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Facilitating carbon (GHG) accreditation schemes for biofuels: feedstock production

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Executive Summary

Agriculture and transport contribute around one third of global greenhouse gas emissions and both their share and gross emissions continues to grow. The growing share of emissions from transport coupled to its increasing dependence on oil, have provided powerful drivers for biofuel production growth over the last few years. However, biofuels remain contentious, not least because the GHG-abatement benefits are widely contested. The research reported here shows that very substantial reductions in greenhouse gas (GHG) emissions are possible from so-called conventional bioethanol and biodiesel fuels manufactured from UK-produced feedstocks (wheat grain and oil seed rape) when substituting for mineral petrol and diesel.

Due to land constraints in the UK, providing a substantial share of the UK's transport fuels from indigenously supplied biofuels may not be possible. However, UK farmers can demonstrate how efficient, modern agriculture can deliver very low GHG emitting biofuels enabling them to be competitive in an emerging global market that rewards such low GHG options and satisfying Renewable Transport Fuel Obligation (RTFO) requirements. Furthermore these standards could serve as a template for crop production in general.

The work outlined below has also shown that it is possible to develop and apply the robust and transparent monitoring and calculation methodologies needed to derive credible GHG balances for those biofuels. An integrated bioethanol and biodiesel GHG calculator has been produced using standardised methodologies and this is now being coupled with on-farm audits. The aim is to provide estimates of GHG emissions for individual batches of UK-biofuel feedstocks and to enable farmers to understand and manage those factors which are most sensitive to the GHG emissions.

Although further work is required, particularly on indirect impacts, it is clear that the provision of the relevant data by farmers is not overly burdensome or costly and that it can be used to provide sufficiently accurate information to reflect local conditions and management practices.

Based on the evidence-base derived from the farm audits and detailed life-cycle assessment studies from which the GHG calculator has been developed, we calculate that it is possible to produce bioethanol and biodiesel in ways that can result in substantially lower GHG emissions than their fossil fuel surrogates:

- For wheat to ethanol, reductions of between 10 and 95% are calculated using standard UK-average agricultural factors and a range of conversion plant configuration options (including those powered by gas-fired and/or straw and co-product-fired combined heat and power (CHP) systems).
- For rape to biodiesel, reductions of between 18 and 39% are calculated. Note that the options considered here do not include biodiesel plants powered by CHP.

The GHG calculator highlights the main areas that farmers need to focus on to deliver low carbon feedstocks for biofuel production, in particular the need to manage nitrogen fertiliser inputs by optimising requirements per unit of output whilst maintaining high yields. Thus:

- Feedstock production accounts for between 50 to over 80% of the total GHG emissions of the biofuel supply chains covered, and is therefore the dominant source of emissions in a biofuel supply chain.

- For biodiesel from rape, nitrogen inputs account for over 90% of the on-farm GHG emissions. For ethanol from wheat, nitrogen use accounts for 80% of the on-farm emissions; nitrous oxide (N_2O) alone accounts for over 60% of those farm-based GHG emissions.

Nitrogen management choices for farmers include sourcing fertiliser from manufacturing plants with nitrous oxide abatement which can reduce feedstock-based emissions by 25-30% (for ammonium nitrate) and selection of varieties which have lower nitrogen requirements and are inherently more suited to biofuel production e.g. low protein / high starch wheat.

In contrast to nitrogen fertiliser-related emissions, on-farm fuel, pesticide and seed supply-based emissions account for about 20% of the total farm-emissions and some gains could be made here, for instance, by minimising cultivation operations. Other areas which could have a significant impact on farm emissions are land–use history, soil type and drying operations.

It is important to note that substantial uncertainties exist in calculating the GHG emissions arising from land-based biological production systems. For biofuels, these uncertainties result from both the complexity of potential supply chains and in the scientific understanding of some of the mechanisms that result in the production of greenhouse gases. This uncertainty is not unique to biofuel production and applies to all forms of land use including for food, materials and timber production. A major report, explaining and clarifying the nature and extent of the uncertainties surrounding the calculation of biofuel GHG balances has been produced in parallel to this report (Kindred et al, 2008).

Much of the reduction potential in GHG emissions from UK-biofuels results from the way energy is produced and used in the biofuel conversion plants. The most substantial reductions in emissions result where co-products are used to produce heat and surplus electricity. However, much work is still to be done to clarify the GHG impacts of alternative uses of co- and by-products, particularly when used as animal feed. Despite this uncertainty, as energy use and GHG emission efficiencies are raised in the conversion plants, pressure will mount on farmers to deliver lower GHG-emission feedstocks.

Agriculture, therefore, has a critical role to play in ensuring that biofuels can provide a robust tool for climate change mitigation. However, to be credible, there is an urgent need for simple, practical and verifiable tools that allow farmers to focus on the main components of biofuel supply chains over which they have control.

The work carried out in this project has delivered a standardised, transparent and clear methodology for calculating both farm and whole-chain biofuel supply GHG balances. It has developed an integrated GHG calculator for bioethanol from wheat and biodiesel from rape and a new electronic questionnaire for farm audits.

By carrying out these activities, a major step towards on-farm GHG certification has been taken and near-term future developments should lead to a simple, robust and transparent audit questionnaire for direct use in biofuel feedstock assurance and certification. The UK currently has a lead in the development and implementation of these tools but many other countries are also developing similar approaches. In order to remain competitive, continued support for the development and implementation of low GHG emitting biofuel provision strategies is required.

1 Introduction

As the science underpinning man's influence on climate change becomes more certain, the opportunities and threats for agriculture in the UK have become apparent. Earlier research work funded by the HGCA and by other agencies began the process of:

1. Developing confidence that annual crops could be used to produce biofuels which, under the right circumstances, result in significant reductions in greenhouse gas (GHG) emissions when used to substitute fossil fuels in transport.
2. Identifying and reducing the range in the uncertainties associated with the calculation of claimed climate change mitigation benefits of biofuels.
3. Developing the tools necessary to show individual farmers how their own farming practices affect, and can be changed to reduce, the GHG emissions associated with biofuel feedstock production.

The project

The main objectives of this project were to:

i. Scope the potential for technological improvement of biofuel feedstock production in terms of GHG emissions.

ii. Scope the uncertainties surrounding the quantification of on-farm factors affecting GHG emissions from wheat and OSR for biofuel production.

iii. Develop methods for converting farm audit information into estimates of GHG emissions.

iv. Recommend the best approaches for dealing with issues reviewed in (ii) for carbon accreditation schemes and highlight future research requirements.

v. Inform the RTFO process and further development of carbon reporting and accreditation.

In order to achieve these objectives the project activities were divided into four discrete but linked tasks led by the individual partners in the project. These activities have resulted in five main outputs as follows:

1. A revised GHG calculator (Excel based spreadsheet) which provides a standardised methodology and tool for calculating the life-cycle GHG emissions from:

    a. UK-based wheat to ethanol

    b. UK-based rape to biodiesel

    The new version of the GHG calculator was demonstrated at Cereals 2007 and is available on the HGCA website: http://www.hgca.com/bioFuelCalc. This work has been an essential part of meeting objective 'ii' above, but also 'iv' and 'v'.

2. This report which includes:

    a. A detailed evaluation of the 'uncertainties' which currently fuel the controversy surrounding biofuel implementation and their role as a practical tool for GHG mitigation at the national and global scales. Developing the methodologies to firstly reduce, and secondly manage these uncertainties is a core part of this research and is critical to the development of a sustainable and publicly acceptable biofuel industry. The outcomes of the evaluation of uncertainty have therefore played a role in meeting all the objectives of the project, particularly objective 'i' and 'ii'.

b. An evaluation of the 2 years of farm audits carried out as a 'bolt-on' to ACCS and recommendations for future improvements and implementation strategies. The development of practical and simple farm audit questionnaires and monitoring schemes has provided a number of recommendations for objectives 'iii', 'iv' and 'v'. The work has also played a role in meeting objectives 'i' and 'ii'.

3. Recommendations for new research work to address the uncertainties and bottlenecks identified and to develop the practical steps necessary to move towards on-farm GHG reporting.
4. A major display at Cereals 2008 demonstrating the new version of the GHG calculator.
5. Close and continuing technical interaction with RTFO methodology development.

This report outlines the UK's current state-of-the-art in the process of assisting it's agricultural sector to play a major role in meeting and mitigating the climate change challenge from the perspective of indigenous biofuel feedstock production. It explains the development of the methodologies and tools necessary to calculate and report with confidence on the GHG emissions of those biofuel feedstocks. Ultimately, the methodology outlined requires the tight integration of the GHG calculator tool and individual farm/field audits[1] (both developed through this project and a previous HGCA project- Billins et al., 2005).

A final, but critical purpose of the work reported here, is to provide clear explanations of the main issues involved in such biofuel feedstock provision, GHG emissions estimates, the uncertainties involved and the likely pathways towards resolving these issues.

Understanding how to manage and reduce the uncertainties in GHG balance calculations for bio-products, including biofuels, will be critical to obtaining credible and therefore publically accepted, GHG reduction factors for biofuels. The analysis of, and options to overcome or mitigate, those uncertainties is extremely complex and diverse, and is covered in detail in a separate report produced as part of this project (Kindred et al, 2008).

Delivering verifiable supplies of low GHG- emitting biofuel feedstocks requires farm-level monitoring and accounting procedures and tools. The farm auditing and GHG calculator tools presented here provide the basis for such monitoring and accounting and can be used by farmers to understand and manage their greenhouse gas emissions. Substantial reductions are possible, particularly through understanding and optimising nitrogen inputs.

[1] These audits have been designed as a bolt-on to ACCS and carried out by CMi over two years

2 Greenhouse Gas Calculator Development

The original HGCA Greenhouse Gas calculator described a wheat-to-bioethanol supply chain (Billins et al., 2005)

This section describes the new developments in the calculator:

- A rapeseed-to-biodiesel chain has now been incorporated and modifications made to ensure that the calculator uses a standardised approach to allow cross-comparisons between the different chains.
- Identified improvements in greenhouse gas calculation methodology and modified default values have been incorporated into the calculator

An upgraded Biofuels Greenhouse Gas Calculator for analysis of wheat-to-ethanol or oilseed rape-to-biodiesel production chains (Figure 1) is one of the main project outputs.

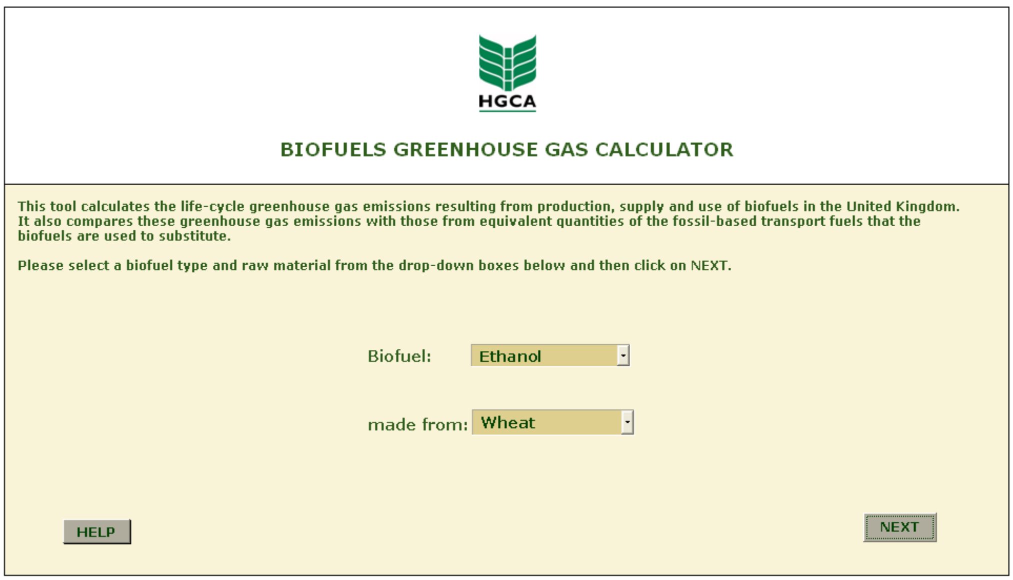


Figure 1: Biofuels Greenhouse Gas Calculator start sheet

2.1 Basic approach and methodology

The Biofuels GHG calculator is a spreadsheet-based tool for calculating the GHG emissions resulting from the production and use of wheat-based bioethanol or rapeseed biodiesel in the United Kingdom. It uses input data describing the entire production chain for any given batch of these biofuels, calculates the GHG emissions associated with that batch and compares the emissions with those produced from the production and use of an equivalent quantity of petrol or diesel. It is based on standard life-cycle analysis (LCA) principles, using user input or default data to produce inventories of inputs, outputs and GHG emissions for all supply chain stages from farming to delivery of produced fuel for use in vehicles. The resulting well-to-tank (WTT) emission figures allow appropriate comparisons between different biofuels and between biofuels and fossil fuels.

The original bioethanol calculator was developed using default factors, assumptions and methodological choices agreed upon in an expert consensus study carried out for the Low Carbon Vehicle Partnership in 2004 (LowCVP, 2004). This basis is largely maintained in the bioethanol section of the new Biofuels Calculator. However, additions and improvements have been made to the calculator as recommended in Kindred, et al., (2008) The biodiesel section of the Biofuels Calculator uses basic data and assumptions primarily from two studies by a leading European Life Cycle Assessment group and partner in this project, North Energy Associates (Mortimer and Elsayed, 2006c and Mortimer, et al., 2003).

For each WTT calculation, the calculator guides the user through a set of steps in a life cycle inventory, before presenting the results and allowing for examination of the detailed calculations. Each step of the calculations is presented on a separate page (in contrast to the previous Bioethanol Calculator), so that users may more easily focus on those steps of most interest to them and simply accept defaults for those steps of less interest or over which they have little control. Thus a farmer can focus on analysing the GHG impacts of farm level choices (Figure 2), while simply accepting suggested defaults for fuel production plant and other supply chain parameters.

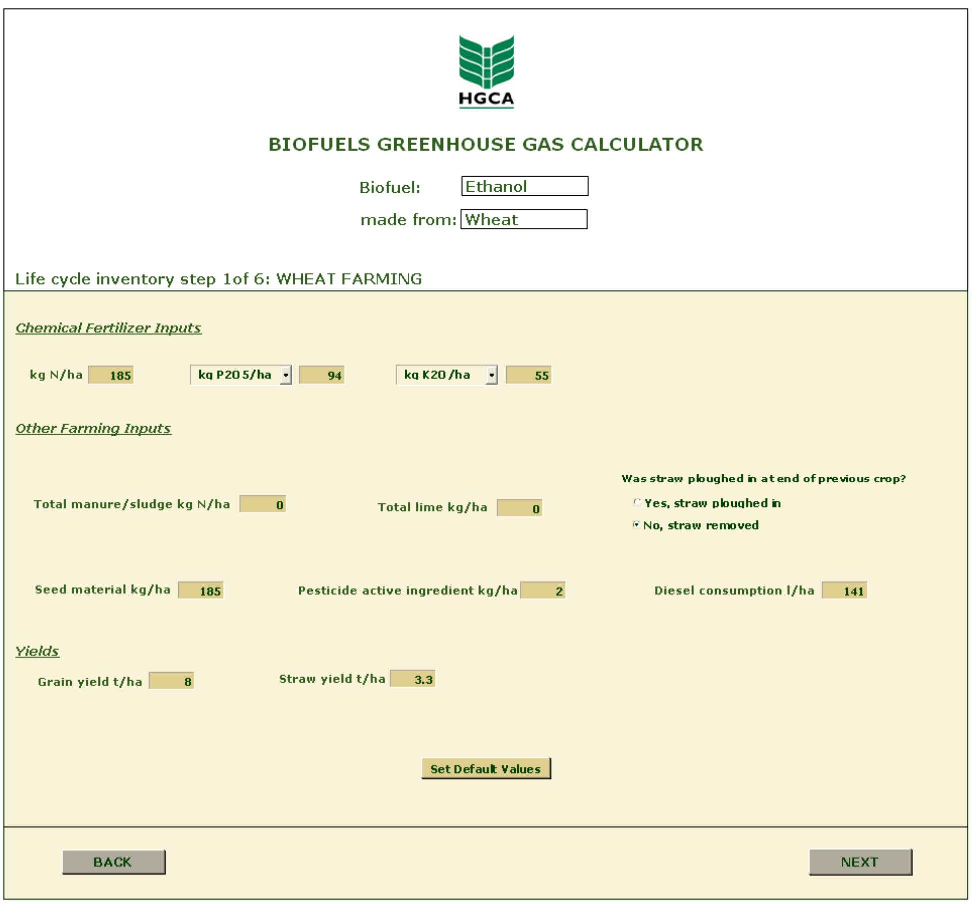


Figure 2: Wheat farming data input sheet

2.2 Underlying emission factors

Greenhouse gas emission calculations consider emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), and global warming potentials used are the IPCC 100-year factors (Table 3). Based on these global warming potentials, total GHG emissions are expressed in units of kilograms of carbon dioxide equivalent (kg CO_2eq).

Table 1: 100-year global warming potentials

Gas	CO_2	CH_4	N_2O
Global Warming Potential	1	23	296

For calculations of greenhouse gas emissions resulting from energy use in the production and distribution of biofuels, the calculator uses representative emission factors for fuels, electricity and transport as shown in the following sections.

2.2.1.1 Fossil Fuels and Electricity

For all consumption of fossil fuels and electricity from the grid, the GHG emission factors shown in Table 1 are used (LowCVP, 2004).

Table 2: GHG emissions factors for fossil fuels and electricity

	GHG Emissions (kg CO_2eq/GJ)
Diesel	87
Gasoline	86
Natural Gas (EU-mix)	61
Grid Electricity (UK-mix)	160

2.2.1.2 Transport

Calculations of GHG emissions resulting from transport of biofuel feedstock and finished product are based on the GHG emissions factors shown in Table 3.

Table 3: GHG emissions factors for freight transport

Transport Mode	GHG Emissions Factor (kgCO_2eq/t.km)
Road	0.081
Rail	0.027
Sea	0.007

The road transport mode option assumes that fossil diesel is used. The GHG emissions factor is based on diesel consumption for road freight of 0.936 MJ/t.km (JEC, 2007) and the GHG emissions factor for diesel burning of 87 kg CO_2eq/GJ as given in Table 2. The diesel consumption for road freight includes an allowance for an empty return trip after delivery of feedstock or fuel over the specified one-way distance. Emissions factors for rail and sea are based on JEC, 2007.

2.3 Wheat-to-ethanol Calculations

The basic approach and methodology of the wheat-to-ethanol calculations in the Biofuels GHG Calculator have not changed substantially from those of the original Bioethanol GHG Calculator (Billins et al., 2005). Rather, detailed considerations of areas of uncertainty and of the Calculator's applicability to future accreditation systems have led to adjustments to some default values and refinements in the methodologies for calculating some production chain emissions, as well as inclusion of some additional data input fields in the Calculator. The methodologies and assumptions of the wheat-to-ethanol calculations in the updated Calculator are described below.

2.3.1 Basis of Calculations

The Calculator sums the GHG emissions directly or indirectly attributable to the inputs and processes involved in the different stages of a specified wheat-to-ethanol production chain. From this total, it subtracts credits for GHG emissions avoided as a result of the bioethanol co-products substituting for other GHG-generating products and processes. Thus, the method of substitution continues to be used for attributing all the GHG emissions from the ethanol production chain to all the co-products from that production chain. It has been proposed that the Calculator should use allocation by co-product price (Kindred, et.al. 2008), but this has not yet been adopted in the Calculator.

To quantify the lifecycle GHG benefits from bioethanol production and use compared with petrol production and use, the Calculator compares the lifecycle GHG emission figures for a given quantity of ethanol with those from a quantity of petrol having equal energy content.

2.3.1.1 Agricultural Inputs

The GHG emissions factors used for agricultural inputs are given in Table 4. The factors for fertilisers, seeds and pesticides are those from the original LowCVP consensus study used for the Bioethanol GHG Calculator and considered to be representative figures for inputs to UK farming (LowCVP, 2004).

Lime inputs are now included in the Biofuels GHG Calculator with the emissions factor being taken from Mortimer, 2003.

Table 4: GHG emission factors for fertilisers, seeds and pesticides

Agricultural Input	GHG Emissions (kg CO_2eq/kg applied)
Nitrogen fertiliser (as N)	6.69
Phosphate fertiliser (as P)	0.71
Potash fertiliser (as K)	0.46
Lime	1.80

Pesticides (as active ingredient)	5.41
Seed material	0.87

The nitrogen fertiliser emission factors are based on ammonium nitrate, the most commonly used nitrogen fertiliser in the UK (DEFRA, 2007). Once transparent and reliable figures for urea and other nitrogen fertilisers are available, these will be incorporated in the Calculator. Pesticides include all insecticides, herbicides and fungicides and are reported as kg of active substance.

2.3.1.2 Effects of Straw Removal

The link between straw removal or incorporation and default fertiliser inputs has been removed from the calculator. The assumptions about the impacts of straw removal on fertiliser requirements as included in the previous Calculator are now considered unreliable, and the default fertiliser application quantities are not automatically adjusted on the basis of straw removal or incorporation.

Selection of either of the option buttons for “straw ploughed in” or “straw removed” provides information to help describe the farming practices employed, but does not affect the calculations. It may be appropriate to use this information in calculations of N_2O emissions from crop residues and derived impacts on soil organic matter, although this would also require data on the fraction of total straw returned, and the quantification of impacts of straw removal on soil organic matter over a number of rotations.

2.3.1.3 Credits for Distillers Dried Grains and Solubles (DDGS)

DDGS has value as an animal feed, and may also be used as a fuel for co-firing in coal power stations. The Calculator allows for a choice between these two options for the use of DDGS co-product. It then calculates credits for GHG emissions avoided through displacement of equivalent amounts of animal feed production elsewhere or electricity generation as per UK grid.

In calculations of animal feed credits, the animal feed product that is substituted by DDGS is soya bean meal imported from the USA. Each kilogram of DDGS is considered to substitute for 0.78 kg of soya bean meal, on the basis of relative protein content. Production in the USA and transport to the UK of each kilogram of soya bean meal result in emissions of 0.46 kg CO_2eq (Transport from US production site to UK port includes travel distances of 50 km on roads, 250 km by river and 5000 km by sea).

For DDGS used as fuel in co-firing for electricity production, a credit of 934 kg CO_2eq per tonne of DDGS is applied. This is based on the assumptions that:

- DDGS (10% moisture) has a lower heating value (LHV) of 18.2 GJ/t.
- DDGS is converted to electricity at the UK average rate of 0.325 GJ electricity output per GJ DDGS used.
- DDGS is transported 150 km by road to a power plant
- The DDGS-derived electricity generated substitutes for average UK ‘grid-mix electricity generation with GHG emissions of 160 kg CO_2eq/GJe (Table 2).

2.3.1.4 Credits for surplus electricity generation

Any surplus electricity produced by an ethanol plant (that is, any electricity that is generated but not used by the plant) is assumed to displace generation of an equal amount of grid-supplied electricity with GHG emissions equal to the UK electricity generation average of 160 kg CO_2eq/GJe, and this value is used to calculate credits for those ethanol production chains which include generation of surplus electricity.

2.3.1.5 Set-aside credit

In the Calculator, all wheat for ethanol production is assumed to be grown on rotational set-aside, and a credit of 922 MJ/ha (equivalent to 25.8 l/ha of diesel fuel, from LowCVP, 2004) is applied for avoidance of maintenance of set-aside land. No credit is given for N_2O emissions. When wheat growing replaces land use other than set-aside, the set-aside credit does not apply and the emissions associated with the alternative reference land use need to be calculated.

2.3.2 Default Bioethanol Production Chains

In order to illustrate typically expected inputs, yields and resultant GHG emissions of different bioethanol production chains, all production chain sub-sections in the Calculator have a “Set Default Values” button that allows for setting of all data values and process characteristics to representative values. The default values used for the wheat-to-ethanol production chain are described below.

2.3.2.1 Basic wheat-to-ethanol pathway

The values adopted by the LCVP study for the basic non-energy inputs and yields of the different processes in the bioethanol production chain are shown in Figure 3.

2.3.2.2 Farming Inputs and Yields

For calculation of default GHG emissions from the farming component of the bioethanol production chain, the values in Table 5 are used (ibid.).

Table 5: Default farming inputs and yields

Inputs	**Straw ploughed back**
Diesel fuel, l/ha	141
K fertiliser (as K), kg/ha	46
P fertiliser (as P), kg/ha	41
N fertiliser (as N), kg/ha	185
Pesticides (as active ingredient), kg/ha	2
Seed material, kg/ha	185
Yields	
Wheat grain, t/ha	8.0
Wheat Straw, t/ha	3.3

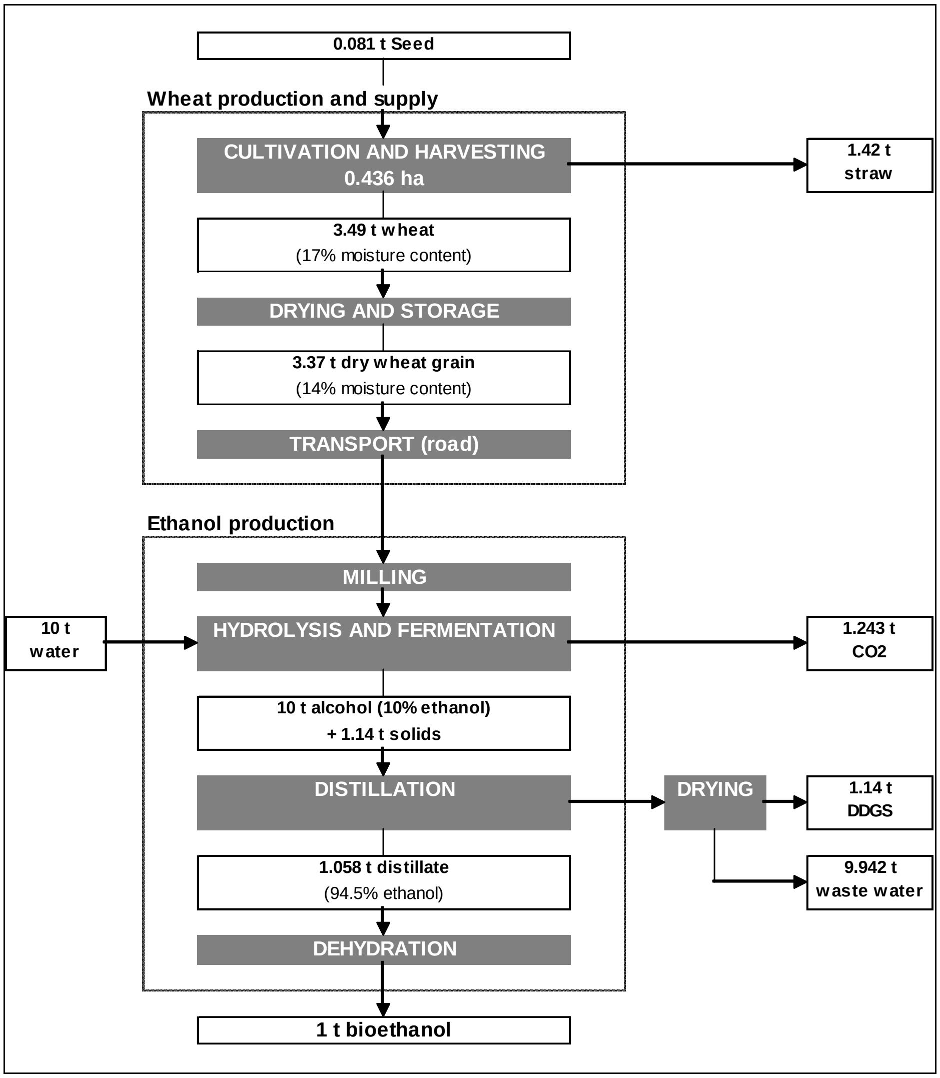


Figure 3: Basic assumptions for default wheat to ethanol pathways (LowCVP, 2004)

2.3.2.3 Drying and Storage

For the default case, wheat grain is assumed to be harvested at 17% moisture and dried to 14% moisture before delivery to the ethanol plant. The drying and storage of the wheat consumes 9.3 litres of diesel fuel and 11.7 kWh of electricity per tonne of dried grain produced. Further work is required to express diesel and electricity requirements on a %mc content removed per t grain basis, using defaults for different drying systems.

2.3.2.4 Transport to Processing

In all default production chains, dried wheat grain is assumed to be transported by road in diesel-fuelled trucks over an average distance of 50 km from the farm to ethanol plant.

2.3.2.5 Processing

The default processing plant yields 374 litres of anhydrous ethanol per tonne of dried wheat grain (14% moisture) delivered to the plant. Additionally, 1.14 tonne of DDGS is produced for every tonne of anhydrous ethanol produced. The entire production process at the plant requires 9.75 GJ of heat and 1.45 GJ (403 kWh) of electricity per tonne of anhydrous ethanol produced.

The first energy supply option in the calculator simply generates the necessary heat using a natural gas-fired boiler and imports the necessary electricity from the grid. The other options use combined heat and power (CHP) equipment sized to match the heat requirements of the plant, and produce varying amounts of surplus electricity. The option details are derived from the LowCVP study, which used typical operating characteristics and actual data from similar equipment currently in operation to determine the fuel inputs and energy outputs of suitably sized combined heat and power generation systems. These default fuel inputs and surplus electricity outputs of the five energy supply options included in the Calculator are summarised in Table 6.

Table 6: Default fuel inputs and surplus electricity outputs

Fuel Inputs and Surplus Electricity Outputs	NG boiler + grid	NG boiler + steam turbine	NG GT+ steam gen+ steam turbine	NG GT+ fired steam gen+ steam turbine	Straw boiler + steam turbine
Natural gas consumption, GJ/t eth	11.8	14.4	27.2	18.2	0
Imported electricity, kWh/t ethanol	403	0	0	0	0
Surplus electricity, kWh/t ethanol	0	396	2525	1389	575
Straw fuel consumption, kg/l ethar	0	0	0	0	1.13

Note: ‘GT’ = gas turbine. ‘NG’ = natural gas

For the straw-burning CHP option, the default characteristics involve the assumption that the quantity of straw available for fuel is equal to the total straw co-produced with the wheat grain being converted into ethanol. Therefore, 1.424 t of straw is burnt per tonne of ethanol produced (Figure 3) equating to 1.13 kg straw/l ethanol (Table 6). It is also assumed that the straw is transported by road in diesel-fuelled trucks an average distance of 50 km from the farm to power plant.

2.3.2.6 Transport to End Use

In all default production chains, ethanol is assumed to be transported by road in diesel-fuelled trucks over an average one way distance of 150 km from ethanol plant to fuel blending/distribution site.

2.4 Oilseed rape-to-biodiesel (rape methyl ester) Calculations

The oilseed rape-to-biodiesel production chains in the Biofuels GHG Calculator are based mainly on production chains described in two recent studies by North Energy Associates (Mortimer and Elsayed, 2006c and Mortimer, et al., 2003). As with the wheat-to-bioethanol calculations, analyses of areas of uncertainty and of the Calculator’s applicability to future accreditation systems have informed the methodology and default characteristics adopted for the rape methyl ester calculations. Those methodologies and default characteristics are described below.

2.4.1 Basis of Calculations

Greenhouse gas emissions resulting from a given oilseed rape-to-biodiesel production chain are calculated by summing the total direct and indirect emissions from all sections of that production chain and subtracting credits for GHG emissions avoided as a result of the biodiesel co-products substituting for other GHG-generating products and processes. The two studies which provided most of the basic data for the development of the rape methyl ester calculator did not use this substitution method for attributing total emissions to all co-products, but instead used allocation by price. It was therefore necessary to extract the raw data from these studies and develop a new life cycle inventory for the calculator. Because both of the North Energy studies presented their methodologies and background data in very transparent ways, it was relatively easy to extract the necessary data on inputs, outputs, efficiencies and other characteristics of the different steps in the oilseed rape-to-biodiesel production chain, and to use these to develop new life cycle inventories. However, a substitution-based LCA required assessments of the likely displacement impacts of the biodiesel co-products, and determination of life-cycle emissions of the products displaced.

2.4.1.1 Agricultural Inputs

The GHG emissions factors used for agricultural inputs are given in Table 7. The factors for fertilisers and pesticides are taken from LowCVP (2004) and those for seeds and lime from Mortimer et al (2003).

Table 7: GHG emission factors for fertilisers, seeds and pesticides

Agricultural Input	GHG Emissions (kg CO_2eq/kg)
Nitrogen fertiliser (as N)	6.69
Phosphate fertiliser (as P)	0.71
Potash fertiliser (as K)	0.46
Lime	1.80
Pesticides (as active ingredient)	5.37
Seed material	0.61

The nitrogen fertiliser emission factors are based on ammonium nitrate, the most commonly used nitrogen fertiliser in the UK (DEFRA, 2007). Once transparent and reliable figures for urea and other nitrogen fertilisers are available, these will be in the Calculator. Pesticides include all insecticides, herbicides and fungicides and are reported as kg of active substance.

2.4.1.2 Effects of Straw Removal

In the calculator, selection of either of the option buttons for “straw ploughed in” or “straw removed” provides information to help describe the farming practices employed, but currently has no effect on the calculations. It may be appropriate to use this information in calculations of N_2O emissions from crop residue, although this would also require data on the fraction of total straw returned, and would strictly require quantification of impacts of straw removal on soil organic matter.

2.4.1.3 Credits for rape meal

Rape meal has value as an animal feed, and may also be used as a fuel for co-firing in coal power stations. The Calculator allows for a choice between these two options for the use of rape meal co-product and then calculates credits for GHG emissions avoided through displacement of equivalent amounts of animal feed production elsewhere or electricity generation as per UK-grid.

Imported soya bean meal from the USA is chosen as the animal feed product that is substituted by rape meal in calculations of animal feed credits. Each kilogram of rape meal is considered to substitute for 0.90 kg of soya bean meal, on the basis of relative protein content. Production in the USA and transport to the UK of each kilogram of soya bean meal result in emissions of 0.46 kg CO_2eq.

For rape meal used as fuel in co-firing for electricity production, a credit of 825 kg CO_2eq per tonne of rape meal is applied. This is based on the assumptions that:

- Rape meal is assumed to have a lower heating value (LHV) of 16.1 GJ/t
- Rape meal is converted to electricity at the UK average rate of 0.325 GJ of electricity output per GJ of primary energy input.
- Rape meal is transported 150 km by road to a power plant
- The electricity generated from rape meal substitutes for other electricity generation with GHG emissions equal to the UK average of 160 kg CO_2eq/GJe (Table 2).

2.4.1.4 Credits for glycerine

The Calculator allows for credits to be assigned for the production of glycerine as a co-product of esterification. The credits depend on the destination of the glycerine. Glycerine has a large number of uses in the pharmaceutical, food and other markets. Therefore, when it is sold as a raw material in the chemical markets, it is difficult to assign a destination. Determining the substitution impacts of glycerine (as well as whether they even exist) is therefore difficult. Nevertheless, the Calculator provides three choices for glycerine destination and its resultant impacts on GHG credit calculations. These utilisation options have not yet been fully characterised in the academic literature , but are seen as possible scenarios:

- **Glycerine used as a bulk chemical**, **displacing production of propylene glycol**. A credit of -6.16 gCO_2eq/MJ biodiesel is assigned for displacing production of propylene glycol, and a cost of 2.63 gCO_2eq/MJ biodiesel is added for purification of the crude glycerine co-product. This equates to a net credit of -1299 kgCO_2eq/t crude glycerine. These GHG credits and costs are based on analyses reported in JEC, 2007.
- **Glycerine used as animal feed**, **replacing wheat feed**. A credit of -0.84 gCO_2eq/MJ biodiesel is assigned for displacing production of wheat grain, and a cost of 2.63 gCO_2eq/MJ biodiesel is added for purification of the crude glycerine co-product. This equates to a net GHG cost of 659 kgCO_2eq/t crude glycerine. This analysis is also based on JEC, 2007.

- **Glycerine co-fired in power plant.** This involves GHG emissions of 13 kgCO_2eq/t glycerine for transporting the glycerine 150km to a power plant and includes further direct emissions during burning in the power plant. At the time of writing, no reliable data was available on GHG emissions from glycerine combustion, so the equivalent value for rape meal burning, 38 kgCO_2eq/t (from Mortimer and Elsayed, 2006c), was used.

2.4.1.5 Credits for potassium sulphate

Potassium sulphate is another co-product of some biodiesel plants. Potassium sulphate may be used as a fertiliser, displacing potassium sulphate fertiliser. In order to calculate the credits to be assigned for production of potassium sulphate, a life cycle inventory was carried out for production of potassium sulphate fertiliser in Europe via the Mannheim process using potassium chloride and sulphuric acid. The credit was calculated as 457 kgCO_2eq/t potassium sulphate produced.

2.4.1.6 Set-aside credit

In the Calculator, all oilseed rape for biodiesel production is assumed to be grown on rotational set-aside, and a credit of 922 MJ/ha (equivalent to 26 l/ha of diesel fuel) is applied for avoidance of maintenance of set-aside land. When oilseed rape farming replaces land use other than set-aside, the set-aside credit does not apply and the emissions associated with the alternative reference land use need to be calculated.

2.4.2 Default Biodiesel Production Chains

In order to illustrate typically expected inputs, yields and resultant GHG emissions of different biodiesel production chains, all production chain sub-sections in the Calculator have a “Set Default Values” button that allows for setting of all data values and process characteristics to representative values. The default values used for the oilseed rape-to-biodiesel production chain are described below.

2.4.2.1 Basic oilseed rape-to-biodiesel pathway

The basic non-energy inputs and yields of the different processes in the biodiesel production chain are shown in Figure 4.

2.4.2.2 Farming Inputs and Yields

For calculation of default GHG emissions from the farming component of the biodiesel production chain, the values in Table 8 are used.

Table 8: Default farming inputs and yields

Inputs	**Defaults**
Diesel fuel, l/ha	67
K fertiliser (as K), kg/ha	40
P fertiliser (as P), kg/ha	22
N fertiliser (as N), kg/ha	196
Pesticides (as active ingredient),	2.8

kg/ha	
Seed material, kg/ha	5
Yields	
Rapeseed, t/ha	3.1
Straw, t/ha	3.0

2.4.2.3 Drying and Storage

For the default case, rapeseed is assumed to be harvested at 13% moisture and dried to 9% moisture before delivery to the crushing plant. The drying and storage of the rapeseed consumes 3.8 litres of diesel fuel and 5 kWh of electricity per tonne of dried oilseed.

2.4.2.4 Oilseed Transport

In all default production chains, rapeseed is assumed to be transported by road in diesel-fuelled trucks over an average distance of 50 km from the farm to a central drying facility.

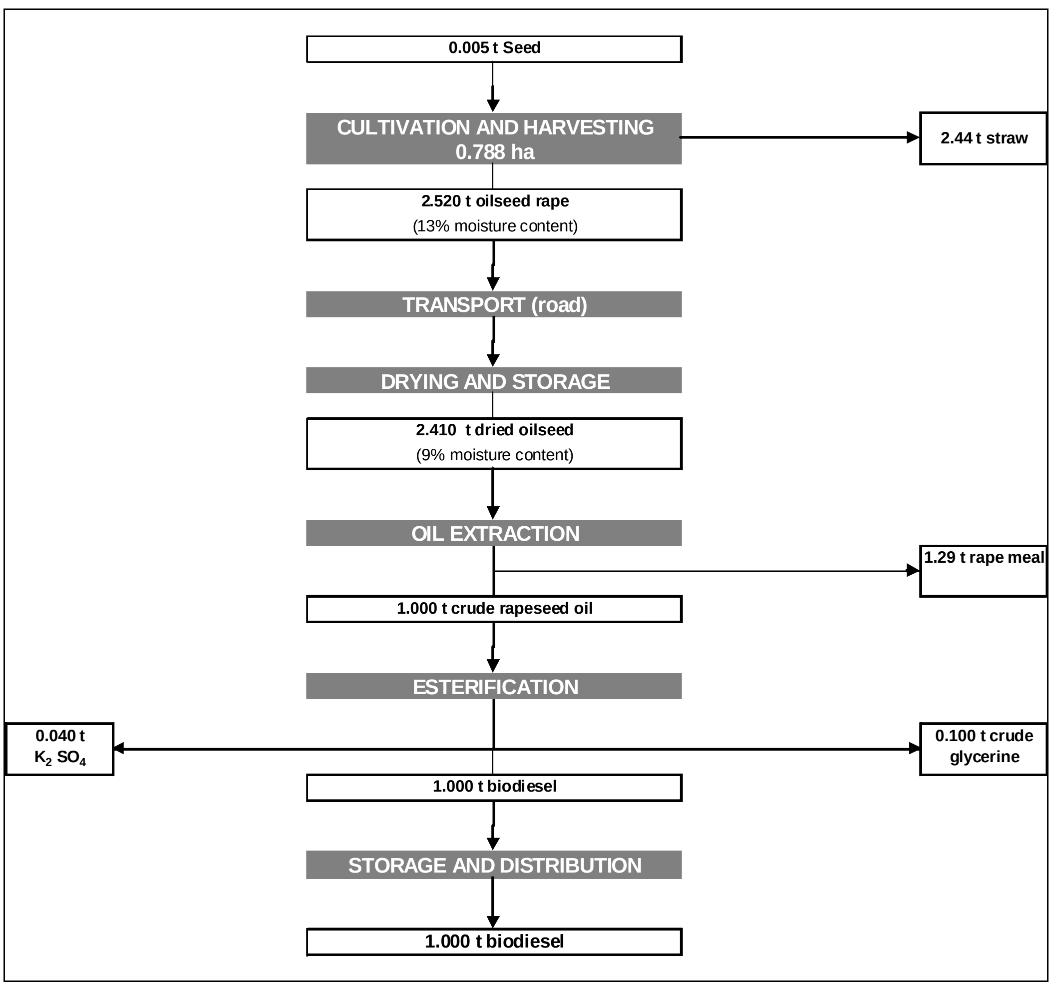


Figure 4: Basic assumptions for default rape to biodiesel pathways (Mortimer and Elsayed, 2006)

2.4.2.5 Oil Extraction

The default oil extraction plant yields 0.41t of crude rapeseed oil per tonne of dried rapeseed. Additionally, 0.54t of rape meal is produced per tonne of dried rapeseed. The oil extraction process requires 2.78 GJ of heat and 0.46 GJ of electricity per tonne of crude rapeseed oil produced. The calculator does not provide for different energy supply options in the esterification plant as it does for the bioethanol plant. This is because an analysis of a range of such options at relevant scales has not yet been carried out. Thus, the only energy supply considered is one using a natural gas-fired boiler to generate the necessary heat and imported electricity from the grid.

2.4.2.6 Esterification

The default esterification plant yields 1.0t of biodiesel per tonne of crude rapeseed oil. Additionally, 0.10t of glycerine and 0.04t of potassium sulphate are produced for every tonne of biodiesel produced. The entire production process at the plant requires 2.85 GJ of heat and 0.33 GJ of electricity per tonne of biodiesel produced. The calculator does not provide for different energy supply options in the esterification plant as it does for the bioethanol plant. This is because an analysis of a range of such options at relevant scales has not yet been carried out. Thus, the only energy supply considered is one using a natural gas-fired boiler to generate the necessary heat and imported electricity from the grid.

2.4.2.7 Transport to End Use

In all default production chains, biodiesel is assumed to be transported by road in diesel-fuelled trucks over an average one way distance of 150 km from biodiesel plant to fuel blending/distribution site.

3 Developing Farm Audit Sheets

Farm audits have been developed as a possible ‘bolt-on’ to the ACCS audits with the aim of allowing the GHG emissions associated with the feedstock production for biofuels to be calculated at the farm-level. To date, two years of audits have been carried out by CMi using questionnaires developed in collaboration with Imperial College London. The following sections provide an overview of the rationale and key findings from the farm audits.

3.1 Overview of approach

In March and April 2007, CMi carried out approximately 100 farm surveys on wheat and OSR production in locations throughout England which were administered in conjunction with ACCS audits. The audits covered production data for the 2005/06 season. These audits follow on from those carried out the previous year which obtained data from the 2004/05 season. Fifty-seven surveys were collected in 2006, and included spring and winter sown wheat and OSR.

A significant change for the 2007 audit was the development and use of an electronic version of the questionnaire (Figure 5). This is an important development, as it is planned that future audit data will be inputted automatically to the Greenhouse Gas Calculator, improving the accuracy and efficiency of obtaining GHG emission levels from individual farms/fields.

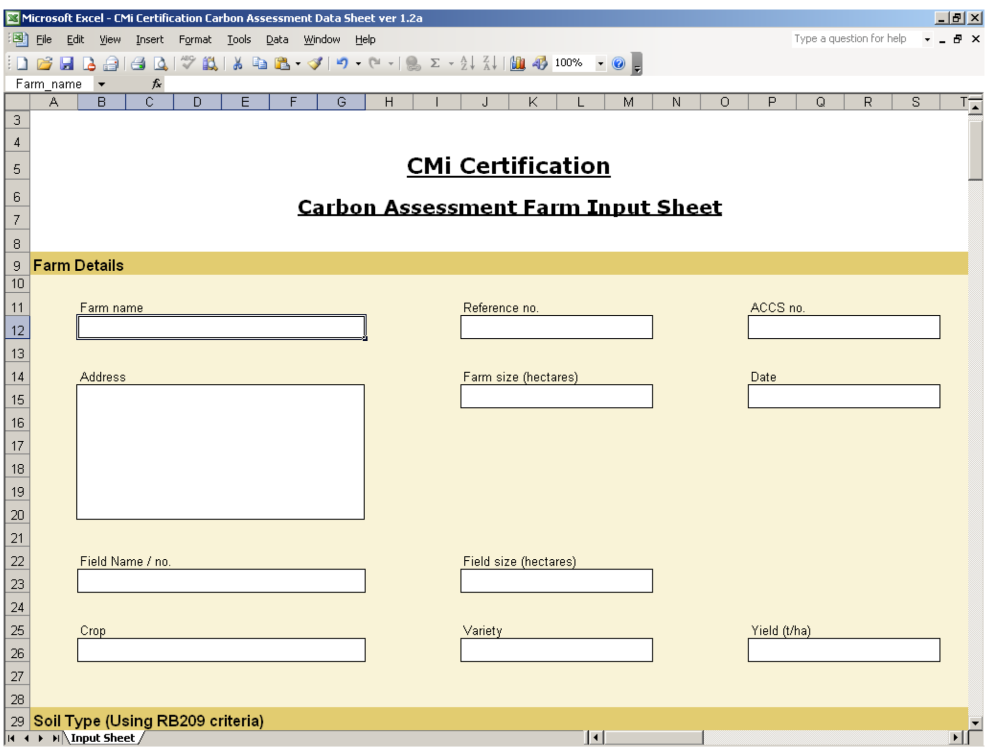


Figure 5: Farm audit sheet

3.2 Audit Questions

The farm audits ask a number of questions about the farming conditions and operations involved in production of biofuel crops on particular fields or farms. It is important to note that the current audit sheet *is not* necessarily the final version. For this stage of the project it was decided to ask a broad, but practical range of questions. The questions were developed in order to assess the practicability of this approach to farm-level GHG emission calculations and to choose the areas that are most sensitive to farm management practices and therefore amenable to change should carbon management become a cost-effective option in the future.

When choosing the specific questions, a balanced approach has been developed between the desire to obtain the 'ideal' information required to calculate a detailed GHG emissions factor and the limits of what information is reasonably likely to be available from farmers.

3.2.1 Cultivations

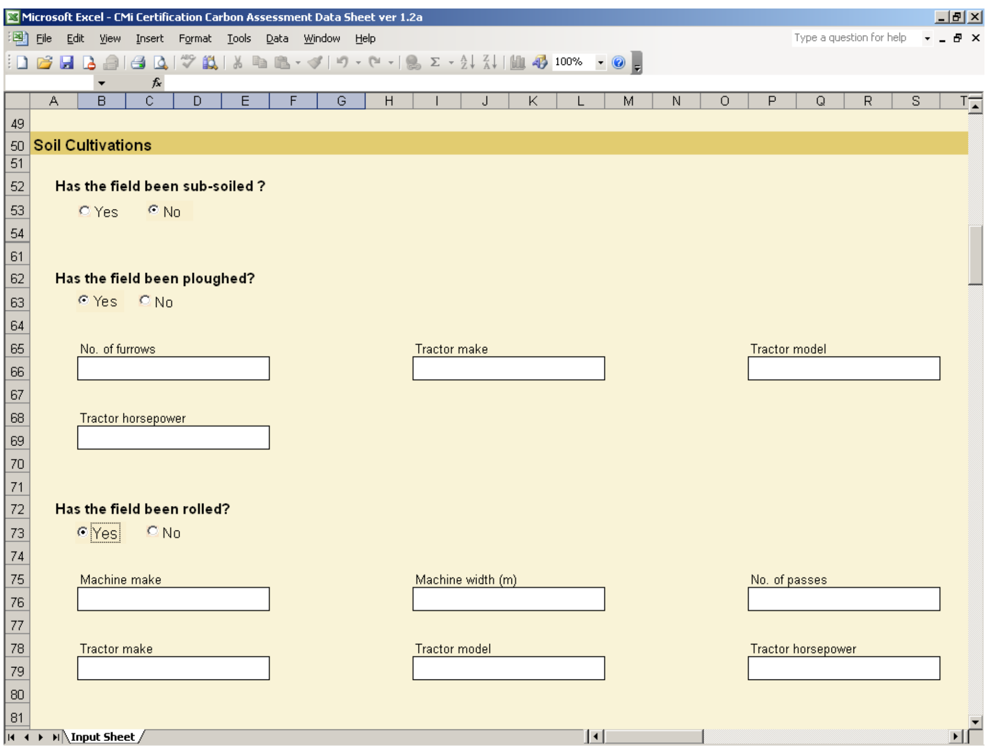


Figure 6: Cultivation input section of audit sheet

These have both direct and indirect impacts on GHG emissions. Direct emissions from diesel use are approximately 10% of on-farm emissions. The main energy expenditure associated with soil cultivations is determined by the physical mass of soil moved, so diesel use is expected to be independent of engine size. For a specific field the energy demanded for cultivations is dependent on many factors including recent weather and soil type, but the only easily available data to collect is the soil type, as discussed later. The different operations also have indirect GHG emission implications, for example ploughing increases the rate of SOC (Soil Organic Carbon) oxidation compared to minimum tillage, suggesting that minimum tillage reduces GHG emissions. Yet ploughing every four years or so in the rotation to control grass weeds is thought to release the majority of C stored during the minimum tillage years. This is discussed in detail in Kindred et al (2008). The effects of ploughing on N_2O emissions are even less well understood, and due to the high levels of uncertainties surrounding these factors they are not presently used in the GHG calculator.

3.2.2 Soil type

A critical change in the 2007 surveys (for 2006 yields) was a more detailed question about soil type. Previously this had been asked as an open ended question, and the answers varied widely and could not be compared. To solve this problem farmers were asked to assess their soils according to the 7 types listed in RB209 (Table 9).

This categorisation was chosen rather than the more traditional soil analysis to provide a single method of easily identifiable and comparable soil types. This information is useful because it may enable a more precise, batch-specific calculation of two factors which have so far only been calculated on a regional basis or by using uncertain default factors:

1. On-farm N_2O emissions
2. Cultivation energy requirements.

Table 9: The 7 different soil types used in the farm audits. Originally from RB209

Soil type		
1	Light sand soils	Soils which are sand, loamy sand or sandy loam to 40 cm depth and are sand or loamy sand between 40 and 80 cm, or over sandstone rock.
2	Shallow soils	Soils over chalk, limestone or other rock where the parent material is within 40 cm of the soil surface. Sandy soils developed over sandstone rock should be regarded as light sand soils.
3	Medium soils	Medium textured mineral soils that do not fall into any other soil category.
4	Deep clay soils	Soils with predominantly sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay or clay topsoil overlying clay subsoil. Deep clay soils normally need artificial field drainage.
5	Deep fertile silty soils	Soils of sandy silt loam, silt loam to silty clay loam textures to 100 cm depth or more. Silt soils formed on marine alluvium, warp soils (formed on river alluvium) and brickearth soils (formed on wind blown material) will be in this category.
6	Organic soils	Soils that are predominantly mineral with between 6 and 20% organic matter. These can be distinguished by darker colouring that stains the fingers black or grey and gives the soil a silty feel.
7	Peaty soils	Soils that contain more than 20% organic matter derived from sedge or similar peat material.

3.2.3 Fertiliser usage

There are three important factors affecting GHG emissions from agricultural fertiliser use – the embodied GHG emissions of the products, the field GHG emissions, and diesel use in application. The emission from diesel is a small fraction compared to the other two factors, which are discussed in detail in Kindred, et al (2008). The audits ask not only the total quantity of each fertiliser applied, but also the type and timing of application, as these have important GHG implications for the embodied and in-field emissions respectively.

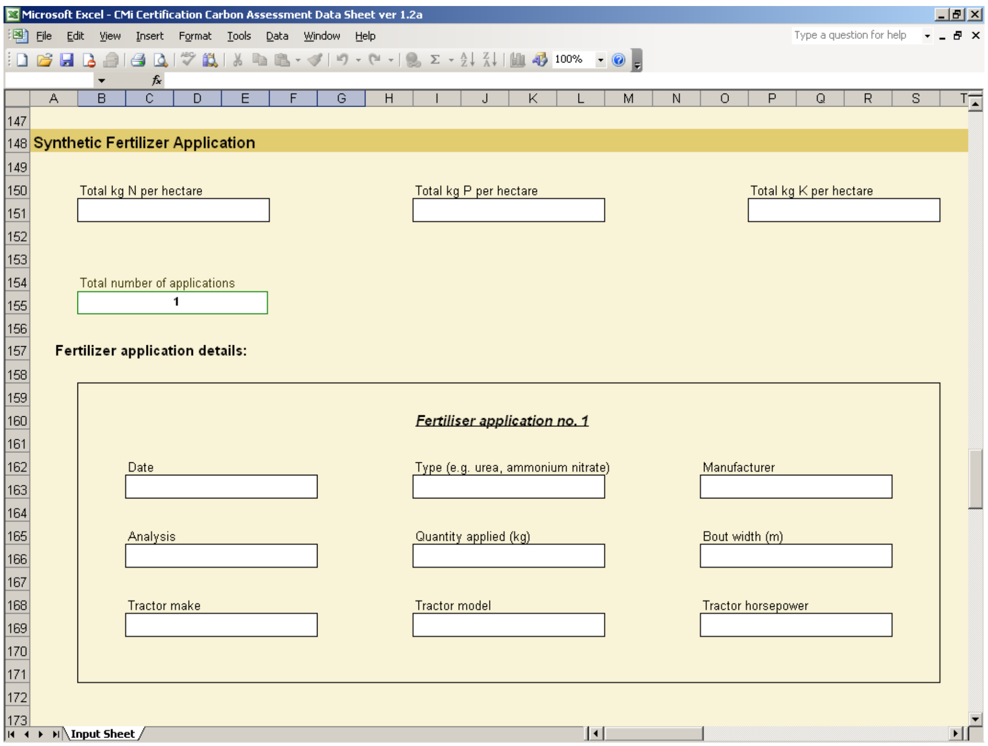


Figure 7: Fertiliser input section of audit sheet

3.2.4 Pesticide usage

There are two GHG implications of pesticide use, the embodied energy of the products, and the diesel required in their application. Diesel use is calculated through the number of applications. The embodied energy is harder to calculate. There is a poor data set for the embodied energy contained in different pesticides, most of the literature relies on or extrapolates from a single piece of dated research. Using averages for different pesticide groups (already a large generalisation), calculations show that pesticides equal a very small percentage (less than 1%) of the on-farm emissions. Due to the unreliability of the original data together with low GHG emissions levels associated with pesticide use, pesticides are ignored from these calculations as their emissions are well within the range of uncertainty. The number of passes that the sprayer makes is used to calculate the diesel used. Detailed pesticide data is still recorded for two reasons – if better information becomes available then this data can be retrospectively used, and the data could be useful for bio-fuel sustainability certification.

3.2.5 Grain Nitrogen

This is recorded as a potential future source of information on the efficiency of N uptake by the plant, and indirectly the level of N application. As yet this is under-researched (see Section 4.2.2.1 for discussion).

3.2.6 Grain drying

Grain may be taken off the field at a variety of moisture levels, but must be reduced to 14% or 9% moisture for wheat and OSR respectively for safe storage. Moisture reduction can occur through a variety of mechanisms, but most commonly used are continuous flow, on floor and batch driers. The amount of energy required depends on the drying method, process and percentage of moisture to be removed. More detailed research in this area would be useful.

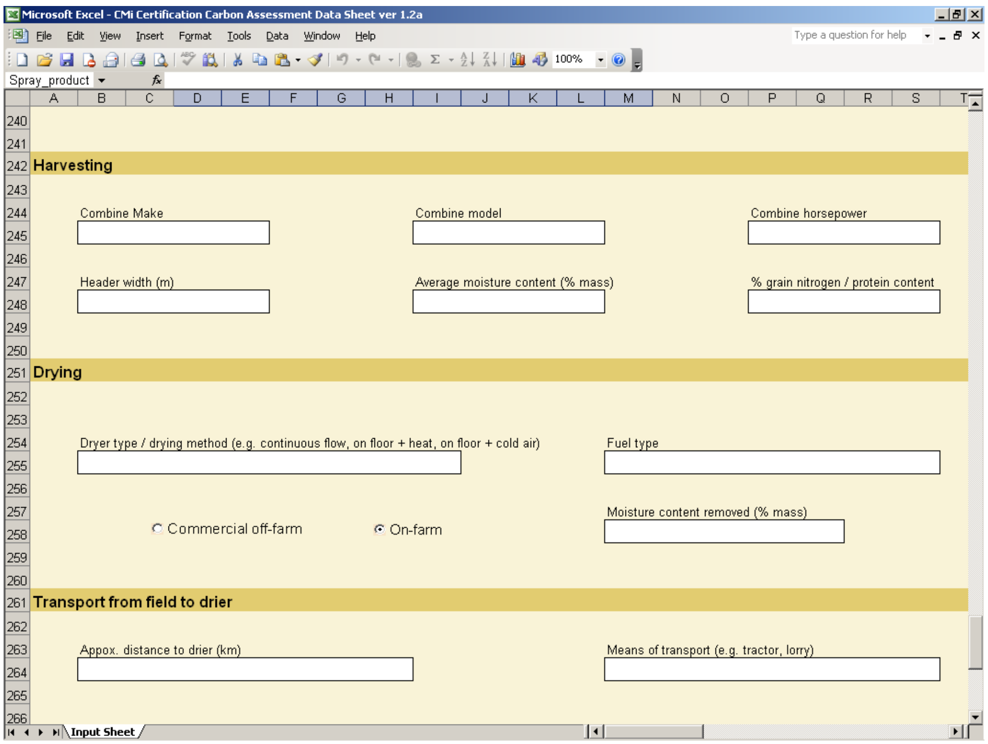


Figure 8: Audit sheet inputs for feedstock harvesting, drying and transport

The full audit sheet is available at http://www.hgca.com

3.3 Results

Table 10: A selection of farm audit data results

	Wheat		OSR	
	Mean	Standard Deviation	Mean	Standard deviation
Feedstock yield*(t/ha)	**8.9**	1.24	**3.55**	0.762
N (kg/ha)	**193.7**	33.6	**191.8**	34.7
P(kg/ha)	**41.6**	n/a	**42.5**	n/a
K(kg/ha)	**36.3**	n/a	**42.2**	n/a
Manure applications	**5**	n/a	**9**	n/a
Moisture content (%) after drying	**14.7**	4.8	**8.59**	3.121
Moisture removed (%)	**1.6**	1.6	**1.2**	1.8
Distance to dryer (km)	**2.6**	4.6	**2.28**	2.23

* After drying to storage moisture content

Figure 9 shows the average GHG emissions associated with different agricultural actions for the production of wheat. We have addressed the farm audit data based on the most important factors, namely fertilisers and cultivations.

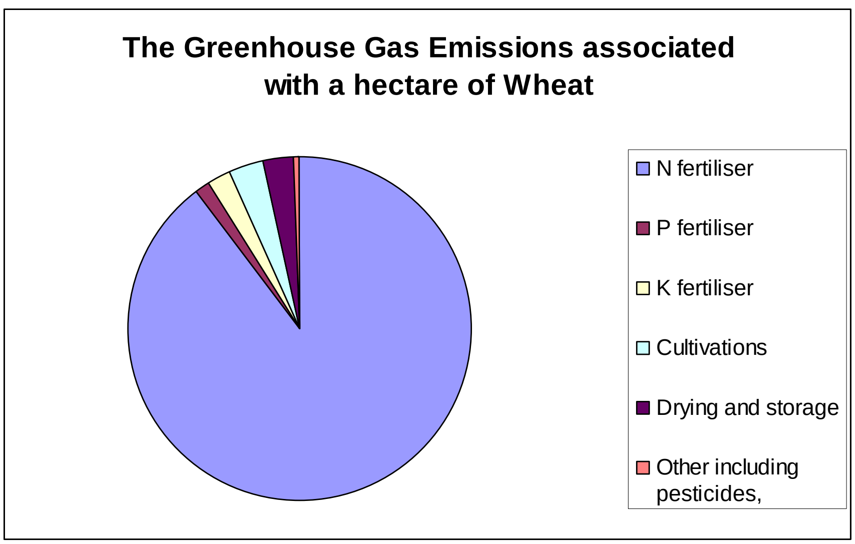


Figure 9: importance of different factors in determining the emissions associated with wheat (from Mortimer, 2003)

3.3.1 Fertiliser use

Fertiliser use is the most significant GHG contribution to the production of biofuel crops, accounting for around 90% of emissions. Of all the fertilisers N is by far the most important, accounting for 96% of fertiliser GHG emissions in the 2007 data

(95% in 2006), compared to just 1% and 2% for P and K respectively. The relationship between fertiliser applied and the emission of N_2O is complicated, with factors depending on soil type, agricultural practices (including cropping) and local weather and climate, but in these calculations we will assume a direct relationship using IPCC data.

Nitrogen use

From the 80 farm surveys carried out by CMi on wheat and rape production, covering the 2005/06 season, N fertiliser additions for wheat ranged from 90 – 283kg/ha, with an average of 194kg/ha (compared to 80 – 300 kg/ha, mean 186kg/ha in 2004/05 data). As Figures 10 and 11 show, there is no obvious relationship between N applications and soil type except in the organic soils, soil type 6. Organic soils received about a third less N than other soils ($p<0.05$), yet there is no significant difference in the yield between soil types (Figures 12 and 13). No farmers classified their fields as 'peaty', so there we have do data from soil type 7 for wheat or OSR. To demonstrate the importance of N, the Greenhouse Gas Calculator has been used to compare the results between the highest and lowest N users – see Box 1.

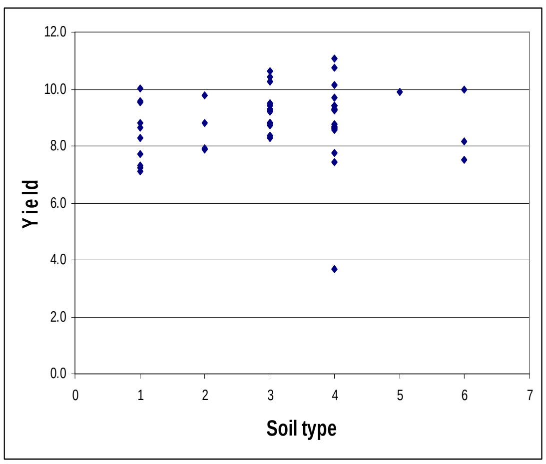


Figure 10: Wheat yield according to soil type

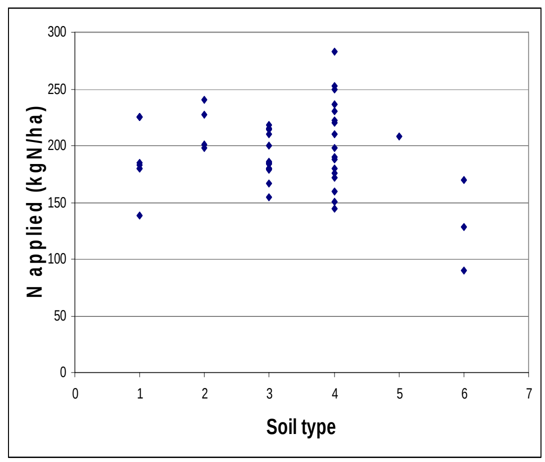


Figure 11: The fertiliser applied per hectare

Box 1. The importance of N in determining the overall GHG savings of biofuels

Farm 1507 applied 283kg N, 92kg P and 108kg K per ha and had a yield of 11.2t per ha.

Farm 3507 applied the least N (90kg/ha), applied no P or K, had a yield of 8.3t per ha.

Neither farm applied manure.

The results show that the wheat grown using 90 kgN/ha had a 38% GHG reduction compared to petrol, whilst the 283 kgN/ha wheat had only a 28% reduction in GHG emissions compared to petrol. It should be noted that these are estimated whole chain (so called Well-to-Tank) calculations and assume an identical process chain.

This constant yield together with lower N application rates for the organic soils, using present calculation methods, gives a significantly lower GHG emissions per tonne from wheat grown on organic soils compared to the other soils ($p=<0.05$). Organic and peaty soils allow farmers to apply lower levels of fertiliser through high nitrate retention, and more importantly because the soils *supply* N as the organic/peaty elements degrade. Thus the farmer is effectively mining N from organic soils, and importantly the N_2O released during this process (as well as the CO_2) is not accounted for in the figures supplied here, but could make an important contribution to the actual GHG emissions. Similar results apply for OSR. This is an important area for further research.

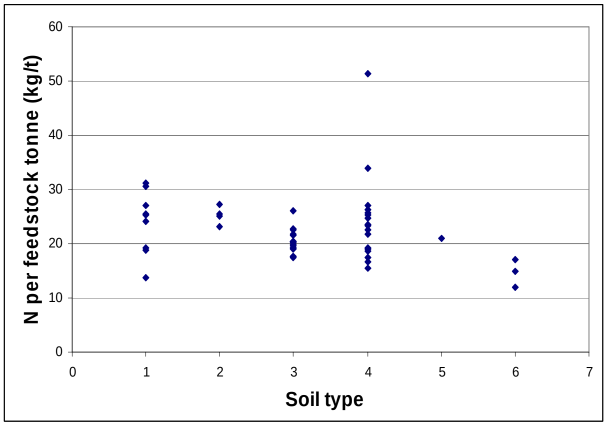


Figure 12: Nitrogen application per feedstock tonne (wheat)

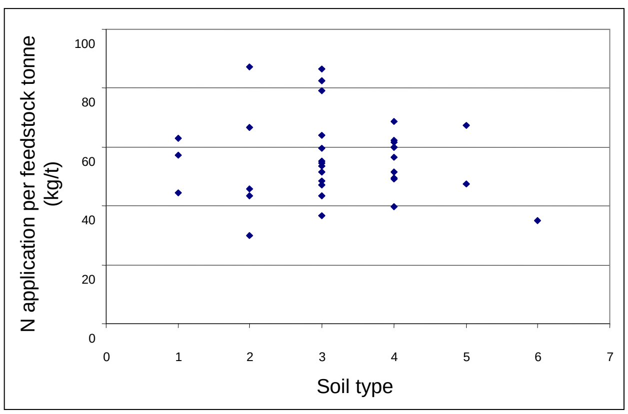


Figure 13: Nitrogen application per feedstock tonne (OSR)

3.3.2 Phosphorous and Potassium use

As expected there is large variation in use, as this depends greatly on alternative fertilisers applied (e.g. manure and/or mineral fertilisers), the fate of straw, and how much was applied in previous years. Almost half of the farmers applied no P and/or K in the audited year (2005/06 season), slightly more than last year (40%). From the GHG perspective these fertilisers are less significant than N, although they have important wider sustainability implications, for example P is the main source of eutrophication in inland UK waters.

3.3.3 Manure applications

In total 14 fields had manure applied. A decrease in synthetic N application levels is expected with manure applications, and a significant reduction was seen in wheat (mean 171kg/N/ha with manure applications, to 188kg/N/ha with no manure applications ($p<0.01$)). In contrast, there was a (non-significant) rise in synthetic N application when manure was applied to OSR, from 188 to 201kg/ha, when manure was not applied and was applied respectively. Further work is required to understand the longer term impacts of manure use on soil organic matter levels and therefore on nutrient and soil water holding capacity which could affect yields and application rates of mineral fertilisers.

3.3.4 Cultivation operations

Diesel use is (normally) the second most important source of GHG emissions in the biofuel production chains assessed. Based on the 2005/06 farm audit data, diesel use accounts for approximately 4% and 6% of total GHG emissions for production of wheat and OSR respectively. These figures vary widely according to the chosen operations, for example in OSR, the GHG emissions associated with cultivations range from 3-16% of the total. Not included in these calculations is the potential for GHG sequestration through choice of cultivation techniques. These points are discussed in more detail in Kindred, et al (2008).

There are different options for calculating the diesel use; hour based calculations, or work based. In this report we have used both, but recognise serious short comings in each. For the hour based analysis, approximate hours to carry out a cultivation on a hectare were used, and this was converted into diesel use through combining with the size of the machine, and diesel use figures from Nix's The Farm Management Pocketbook, and finally using a multiplier to accommodate for soil type. The problems with this method include poor initial data sets, especially the poor reliability of data for hour based tasks. More commonly used in the literature are work based calculations, the energy required, for example, to plough a hectare. Unfortunately these are often based on limited data sets, and rarely take account of different soil types. The analysis of 2007 farm audits are based on calculations derived by amassing many previous calculations of diesel use from the literature, and dividing this by the spread of soil types we have used. So soil type1 (light and sandy soil) correlates with the lowest recorded figures while soil type 4 (deep clay soil) requires the most. Other soil types were graded between these two scores.

A further problem with assessing diesel requirements for cultivation is the range of equipment available for use; it is hard to categorise many of the machines now available on the market. Although diesel use for cultivation is relatively minor in terms of GHG emissions, further work is required to ensure that this is the case and to minimise the uncertainty currently associated with these calculations.

Our results showed no significant trend between different soil types and specific operations and, as expected, individual operation types represented only very low percentages of the total GHG emissions. For example ploughing wheat, when it occurs (45% of total in 2004/05, 41% in 2005/06) was responsible for 4.5% of the overall GHG emissions, while sub-soiling the tramlines was only 0.6%. Yet the impacts not yet accounted for; the effect of cultivation on soil N and CO_2 fluxes could increase the importance of cultivation in the overall GHG balance of biofuel feedstock. As a management practice that is amenable to change it is important to continue using this area in the calculations.

3.3.5 Grain drying

Moisture reduction can occur through a variety of mechanisms, but most commonly used are continuous flow, on floor and batch driers. The amount of energy required depends on the drying method, process and percentage of moisture to be removed. More detailed research in this area would be useful. According to Mortimer 2003 (see Figure 9), drying is as important in terms of GHG emissions as the impact of cultivation regime. Opportunities to reduce GHG emissions either through changes in drying system, harvesting time or through consolidated drying should be considered.

3.4 Conclusions

The farm audits have been developed with two questions in mind, what information we would *like* from farmers, and what information can reasonably be *collected* from farmers. The last two years have demonstrated that the majority of the desired information from farmers is readily available, but the problem has been interpreting this data. A wide variety of different practices are carried out on farms, and this has been easily recorded. However what influences these practices and what the GHG implications resulting from them are, is less certain.

The most influential GHG emissions factor, N fertiliser application rate, is highly variable, for example from 90 to 283kg/ha in wheat. There is a pattern that, for organic soils, N fertiliser rates are significantly reduced, possibly due to the higher N levels present in the soil. However, the gains from the resulting lower emissions may need to be offset by increased carbon-based emissions resulting from the oxidation of the SOC in these high-organic-matter soils.

Cultivation options show no apparent relationship between soil or crop type, but are likely to be determined by previous cultivations, as well as local preferences / situations / habits. Using present GHG emission calculations, cultivation has relatively low emission factors, but further research on the role of cultivation in soil CO_2 and N_2O fluxes might alter this.

When more accurate information on the implications of different cultivation regimes, soil types and fertilisers is available, the audit system, together with the calculator, will allow accurate GHG assessments of each feedstock tonne. With this in mind, the next two steps are to allow farmers to ‘virtually’ farm their land, experimenting with different practices to create the lowest possible ‘carbon tonne’ of feedstock fuel, and also to potentially widen the scope of the audit system to include the whole farm, as discussed in Kindred, et al (2008).

4 Potential future developments

This section focuses on possible developments in biofuel crop production over the coming years and considers how these may impact on total GHG emissions. Also assessed are ways in which monitoring and reporting schemes may be developed to act as incentives to induce changes that reduce emissions, and crucially, not act as unintended disincentives to positive changes.

4.1 Crop breeding

The emergence of biofuels as a new market for crops is likely to stimulate crop breeders to breed crop varieties specifically suited to the biofuel process, both in terms of crop quality and agronomy.

4.1.1 Breeding for improved crop quality and processability

HGCA Research Review 61 (Smith et al., 2006) identified the ideal specifications for wheat for alcohol production. In order to be of most value to bioethanol processors, wheat grain should have high starch / low protein contents so that it gives high alcohol yields. The grain should also be easy to process, with past experience from the distilling industry suggesting that soft varieties with low non-starch polysaccharide (NSP) contents and low residue viscosities give the least processing problems. Improving these attributes of grain could potentially give material benefits to the GHG and energy costs of processing the biofuel.

The wheat to bioethanol production process is more limited by the amount of grain going through the process, rather than the amount of bioethanol produced. Using grain with higher alcohol yields therefore means that more bioethanol is produced for a similar energy input to the process, hence the GHG costs per unit of biofuel are reduced. In addition to this, grain that gives high alcohol yield has more of its mass converted to alcohol, and hence it gives less remaining residue, or DDGS. As much of the energy requirement of a bioethanol facility is used to wet, heat, cool and dry this residue material, reducing the amount of residue can give significant reductions in energy requirements.

The processability of the grain is also important to the energy requirements of the processing plant; the grain is mixed with water to around 30% dry matter whilst it is pumped around the plant. Wheat that gives a very viscous mash needs to be mixed with more water (i.e. used at a lower dry matter content) in order to avoid processing problems Varieties that give a very low viscosity can be run at a higher dry-matter content and hence less water is required in the process. As the energy costs of heating and subsequently evaporating this water are high, wheat varieties that give low viscosity mixes could potentially allow significant energy and GHG savings.

Breeding for low protein/high starch varieties is likely to be relatively straight forward, as protein is easily and routinely measured, and good genetic variation for it is known to exist. There is a good chance that breeding for reduced protein content will be successful, as this is the opposite of the main breeding target for the past 30 years, namely high protein content for bread and biscuit making.

Breeding for better 'processability' (for example through reduced NSP content) may be less straight forward, as measurement techniques and the underlying understanding is less advanced. HGCA Project 3314 is seeking to address the issue of NSP content effects on alcohol yield and processing efficiency. It is likely, however, that many of the factors that can result in poor processability are major gene effects (e.g. hardness, 1B/1R) that breeders can avoid by selecting suitable parents for crossing programmes.

For oilseed rape, breeding for biodiesel use is little different to breeding for conventional end markets; in both cases the important quality trait is oil content. Breeders improved oil content of the seed from under 40% to around 44% by the 1990s (Spink & Berry, 2004; Berry & Spink, 2006) but there has been little increase since then, suggesting that the scope for further improvement may be limited. As well as oil content, breeding efforts seek to improve oil quality (e.g. fatty acid composition) for specific markets, and biodiesel is likely to be no exception. Whilst better oil quality may improve the final quality of the biofuel, it is unlikely to give significant improvements in the GHG intensity of the final biofuel through reduced energy costs in processing.

The concept of the biorefinery, where the grain or seed is fractionated into its different components, and maximal value sought for each, may mean that a different emphasis would be required for thinking about the quality of the grain, depending on the value of the different fractions. Fractionation in wheat is currently being investigated by HGCA project 3176.

4.1.2 Breeding for improved agronomic performance

As well as breeding for improved grain/seed quality for the biofuel market, it is also likely that breeding will improve agronomic characters of crops for biofuels which may affect the GHG intensity. Most simply, continued crop yield improvements from breeding should improve the GHG intensities of the resulting biofuel. Whilst higher yields from crop breeding may be associated with higher crop inputs per ha, the main research target should focus on decreasing GHG emissions per unit output and not on gross yields or inputs.

As the major GHG cost of crop production involves N fertiliser, any crop breeding improvement that reduces the crop's need for fertiliser could be of major benefit in producing low GHG intensity biofuels. Because use for biofuels requires the high energy carbon rich portions of the seed (starch and oil for bioethanol and biodiesel respectively) and not the protein component, there is a more limited need for nitrogen as protein in the seed. This may give the opportunity to reduce the N requirement for the crop as a whole, if yields can be maintained with reduced N content in the crop canopy. Two LINK projects sponsored by Defra and SEERAD are specifically looking to facilitate the breeding of wheat and oilseed rape varieties with reduced N fertiliser requirements. GREEN grain (Defra Project LK0959) is aiming to reduce the fertiliser requirement of wheat by identifying nitrogen 'stores' in the crop and seeking genotypes with reduced stores. Defra project LK0979 is seeking to do the same in oilseed rape.

Another approach to reducing the N requirements of crops is to make them fix their own nitrogen, as is the case with legumes such as soya. Fundamental research work has been ongoing to develop N fixing wheat varieties for many years, however successes to date have been limited (e.g. Gantar & Elhai, 1999) and it seems unlikely that it will be a simple target for genetic manipulation (Saikia & Jain, 2007).

Breeding for traits such as reduced N requirements is unlikely to be straightforward, and it seems unlikely that varieties requiring significantly less N fertiliser will be available commercially within the next five years.

4.1.3 Novel crops

It is also worth considering that the crops currently grown in the UK which are suitable for biofuels may not be the only crops that could be grown. It is possible that crops such as Triticale could give similar alcohol yields per ha as wheat but with much reduced input and hence GHG costs. HGCA project 3348 is currently investigating the suitability of Triticale for bioethanol. It is also possible that grain maize could be grown more widely in the UK, especially if the climate warms and varieties which better match UK conditions could be bred.

Potentially, leguminous crops such as soy could be grown for biofuel use, with no need for N fertiliser and hence lower GHG intensities. However, considerable breeding effort would be required to make them suitable for the UK.

4.2 Premium schemes

4.2.1 Premiums for feedstock quality

It is likely that as the biofuel industry develops, premiums will be paid for feedstocks that are of greater value. This is already the case for oilseed rape where premiums are usually given for high oil content. Similarly, many bioethanol processors in Europe are offering premiums for high starch or high alcohol yield wheat. Such premiums would encourage farmers to grow crops that are most appropriate for biofuel use, both in terms of the varieties grown and crop management. Premiums would also encourage the development of new varieties as discussed above.

The most important management factor that farmers can influence to improve the potential biofuel yield is nitrogen fertiliser application. Applying N fertiliser increases protein content of the grain, and hence reduces starch content and alcohol yield (Smith et al., 2006; Kindred et al., 2007b). The relation between N fertiliser and alcohol yield per ha is investigated in detail in HGCA Project Report 417 (Kindred et al., 2007a). This suggests that the economic optimum N fertiliser rate for alcohol yield per ha is around 12% lower than that for grain yield, assuming that the bioethanol processor was also growing the crop. In commercial reality the N rate that a grower applies to a biofuel crop will depend on the premium available, if any. Given that low protein wheat may be worth considerably more to a bioethanol processor, both because of the higher likely alcohol yield and reduced processing costs as described above and, given that lower protein grain can be achieved with reduced N fertiliser applications, it is likely that premiums for low protein/high starch/high alcohol yield wheat grain would result in reduced fertiliser rates by growers. In this case the GHG intensity of the biofuel may be improved, both by improved processing efficiency and reduced GHG emissions from reduced fertiliser use.

It may also be argued that general increases in crop prices, partly due to increased demand from biofuels, may lead to increased productivity and greater yields with minimal increases in inputs. Whilst crop prices have been relatively low for the past 10 years there has been little evidence that on-farm yields in the UK have increased, despite there seeming to be continued yield improvements with new varieties. Crop prices in excess of £100 per tonne for wheat may provide the impetus for greater yields to be realised.

4.2.2 Premiums for low GHG feedstocks

With the onset of Carbon Reporting in the RTFO and a subsequent move to targets based on GHG reductions the carbon intensity of the biofuel will become increasingly important in economic terms, and it is possible that feedstocks with a lower GHG intensity will be more valuable to the processor. In such a case, premiums could be paid for crops that have a low GHG intensity, and farmers could be rewarded for practices that produce crops with low GHG costs. Again, given the importance of N fertiliser to the overall GHG intensity, it is likely that nitrogen would be the main management factor to be affected by such considerations.

Kindred et al. (2007a) have conducted a preliminary analysis of how GHG costs of a biofuel change with N fertiliser application. This suggests that the GHG intensity of the biofuel is lowest when no fertiliser is applied. However, accepting that biofuel production, and hence savings against fossil fuels, is limited by the amount of land available, it may be argued that it is the potential GHG savings per ha of land which is of most importance. N fertiliser initially increases GHG savings per ha as yields per ha and hence biofuel production increase. However, the initial findings of Kindred et al (2007a) suggest that the GHG savings per ha for wheat for bioethanol begin to decline after applications of around 100kg N/ha. This would suggest that, if the prime objective of biofuels is to reduce GHG emissions, that N applications to biofuel crops should be significantly reduced. There is a need to conduct these analyses more thoroughly, considering the economic costs (in terms of yield foregone) of reducing the N fertiliser rate to that which optimises GHG savings, rather than grain yield.

It seems likely that if reasonable premiums were available to incentivise the production of crops with reduced GHG emissions there would be scope for significant reductions in N fertiliser applications by growers.

For growers to be able to contribute to reduced GHG intensity of biofuels by reducing N fertiliser application, and to benefit from this economically, it will be necessary for growers to demonstrate what the application rate has been, and for this to be verifiable.

4.2.2.1 Grain N% as a signature of GHG emissions

As suggested in section 3.2.5, it may be possible to use grain N% (or its equivalent grain protein %) as an indicator of N use by the crop and hence as an indicator of the GHG emissions relating to N use. This is because grain N % relates well to N-use, being relatively constant at the optimum at around 2% N for feed wheat, with higher grain N% being indicative of over-fertilising and vice versa. Such an approach may help cut through the difficulties in quantifying the N_2O emissions from non-mineral fertiliser N inputs, such as organic manures, crop residues and soil organic matter and the difficulties that may arise through different rotational situations.

The ‘N signature’ in grain may offer a novel solution to the prospect of detailed field-to-factory GHG accounting, and may overcome the unfairness of considering mineral fertiliser and not other N forms. It might be used to indicate GHG costs of any grain parcel, on-farm and through the supply-chain, minimising the GHG paper trail and circumventing the difficulties of verifying on-farm emissions. Such an approach may also be applicable to oilseed rape. As well as being understood by farmers, grain N%

(or grain protein %) is also a useful measure for biofuel processors as it is indicative of alcohol yield as discussed above. Detailed work would be required, however, before the use of Grain N% as a GHG signature could be established. There is a need to examine available N% data, examine the logistics of using such a system through the supply chain and examine the implications for GHG accounting.

4.2.2.2 Effects of low-GHG premiums on the farming system

As well as impacting on fertiliser use, it is possible that economic incentives to produce feedstocks with low GHG intensities would encourage growers to change other parts of the farming system.

It is possible that different fertiliser products have substantially different GHG costs. It is possible that growers could choose to use fertiliser products with lower GHG emissions (perhaps due to N_2O abatement technologies) which would result in a lower GHG intensity for the crop. Such a situation could encourage fertiliser manufacturers to report on the GHG intensity of their products. For growers and fertiliser manufacturers to benefit from these reduced GHG emissions it would be necessary to allow the emission factor of the fertiliser used to be specified in the carbon reporting methodology.

It may be appropriate that cultivation practices that use less fossil energy should be rewarded with lower calculated GHG emissions. This could potentially encourage the development and uptake of machinery and practices that require less energy, such as minimum tillage. To enable these differences to be accounted for in carbon reporting, a way of estimating diesel use on-farm would be needed, as discussed in section 3.3.4 and Kindred et al (2008). This would need to be backed up with robust information on the diesel use of different cultivation methods, which may require in-field experiments and measurement.

5 Conclusions and Future Research Requirements

This research outlined in this report and in the parallel report on the uncertainties associated with such GHG calculations for biofuels (Kindred et al, 2008) highlights a number of important issues for the farming sector. It concludes that real gains are possible in reducing GHG emissions from UK feedstock-derived biofuels (ethanol from wheat and biodiesel from rape). Such gains are however, sensitive to location (including soil type and climate) and to management practices. In turn, this means that tools that are able to adequately monitor and account for these factors should allow farmers to target the main areas that will cost-effectively enable them to reduce the GHG emissions associated with biofuel feedstock provision.

On current evidence, biofuels can be produced in the UK in ways that result in substantially lower GHG emissions than the fossil fuel alternatives:

- For wheat-to-ethanol, reductions of between 10 and 95% are calculated by the GHG calculator using UK-average agricultural factors.
- For rape-to-biodiesel, reductions of between 18 and 39% are calculated by the GHG calculator.

The more efficient the conversion processes become in turning the feedstock into biofuels, the greater the share of the whole chain emissions will be from the feedstock production unless commensurate gains in efficiency are also seen in farming. Feedstock production is currently projected to account for between 50 to over 80% of the total GHG emissions of the biofuel supply chains covered, and is therefore the dominant source of emissions. The requirement for nitrogen emerges as the dominant source of GHG emissions from feedstock production:

- For biodiesel from rape, nitrogen inputs account for over 90% of the on-farm GHG emissions. For ethanol from wheat, nitrogen use accounts for 80% of the on-farm emissions; nitrous oxide (N_2O) alone accounts for over 60% of those farm-based GHG emissions.
- In contrast to nitrogen fertiliser related emissions, on-farm fuel, pesticide and seed supply-based emissions account for about 20% of the total farm-emissions.

It is important to note that substantial uncertainties exist in calculating the GHG emissions arising from land-based biological production systems. For biofuels, these uncertainties result from both the complexity of potential supply chains and in the scientific understanding of some of the mechanisms that result in the net production of greenhouse gases. This uncertainty is not unique to biofuel production and applies to all forms of land use including for food, materials and timber production. The systems needed to manage the uncertainty are being developed and include the GHG Calculator developed through this work.

Much of the potential reduction in GHG emissions for UK-sourced biofuels highlighted above, results from the way energy is produced and used in a biofuel conversion plant. The most substantial reductions in emissions result where co-products are used to produce heat and surplus electricity. As noted above, as emissions are reduced in the industrial sector the focus of emissions reduction will change to the farming sector. Here, savings from optimised use of N fertilisers in particular, location including soil type, and on management practices (particularly drying), will become increasing important.

The role for agriculture?

What is the UK farmers' role in helping to deliver competitive and low GHG biofuels?

The arrival of the UK Renewable Transport Fuels Obligation (came into force in April 2008) has focused attention on the need for UK farmers to supply the feedstocks needed to deliver low-GHG biofuels. UK farmers will have an opportunity to play major role in supplying the feedstocks and in demonstrating the methodologies needed to deliver low-GHG biofuels. In doing so, they can play a global leadership role.

The Greenhouse Gas calculator highlights the main areas that farmers need to focus on to deliver those feedstocks. In particular, the most urgent need is to manage nitrogen fertiliser inputs by optimising the nitrogen requirements per unit of output whilst at the same time maintaining high yields. Part of delivering decreased nitrogen-use intensity could be achieved by selecting varieties that are inherently more appropriate for biofuel production and with lower nitrogen requirements e.g. high-starch wheat. Additionally, choosing nitrogen fertiliser supplies that come from fertiliser manufacture plants with nitrous oxide abatement, and an increasing number of such plants are deploying this technology, could reduce feedstock-based GHG emissions by 25 to 30%[2].

In contrast to nitrogen fertiliser related emissions, on-farm fuel, pesticide and seed supply-based emissions account for about 20% of the total farm-emissions; some gains could be made here, particularly by minimising cultivation operations. Other areas that could have a substantial impact on each farm's emission factor include: land-use history, soil type, timing of field-operations, particularly nitrogen fertiliser applications and any drying operations.

UK agriculture, has an important role to play in ensuring that biofuels can provide a robust tool for climate change mitigation. However, to be credible, simple, practical and verifiable, tools that allow farmers to focus on the main components of biofuel supply chains over which they have control are urgently needed. The work carried out in this project aims to deliver a standardised, transparent and clear methodology for calculating both farm and whole-chain biofuel supply GHG balances. It has developed an integrated GHG calculator for bioethanol from wheat and biodiesel from rape and a new electronic questionnaire for farm audits. A major report, explaining and clarifying the nature and extent of the uncertainties surrounding the calculation of biofuel GHG balances has been produced in parallel to this report (Kindred et al, 2007c). By carrying out these activities, a major step towards on-farm GHG certification has been taken and near-term future developments should lead to a simple, robust and transparent audit questionnaire for direct use in biofuel feedstock assurance and certification.

5.1 Main conclusions

In order to maximise the potential benefits of a UK biofuels industry, and in particular to maximise GHG savings, there is a need to promote farm-level reporting of GHG emissions. The aim of this reporting would be to allow a share of the value arising from avoided GHG emissions to be retained by growers and to incentivise continued improvements in GHG intensity of biofuel crop production. The parallel development

[2] Assumes all the farm's nitrogen fertiliser use is as ammonium nitrate

of the science-base and the practical tools necessary to implement farm-level GHG auditing are also required.

This work has shown that whilst there are a range of important issues that remain to be resolved before farm-level GHG (carbon) reporting can become basic farming practice, these issues are not insurmountable. The farm audit trials and development of the calculator show that it is possible to use data obtained directly from farms to get credible individual GHG intensities. The resulting improved levels of accuracy of reported GHG emissions will be incentivised in the UK RTFO through adoption of conservative default values for GHG intensities (E4Tech, 2006).

Issues of approach, such as allocation procedures, have implications on the final carbon intensities and potentially on behaviour, though ultimately any approach adopted should accurately reflect reality without entailing excessive bureaucratic or regulatory burdens. There is a need for consensus-building across stakeholders and the LCA community in the approaches adopted. Continued development of the farm audits is necessary to demonstrate to the farming and biofuel production communities that the collection, compilation and evaluation of farm-level data are both practical and accurate.

Before such consensus emerges, a number of areas that cause the greatest uncertainty in GHG balance calculations need to be resolved. These are outlined below.

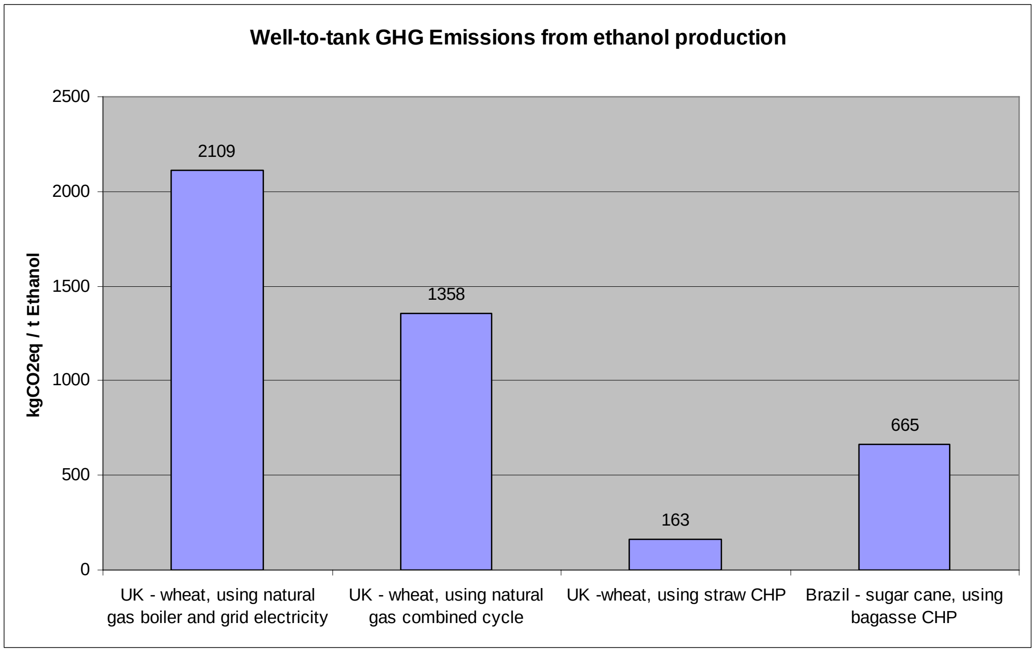
5.2 GHG Calculator Development

A new version of the GHG calculator has been developed through this work. It demonstrates that the integration of multiple biofuel supply chains is possible within a single, standardised methodology for GHG accounting for biofuels. Where possible and relevant, the same default factors and procedures have been used making cross-comparison between the chains possible. The calculator now includes wheat-to-ethanol and rape-to-biodiesel options and other biofuel supply chain options could now be included.

The work confirms that substantial reductions in GHG emissions are possible through compound efficiency gains along 'conventional' biofuel supply chains in the UK. These gains can be so large that the most efficient UK-chains can compete with ethanol from sugarcane produced in Brazil and possibly with advanced, so-called 2nd generation, lignocellulosic technologies, on the basis of GHG-emission reduction factors.

	Well-to-tank GHG emissions, kgCO_2eq/t ethanol			
	UK - wheat, using natural gas boiler and grid electricity	UK - wheat, using natural gas combined cycle	UK -wheat, using straw CHP	Brazil - sugar cane, using bagasse CHP[1]
Feedstock production	1475	1475	1475	348
Feedstock Transport	12	12	18	49
Ethanol Manufacture	1016	1720	66	0
Ethanol Distribution	13	13	13	268
Credits	-407	-1862	-1410	0
Total	**2109**	**1358**	**163**	**665**
Reduction relative to petrol	**8.3%**	**41%**	**93%**	**71%**

Note: 1: based on Brazilian average cane-based ethanol factors taken from the UK Renewable Fuels Agency (*www.dft.gov.uk/rfa/*; 10 April 2008).



Also highlighted is the need to continue research to reduce the uncertainty associated with current GHG balance calculations and to overcome the remaining obstacles to developing directly coupled farm auditing and GHG calculations.

5.3 Farm Audit Developments

During 2007, a second set of farm audits was carried out by CMi following on the audits carried out in 2006, providing an additional 100 audits to the 57 available from the previous year.

To our knowledge, the 2006 audits were the first example of this kind of auditing attempted anywhere in the world. The audits this year were developed using a simple questionnaire implemented in electronic spreadsheet format. They aimed to build on the success of the previous year by:

- Focusing the questions to be more tightly coupled to an integrated audit and GHG balance calculation
- Learning through feedback and by engaging with a wider farmer-base
- Developing a simple interactive interface
- Developing more accurate fossil fuel and soil factors

The audits have highlighted the large diversity in management approaches, input requirements and monitoring activities that occur on UK-farms. Despite this diversity it is possible to obtain most, if not all, of the relevant data required to calculate a robust GHG balance for biofuel feedstocks. Furthermore, a number of factors which affect the accuracy and confidence in the calculations are outside the capacity or control of farmers to influence and will require alternative mechanisms to gather and analyse the data required. Such factors include indirect land-use and direct and indirect nitrous oxide emissions.

Future audits should directly couple the GHG calculator to questionnaire but caution must be used in interpreting the results until a number of the uncertainties are resolved (see below).

5.4 Reducing and managing uncertainties

The uncertainties implicit in GHG accounting can be divided into those that predominantly stem from the approach taken (what actually happens), and those that are more technical in nature (e.g. scientific uncertainty in key emission factors and in indirect impacts). Much of the uncertainty lies in attempting to understand what level of detail is required in the monitoring and accounting procedures to provide a valid average for a field or farm level operation. There are also issues of fundamental scientific uncertainty where insufficient knowledge is available to provide an adequate level of precision. Despite these uncertainties sometimes being possibly large enough to change the outcome of the GHG balance, considerable knowledge will be gained through learning-by-doing. Indeed, it may not be possible to gain sufficiently broad data sets through any other means. The coupling of the GHG Calculator's development to the development of the farm audits has already helped to identify the nature and scope of the uncertainties and practical methods to account for and ameliorate a wide range of these factors as detailed in Kindred et al, 2008.

5.4.1 N_2O emissions

The biggest uncertainty surrounding GHG intensity concerns N_2O emissions. The IPCC approach advocated in the proposed RTFO Carbon reporting methodology (DfT 2007) provides the simplest, most transparent and defensible basis for quantifying N_2O emissions and may be suitable in the first instance. It is appropriate that emissions are driven by N fertiliser application. However, emissions from organic N sources (manures/compost/sludge), organic soils and crop residues are currently ignored. Accounting for N_2O emissions from these sources using an adapted IPCC approach seems likely to allow the fastest progress.

Regard will have to be given to potential consequences, intended or not, of on-farm practices that could result from untried accounting procedures. These issues will need to be reviewed before economic incentives are derived from low carbon intensities, or perverse practices could be encouraged.

In terms of producing a conservative methodology for dealing with N_2O emissions, it is recommended here that:

- Organic additions are accounted for using the IPCC approach on the basis of *available* N content rather than *total* N content.
- Crop residues are accounted for using the IPCC approach assuming a modest N addition that is included irrespective of yield, N fertiliser and whether or not straw is removed.
- That appropriately large emissions should be assumed for cropping on organic and humose soils.

There is a need to reconcile the IPCC approach to N_2O emissions, DNDC outputs and findings from recent work e.g. Crutzen *et al*. 2007. Whilst the work of Crutzen *et al*. (2007) suggests that real N_2O emissions from biofuel cropping may be higher than calculated from the IPCC approach, there is considerable evidence from field experimentation and modelling that the IPCC approach may significantly *overestimate* the real N_2O emissions from cropping in the UK. In this case, biofuel production in the UK could be unfairly penalised. Given the markedly different conditions and climates in different countries of production there is a need to evaluate whether using the same IPCC default emission factors for all countries is appropriate, or even for regions within the UK. It would be possible to advocate a regional approach to N_2O emissions, using DNDC to calculate emissions from crop types in specific regions for specific soil types assuming certain N fertiliser and manure inputs. However, GHG emissions from farms producing crops with lower nitrogen inputs and hence, reduced N_2O emissions would not be fairly accounted for. Thus activities to reduce N_2O emissions would not be properly incentivised.

The most promising approach for the future for quantifying N_2O emissions on a farm-by-farm basis will be to use different emission factors for different scenarios, e.g. soil types, climates, regions, etc, as per Tier 2 of the IPCC methodology. Such emission factors could be derived using UK-DNDC in combination with experimental and field validation.

Generally, it will be important that changes to the approach used for quantifying N_2O emissions in carbon reporting methodologies can be made as more accurate approaches and emission factors are developed.

5.4.2 Other issues of uncertainty

There is significant uncertainty over the emission factors used for nitrogen fertiliser manufacture. The different emission factors assumed in the RTFO draft Carbon Reporting methodology (Department for Transport, 2007b) give substantially higher emission factors for ammonium nitrate manufacture over that of urea (6.8 versus 2.9 kg CO_2eq/kg N respectively). Such a difference potentially penalises the UK (where ammonium nitrate is predominantly used to provide nitrogen to crops) against other parts of the world. Given that many of the N fertiliser manufacturing plants in the UK and Western Europe are installing N_2O abatement technologies, there is a need to assess the difference in the GHG emissions of different N fertiliser products, to ensure that appropriate emission factors are used for the UK situation. Emerging data suggests that choosing nitrogen fertiliser supplies that come from fertiliser manufacture plants with nitrous oxide abatement could reduce feedstock-based GHG emissions by 25%[3].

It is also important that if the use of urea is effectively incentivised by carbon reporting methodologies that full consideration is given to the likely impacts on national and global ammonia emissions.

This research project also finds that there may be significant additional CO_2 emissions associated with the acidification of lime and chalk that have hitherto been ignored. The IPCC methodologies assume that CO_2 release only occurs from applied materials, and not from chalky soils. Calculations of CO_2 emissions on emission factors related to the acidifying nature of the nutrients applied may be needed in future. There is a need for further work to clarify this issue.

There is a good deal of uncertainty over the most appropriate default values to use for grain drying. There is also uncertainty surrounding the diesel used in farm cultivations, with the true benefits of minimal cultivation techniques on fuel use being unclear and difficult to quantify.

[3] Assumes all the farm's nitrogen fertiliser use is as ammonium nitrate

5.5 Identified research requirements

There are two broad areas of research needed with regard to developing the direct quantification of farm-level biofuel-based GHG balances. They can be split into issues that are solely relevant to biofuels and those that are required to understand the GHG impacts of agricultural production systems in general.

1. Establish direct coupling between the farm audit questionnaire and the GHG calculator. The main areas to be resolved are:

   i. Derive robust land-use change indicators (direct and indirect).

   ii. Adequately quantifying actual energy use in cultivations.

   iii. Develop methodologies for estimating energy use in grain drying.

   iv. Fertiliser requirements and plant-available nutrient estimates throughout a rotation.

   v. Develop new combined audit and calculator.

The following issues are relevant to biofuels but also to any agricultural production system.

2. Fertiliser management (mainly nitrogen) and impact assessments:

   i. Provide detailed analyses of in-field N_2O emissions. Evaluate the appropriateness of the IPCC emission factors for N_2O emissions from UK arable biofuel cropping. Approaches for dealing with organic manures, crop residues, organic soils and baseline emissions from non-cropped land need to be developed and evaluated. Given the relative paucity of published data on N_2O emissions from arable soils, and the large expense of experimental N_2O measurement, the UK-DNDC model will be useful in answering these questions.

   ii. There is a need to evaluate the most appropriate emission factors for fertiliser manufacture for ammonium nitrate and other N fertiliser products in the UK. The variation in manufacturing emissions between products, manufacturing plants and country of origin needs to be assessed.

   iii. Exploration of how N fertiliser rates could be optimised for GHG savings could be very instructive for the agricultural and biofuels industry. The N fertiliser rates that maximise GHG savings should be determined, and the economic costs of optimising GHG savings should be assessed.

   iv. The potential for using grain N% (or grain protein) as a ‘signature’ for GHG emissions from nitrogen needs to be evaluated.

3. Quantify the CO_2 emissions resulting from the acidification of lime or calcareous soils. The current understanding in the literature needs to be reviewed, and there may be a need for experimentation.

4. Develop globally agreed standardised allocation procedures for co-products

5. Develop and employ standardised comparative reference systems – requires the development of a global land use inventory

6. Gain a better understanding of the links between investment in biofuel feedstock production with crop productivity

5.6 Conclusions on future developments

Whilst it is not possible to predict all the future developments likely to face the arable industry in the coming years, or to predict the possible ramifications of the emerging biofuel industry and carbon reporting, it is clear that given the right incentives, growers and the wider agricultural industry could make changes that would improve the GHG intensity of crops and the resulting biofuels. In order for these improvements to be made it will be important that the carbon / GHG reporting methodology allows for these changes to be fully accounted for. In turn, farmers need to know the conditions (climate, soils and management) under which the least-cost gains can be made.

Crop breeding and changes to fertiliser manufacture and application to land appear to provide the biggest and most immediate opportunities for improving GHG intensities. Whilst changes to yield and N fertiliser input can easily be accounted for in the GHG reporting methodology, as they are key input values; more subtle effects on biofuel processing efficiency are less easily accounted for.

Most of the changes that improve the GHG intensity of biofuel crops are equally applicable to reducing GHG emissions from arable cropping in general. It is possible that economic incentives to farmers could transpire through carbon trading mechanisms. The potential for this is being investigated in Defra project SFF0602.

For farmers to gain from the emerging policies directed at reducing GHG emissions on a national basis e.g. the Renewable Transport Fuels Obligation (RTFO) and the UK and European Emissions Trading Schemes (ETS), the sector needs to demonstrate transparent and practical methodologies for accounting for GHG emissions. The work highlighted here provides a pathway for delivering such an accounting system.

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