MM01: Improved Crop Varieties

Category

Cropland and grassland management: crop management

Overview

Nitrogen (N) 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 nitrogen being lost to the environment as ammonia, nitrate and nitrous oxide, causing multiple environmental problems.

Improving the efficiency of crops to utilise the N fertiliser is therefore key in mitigating emissions as well as reducing the economic loss as unrecovered nitrogen. Nitrogen use efficiency (NUE) is defined as yield per unit of N available to the crop (Moll *et al.* 1982) Barraclough *et al.* (2010) demonstrated that season and N 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 and 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 three-fold (from 27 to 77 kg DM (kg N)$^{-1}$), as Barraclough et al. (Barraclough *et al.* 2010) found in wheat varieties from four different countries in Europe.

Additionally, radically new cultivars, e.g. perennial wheat which can help retaining more C in the soil as well as reduces fertiliser, pesticide and fuel use (Bell *et al.* 2008) or N fixing cereals, for which three main research streams are ongoing, targeting nodule development, identification of N fixing biofertilisers and the introduction of nitrogenase enzyme and pathway into the plant (Beatty and Good 2011). This mitigation measure examines using traditional breeding to improve NUE.

Breeding for improved NUE can target both the efficiency of N uptake and N utilisation in the plant; as these are different physiological processes they are genetically independent, raising the potential for parallel gains (Hawkesford 2014). However, it 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 experimental studies that have looked at the improvements in NUE of different varieties of the same crop (see section 0) 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 N applications in the past two decades for newer varieties which require higher N 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, research and farmers to develop and adopt such cultivars. The measure considers three major crops in the UK: wheat, barley and oilseed rape.

Mitigation summary

Table 1 Effects on emissions

GHG categories	Effect*	Notes
Enteric CH_4		
Manure CH_4		
Manure **N_2O**		
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	-	Fertiliser production
Post-farm emissions		
Substitution of higher C products		
Production increases by more than the emissions		
	Rating	
Confidence in mitigation effect	Moderate	
Cost-effectiveness**	Moderate	
Confidence in cost-effectiveness	Low	

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

Related measures and potential synergies

Table 2 Likely effects on the abatement potential of other measures

Measure	Impact
	-
	-

Inclusion in other marginal abatement cost curves

Table 3 Past assessment of the measure

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

What does the measure entail?

The measure means cultivating varieties of already common crops in the UK which have higher NUE than the currently common varieties.

Abatement rate

The abatement rate is approximated from an estimate of the NUE or yield improvement, assuming that yields are kept constant and N 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 N reduction effect (even though new cultivars with improved yields tend to require increasing N 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 (Table 4), which is equivalent of 0.2% and 0.4% yield increase annually. The assumed annual N reduction is therefore 0.2% and 0.4% for these two crops, respectively. The barley annual NUE gain is 1.2% (Table 4), 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 N reduction of 0.24%.

Table 4 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)
Barley			
Yield	+1% y^{-1} (cumulative) historically over 75 years (1931-2005)	Western Europe	(Bingham *et al.* 2012)
NUE (kg yield DM (kg N)$^{-1}$)	+1.2% y^{-1} (cumulative) historically over 75 years (1931-2005)	Western Europe	(Bingham *et al.* 2012)
Oilseed rape			
Yield	+0.06 t ha^{-1} y^{-1} (cumulative) of new cultivars (~2%)	UK	(Knight *et al.* 2012)

Abatement	Value	Country	Reference
Yield	+0.048 t ha^{-1} (cumulative) realised on farms	UK	(Knight *et al.* 2012)

Cost

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 N savings are included in the calculations. The seed price premium is estimated to be 10% of the price.

Applicability

The measure is in theory applicable to all crops, though here we considered only three major crops of the UK: wheat, barley and oilseed rape.

Current uptake and maximum additional future uptake

The current NUE of the common cultivars is regarded as the baseline, and thus the current uptake is assumed to be zero.

Assumptions used in the MACC

Parameter	Change in value	Notes
N application	-0.13% annually (cumulative)	
Crop yield	No change	
Seed cost	+10%	
Seed cost – winter wheat	£92 ha^{-1}	(SAC 2018)
Seed cost – spring wheat	£95 ha^{-1}	(SAC 2018)
Seed cost – winter barley	£87 ha^{-1}	(SAC 2018)
Seed cost – spring barley	£79 ha^{-1}	(SAC 2018)
Seed cost – winter oilseed rape	£55 ha^{-1}	(SAC 2018)
Seed cost – spring oilseed rape	£60 ha^{-1}	(SAC 2018)

Wider effects

Table 5 Wider effects of the measure

Aspect	Effect	Reference
Positive effects		
Off-farm GHG		
Production		
Adaptation		
Environment	Reduced reactive N pollution	
Negative effects		
Off-farm GHG		
Production		
Adaptation		

Aspect	Effect	Reference
Environment		

Identified implementation challenges and barriers

Table 6 Potential barriers of the measure

Barrier to uptake	Reference
Potential negative effect on grain quality (lower N content)	
Current breeding focuses on higher yield	
Other key risks/uncertainties	**Reference**

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