriculture Marginal Abatement Cost Curve to assess the greenhouse gas abatement potential for the 5th carbon budget.

Frelih-Larsen, A., MacLeod, M., Osterburg, B., Eory, A. V, Dooley, E., Katsch, S., Naumann, S., Rees, B., Tarsitano, D., Topp, K., Wolff, A., Metayer, N., Molnar, A., Povellato, A., Bochu, J.L., Lasorella, M. V & Longhitano, D. (2014) *Mainstreaming climate change into rural development policy post 2013*.

Gooday, R.D., Anthony, S.G., Chadwick, D.R., Newell-Price, P., Harris, D., Duethmann, D., Fish, R., Collins, A.L. & Winter, M. (2014) Modelling the cost-effectiveness of mitigation methods for multiple pollutants at farm scale. *Science of the Total Environment* 468–469, pp. 1198–1209. Available at: http://dx.doi.org/10.1016/j.scitotenv.2013.04.078.

Gooday, R.D., Anthony, S.G., Durrant, C., Harris, D., Lee, D., Metcalfe, P., Newell-Price, P.

& Turner, A. (2015) *Farmscoper Extension: Defra Project SCF0104*. ADAS.

Graves, A., Morris, J., Deeks, L., Rickson, J., Kibblewhite, M., Harris, J. & Fairwell, T. (2011) *The Total Costs of Soils Degradation in England and Wales. Project Report to Defra*. Cranfield University.

Hallett, P., Balana, B., Towers, W., Moxey, A. & Chamen, T. (2012) Studies to inform policy development with regard to soil degradation. Subproject A: Cost curve for mitigation of soil compaction. 1305(Cte 1024), p. Defra SP1305 (CTE 1024), 1-97.

de Klein, C., Novoa, R.S.A., Ogle, S., Smith, K.A., Rochette, P. & Worth, T.C. (2006) Volume 4, Chapter 11 - N2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application. In: *IPCC Guidelines for National Greenhouse Gas Inventories*.

Krol, D.J., Carolan, R., Minet, E., McGeough, K.L., Watson, C.J., Forrestal, P.J., Lanigan, G.J. & Richards, K.G. (2016) Improving and disaggregating N 2 O emission factors for ruminant excreta on temperate pasture soils. *Science of the Total Environment* 568(June), pp. 327–338. Available at: http://dx.doi.org/10.1016/j.scitotenv.2016.06.016.

Lilly, A., Baggaley, N., Rees, B., Topp, K., Dickson, I. & Elrick, G. (2012) Report on agricultural drainage and greenhouse gas abatement in Scotland. *The James Hutton Institute* (November), pp. 1–41.

MacDonald, J.D., Rochette, P., Chantigny, M.H., Angers, D.A., Royer, I. & Gasser, M.O. (2011) Ploughing a poorly drained grassland reduced N2O emissions compared to chemical fallow. *Soil and Tillage Research* 111(2), pp. 123–132. Available at: http://dx.doi.org/10.1016/j.still.2010.09.005.

Macleod, M., Moran, D., Mcvittie, A., Rees, B., Jones, G., Harris, D., Antony, S., Wall, E., Eory, V., Barnes, A., Topp, K., Ball, B., Hoad, S. & Eory, L. (2010) *Review and update of UK marginal abatement cost curves for agriculture*. Edinburgh.

Moran, D., MacLeod, M., Wall, E., Eory, V., Pajot, G., Matthews, R., McVittie, A., Barnes, A., Rees, B., Moxey, A., Williams, A. & Smith, P. (2008) *UK Marginal Abatement Cost Curves for the Agriculture and Land Use, Land-Use Change and Forestry Sectors out to 2022, with Qualitative Analysis of Options to 2050*. Edinburgh.

Posthumus, H., Deeks, L.K., Rickson, R.J. & Quinton, J.N. (2015) Costs and benefits of erosion control measures in the UK. *Soil Use and Management* 31(September), pp. 16–33.

Rochette, P. (2008) No-till only increases N2O emissions in poorly-aerated soils. *Soil and Tillage Research* 101(1–2), pp. 97–100.

SAC (2017) *Farm Management Handbook 2017/18*. 37th ed. Craig, K. ed. SAC Consulting.