MM08: Integrating Grass/Herbal Leys into Arable Rotations

Measure category

Cropland management: agronomy

Overview

Introduction of perennial plants, including grass leys, into an arable crop rotation can increase the positive effects of rotation practices (Gentile et al., 2005; Prade et al., 2017). Loss of soil organic matter (SOM), with corresponding negative effects on crop yield and CO_2 emission, is possible if arable-only rotations are practiced long-term (Prade et al., 2017). Likewise, the practice of leaving land to fallow has been shown to contribute to loss of soil C stocks (Persson et al., 2008; Rutledge et al., 2017). Diversification of arable cropping systems with grass leys serves to increase the quantity and continuity of below-ground residue returned to the soil (West & Post, 2002; Fu et al., 2017). This in turn can support microbial activity and diversity, and ensures continuity of root-derived C inputs to soil, increasing soil organic matter (SOM). A key issue in the integration of grass leys into arable rotations is loss of crop production (Maillard et al., 2018), though optimal implementation of the measure should increase arable crop annual yields; this may offset loss of harvests while the land is under grass leys (e.g. Persson et al., 2008; Prade et al., 2017). Additional production stemming from the grass ley is also likely if the grass is used as grazed or cut forage for livestock (NSA, 2018).

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	High	
Cost-effectiveness**	Low	
Confidence in cost-effectiveness	Moderate	

* ”-“ 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
2. Catch/cover crops	May be some definitional overlap (NSA, 2018). Implementation of this measure may also alter the frequency or timing of cover cropping.
12. Improving/renovating drainage on mineral soils	This measure is likely to improve soil structure and drainage, reducing additional AR and CE.
26—38. All livestock management measures	This measure involves the production of livestock forage on arable land, so may have direct and indirect impacts on livestock management measures.
7. Crop health	This measure may improve weed and pest control, with associated benefits for crop health, reducing additional AR and CE.
11. Avoiding N excess	This measure may reduce N leaching, reducing additional AR and CE.
18—21. All grazing land management measures	This measure effectively incorporates grazing land into arable rotations, so can be co-implemented with all grazing land management measures.

Inclusion in other marginal abatement cost curves

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

*Extending the perennial phase of rotations was considered for these MACCs, but excluded due to small abatement potential.

What does the measure entail?

The measure involves breaking up arable-only crop rotations with the integration of a regular one-or-more-year grass ley. This grass is typically used as livestock forage, either as grazing land or as a cut-and-carry forage crop (AHDB, 2014; NSA, 2018).

Abatement potential

Extension of the perennial phase of crop rotations was considered in the 2008 UK MACC (Moran et al., 2008; Macleod et al., 2010), but rejected on the basis of low abatement potential (excluding soil C effects). Persson et al. (2008) assessed a continuous arable rotation with one year of fallow every six, in contrast with two arable rotations incorporating two years of grass-clover ley every six. The authors found that the inclusion of the grass sward had positive effects on arable yields in addition to some indication of benefits to soil C stocks. Benefits to soil and yield are long-term; these may take up to 120—130 years to be fully realised (Prade et al., 2017).

Posthumus et al. (2015) synthesise the literature to estimate that land use change from arable to pasture will sequester 612 kg C (2,244 kg CO_2-eq) ha^{-1} $year^{-1}$. This value assumes permanent change; linear interpolation of this to a one-year-in-four grass ley would suggest sequestration rates in the region of 561 kg CO_2-eq ha^{-1} $year^{-1}$. However, it is difficult to be certain that this effect would indeed be linear. Based on a modelling approach, Prade et al. (2017) estimate a much higher net soil sequestration rate of 1,789 kg CO_2-eq ha^{-1} $year^{-1}$ for a four-year arable rotation with a one-year grass ley integration. Knight et al. (2019) synthesise the extant literature (Post & Kwon, 2000; Poeplau et al., 2015; Johnston et al., 2017) and find that various implementations of grass-arable rotations may sequester 0.26—0.36 tonnes C ha^{-1} $year^{-1}$ (953—1,320 kg CO_2-eq ha^{-1} $year^{-1}$), or an annual increase 0.3—0.9% of existing C stocks. Knight et al. (2019) stress that these estimates reference a baseline of arable-only rotations; if permanent grassland converted to arable-grass rotations, a net loss of soil C is probable.

Field trials have also shown that the presence of grass leys is also likely to reduce N leaching (Webster et al., 1999); this is incorporated into the modelling approach of Prade et al. (2017), where the authors also estimate a smaller amount of increased nitrogen uptake by soil organic matter, offsetting N_2O emissions. Another interpretation of this effect is that crop N requirements may be reduced. Where grass leys are grazed, urine and dung patches from livestock are likely to be the main sources of N_2O; however, most emissions accounting methodologies would allocate these emissions to the livestock (Sykes et al., 2017).

Given their scenario-specificity and basis in validated models, GHG estimates from Prade et al. (2017) are deemed the most robust available for this measure in the extant literature. These estimates are based on models calibrated for southern Sweden, with a comparable latitude and climate to the United Kingdom. Table 1 summarises the estimated GHG impacts calculated by Prade et al. (2017).

Table 1. Estimated on farm emissions for comparable four-year rotations, including and excluding a one-year grass ley. Data for rotation with grass ley incorporates soil carbon sequestration estimated at 1,789 kg CO_2-eq ha^{-1} $year^{-1}$. Adapted from Prade et al. (2017).

Year	**Arable-only rotation**		**Arable rotation with grass ley**			
	Crop	**Net GHGs (kg CO_2-eq ha^{-1} $year^{-1}$)**	**Crop**	**Net GHGs (kg CO_2-eq ha^{-1} $year^{-1}$)**		
				Emissions	**Sequestration**	**Net**
1	Oilseed Rape	1,704	Oilseed Rape	1,436	1,789	-353
2	Wheat	1,892	Wheat	1,615	1,789	-174
3	Wheat	1,892	Wheat	1,615	1,789	-174
4	Oats	1,305	Grass*	1,200	1,789	-589
Average		1,698		1,467	1,789	-323

*Grass ley undersown in year 3.

The data are based on modelling studies, but are well supported by empirical assessments (e.g. Persson et al., 2008). It also is worth noting that retaining crop residues on the field may serve to increase sequestration rates (though not the final SOC equilibrium concentration) resulting from this measure by 25—33% (Prade et al., 2017), though this would have associated costs; straw from arable crops are typically sold or used as bedding or feed livestock (SAC, 2017).

Implementation costs

To calculate the estimated cost of implementing this measure, two comparable gross margin scenarios were calculated using the rotations shown in Table #IGL.1. The following data sources and assumptions were used in the calculation of these margins:

1. For both scenarios, the arable crop base yields, cultivation costs and selling prices were calculated according to data from SAC (2017).
2. For grass production, two separate scenarios were considered; the margins from these scenarios represented the range of values considered for this variable.
    a. Preserved grass production (silage) using yields and production costs from SAC (2017) and silage cash sale prices from AHDB Dairy (2011).
    b. Land rental for grazing animals, using rental prices estimated from Defra (2018a).
3. Assumption of crop yield increases in the grass-arable rotation based on results from Prade et al. (2017); these authors estimated 8—16% increase in wheat yield by 50 years as a result of including a one-year grass rotation in crops.
4. Assumption that the yield increase modelled by Prade et al. (2017) would be linear over the 50-year period.
5. Discounting of the crop revenue from future yield increases to its (2017) base year net present value (NPV) at a rate of 3.5%.

The results of this calculation are presented in Table 2.

Table 2. Gross margins and implementation costs for a) a typical four-year arable rotation, and b) integration of grass leys into this rotation. Margins assume a linear yield increase of 8—16% as reported in Prade et al. (2017).

	Rotation Year	Crop	Gross margin (2017 £ ha^{-1})		
			Best estimate	Min	Max
Arable only	1	Oilseed Rape	934	609	1,259
	2	Wheat	1,064	687	1,440
	3	Wheat	1,064	687	1,440
	4	Oats	626	352	902
	Average annual margin		**922**	**584**	**1,260**
Arable/grass rotation	1	Oilseed Rape	961	622	1,304
	2	Wheat	1,096	703	1,492
	3	Wheat	1,096	703	1,492
	4	Grass	-209	-353	-11
	Average annual margin		**736**	**419**	**1,069**
Implementation cost			**186**	**165**	**191**

Implementation of this measure would result in loss of grain production. This value is likely to vary from around 1.25 tonnes ha^{-1} $year^{-1}$ in year 1 through to around 0.85—1.05 tonnes ha^{-1} $year^{-1}$ in year 50. Prade et al. (2017), in their grass-arable rotation model, estimated that it is possible that steady-state yield increases may completely offset yield loss from grass after 130—140 years. Acting to partially offset production losses, if the grass ley were to be used for grazing or silage production, the resulting meat production would be in the order of 133—186 kg carcass weight ha^{-1} $year^{-1}$. This number assumes a dry matter grass yield of 7 tonnes ha^{-1} (SAC, 2017), a feed conversion efficiency of 5—7 kg DM kg LWG^{-1} (Morgan & Vickers, 2016) and a KO% of 53%.

Applicability, current uptake and potential additional maximum uptake

No data explicitly quantifying baseline uptake of grass ley integration into arable cropping was found. The following data from the 2018 June Survey of Agriculture (Defra, 2018b) give some indication as to where baselines for this practice may lie:

- In a total UK croppable area of 6,203 thousand hectares, 1,163 thousand hectares (18.7%) were covered in grass less that 5 years old.
- For holdings categorised as cereals or general cropping, 3.95% of the farmed area was under temporary grassland.
- Holdings classified as mixed occupied 9.7% of total farmed area.
- Cereals were grown on 2.8% of the farmed area for holdings in the grazing livestock category (both lowland and LFA).

In interpreting these statistics, we must note that the presence of cereals on grazing livestock holdings does not necessarily imply the integration of grazing and cropping land; in all likelihood, the majority are permanently separate, but coexist on the same holding. We can infer more from the presence of grass leys of an age less than five years on 3.95% on land belonging to cropping holdings, as the age of this land category implies this land is more likely to be in rotation. However, given the low likelihood of a positive margin for single years where a grass ley is integrated into an arable rotation (Table #IGL.2), it seems unlikely that a large proportion of this grassland is integrated in this way.

Assumptions used in MAC

Making a conservative assumption that 10% of grassland aged less than five years on crop holdings is integrated as a grass-arable rotation, and assuming rotation lengths of 4—7 years, it can be estimated based on the areas presented in Defra (2018b) that grass-arable rotations are currently implemented on between 2.0—3.5% of the total croppable area.

The total area of temporary grassland is relatively constant; it varied from 98—103% of average area between 2007—2017. Assuming that implementation of this measure involves the integration of this existing temporary grassland area into arable rotations (i.e. the net grass area does not change) we can say that the maximum technical potential uptake area for this measure (assuming the four-year rotations specified here) can be assumed to be 4× the 2017 temporary grassland area of 1,163 thousand hectares, or 75% of croppable area. Assuming a conservative upper bound from the assumptions on existing uptake, maximum additional uptake is therefore 71.5% of croppable area, or 4,435 thousand hectares. Based on this potential uptake, and the abatement and cost values derived in Tables #IGL.2 and #IGL.3, the marginal abatement costs, rates and potential are presented in Table 3.

Table 3. Potential uptake and marginal abatement costs for integration of a single year of grass leys into four-year arable rotations. Maximum uptake assumes all temporary grassland on potentially croppable land is integrated in this way; 10% uptake assumes the integration of 10% of temporary grassland. Abatement rates and costs based on values derived in Tables 1 and 2 respectively.

Metric	Units	Min	BE	Max
Existing uptake area	'000 ha	95.4	—	167.0
10% uptake area	'000 ha	—	465.2	—
Maximum potential uptake area	'000 ha	—	4,652.0	—
10% uptake additional area	'000 ha	298.2	—	369.8
Maximum uptake additional area	'000 ha	4,485.0	—	4,556.6
Abatement rate	tonnes CO_2-eq ha^{-1} year^{-1}		2.02	
10% uptake abatement potential	kt CO_2-eq year^{-1}	602.6	—	747.2
Maximum abatement potential	kt CO_2-eq year^{-1}	9,063.1	—	9,207.7
Implementation cost	2017 £ ha^{-1} year^{-1}	165	186	191
Marginal abatement cost	2017 £ tonne CO_2-eq^{-1}	81.6	92.1	94.4

It should be noted that there is an important trade-off between abatement potential and production loss inherent in the implementation of this measure. There is also the potential for emissions ‘leakage’ if existing agricultural land uses are altered. To illustrate this, consider the following scenarios:

1. Assume this measure is applied on an area of land previously used for arable-only rotations (as in Prade et al., 2017). In this case, the baseline soil C stocks can be assumed to be low, and will increase under grass-arable rotations. However, arable production will be lost, and (assuming no external land use changes), the net area of grassland will increase.
2. Assume this measure is applied on an area of land which is rotated between grass and arable production on a long-term basis (say, to take a simple example, 15 years arable followed by 5 years grass). In such a scenario, implementing a rotation comprising 3 years of arable, followed by 1 year of grass would have the following implications:
    a. The net area of grass and arable land would be the same.
    b. Net arable production over the long term would increase from the baseline, assuming the yield increases included in this assessment.
    c. Average soil C stocks would likely increase somewhat, but not as dramatically as if the baseline scenario was an arable-only rotation, since part of the affected area would have been previously under grass.

In this assessment, the abatement rates assume an arable-only rotation as the baseline. To scale the measure uptake to a realistic level (in the absence of specific data on uptake or applicable area), the current area of temporary grassland has been used as a guide to the maximum technical potential uptake for this measure. To receive the abatement modelled for this measure, it would need to be implemented on previously permanently arable land, with associated production loss. An alternative scenario would be to integrate existing grassland into short-term arable-grass rotations; however, in order to assess the potential of such a measure, appropriate abatement rates, which account for the different baseline, would need to be defined.

Ancillary effects

The following ancillary effects are important to consider for this measure.

- **Improved SOM and soil structure; reduced erosion loss.** The primary impact of this measure is to improve soil SOM with resulting positive impacts on crop yield, soil structure and resistance to erosion losses (Persson et al., 2008; AHDB, 2014; Prade et al., 2017).
- **Production losses from arable rotations**. Although some studies suggest that it may be possible to entirely mitigate production loss via increased yield in arable years (Prade et al., 2017), this is highly baseline-dependent and unlikely to be uniformly realised. Yield loss is also inevitable in the 50—100 years it will take for these improvements to be fully recognised. However, there exists considerable temporary grassland on potentially croppable land (Defra, 2018b), so it is possible that this measure could be partially implemented without reducing net annual crop area; this, however, does engender questions of the baseline from which this measure should be assessed in terms of soil carbon sequestration.
- **Control of weed species**, e.g. herbicide resistant black-grass. Grass ley breaks are a recognised non-chemical intervention for multiple weed species, and particularly useful in the case of those with herbicide resistance (Lutman et al., 2013).
- **Use of herbicides**. Increased use of herbicides to remove the grass ley prior to arable re-planting is possible, with associated impacts (AHDB, 2014). However, the measure may also be implemented in an organic system; Taylor et al. (2006)

assessed grass-arable rotations in an organic system, and found this approach to be financially sustainable solution to the absence of pesticide or fertiliser availability.

Identified implementation challenges and barriers

The main barrier to implementation is likely to be the high cost of loss of arable production; this is likely to be partially offset by yield increases, but this will take time to realise. Yield increases are largely based on assumed SOM increases (Persson et al., 2008; Prade et al., 2017), which are baseline- and scenario specific, so may be realised to different extents in different situations. The measure is therefore likely to engender overall production losses.

Knight et al. (2019) identify three main categories of knowledge gap which currently represent a barrier to implementation:

1. Broad/macro-scale considerations, e.g. market capacity and impacts on other agricultural systems
2. Farm/catchment-scale considerations, e.g. impacts on the farming system in question over short and long timescales
3. Social science at farm and catchment scale, i.e. understanding the drivers and barriers for this change

The authors conclude that the measure shows promise in a number of areas (GHG abatement, diffuse pollution risk, soil health, biodiversity) but recommend that the above research requirements be further addressed before the measure is accepted as best practice. Based on the results of stakeholder interviews, the following potential barriers were also identified (summarised from Knight et al., 2019):

- Profitability and uncertainty — adding livestock to previously arable-only enterprise adds complexity and uncertainty, and may reduce profits.
- Knowledge/skill barrier — the ability to keep and market livestock may have been lost in some areas, and it may not always be straightforward to sublet grass leys to livestock farmers.
- Equipment and infrastructure — having livestock on previously arable systems may require different/additional machinery, as well improvements to fencing and shelterbelts/hedges for livestock welfare.
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Finally given the long-term nature of key variables in this measure, it is difficult to source reliable data from field trials indicative of its efficacy (Persson et al., 2008); for this reason, a substantial proportion of the assumptions used in this assessment were based on results of a modelling approach (Prade et al., 2017). This analysis also focused on four-year rotations only, given that quality data existed for a scenario of this type. However, it would be possible to implement variations of this measure with rotations of varying lengths, with corresponding impacts on abatement and implementation cost. The development of a comprehensive modelling approach would likely be the most effective way to quantify these variables.

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