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Environmental impacts of cereal and oilseed rape cropping in the UK and assessment of the potential impacts arising from cultivation for liquid biofuel production

by

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With thanks to staff at HGCA, external peer reviewers, the Royal Society for the Protection of Birds and representative organisations associated with HGCA's Biofuel Forum for comments on the drafts of the original report published in 2005.

Postscript

The **'Gallagher Review of the indirect effects of biofuels production'** was published in July 2008, just before the present review was published. It is available at:

http://www.dft.gov.uk/rfa/_db/_documents/Report_of_the_Gallagher_review.pdf

Professor Gallagher's review was commissioned by the Secretary of State for Transport, Ruth Kelly. The report concludes that there is a future for a sustainable biofuels industry, but proposes that the introduction of biofuels in the UK should be slowed to enable robust sustainability standards to be developed and implemented. The main recommendation of the review is that the current RTFO target of 2.5% biofuel for 2008-09 be retained, but the proposed target of 5% inclusion, originally scheduled for 2010-11, be put back to 2013-14. Further increases in the target should be implemented only if the biofuels can be shown to be demonstrably 'sustainable' (in particular avoiding indirect land-use change).

ABSTRACT

PART 1 - ENVIRONMENTAL IMPACTS OF CEREAL AND OILSEED RAPE CROPPING IN THE UK

Cereals, and in particular wheat, dominate the UK arable area. The oilseed rape area covers more than that of all other major arable break crops put together. Production, particularly of oilseed rape, is concentrated in central and eastern areas of the UK. Current market conditions, driven by increasing demand, will ensure that wheat and oilseed rape will continue to dominate UK arable agriculture and areas of both will expand as set-aside requirements are removed.

In terms of environmental profile and impacts of wheat and oilseed rape cropping, the following key aspects are highlighted:

1) Pesticide use

- Both wheat and oilseed rape are relatively moderate users of pesticide compared to other arable crops in the rotation.

- Over that past 10 years the weight of pesticide active substance applied to wheat has declined by 8%. There has also been a reduction in application rates applied to wheat for herbicides and plant growth regulators. Molluscicide use in wheat has increased in recent years, and fungicide use has also begun to increase after a period of decline. In oilseed rape both the area treated and total weight of pesticide applied has increased significantly since 1996, but with declines in application rates for all but herbicide and insecticide use

- Isoproturon (IPU) has been one of the most prominent pesticides associated with water quality problems. Use on wheat (the main area of use) in recent years has declined as a result of tightening restrictions and there have been fewer reports of IPU appearing as a water contaminant, particularly of ground water. IPU will be removed from sale in September 2008, and phased out of use by 30 June 2009.

2. Fertiliser use

- The efficiency of fertiliser use in wheat has increased in line with increasing yield, such that, to date, increases in yield have not required significant increases in nitrogen fertiliser input. Nitrogen use in oilseed rape has remained fairly static, as have yields. However use of autumn applications has continued to decline.

- Wheat crops pose a relatively low risk of nitrate leaching loss where fertiliser applications are optimised. In contrast, oilseed rape poses a relatively higher risk due to relatively high levels of residual fertility left behind after harvest.

- Phosphate applications to both wheat and oilseed rape are declining.

- Biosolids can be applied to wheat crops. This is a useful disposal option on land for a material for which other permissible disposal options are limited.

3. Soil impacts

- On most soil types, there is a low risk of severe soil erosion with most cereal and oilseed crops compared to risks with root crops and other spring-sown crops. Risk of loss increases where land is disturbed at critical periods on susceptible soil types.

- Phosphate loss from soils is linked to erosion and soil particulate movement. These risks are reduced if cereal and oilseed crops are well established before winter on land susceptible to erosion.

- Incorporation of post-harvest cereal residues makes a valuable contribution to organic matter retention in arable soils. Incorporating cereal straw can increase soil organic carbon levels by 50 (±20) kg/ha/year/tonne of fresh straw incorporated.

4. Air impacts

- Oilseed rape and cereal production make a negligible contribution to overall UK CO_2 emissions.

- Agriculture is a major source of emissions of nitrous oxide, an important greenhouse gas. In terms of direct measured emissions, cereals and oilseed rape pose less risk than root crops and fertilised grassland.

5. Water impacts

- The number of water quality failures caused by pesticides is declining. A few pesticides used on cereals are responsible for a small number of pesticide-related water quality failures. Very few water quality failures have been reported with the most problematic herbicide isoproturon in recent years. Of the pesticides most commonly associated with water quality failures, only one (carbendazim) is currently used on oilseed rape, but only on a small area.

- Nitrates in water continue to be a problem, but well-fertilised cereals pose a lower risk than many other arable crops.

6. Biodiversity impacts

- Weedy oilseed rape and cereal stubbles are key habitats for farmland birds. Wheat stubbles are commonly used by species like skylarks, finches and buntings.

- Oilseed rape crops are preferred by some birds. Skylarks, yellow wagtails, sedge warblers, reed bunting and corn bunting nest in oilseed rape. During the breeding season the crop is also used by tree sparrows and yellow hammers. Oilseed rape is an important breeding habitat for reed bunting. Hedges close to oilseed rape are preferred by whitethroats, linnets and other common hedgerow bird species.

- Wheat and oilseed rape host relatively high populations and abundance of invertebrates when compared to crops such as potatoes. Cereals in particular host many spiders and carabid beetles. Insecticide use in both cereals and oilseed rape poses a potential risk to invertebrate diversity because of non-target effects associated with products commonly used. However, this risk is minimised when applications are restricted to particular periods of the growing season.

- Molluscicide use in cereals and oilseeds is a risk to ground beetles and small mammals. Greater use of slug monitoring is required to help target use when most necessary.

All cereal and oilseed rape growers scrutinise the value of crop inputs to justify and optimise their use, which will minimise potential adverse environmental impacts. In addition, many negative effects of cropping can be moderated or mitigated by adopting different management practices, either on a whole field basis (e.g. through ICM and sustainable farming techniques or precision application of inputs) and/or through measures targeted at particular field crops (e.g. spring cropping to provide overwinter stubbles) or field margins (e.g. agri-environment schemes) to support biodiversity in farmland landscapes. Therefore, there is potential to significantly influence the environmental footprint of UK cereals and oilseed crops.

PART 2 - ASSESSMENT OF THE POTENTIAL ENVIRONMENTAL IMPACTS ARISING FROM CULTIVATION OF WHEAT AND OILSEED RAPE FOR LIQUID BIOFUEL PRODUCTION

As part of a range of measures to reduce greenhouse-gas emissions, the UK government has set a target that 5% of UK transport fuel should be replaced by designated biofuels by 2010, using the Renewable Transport Fuels Obligation (RTFO) as a driving initiative. The European Commission has agreed further binding transport targets that 10% of transport fuel should be derived from biofuels by 2020.

The two main renewable so-called 1st generation liquid biofuels commercialised to date are biodiesel, derived from vegetable oils or animal fats, used as a diesel substitute and bioethanol (ethyl alcohol), derived from fermentation of sugar or starch feedstocks and used as a petrol substitute.

Both biodiesel derived from rape and bioethanol derived from wheat have the potential to significantly reduce both energy use in transport fuel production and reduce greenhouse-gas emissions over the full life cycle of production to point of use. However the scale of the saving depends upon how feedstocks are grown (carbon intensity/tonne of produce), how crop by-products are used (e.g. as animal feed or as fuel in the processing of biofuels) and how efficiently feedstock is converted into biofuel. Work establishing default reference values for HGCA’s GHG calculator suggests that both bioethanol and biodiesel can be produced in the UK in ways that result in substantial greenhouse gas (GHG) savings compared to fossil fuel alternatives. Reductions of between 10 and 95% are reported for the production of wheat to ethanol, and reductions of 18 to 36% for biodiesel production from oilseed rape.

Feedstock production accounts for between 50% and over 80% of the GHG emissions associated with biofuel supply and production chains. Nitrogen fertiliser and diesel fuel use represent the most significant energy inputs into wheat and oilseed rape crops, accounting for between 47 and 64% (ammonium nitrate) and 21 to 29% (diesel) of direct and indirect energy use in biofuel crop production. There is ongoing debate over the emission levels associated with nitrogen inputs, particularly direct impacts of N_2O emissions from soil and other indirect impacts.

The targets for fuel replacement in 2010, and particularly 2020 are demanding, particularly for diesel replacement. To meet them, it is likely that the UK will rely on significant import of biofuels and biofuel feedstocks. The UK will need a range of feedstocks and new 2nd generation technologies to meet proposed 2020 substitution targets. However, biofuels produced from UK oilseed rape and wheat feedstocks should make a significant contribution to such targets.

Competitor biofuel feedstock vegetable oils such as palm and (until very recently) soya are relatively cheap compared to rape oil, and have been widely used in EU and UK biofuel blends. Both of these oils are traded in large volumes on the world market, and represent a readily available source of feedstock. Leading exporters plan for significant expansion in palm oil plantations, to meet growing food and fuel demands. World ethanol production is increasing, by around 11-13% per annum currently. Production is dominated by Brazil and the US, which account for around 33% and 36% of world production respectively, with the former responsible for much of the world export of ethanol.

Unless steps are taken to reward production of low carbon feedstocks, it is anticipated that there will be small (for higher alcohol yielding grains) or no financial premium for production of biofuel feedstocks, as raw material cost represents a significant part of the cost of biofuel production. Significant shifts in areas devoted to wheat or oilseed production will therefore be most significantly influenced by trends in world prices, which reflect supply/demand balances. Continued political support for 1st generation biofuel development, should help increase market demand and help support market prices for growers. However, growers will still need to optimise returns from inputs where rewards will be based on production alone. Maximising output/ha will also help minimise the area of crops required to meet biofuel targets.

Existing areas of wheat and oilseed rape production for feed and food use can be transferred to biofuel production, in the case of wheat reducing export surpluses. Demand for feedstock from the UK is tempered by import of, often cheaper, alternative feedstocks. However, in the right financial market, use of UK feedstocks could be significant. There is current and planned UK biodiesel capacity of 0.5 million tonnes that could utilise the output of half of UK OSR production, and current planned bioethanol plants could utilise 2.6 million tonnes of UK wheat. Clearly in the short to medium term, there is likely to be more pressure on OSR supplies than wheat. However, with sufficient financial incentive and the current reduction in set-aside rate to zero there is potential to expand oilseed rape production. The opportunity for expansion of the cereal acreage is likely to be limited by its existing dominance in UK arable rotations.

The relative environmental impacts of production of feedstocks for biofuel production will depend on whether crops grown for biofuel markets are managed differently to those destined for food and feed markets and whether the current crop area expands to meet any increased market demand, replacing other crops in the process. Under current market conditions it is most likely that a proportion of the conventional crop will be sold speculatively for fuel use where the price is favourable, supplemented by vegetable oil, oilseed, cereal or biofuel imports. There is also likely to be some expansion on to former set-aside land. The introduction of relatively small premiums, to reward high alcohol yields could significantly reduce nitrogen use on cereals which could have several important environmental benefits.

Impacts on the environment

Diversion of crops from existing market outlets to biofuel markets will have the least environmental impact. Up until the end of the 2006/07 growing season, it was possible to produce crops for biofuel use on set-aside land (a permitted industrial use under set-aside rules) that would otherwise be left fallow, which potentially has the most significant environmental impact. The situation of set-aside is changing. In the face of tightening cereal stocks (through tightening world demand) the compulsory EU set-aside rate was set to zero for the 2007/08 cropping season. Furthermore, the continued use of set-aside as a supply/demand control measure is to be reviewed under the 2008 CAP health check. As a result, irrespective of whether grown for biofuels or conventional food markets, wheat and oilseed rape cropping will expand onto former set-aside areas. Current indications are that reducing the set-aside rate to zero has reduced the area of un-cropped land in England (bare fallow and compulsory set-aside) by 40%, while the 2007/08 season winter wheat area has increased by 10.4% and the winter-sown oilseed rape area by 2.3% (Defra Survey of Agriculture, December 2007). This expansion has been driven by market forces including increasing food demand and impacts of weather patterns on world supply. It is difficult to determine how much of this expansion has been driven by development of biofuel markets alone and therefore on what scale any environmental impacts can be attributed to biofuel developments. However, while the area of rape grown has increased only slightly, the proportion entered for EU energy crop schemes has continued to increase significantly, to the point where in 2007, around 40% of the UK oilseed rape area was earmarked for energy market outlets (excluding rape grown on set-aside).

A series of case studies are considered to assess the impacts of change in land use. The case studies associated with replacement of set-aside are retained and updated in the current report, though clearly if set-aside is removed as a market control measure then such comparisons will no longer be relevant.

CASE 1 - Oilseed rape for biodiesel replaces conventional oilseed rape crop

Managing oilseed rape for biofuel production offers little or no opportunity to reduce agrochemical or fertiliser inputs, but there is potential to reduce energy use during cultivation. Reducing the intensity of soil cultivations would reduce greenhouse-gas emissions and could contribute to reductions in nitrate leaching risk by reducing the intensity of soil disturbance and soil mineralisation of nitrogen.

CASE 2 - Wheat for bioethanol replaces conventional wheat crop

Recent HGCA and Defra-funded work, led by ADAS, looking at grain and alcohol responses to nitrogen suggests that where grain and alcohol values are equivalent, nitrogen rates can be reduced by around at least 10-12% compared to those used for feed wheat. This could be encouraged by access to a small premium of around £2-3/tonne, depending on prevailing costs. As well as improving GHG balances, reducing nitrogen application would reduce pressures on nitrate leaching. In the current absence of a UK wheat-based bioethanol processor, it is difficult to assess whether such premiums will be made available by processors, to reflect improvements in efficiency.

When compared to the UK average for wheat (which includes management for both milling and feed markets), the pool of biofuel wheat crops is likely to demonstrate small reductions in insecticide, fungicide and plant growth regulator use and reductions of up to 1-3 spray passes per annum. In addition, in the absence of premiums for alcohol content that could reduce applications further, nitrogen use will be lower than the UK average (by around 13 kg/ha N at current application rates), with benefits in terms of lower indirect energy use and green-house gas emissions, reduced risk of nitrate leaching and emission of ammonia. There may also be opportunities to reduce the intensity of cultivations with benefits in terms of savings in energy use and reduced risk of nitrate leaching and an opportunity to build up soil organic matter levels.

CASE 3 – Replacement of natural regeneration set-aside with oilseed rape

Replacing set-aside with oilseed rape increases the physical inputs of pesticides, fertilisers and energy utilisation. Impacts on nitrate leaching are not clear cut as typically set-aside has higher residual nitrogen levels that are subject to overwinter loss. It is anticipated that there could be a small increase in risks of soil erosion and phosphate loss. Overall greenhouse-gas emissions including CO_2, and N_2O would rise, largely as a result of nitrogen use. Little impact on soil water quality is expected. Replacement of set-aside with oilseed rape would reduce farmland habitat diversity (in terms of habitat, weed and invertebrate diversity) and would have a detrimental impact on some farmland birds, but other bird species of specific interest and concern that use oilseed rape as a resource in summer would benefit. However, many of these same species also use winter stubbles which may be reduced where winter sown crops replace naturally regenerating set-aside, such that overall there may be little or no beneficial impact on such species.

CASE 4 – Replacement of natural regeneration set aside with wheat

Replacing set-aside with wheat increases physical inputs of pesticides, fertilisers and energy. However, impacts on nitrate leaching are not clear-cut as typically set-aside has higher residual nitrogen levels subject to over-winter loss. There could be a small increase in the risk of soil erosion and phosphate loss. Overall greenhouse-gas emissions including CO_2, and N_2O would rise, largely as a result of nitrogen use. There could be impacts on soil water quality arising from a few specific herbicides use in cereals. Replacement of set-aside with wheat would reduce farmland diversity (in terms of habitat, weed and invertebrate diversity) and have a detrimental impact on farmland birds, but weedy wheat crop stubbles provide a valuable overwinter resource for birds if followed by spring-sown crops, which would mitigate to a limited extent losses of overwinter stubbles on set-aside.

In the case of replacement of set-aside by wheat or oilseed rape, the most significant impacts of replacing set-aside are likely to occur through reduction in diversity of habitat (which affects nesting opportunities and success) and impacts on arable flora, their associated invertebrates and knock on impacts on bird species which forage and nest on such areas.

CASE 5 – Replacement of break crops by oilseed rape

Impacts of replacing legumes with oilseed rape include an increase in fertiliser nitrogen inputs which would increase indirect energy use and overall greenhouse-gas emissions (which are typically doubled when accounting for typical rates of nitrogen applied to oilseed rape). There would also be a slightly increased risk of nitrate leaching by shifting to winter cropping/cultivations. Pesticide inputs, including carbamate insecticides and fungicide treatments, would be reduced. The main impacts on biodiversity include loss of relatively open canopy crops in the farmed landscape, favoured by birds such as lapwings and skylarks and used for foraging activity by many other species. Where break crops are spring-sown, there are benefits for overwintering birds from cereal stubbles left after harvest of the previous crop; these would be lost by replacement with winter-sown oilseed rape.

Landscape scale impacts

There have been few attempts to identify or model what the impacts might be of expansion of oilseed rape and cereal cropping at a landscape scale, though related project experiences offer insights. Work carried out for the Defra Agricultural Change and the Environment Observatory examined the impacts in an arable landscape in Eastern England of a 21% increase in wheat area, a 69% increase in oilseed rape and a 74% reduction in set-aside. Nitrate losses were reduced slightly (where crops replaced set-aside), phosphate loss increased (by 6.3%), skylark density decreased, finches were relatively unaffected and wood pigeon increased. The increase in crop areas used in this scenario are much greater than those envisaged in meeting the 2010 biofuel targets (utilising a mix of UK cropping and import), however, such exercises help examine the potential impacts of wider expansion and highlight particular areas of concern where environmental impacts need to be carefully monitored and buffered where undesirable change is observed.

Amelioration of biodiversity impacts

Detrimental effects on biodiversity in agricultural landscapes could be mitigated to some extent by ameliorating measures along field margins and within fields. Where biofuel crops are grown, a requirement to undertake measures such as use of unsprayed crop margins, adoption of un-cropped or sown field margin treatments, use of in-field fallow patches and beetle banks to encourage flora and fauna, could mitigate against at least some of the loss of diverse habitat on farmland. In the short to medium-term, the most environmentally neutral option would be to divert existing crops towards biofuel production and this, along with some limited expansion of production onto set-aside is likely to be the main route of raw material supply for the foreseeable future.

Further work

Areas where further work is required includes continued work to screen and develop wheat cultivars with high fermentable starch contents (which equates to high alcohol yield) and reduced nitrogen demand (for both wheat and oilseed rape). This could significantly improve the performance of biofuel crops in terms of greenhouse-gas savings and reduce energy requirements which will be a significant incentive to ensure continued wide-scale use of such feedstocks. Similar work is required in oilseed rape to increase yield performance and efficiency of biofuel production and carbon savings. Areas for agronomic improvement in the environmental profile of wheat and oilseed rape biofuel crops are also identified.

All cereal and oilseed rape growers are scrutinising the value of crop inputs to justify and optimise their use to minimise any potential adverse environmental impacts. In addition, many negative effects of cropping can be moderated or mitigated by adoption of different management practices either on a whole field basis (e.g. through sustainable farming techniques or precision application of inputs) and/or through measures targeted at particular field crops (e.g. encouragement of spring cropping to provide overwinter stubbles) or field margins (e.g. prescriptions covered by agri-environment schemes) or in-field (fallow ‘skylark scrapes’) to support biodiversity in farmland landscapes. Through such means there is potential to significantly influence the environmental footprint of UK cereals and oilseed crops.

PART 1

ENVIRONMENTAL IMPACTS OF CEREAL AND OILSEED RAPE CROPPING IN THE UK

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SUMMARY

Arable cropping occupies around one third of UK agricultural land. Of this, around 70 % is cereal crops and oilseed rape typically 10-14%. Most production is concentrated in eastern and central England in mainland UK. Cereals and oilseeds perform well in the UK and over the last 10 years, the UK has typically supplied an average of 10% in excess of its home demand for wheat. For oilseed rape, the import/export position is finely balanced in the UK, but in recent years the UK has been a net exporter of rapeseed, though only in small quantities. Cereal and oilseed rape crops remain the most profitable, consistently performing, combinable crops in UK arable rotations.

The cereal area in totality is now actually lower than it was 20 years ago, but production per unit area has increased significantly over that period (e.g. wheat yields have increased by 0.12 t ha^{-1} per year). In contrast the oilseed rape area has doubled over the last 20 years, though in contrast to wheat, there has been little improvement in oilseed rape yield. However in recent years, the best growers have increased yields, but there is still as yet unrealised potential, as demonstrated by better performance in variety trials achieving nearly 5t/ha.

Pesticide inputs

The non-target environmental impacts of pesticides depend on the active ingredients used and environmental conditions. Risks can be minimised, for example to features such as water courses, by means of obligatory unsprayed crop buffer strips. A number of legislative initiatives (e.g. LERAPS) and developments by the agriculture sector are designed to reduce the non-target impact of pesticides, including Codes of Good Agricultural Practice, Crop Assurance Schemes and measures implemented under the industry-led Voluntary Initiative. In addition, development of sustainable farming systems and precision application of inputs ensure inputs are targeted according to need. Alongside this, more environmentally damaging pesticides are being phased out though current EU review processes.

In general, there has been an increase in the number and range of active substances typically applied to wheat and oilseed rape crops over the past 10 years. However, new developments has led to pesticides with increased levels of activity and research and development has provided information and support measures (e.g. decision support systems) to help growers to tailor pesticide application rates according to need and in response to field assessment of treatment thresholds.

Over that past 10 years the weight of pesticide active substance applied to wheat has declined by 8%. There has also been a reduction in application rates applied to wheat for herbicides and plant growth regulators. Molluscicide use in wheat has increased in recent years, and fungicide use has also begun to increase after a period of decline in response to emerging resistance problems. In oilseed rape both the area treated and total weight of pesticide applied has increased significantly since 1996, but with declines in application rates for all but herbicide and insecticide use

Wheat accounts for 52% of pesticide use in the UK (by weight of active substance used). In contrast, oilseed rape only accounts for 8% of pesticide use. On a use per unit area basis, winter wheat typically represents a moderate use of pesticide inputs. In contrast, oilseed rape is a relatively low to moderate user of pesticides.

Nutrient inputs

Despite increasing productivity of wheat, nitrogen use on cereals has remained relatively static over the past 20 years, which suggests that there has been ongoing improvement in nitrogen use efficiency in wheat crops. Overall, there is a relatively low risk of nitrate leaching from well-fertilised cereal crops, while oilseeds represent a relatively higher risk, largely as a result of residual fertiliser nitrogen left in soil after harvest. There is growing interest in tailoring fertiliser inputs to individual crop need, targeting nitrogen applications strategically in response to crop growth and difficulties encountered during crop development to help optimise fertiliser inputs to individual crop needs.

Phosphate applications to both winter wheat and oilseed rape have continued to decline since 1983. This probably reflects improvements in fertiliser advice and increasing financial pressure on inputs in recent years.

Long-term application of potassium to wheat has remained relatively constant, although application rates have tended to decline in recent years. Applications to oilseed rape have fallen.

In 2006 72% (995,000 tonnes) of biosolid waste produced in the UK were applied to agricultural land. Due to restrictions on use, around 90% of these biosolids were disposed of by application to cereal crops and a further 8-10% by application to grassland. This represents a positive environmental benefit, as organic matter and plant nutrients are returned to land. Controls and limits on use of biosolids ensure that the heavy metal content of such wastes do not pose any environmental problems.

Energy Inputs

In all crop production systems, nitrogen fertiliser and fuel use represent the most significant energy inputs. Therefore any means of reducing such inputs or increasing efficiency of nitrogen utilisation can significantly affect the total energy requirement. Reducing pesticide inputs has a relatively small impact on total energy requirement for crop production.

Adoption of minimal tillage for oilseed rape could save up to 100 Mega Joules/ha with use of appropriate machinery. However, the ability to adopt minimum tillage on a wide-scale is dependent on achieving good establishment in a wide range of soil conditions and on maintaining good grass weed control across the rotation. There is currently interest in using non-plough minimum tillage to retain soil moisture and achieve rapid oilseed rape establishment. The friable and weed-free nature of soils left after oilseed rape cropping also means that non-plough tillage is well suited to establishing following cereal crops.

Impacts on the soil resource

Erosion only affects a relatively small proportion (17%) of UK soils. The main environmental concerns are associated with movement of soils to water, which carry adsorbed agrochemicals and nutrients via particulate movement. In arable areas, the most severe erosion problems are associated with spring-sown crops and row crops. Though erosion can commonly be observed in winter cereal fields, the severity of erosion is low in relative terms

Emissions to the atmosphere

UK agriculture contributes to less than 1% of the UK's CO_2 emissions. Arable crops make relatively very little contribution to the problem, but do provide a significant carbon sink where residues are returned to soil.

Though emissions of N_2O are relatively low in the UK, compared to those of CO_2, (124,000 tonne v 0.56 billion tonne) N_2O is still an important greenhouse gas with potential impacts similar to those of UK methane emissions (a significant proportion of which are derived from livestock farming and handling of wastes). The importance of N_2O arises from its relative greenhouse gas impact, as N_2O has 320 times the impact of CO_2. As emissions have declined in other sectors, agriculture has become the major source of N_2O emissions, with arable agriculture accounting for 67% of the UK's N_2O emissions. Emission of N_2O from soils is affected by environmental factors including water content, temperature, aeration, ammonium and nitrate concentrations, the amount of mineralisable carbon and pH. Measured emissions from agricultural soils vary widely, and studies suggest a relative emission order by crop type of grassland > potatoes > cereal crops. Cereals therefore appear to pose a low to moderate risk compared to grassland and root crops. A key consideration in relation to impacts on N_2O emissions therefore is how land would be managed if it were not being used to grow biofuel feedstocks.

Ammonia emissions are associated with eutrophication of natural habitats and soil acidification. Agriculture is the largest source of emissions, but arable agriculture (through use of nitrogen fertiliser) accounts for only 9% of the ammonia produced in the UK. Losses are greater from urea-nitrogen sources than ammonium-nitrate. Impacts of individual crops therefore predominantly relate to levels of fertiliser use.

Impacts on the water resource

Leakage of nitrate from agricultural soils has been linked to failure of ground-water sources to meet the EU Drinking Water Standards. As a result 55% of England and 3% of Wales have been designated as Nitrate Vulnerable Zones. Areas where groundwater aquifers exceed the 50mg/l EC limit for nitrate are located mainly in the south, east and centre of the country that correspond with predominantly arable areas on soils underlain by chalk, limestone and sandstone.

The concentration of nitrate in groundwater depends on the balance of agriculture in the catchment area. The quantity of nitrate lost depends on the balance of nitrogen inputs and recovery by crop and measures adopted to reduce leaching. In relative terms, when fertilised correctly, cereals represent a relatively low risk of leaching loss, while oilseed rape represents a higher risk relative to other arable crops in the rotation, due to high levels of residual fertiliser-N left in soil after harvest, which are subject to risk of leaching loss.

In terms of impacts on surface waters, overall there has been a substantial improvement in the biological and chemical quality of rivers since 1990. This has arisen from clean-up of sewage discharges and an increase in application of biosolids to land plus other actions to control pollution. The number of rivers exhibiting high phosphate concentrations (>0.1 mg/l) is high (around 50%), however there is continuing improvement on previous gains and the number of cases is 4% less than in 2000 and 14% less than in 1990. However, the percentage of rivers in England and Wales classed by the Environment Agency as having high nitrate concentrations (i.e. >30 mg/l (rather than EC limit of 50 mg/l)) has only declined slightly from 32% in 2000, to 28% in 2006.

Agricultural land is still a significant source of phosphate input to surface waters, primarily via erosion of soil particles and through dissolved and particulate suspension in run-off. The impact of individual crops on phosphate loss reflects on the soil phosphate status built up over time and factors affecting the risk of soil erosion. Cereals and oilseeds are relatively beneficial on all but the most erosion prone soils where permanent cropping or other amelioration measures need to be considered.

Pesticides in water

The EU Drinking Water Directive sets a limit of 0.1µg l^{-1} for any individual pesticide and 0.5 µg l^{-1} for total pesticides. Seventy percent of drinking water supplies are derived from surface waters. The number of quality failures related to pesticide contamination has been decreasing in recent years, and only a handful of the pesticides responsible are commonly used on cereals and oilseeds crops, other sources of pesticide input to surface waters include approved discharges from industry and livestock treatments.

Mecoprop, isoproturon (IPU) and chlortoluron herbicides are commonly detected arable herbicides in surface waters exceeding quality thresholds on occasion, all of which are used on winter-sown cereals, with peak concentrations detected following winter rainfall. However, only mecoprop and, until recently, IPU are used on a large area of wheat and IPU will soon be removed from sale and its use phased out. Of the 9 pesticides most commonly detected in surface waters, none are approved for use on oilseed rape. The continued appearance of mecoprop in water, despite the introduction of mecoprop-p formulations (and their consequent lower rates of application) has been blamed on use in the amenity sector.

Carbendazim and isoproturon and have been detected in a small percentage of samples taken from groundwater sources giving them a ranking of 7th and 12th respectively in terms pesticide contaminants found to exceed water quality limits. Small amounts of carbendazim are used on oilseed rape.

Biodiversity

Any form of land management has an impact on biodiversity, both positive and negative in relation to individual species requirements. Winter wheat and autumn-sown oilseed rape cropping systems will affect a wide range of wildlife associated with the agricultural environment through a number of factors such as fertiliser and pesticide inputs, the season of planting, method and frequency of cultivation, crop and weed cover and seed return from crop and weeds. Pesticide impacts on non-target species will include both direct effects and indirect effects through modification of the habitat (e.g. removal of food sources).

For some declining farmland seed-eating birds, a reduction in the area of weedy winter stubbles is thought to have contributed to increased winter mortality. Weedy winter oilseed rape and cereal stubbles are strongly favoured as a foraging habitat by finches and buntings such as cirl buntings, while skylarks particularly favour cereal stubbles. Growing cereal crops appear to be less attractive to key farmland bird species while oilseed rape crops are actually preferred by some species. Species such as skylark, yellow wagtail, sedge warbler, reed bunting and corn bunting nest in oilseed rape crops and rape crops are used during the breeding season by species such as tree sparrow, reed bunting and yellow hammer. Whitethroats and linnets also show a preference for hedgerow sites adjacent to oilseed rape and many other hedge species are positively encouraged.

Molluscicides have been shown to have an impact on populations of carabid beetles and wood mice. Wheat and oilseed rape are of concern because of the large area treated (together they account for around 75% of all molluscicide use). However, HGCA-funded research has demonstrated the value of using bait traps as a means of forecasting risk of subsequent slug damage. Greater adoption of such techniques could help reduce the use of slug pellets in wheat and oilseed rape.

The incidence of invertebrate groups is strongly correlated with the presence of arable weeds, which provide both a source of food and crop cover. Abundance of invertebrate groups also commonly shows a negative relationship to the use of insecticides and in some cases with use of fungicides. Invertebrate abundance and species richness is greater under wheat than crops such as potatoes. One reason is that crop cover early in the growing season is a key factor affecting invertebrate populations. Carabid beetles and linyphinid spiders, which are useful biocontrol agents, tend to be present at higher levels in cereals and oilseed rape than in potatoes, peas and other non-cereal spring crops.

There are an increasing number of field and farm scale measures and approaches adopted by some growers, which could be more widely adopted, to decrease the environmental impact of combinable cropping in the UK. These include use of agri-environment schemes, use of integrated/sustainable farming systems and precision application of inputs.

Industry-led voluntary initiatives have also had an influence in reducing the indirect impacts of pesticides. More than 1.5 million hectares of arable land in the UK are covered by documented crop management plans, 34,500 spray ‘MOT’ tests have been completed (accounting for sprayers covering 82.4% of the sprayed area) and 20,947 farm workers have registered as spray operatives, which includes continued professional development to ensure best practice and efficient and effective use.

At current grain prices and in light of future uncertainty over returns, all cereal and oilseed rape growers are scrutinising the value of crop inputs, to justify and optimise their use, which will minimise any potential adverse environmental impacts.

1.0 CEREAL AND OILSEED RAPE CROPS IN UK AGRICULTURE

The 18.7 million hectares of land classed as ‘agricultural use’ in the UK accounts for 75% of the UK land area. Of this, the area dedicated to arable cropping represents around a third of the UK agricultural land area (Figure 1). The remaining area is dominated by grass and rough grazing for livestock production. Over the past 10 years the compulsory set-aside rate set by the EU Commission ranged from 5 to 15% of the UK arable area. However, the situation with set-aside is changing. In the face of tightening cereal stocks (through increased world demand) the set-aside rate was set to zero for the 2007/08 cropping season. Furthermore, the continued use of set-aside as a supply/demand control measure is to be reviewed under the 2008 CAP health check. Current indications are that reducing the set-aside rate to zero has reduced the area of uncropped land in England (bare fallow and compulsory set-aside) by 40%, while the 2007/08 wheat area has increased by 10.4% and the oilseed rape area by 2.3% (Defra Survey of Agriculture, December 2007).

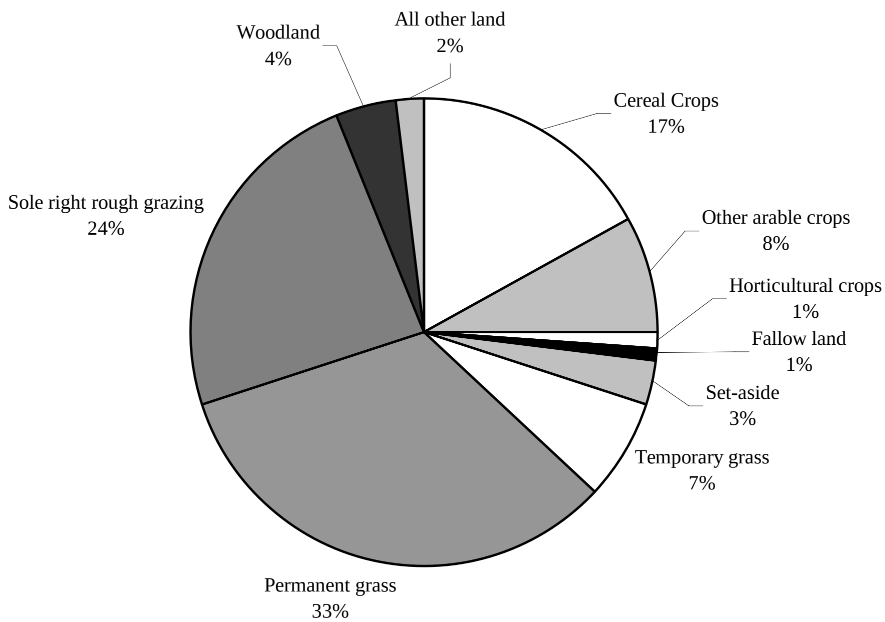


Figure 1. Breakdown of the UK total area on agricultural holdings, June 2007 (Source: Defra)

1.1 Cereals and oilseed rape in UK rotations

The UK arable area is dominated by cereal production, mainly wheat, closely followed by barley, which together represent around 70% of the UK arable area (Table 1). This reflects on the common occurrence in rotations of a second wheat crop and winter barley, which due to its early harvest, is the most common entry crop for oilseed rape. Therefore, typical UK arable 4-5 course rotations are dominated by cereal species and cereal and oilseed production dominate large areas of the Midlands and Eastern counties (Figures 2 & 3).

Table 1. Breakdown of the UK arable area by main crop type (2007) (excluding set-aside (440,000 ha in 2007)) (Source: Defra)

	Thousand hectares	% of total
Wheat	1816	46.8
Spring barley	515	13.3
Winter barley	383	9.9
Oilseed rape	601	15.5
Field beans and combinable peas	161	4.1
Sugar beet	125	3.2
Potatoes	140	3.6
Oats	129	3.3
Linseed	11	0.3
	3881	100%

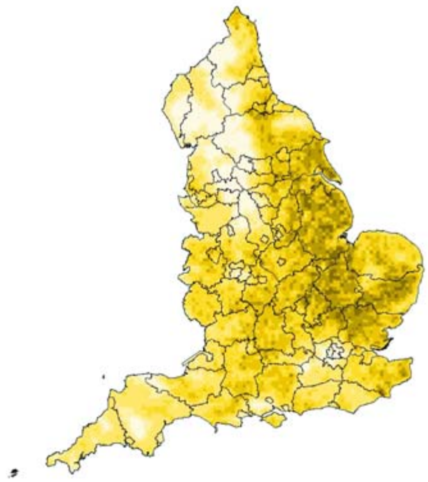


Figure 2. Distribution of wheat in England 2006 (Source Defra)

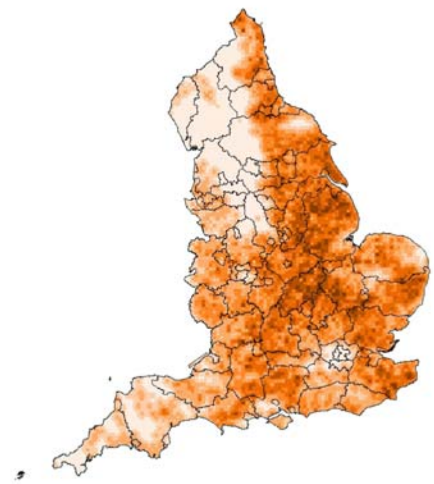


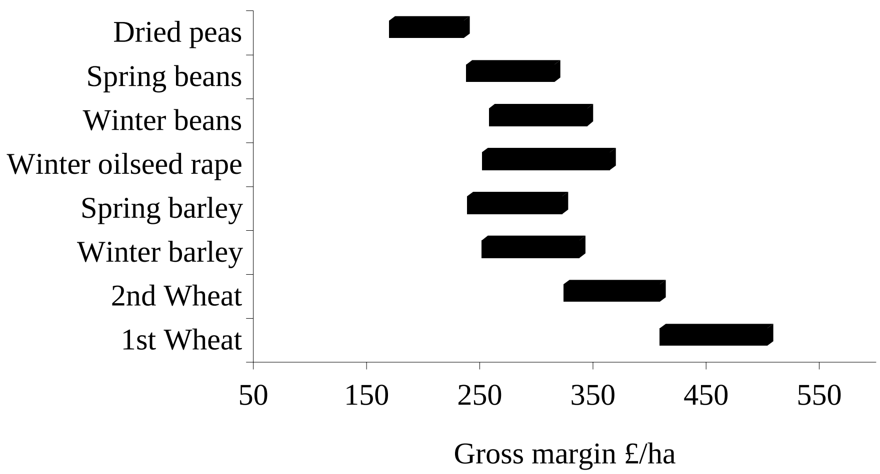
Figure 3. Distribution of oilseed rape in England (2006) (Source Defra)

The UK is well suited to production of cereals, which prefer a temperate climate and cereal crops yield well in the UK. In addition there is a well developed human consumption, animal feed and export markets which ensures a competitive and transparent market for growers. The UK has a domestic demand for in excess of 13 million tonnes of wheat per annum and, over the past 10 years the UK has typically supplied an average of 13% in excess of demand. The export demand for quality wheat samples remains strong.

Grain price in the EU is strongly influenced by world trade impacts and as such has been subject to significant fluctuation in recent years following CAP reform reductions in market support. For example, prices in recent years have ranged from less than £60/tonne in 2002, rising to £182/tonne (for feed wheat) in 2007, with possible further price rises anticipated. Cereal crops remain the most profitable, consistently performing, combinable crops in typical arable rotations (Figure 4).

Oilseed rape also suits the UK's temperate climate. Oilseed rape became established in the UK in the 1970's following increasing world demand for edible oils and protein for animal feed (high protein rape meal is produced as a by-product of oil extraction). Oilseed rape is an excellent 'break crop' and allows clean-up of grass weeds that are otherwise difficult or expensive to control in cereal crops. The crop requires little or no specialist machinery and is early to harvest. This helps spread the farm workload and allows timely seedbed preparation to optimise yield potential of following cereal crops. The crop performs well on all but the lightest soils where drought restricts crop growth. The deep tap-root produced by oilseed rape helps to improve soil structure. The value of oilseed rape, like cereals, has seen significant fluctuation in value in recent years, ranging from as low as £110/tonne up to around £360/tonne. Oilseed rape is typically the most profitable combinable non-cereal crop in arable rotations (Figure 4). In recent years the UK has produced between 1.1 and 1.9 million tonnes of rapeseed per annum and the UK crush between 570 and 670 thousand tonnes of oil. The import/export position is finely balanced in the UK, but in recent years the UK has been a net exporter of rapeseed, though the volumes are relatively small (circa 100,000 tonnes), equivalent to around 5% of production.

a) At typical former harvest prices (2007 predicted prices)



b) At recent high commodity prices (2008 actual spot price highs)

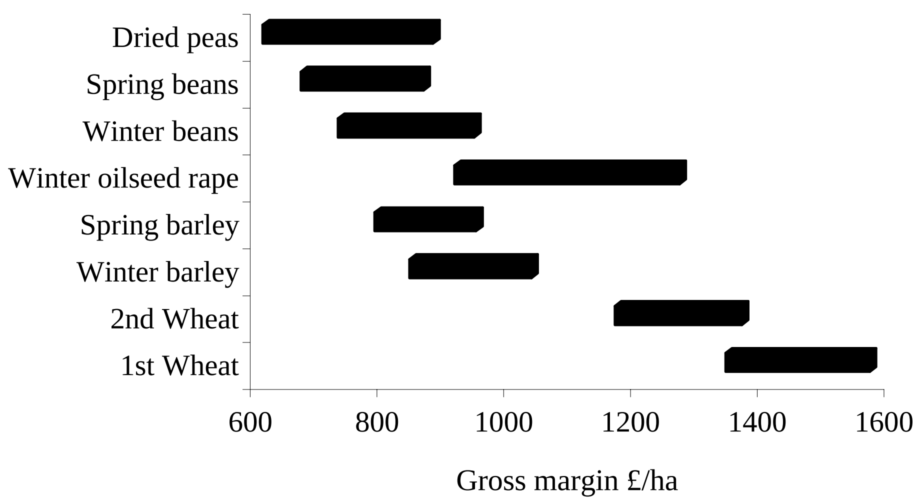


Figure 4. Range of gross margins (2007) for average and high yielding combinable crops at former (a) and current (b) commodity prices (utilising input costs from Nix, 2006)

1.2 Cereal crop areas and yields

The UK cereal area has seen significant fluctuation over the past two decades, but in general has declined slightly over this time. According to Defra figures, the UK cereal area as a whole is now around 1 million ha smaller than it was 20 years ago, due to the introduction of set-aside and some reversion to long-term grass. The moves towards removal of set-aside and current high cereal prices, as world demand grows, is likely to buck this trend in the coming years. The UK wheat area to date has remained relatively stable, albeit with annual fluctuations, at between 1.6 and 2.1 million hectares (Figure 5). At the same time the productivity of wheat has increased significantly (Figure 5), with yields in recommended list trials increasing by around 0.12 t/ha/year (Sylvester-Bradley *et al.*, 2004), reflecting advances in both breeding and crop protection. It is anticipated that there is still potential for continued increase in average farm yields (Sylvester-Bradley *et al.,* 2004).

1.3 Oilseed rape crop areas and yields

Over the past two decades the oilseed rape area has risen gradually and the area is now more than double that grown in 1984. In recent years the crop area has varied between 400 and 592 thousand hectares (Figure 6), and as with wheat, it is anticipated that current high market prices, and with removal of set-aside, the crop area could see further expansion. Over the same period there has been little improvement in crop yield potential on farm despite the introduction of high-yielding hybrids (Figure 6). This is despite the fact that yields in national list trials have increased by around 0.05 tonne ha^{-1} per annum since 1980 (Spink and Berry, 2004). This indicates that management of oilseed rape on farm is not always optimal. However, in recent years, through better understanding of oilseed rape crop physiology, autumn canopy management and autumn disease control, yields amongst the best growers are now commonly approaching 4 t/ha or more which shows signs of increased efficiency, though yields in recommended list trials are closer to 5t/ha. Tackling yield improvement in oilseed rape is the subject of number of HGCA-funded reviews and projects including HGCA Research Review 53 (*Evaluation of factors affecting yield improvement in oilseed rape*), where inadequate disease control was highlighted as a limiting factor. HGCA Research Project 2892 (*The management of oilseed rape to balance root and canopy growth*) also identifies the crop physiological traits where improvements are required to achieve a theoretical yield potential of 8 t/ha for oilseed rape.

1.4 Other issues affecting on-farm cropping decisions

Continued rationalisation of the industry into fewer landowners or land managers, coupled with a continual decline in labour on farm (by 100,000 farm workers in the UK over past 10 years) encourages growers to look for time-saving options in terms of crop choice and crop management and ease of management in terms of available labour at peak workloads. These factors combine to drive growers into set cropping and management options and increase resistance to change. In addition, with income from farming set to become more volatile in response to global trade impacts, the future ability to invest and support change in farming practice is likely to be affected.

2.0 PESTICIDE INPUTS

2.1 Pesticides - Current trends in use

Trends over the past 10 years have been identified by the latest pesticide usage survey for arable crops (Garthwaite *et al.* 2006). There has been a 6% increase in the arable area treated but a

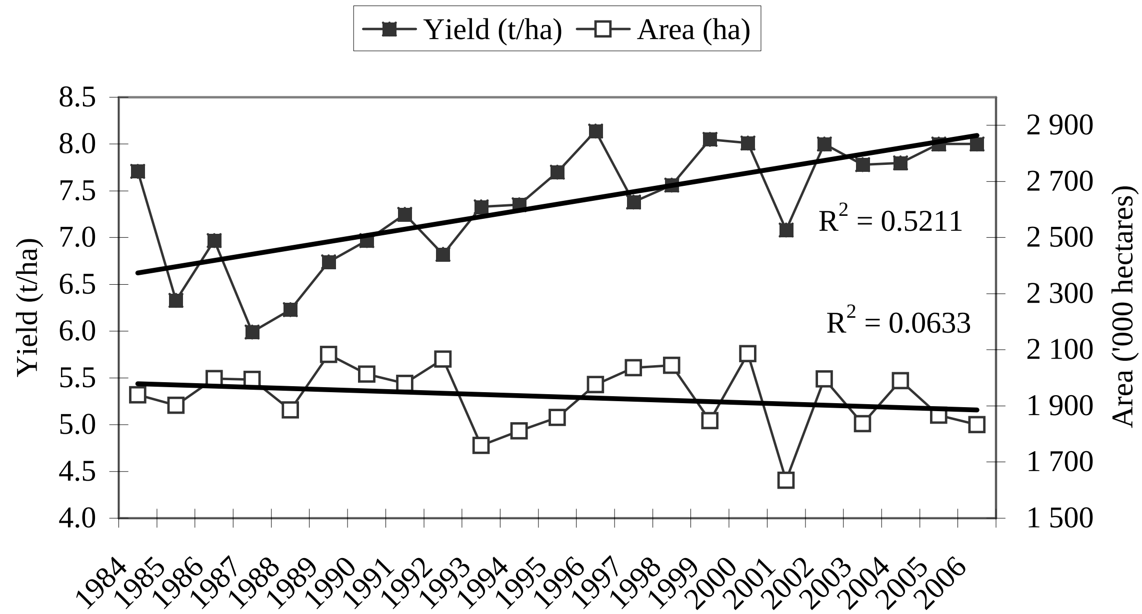


Figure 5. Long-term trends in wheat average field yields and UK wheat production area (derived from Defra Statistics)

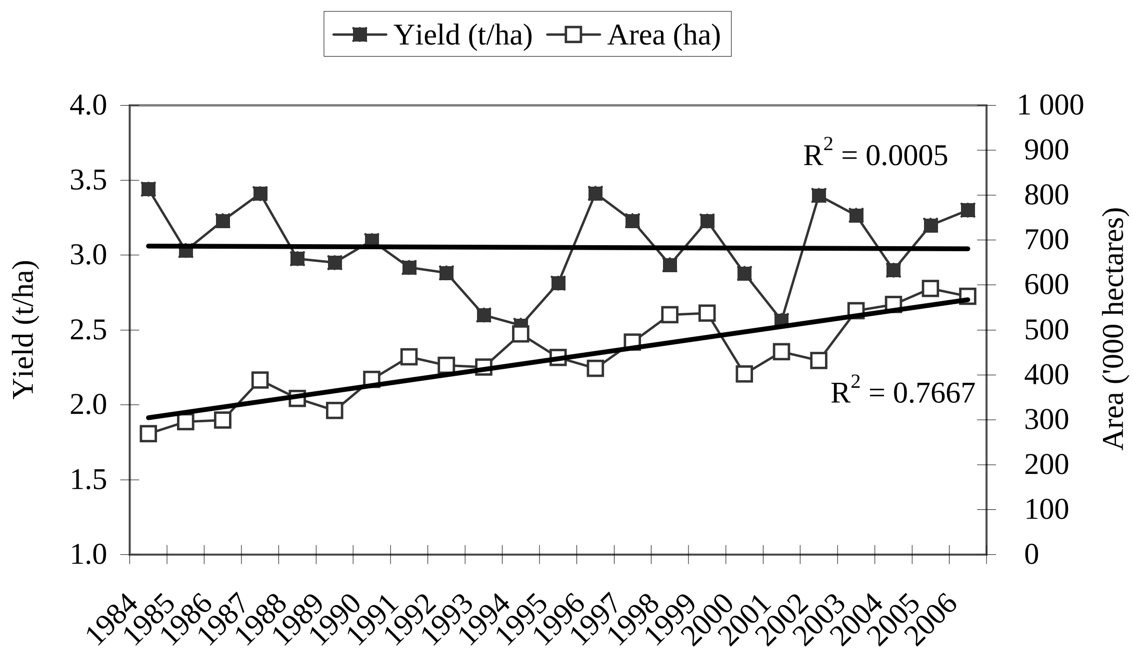


Figure 6. Long-term trends in winter oilseed rape average field yields and UK oilseed rape production area (derived from Defra Statistics)

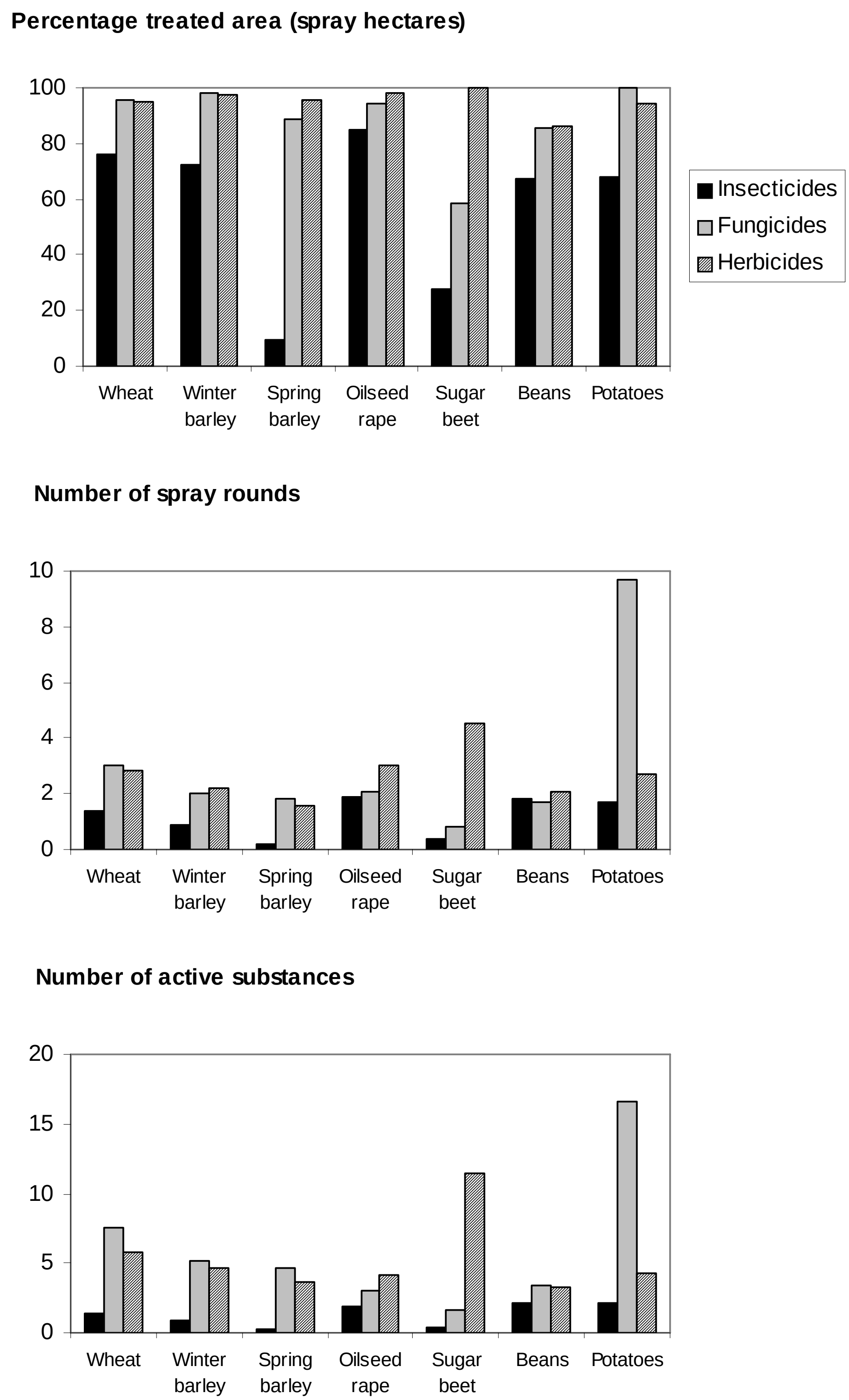


Figure 7. Area treated with pesticides (%), number of spray rounds and number of active substances applied, for the major arable crops in Great Britain (nematicides are included in insecticides, but seed treatments are excluded)) (Garthwaite *et al.*, 2006).

decrease in the weight applied (by 39%.) These changes reflect an increase in the average number of sprays applied to crop from four in 1996 to over five in 2006. In addition the number of products used, and therefore the degree of tank mixing, also increased from an average of eight products per crop in 1996 to almost ten products in 2006.

Despite the increase in the number of sprays and products used, the weight of active substances applied has continued to fall over the last ten years as growers move to products containing newer molecules, more active at lower doses, and the increasing use of reduced rates by farmers and growers.

Table 2. Share, by crop type, of total UK pesticide application (by weight of active substance) (excluding sulphuric acid)) and total pesticide application/unit area of crop in 2006 (Derived from Garthwaite *et al.* 2006).

	Crop share of UK pesticide use (% by weight of a.s. applied)	Weight of a.s. applied/ha (kg)
Wheat	52%	4.72
Winter barley	9%	3.64
Ware potatoes	12%	16.02
Oilseed rape	8%	2.59
Spring barley	4%	1.38
Sugar beet	5%	6.43
Field beans	3%	2.87
Set aside	3%	1.00

2.2 Pesticide use on cereals and oilseeds

The contribution of winter wheat and oilseed rape crops to use of pesticides in Great Britain in 2006 is shown in Table 2. As a result of its dominance of the UK arable area, cereals account for the largest share of pesticide inputs to UK crops. In contrast, oilseed rape accounts for a relatively small proportion of pesticide use in the UK.

The percentage of winter wheat and oilseed rape crops treated with pesticides is high relative to other major crops (Figure 7), particularly in relation to use of insecticides and fungicides.

It is difficult to compare pesticide inputs between crops, due to the difficulty in defining a common unit of comparison. However using the information from the 2006 pesticide survey (e.g. Table 2 and Figure 7) as a guide, ware potatoes represent a crop group with relatively high use of pesticides, while spring cereals typically represent crops with very low use of pesticides. By comparison, cereal crops have a relatively moderate pesticide demand. Oilseed rape has a relatively moderate to low pesticide use demand.

2.3 Pesticide inputs to cereals

Changes over the last decade

The area of wheat grown has fluctuated, but the trend in production area has remained relatively static since 1996 (Figure 5). At the same time, the area treated with pesticides has increased by 10%, but the weight of active substance applied has decreased by 8% due to the introduction of new products and to growers applying lower dose rates. The trend in dose rate across all product groups is shown in Figure 8.

The pyrethroid, cypermethrin, has been the principal insecticide active substance used on wheat since 2000. However, the use of cypermethrin and other pyrethroids including lambda-cyhalothrin, tau-fluvalinate and esfenvalerate have all declined since 2004. By contrast, the use of chlorpyrifos, for orange wheat blossom midge control, has increased steadily since 1996, with the area treated almost doubling between 2004 and 2006 due to increased incidence of the pest and recognition that chlorpyrifos is the most effective material for this purpose. However, when treated area is expressed as a percentage of the area grown, the use of organophosphates has remained constant, at 15%, between 1996 and 2006, with the use of pyrethroids increasing from 85% to 96% over the same period.

Although isoproturon has been the principal herbicide used since 1992 its usage has declined since 1998, and use of the product will be phased out by June 2009. The area treated with iodosulfuron-methyl-sodium/mesosulfuron-methyl had more than doubled since 2004 when it was first recorded in the arable pesticide usage surveys.

The dose rate for fungicides remained higher than pre-2004 levels, in continuing response to concerns over resistance to strobilurin and azole fungicides in the *Septoria tritici* population. For herbicides, while individual treatment dose rate has declined, there has been a trend towards increased total dose, reflecting increased incidence of resistance in weed species such as black-grass, wild-oats, Italian ryegrass and more recently chickweed and common poppy.

Current use

Nearly all wheat is treated with fungicide and herbicide (on average 2-3 times a year) and 76% of the wheat area is treated with insecticide (on average 1.4 times/year). Reduced application rates are widely used on cereals; most fungicides are applied at one third to a half the full label rate and most herbicides are used at or less than half the full label rate. Growth regulators are typically applied to the majority of wheat crops. They are typically applied between March and May, at around half the full label rate.

The majority of insecticides (typically cypermethrin at or near the full label rate) are applied to wheat in autumn (October/November) for control of aphid vectors of Barley Yellow Dwarf Virus. A smaller peak in use occurs in early summer (May/June) primarily for aphid control. Fungicides are typically applied between March and June, to control a broad spectrum of disease pressure.

Most herbicides are applied to wheat in October/November, with a smaller peak in early spring for follow-up treatments. Particular weed problems (other than general weed control) such as black-grass or wild-oat control, account for herbicide treatments on approximately 16% and 7% of the treated area respectively.

In addition to use of reduced dose rates, there has also been a move towards reducing spray water volumes (100-150 l/ha) to increase efficiency (i.e. number of acres treated per tank filling).

2.4 Pesticide inputs to oilseed rape

Changes over the last decade

Between 1996 and 2006, the area of oilseed rape increased by 39%, the area treated with pesticides increased by 86% and the average weight of active substances applied per hectare increased by 56%. The number of fungicide applications to the crop has increased but the average rate of application for each product decreased from 0.3 kg/ha in 1996 to 0.2 kg/ha in 2006. The use of herbicides and herbicide dose rates in oilseed rape has increased over the last decade (Figure 9). As for arable crops in general, the use of organophosphate insecticides has declined (none are applied to oilseed rape) and use of pyrethroids has increased. The use of glyphosate has increased and sprayer water volumes have decreased. Despite the trend towards new molecules, carbendazim continues to be widely used as a fungicide on oilseed rape.

Nearly all oilseed rape is treated with herbicides (on average 2.3 times/year (2006)), 94% is treated with fungicides (on average 2.1 times/year) and 85% with insecticides (on average 1.9 times/year).

For oilseed rape, the majority of insecticides, including cypermethrin, are applied in autumn for control of cabbage stem flea beetle, with further applications being made between March and June predominantly for pollen beetle and seed weevil control.

The majority of herbicides are applied to winter oilseed rape between July and November (as pre-emergence and early post-emergence split treatments, or for grass weed control) with a smaller peak around March, mostly to rectify any poor performance associated with earlier weed control programmes. Herbicides are also commonly applied pre-harvest to desiccate the crop as an aid to harvesting. Herbicides (including glyphosate the most commonly used herbicide on the crop) are used at or near three-quarters of the full label rate, though some (including many actives used for grass weed control) are used at or less than half the full label rate.

The majority of fungicides are applied to winter oilseed rape between October and November and/or March for general disease control, particularly for control of damaging light leaf spot and phoma disease. Further applications in May are occasionally required for control of stem canker and sclerotinia. Most fungicides tend to be applied to oilseed rape at, or just above, half the full label rate.

2.5 Measures to reduce the environmental impacts of pesticides

Codes of practice

The use of pesticides in agriculture is covered by EC Directive 94/414 and The Plant Protection Products Regulations (see Annex 4) which requires EU Member States to provide approved lists of products for commercial use and to undertake periodic review of products taking account of any new information and concerns regarding products. All plant protection products have or are currently being reviewed in detail by the EC under EC Directive 91/414, to assess suitability for continued approval for use. This includes an assessment of their environmental impact. This review process has resulted in a number of active substances being removed from the marketplace.

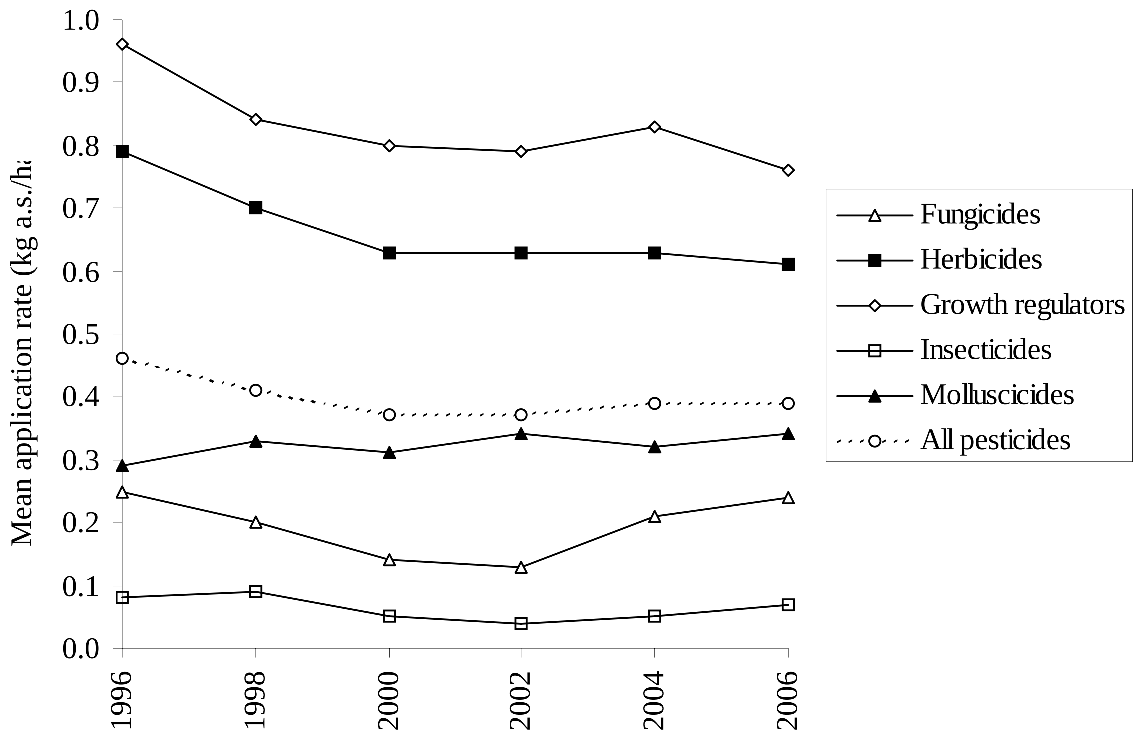


Figure 8. Average dose rate of active substance applied to wheat 1996 – 2006 . (Garthwaite *et al.* 2006).

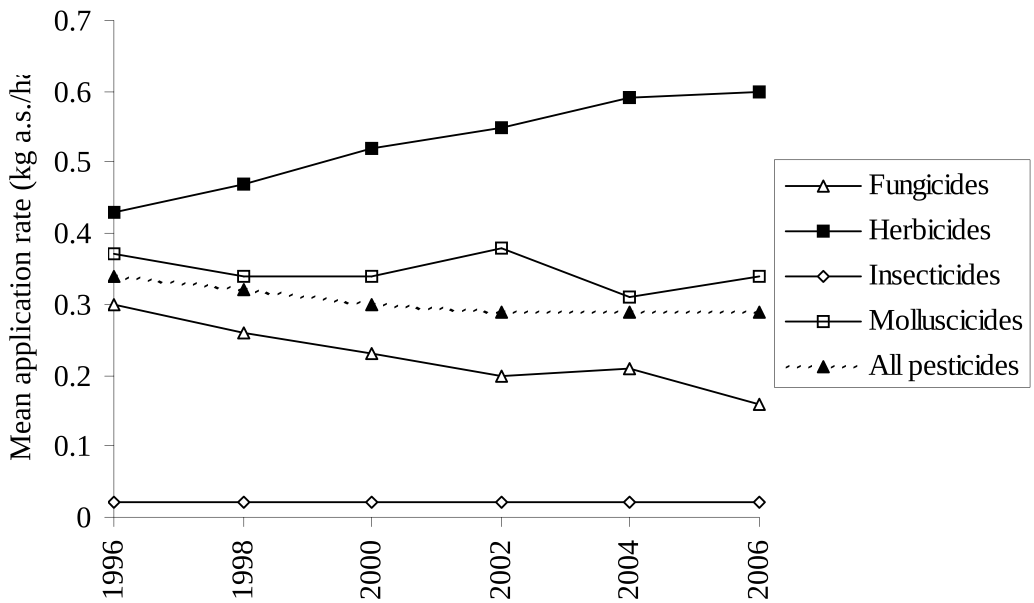


Figure 9. Change in average application rate (kg active substance/ha) of pesticides applied to oilseed rape between 1996 and 2006 (Garthwaite *et al.* 2006).

In addition to legislative controls there are a number of voluntary Codes of Practice for safe use and handling of pesticides and for protection of soil and water resource (Defra Codes of Practice For Protection of Soil, Air and Water). Farmers and growers are required to comply with these codes in many crop assurance schemes. Compliance with such schemes is now demanded by many end users to ensure end products are unlikely to pose a risk to consumers etc. Advisors making spray recommendations are now commonly registered and accredited professionals and have to prove they are undergoing continuous professional development and training to retain registration as providers of professional advice. In addition, there are a number of other voluntary initiatives set in place by industry to provide stewardship of chemical use by the industry as a whole.

Crop Assurance

The main assurance scheme covering wheat and oilseed crops is the Assured Combinable Crops Scheme which now covers 15,000 producers, accounting for around 85 -87% of UK combinable crops and 94% of oilseed rape[1]. The scheme, which is audited on-farm ensures growers comply with legislation and the following points (not exhaustive):

- Farmers must hold copies of the DEFRA codes of practice for the protection of soil, air and water, also the codes of practice for the Safe Handling of Pesticides on Farms and conform with practices detailed in these codes.
- Growers must employ a crop protection strategy intended to avoid unnecessary chemical applications and take account of environmentally sensitive areas on the farm.
- Growers should choose pest and disease resistant varieties where available and choose seed treatments appropriate to the perceived risk to the crop and use threshold-based or other recognised decision-making systems to target appropriate chemical use.
- Chemical advisers or consultants should have appropriate BASIS (British Agrochemical Standards Inspection Scheme) qualifications. All sprayer operators/contractors must have relevant Food and Environmental Protection Act (FEPA) certificates of competence.
- Chemicals must be stored in accordance with appropriate legislation.
- Members who use the services of contractors must ensure they have the necessary certificate of competence and that they observe both provisions of the Law and the assurance scheme in respect of all aspects of the use of pesticides.
- Pesticides must never be applied to crops in unsuitable conditions.
- Members must comply with statutory no spray (buffer) zones and be aware of, undertake and record Local Environmental Risk Assessments for Pesticides (LERAP) (see Annex 4).
- Application of pesticides post flowering is restricted and can only be made for reasons of pest and disease control where thresholds are exceeded, as a harvest desiccant, or to control couch or other perennial grasses.

Voluntary Initiative (VI)

The Voluntary Initiative is a programme of voluntary and other measures established and led by the Crop Protection Association that aims to reduce the impact of pesticides on the environment and to promote best practice and biodiversity in the farmed environment. This includes measures to ensure farmers are applying pesticides at appropriate rates and have appropriate crop protection management plans in place to ensure compliance with relevant legislation and Codes of Practice governing use of pesticides. Other measures include: help to improve means of disposal of

[1] Source: Assured Combinable Crops, personal communication

unwanted or obsolete pesticides, biodiversity training for farmers; a sprayer testing scheme (sprayer 'MOT'), a register of sprayer operators (The National Register of Sprayer Operators (NroSo) had more than 20,947 members against a target of 19,500 by 31st March 07) and work in water catchments to identify the most appropriate application times and rates to reduce the risk of surface water contamination by evaluation of rates of field drainage flow (for further information see the VI web site at www.voluntaryinitiative.org.uk). The National Sprayer Testing Scheme has tested sprayers responsible for applications on 82.4% of the sprayed area against a target of 80% by 31st March 07, and 12,500 machines were tested in 2006/7, bringing the total of tests completed since NSTS was launched in January 2003 to over 34,500[2].

Completion of Crop Protection Management Plans (CPMPs) was included as an option within the Entry Level Stewardship Scheme, England and Wales (agri-environment scheme). A separate VI Target of implementing CPMPs on 1,500,000 ha was exceeded in 2007. CPMPs have now been withdrawn as an ELS option, as a condition of approval of the England Rural Development Plan for 2007-2013 by the European Commission. However, the elements of the Crop Protection Plan are still expected to be implemented under requirements for following the principles of good farming practice as part of the single farm payment scheme.

Manipulating farming practice can also mitigate the environmental impacts of cropping systems and this is discussed further in section 9.

2.6 Pesticide residue monitoring in derived products

A wide range of food products are examined for the presence of pesticide residues on an annual basis. Statutory maximum residue limits (MRL's) are set at levels which indicate whether pesticides have been used according to recommended good agricultural practices. In recent UK tests, no flour or bread products were found to exceed MRL's. The Pesticide Residue Committee (PRC) reports on surveys of pesticide residues can be found at www.pesticides.gov.uk/prc_home.asp. Rapeseed oil samples have not been examined recently by the PRC, but analysis of a relatively small number of samples submitted to CSL's pesticide residue testing service also indicates that MRL's have not been exceeded (S. Brewer, personal communication).

2.7 Impacts of commonly applied pesticides

The risks posed by pesticides to agricultural ecosystems and the wider environment will depend on mode of use, ecotoxicity, and physiochemical characters as well as factors such as soil type and weather patterns just prior to and post application (i.e. risk of leaching). Some pesticides pose a risk to water but the impacts of this can be managed to mitigate the risk by implementing buffers along sensitive habitats (e.g. water courses). A number of legislative (e.g. LERAPS (see Annex 4)) initiatives and developments by the agriculture sector have been introduced to try and reduce the non-target impact of pesticides and ensure that pesticides are applied according to best practice.

2.8 Risk from pesticide use in wheat and oilseed rape

Insecticides

Though the level of risk and potential impacts will vary depending on the pesticide applied and time and method of application etc, insecticides and molluscicides rather than fungicides or herbicides

[2] http://www.aea.uk.com/sprayer/index.htm

pose the highest risk of direct impact on non-target invertebrate organisms (Defra 2001). The most problematic chemicals (e.g. organochlorines) are either no longer used, or use is severely restricted (e.g organophosphates). These have largely been replaced by pyrethroids (e.g. cypermethrin) which typically exhibit low toxicity to mammals and birds. The risk of pyrethroids and other pesticides entering water courses is significantly reduced by LERAP requirements (see Annex 4).

The most commonly used insecticides on wheat and oilseed rape are listed in Table 3. Cypermethrin is the most widely used insecticide used on wheat (which accounts for 55% of use on a treated area basis) and oilseed rape. Such chemicals are subject to a 6m 'no-spray buffer zone' restriction when used near to open water sources and application is not permitted during flowering in crops like oilseed rape. Chlorpyrifos is the only organophosphorous insecticides currently registered for use in the UK. Very little chlorpyrifos is used on wheat (use is too small to register as an individual pesticide compound in usage surveys). Trifluralin use on wheat accounts for the majority of applications, but it is soon to be removed from sale, and any stocks must be used before March 2009. Many other actives in the list are also currently under environmental review by the EU.

Fungicides

Fungicides generally have a low toxicity to mammals, birds and earthworms and risks to water courses are reduced by LERAPS requirements.

Herbicides

Herbicides generally have low mammalian and avian toxicity. Isoproturon (IPU) is the most commonly used herbicide on wheat and glyphosate (as a pre-drilling treatment or crop dessicant) on oilseed rape (Table 3) (though use of IPU will be phased out by 30 June 2009). The usage (in terms of spray hectares) of isoproturon and glyphosate is greater on wheat than on any other crops. Glyphosate is used as a pre-drilling clean-up and a pre-harvest desiccant on oilseed rape, but more is used on set-aside than on oilseed rape. Soil degradation rates are variable between active substances but half lives are commonly measured in 'days' and 'tens of days' rather than weeks, though some older 'residual acting' herbicides like trifluralin show high levels of persistence (half life of 116-200 days in soil). Herbicides are subject to the requirements of LERAPs, however their persistence does mean that in a small number of cases some active substances (isoproturon in particular) can be found in surface or ground water (see section 7.0).

Molluscicides

Metaldehyde and methiocarb are used as molluscicides on wheat and oilseed rape, and use varies widely from year to year depending on the risk of damage. In 2006, 19% of the wheat area and 41% of the oilseed rape area was treated with molluscicides. Wheat and oilseed rape accounted for 82% of all molluscicide use. However, HGCA-funded research has demonstrated the value of using bait traps as a means of forecasting risk of subsequent slug damage (Glen and Wiltshire 1992), reducing the need to treat crops.

Metaldehyde poses a risk to game, wild birds and other animals if ingested, as well as fish and other aquatic organisms. Methiocarb can also affect beneficial invertebrates such as carabid beetles. Purvis and Bannon (1992) found that broadcast applications of methiocarb reduced activity of winter-active carabid beetles to less than 5% of that on untreated plots and this suppression continued for the remainder of the season. Spreading methiocarb on the soil surface has also been reported to cause high mortality in wood mice (e.g. Johnson *et al.*, 1991, Shore *et al.*, 1997). Greater adoption of risk forecasting techniques could help reduce the risks to non-target organisms.

Table 3. Pesticides most commonly used on wheat and oilseed rape in Great Britain in 2006 (Garthwaite *et al.,* 2006) (expressed as sprayed hectares and as % of total area treated with each active substance)

	Wheat	Spray hectares	(% of total)	Oilseed rape	Spray hectares	(% of total)
Insecticides	Cypermethrin	935,821	(55%)	Cypermethrin	343,036	(20%)
	Chlorpyrifos	224,283	(94%)	Alpa- cypermethrin	118,936	(48%)
	Lambda-cyhalothrin	216,861	(35%)	Lambda-cyhalothrin	117,587	(19%)
	Esfenvalerate	159,854	(79%)	Zeta- cypermethrin	82,866	(35%)
	Tau-fluvalinate	136,456	(52%)	Tau-fluvalinate	81,168	(31%)
Fungicides	Chlorothalonil	1,794,633	(76%)	Metconazole	240,749	(72%)
	Epoxiconazole	1,089,894	(92%)	Carbendazim/ flusilazole	134,063	(69%)
	Prothioconazole/tebuconazole	533,399	(83%)	Flusilazole	131,125	(63%)
	Prothioconazole	449,266	(77%)	Boscalid	122,360	(88%)
	Pyraclostrobin	409,729	(94%)	Carbendazim	98,597	(68%)
Herbicides	Isoproturon	907,690	(77%)	Glyphosate	309,662	(19%)
	Iodosufuron-methyl-sodium/mesosulfuron-methyl	226,831	(100%)[3]	Propaquizafop	222,802	(74%)
	Fluroxypyr	760,181	(85%)	Metazachlor/quinmerac	159,170	(83%)
	Glyphosate	512,603	(31%)	Propyzamide	142,247	(81%)
	Trifluralin	626,197	(68%)	Metazachlor	122,943	(87%)

2.9 Risk indicators

Attempts have been made to try and generate indices of risks associated with pesticide use across crops and rotations. They are affected by a number of problems but currently represent one of the best means of readily evaluating the risks associated with pesticide application regimes. The pEMA (Pesticide Environmental Management Audit) software (Lewis, et al., 2003) has increasingly been used to model and assess risks to key waterborne, invertebrate, mammal and bird species. pEMA produces 'eco-scores' based on modelling of risks associated with the physicochemical and ecotoxicity characters associated with pesticides. These can be averaged across a range of crop inputs to provide a risk index score. Such scores are significantly affected by field boundary aspects (Tzilivakis *et al.,* 2004) which affect the degree of risk of exposure. Recent work funded by the British Beet Research Organisation (Jaggard *et al.,* 2004) used the pEMA approach to derive scores (based on risk alerts generated by particular pesticide inputs) for a range of arable crops to see how they compared with sugar beet. The results suggest that the highest impacts arising from

[3] A very small proportion is also applied to winter barley

pesticide use were likely to arise from potato cropping (index score 230), while sugar beet and winter wheat had similar scores (26 and 35 respectively). Oilseed rape and pea crops were assessed as having intermediate scores (85 and 75 respectively). This in part follows the trends highlighted earlier in relation to total pesticide use (section 2.2) though impacts of pesticide use in oilseed rape use are scored higher here. However, in the Jaggard *et al.* (2004) study, the datasets for crops other than sugar beet were not comprehensive and it is not clear whether boundary features were assessed as being common to each crop type. Work by Tzilivakis *et al.* (2004) comparing crops on the same field sites over a whole rotation (i.e. in the same location) found little difference in eco-scores between crops. However, oilseed rape crops were generally associated with higher levels of risk to the environment than pesticide regimes applied to cereals (matching the Jaggard *et al.* (2004) observations) under what were current pesticide management practices between 1993 and 1997. Clearly the impact of pesticides on the environment is complex and assessments from different perspectives can be contradictory.

3.0 FERTILISER INPUTS

3.1 Current trends in fertiliser use

The balance between fertiliser inputs, removal in crops and retention in soil influences the scale of loss of nutrients from agricultural systems which can lead to pollution of ground and surface waters and the atmosphere. This can have consequences for the quality of drinking water as well as biodiversity (see later sections on impacts on water and air resource). The nutrients of particular concern are nitrogen, phosphate and to a lesser extent potassium. In an ideal situation, the amount of fertiliser applied is balanced by the crop offtake and leaching is minimised. The degree to which this balance is achieved varies between crops.

Examination of mean nitrogen (N) fertiliser application rate to arable crops over the last two decades (Figure 10) shows a decline until the 1990s and then relative stability. However, these figures include set-aside land, and so will be affected by changes in the annual set-aside rate set by the European Commission.

Both winter wheat and oilseed rape are nitrogen-demanding crops relative to other crops in the arable rotation (Figure 11).

Use of straight and compound nitrogen on cereals has remained relatively static since the mid-1980s (Figure 11). In the last five years the mean application rate has risen slightly to an average of 195 kg/ha, this is despite the increasing yield productivity of winter wheat, demonstrating the high N use efficiency of modern cultivars. N applications to milling wheats (with a higher grain protein requirement) have been increasing in recent years, and in 2006 the average application rate was 218 kg/ha N. In contrast, nitrogen application rates to feed wheats have tended to fall slightly in recent years to an average of 182 kg/ha N in 2006. In recent years feed wheat has accounted for 66%-70% of the UK wheat area.

Total nitrogen use on oilseed rape decreased significantly between 1984 and 1994 (Figure 12) mainly due to reductions in use of autumn-applied nitrogen, following concerns over the risk of N leaching, but also reducing returns at the time. After reaching a low of 179 kg/ha in 1994, nitrogen rates have tended to increase. Mean application rate for 2006 was 192 kg N/ha, and for the last five years averaged 205 kg/ha.

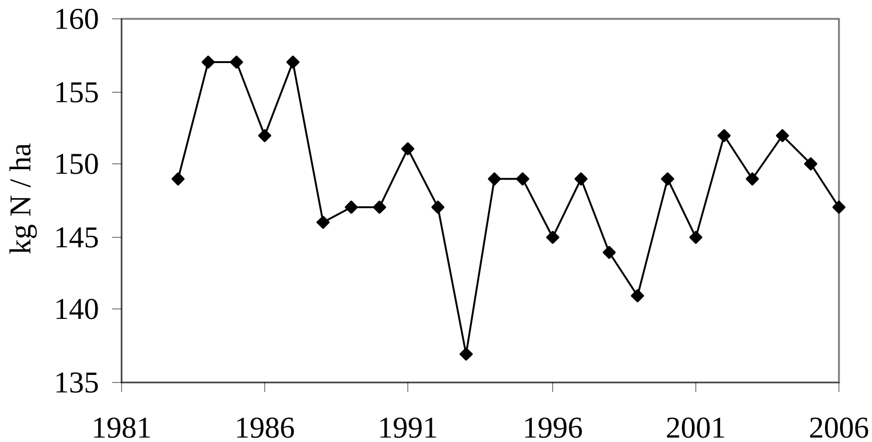


Figure 10. Mean nitrogen fertiliser rate applied to arable tillage crops in the UK (Source: British Survey of Fertiliser Practice 2006). *(Note: tillage crops are defined as all crops except grass, forestry, glasshouse crops and land designated as 'set-aside' under the Arable Area Payments Scheme.)*

Current recommended phosphate and potash inputs

Phosphate applications to winter wheat and oilseed rape have declined since 1983, while a move to malting cultivars means inputs to spring barley have remained relatively stable, until recent declines (Figure 13). The trends in wheat and oilseed rape reflects improvements in fertiliser advice and increasing financial pressure to justify inputs.

Until recent years use of potassium (Figure 14) remained relatively constant on wheat but use on both wheat and oilseed rape is declining.

The amount of phosphate and potash applied to cereals depends on the soil type, grain yield, and whether the straw is ploughed in or removed. Amounts up to 120 kg/ha phosphate and 145 kg/ha potash are recommended for winter wheat (straw removed, P or K Index 0). Up to 100 kg/ha of phosphate and 90 kg/ha of potash is recommended for winter oilseed rape (P or K Index 0). However, to ease crop management, these fertilisers are typically applied on a rotational basis in relation to rotational needs rather than individual crop needs.

3.2 Improving the efficiency of fertiliser use

The risks of nitrate leaching are reduced by estimating, as accurately as possible, the amount of nitrogen required by a crop and applying it in response to periods of crop demand. The amount of fertiliser required will be influenced by yield potential, but also by soil type, previous crop, previous fertiliser and manure use and winter rainfall which will all affect soil nitrogen supply.

With phosphate and potash, there is only a need to maintain basal levels of availability to balance crop need (as the relationship to yield is less responsive than that for nitrogen). The amounts of potash and phosphate removed by the previous crop can be calculated and used along with estimates of crop demand to determine the requirements of following crops.

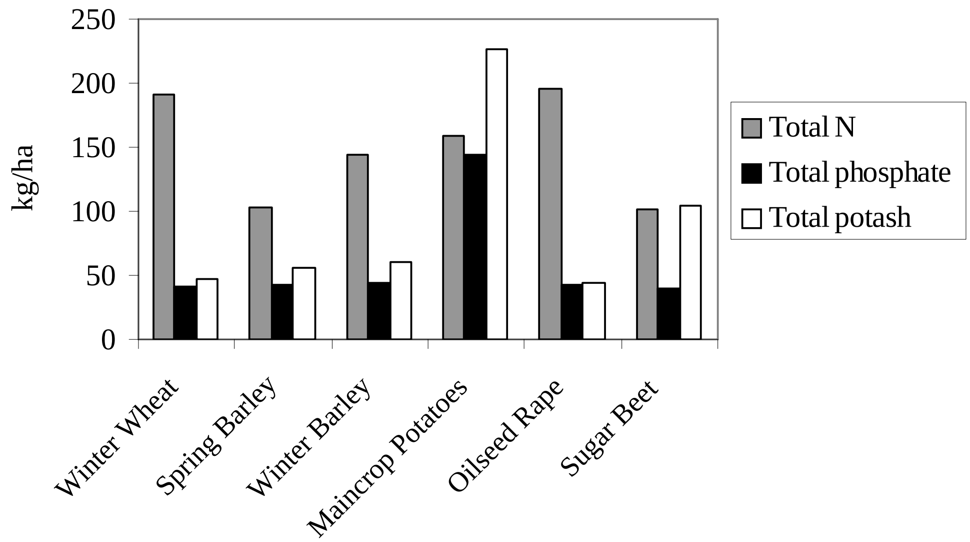


Figure 11. Mean fertiliser application rate on major crops in Great Britain. (mean for period 1998-2006) (Source: British Survey of Fertiliser Practice 2006)

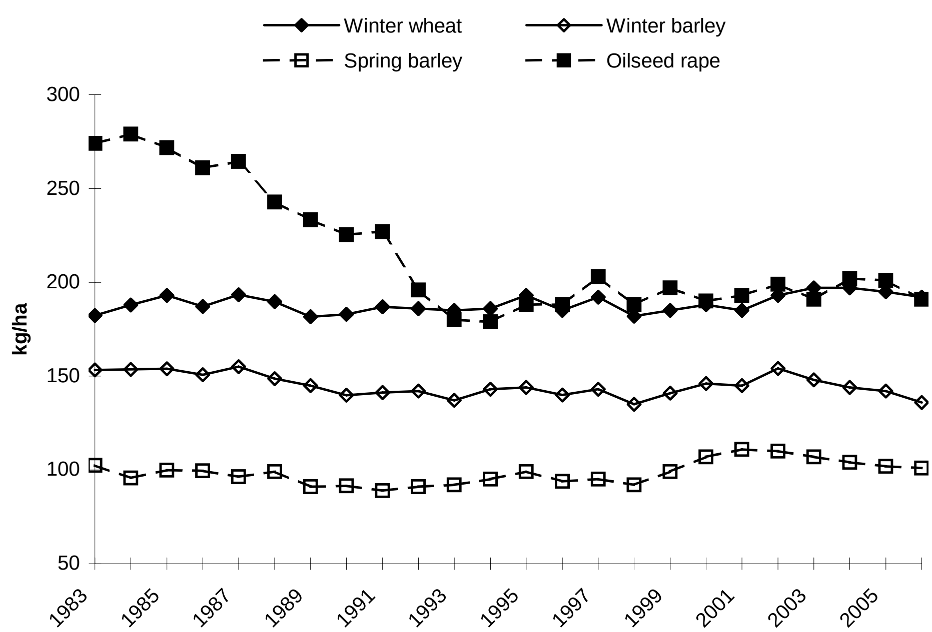


Figure 12. Changes in the use of nitrogen fertiliser on major crops, 1983-2006. (Source: British Survey of Fertiliser Practice 2006)

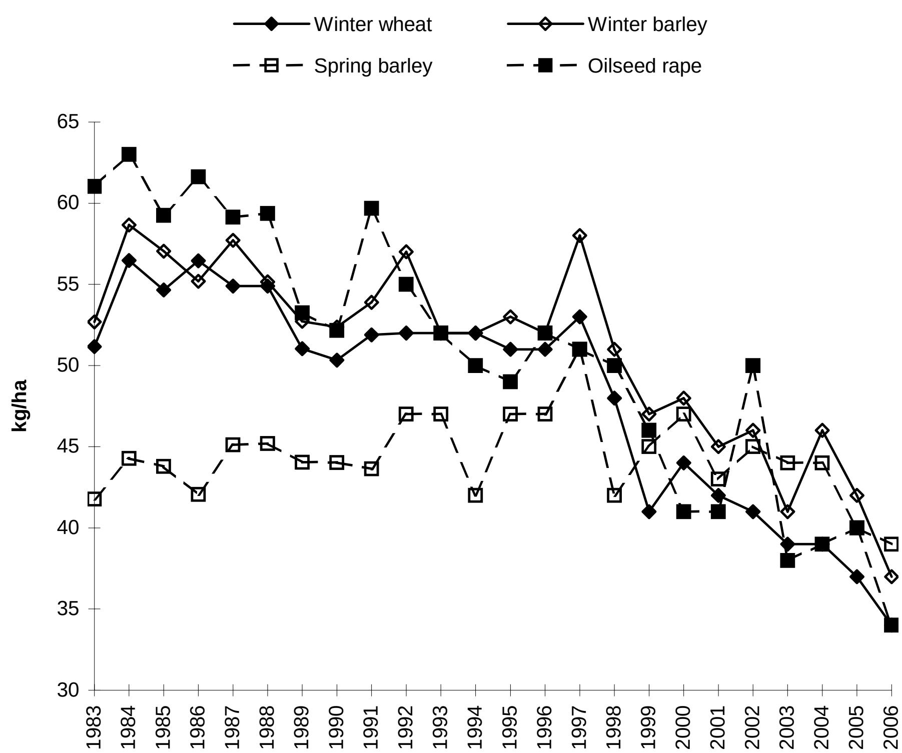


Figure 13. Changes in the use of phosphate fertiliser on major crops, 1983-2006. (Source: British Survey of Fertiliser Practice 2006)

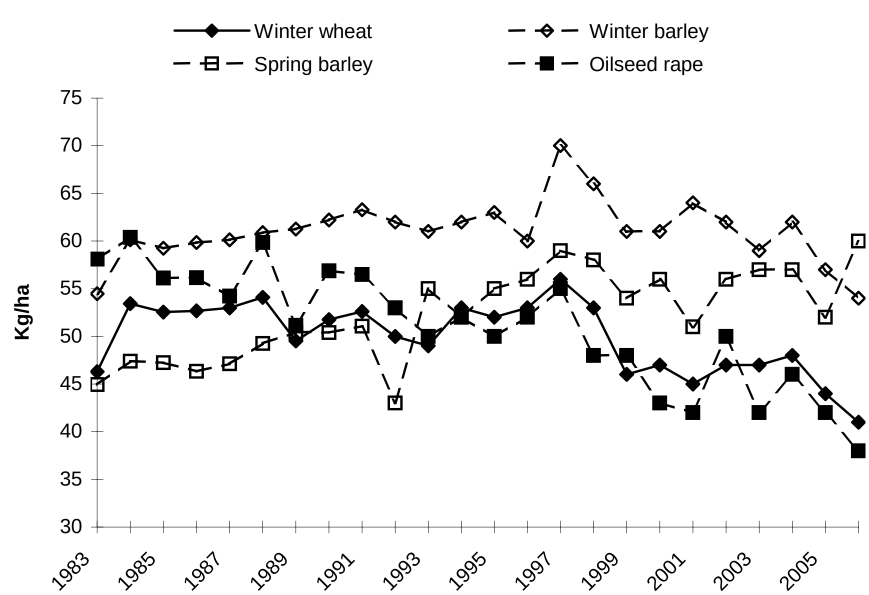


Figure 14. Changes in the use of potassium fertiliser on major crops, 1983-2006. (Source: British Survey of Fertiliser Practice 2006)

Autumn applications of fertiliser are most vulnerable to leaching loss. Economic yield response to autumn applied nitrogen is rare in wheat. Applications of up to 30 kg/ha N to the seedbed are advised for winter oilseed rape crops in a limited number of situations where crops are backward. The proportion of winter oilseed rape dressed with autumn applied nitrogen fell rapidly between 1985 (90% of crops treated) and 1989 to about a half of all crops, but showed little further change until 1997/98, when it dropped to one third of all crops (with a mean autumn application rate of about 43 kg/ha). Currently less than 10% of oilseed rape crops receive autumn nitrogen dressings.

Nitrogen applications are applied as split dressings to both wheat and oilseed rape, tied in to key growth stages to minimise excessive loss from very early applications.

Aside from continual refinement of generalised recommendations on fertiliser rates targeted at differing soil and crop fertility situations, there is growing interest in tailoring fertiliser requirements to individual crop need. Targeting nitrogen applications strategically in response to crop growth and any difficulties encountered during crop development (e.g. poor rooting or dry soil conditions) has been cited as means by which nitrogen could be used more efficiently in crop nutrition. MAFF and HGCA-funded research work (Stokes *et al*., 1998) has demonstrated the value of the concept of 'canopy management' in optimising the efficiency of fertiliser nitrogen use for cereal grain production on a site-specific basis. By this method, nitrogen is applied judiciously in response to canopy growth and expansion to more closely match crop demand. Related work has looked at using the same approaches in oilseed rape (Lunn *et al.* 2001) and further work is ongoing supported by the HGCA (project 3277 – Improving yields of oilseed rape with late nitrogen applications). Such approaches offer opportunities to fine tune nitrogen application, reduce N applications and risk of lodging in some crops and minimise loss of nitrogen to the environment.

As a result of the above methods of determining fertiliser demand and means of optimizing application, in relative terms, there is typically a low level of risk of nitrate leaching from well-fertilised cereal crops while oilseeds represent a relatively high risk of leaching loss, largely as a result of high levels of residual fertiliser left in soil after harvest (see Figure 15, section 7.3).

3.3 Biosolid application

According to Defra, in 2006, 72% (995,000 tonnes dry weight) of sewage sludge was applied to agricultural land. This is a positive environmental benefit, returning organic matter to land. Application to land is controlled by regulation (Sludge (use in agriculture) Regulation 1989) and Codes of Practice, designed to protect the environment from overuse of such materials. Given restrictions on the use of sewage on fresh produce (e.g. salad and vegetable crops) and harvest intervals applicable to use on potatoes, legumes and root vegetables (10 months), most biosolid waste applied to land is disposed of by application to combinable crops. Around 90% of biosolid waste is disposed of by application to cereal crops and a further 8-10% by application to grassland. Due to the high heavy metal loading of biosolid sludges, limits on permissible soil metal concentrations are set which encourages rotational application of sludge and deter repeated sequential applications. Cereal crops therefore provide a valuable outlet for disposal and recycling of biosolid wastes. Concerns are addressed by use of a 'Safe Sludge Matrix' designed to control the use of biosolid wastes and reduce any risks associated with its use.

Compost

It is difficult to obtain figures on how much green waste is recycled to agriculture, but this also has potential to add organic matter to soil and provide a source of nitrogen and other key nutrients. Recent work suggests wheat yield benefits of up to 7% can be achieved from improvements in soil conditions where 30t/ha of compost has been regularly applied. Cereals could provide a useful outlet for disposal of green waste compost.

4.0 ENERGY INPUTS

Derivation of estimates of energy inputs for crop production is beset with many problems, as the estimate is based on numerous assumptions and on accumulation of data from a wide range of sources to ascertain both the direct energy inputs (i.e. energy content of fuel used in cultivation) and indirect energy (i.e. energy expended in producing nitrogen or pesticides etc). This can make comparisons between studies difficult. Table 4 below provides an estimation of energy inputs to wheat, oilseed and sugar beet production in the UK, which build on reviews of a number of recent studies.

In all crop production systems, nitrogen fertiliser and fuel use represent the most significant energy inputs. Therefore any means of reducing nitrogen inputs or increasing efficiency of nitrogen utilisation can significantly affect the total energy requirement. Both wheat and oilseed rape are relatively high users of nitrogen. In contrast, root crops such as sugar beet use relatively high levels of fuel in cultivation and harvesting operations. Inputs such as phosphate also have a high indirect energy component in many crop production systems. In contrast, reducing pesticide inputs has a relatively small impact on the total energy requirement for crop production.

Table 4. Estimates of direct and indirect total energy inputs (M. Joules/ha) expended in crop production (Billins, Woods and Tipper, 2005*, Mortimer and Elsayed, 2006†, Mortimer *et al.*, 2004$^{\phi}$)

Inputs	Wheat*	Oilseed rape†	Sugar beet$^{\phi}$
N fertiliser	7500	7472	4182
P fertiliser	700	869	1375
K fertiliser	400	595	1165
Herbicide			110
Insecticide			66
Fungicide	600 (Herbicide, Insecticide, Fungicide, Other pesticide α combined)	767 (Herbicide, Insecticide, Fungicide, Other pesticide α combined)	135
Other pesticide α			795
Seed	2500	39	135
Diesel fuel	4700	2489	9846
	16000	**11660**	**17809**
± Range	-	±1103	±2610

α Other pesticides includes molluscicides, growth regulators and seed treatments

Another means of reducing energy input is to adopt minimum tillage techniques. Unpublished work by John Deere (Table 5) suggests that adoption of a minimal tillage regime for oilseed rape establishment could save up to 100 M Joules/ha with use of appropriate machinery. However, the ability to adopt minimum tillage on a wide-scale is dependent on the ability to achieve and maintain good grass weed control across the rotation.

Data on surveys of recent trends in cultivation practices is difficult to obtain, but available data suggests that until recently the vast majority of land on all soil types was ploughed, even on the heaviest soils (Table 6). Recent trends towards reducing costs mean there has been a significant move towards adoption of non-plough cultivation techniques on all soil types (Table 6).

With oilseed rape there is even greater interest in, and use of, non-plough minimum tillage to ensure rapid sowing (by minimising the number of cultivation passes and time required for soil 'weathering') and increase soil moisture retention. In addition, the friable and weed-free nature of soils left after oilseed rape cropping means that non-plough tillage is often the preferred method of establishing following cereal crops.

Table 5. Fuel use in conventional and minimum till cultivation systems for oilseed rape (based on 20ha field) (John Deere Technical Division (unpublished))

Cultivation system	Tractor power (kW)	Time spent/ 20 ha (hrs)	Fuel used (litres)
Conventional			
Subsoil tramlines	92	2	49
Deep disc x 2 & pack	92	20	492
Combination drill	92	26	640
Ring roll	59	8	132
			1313
*Energy input/ha (M joules)			**2900**
Minimum till			
Subsoil tramlines	92	2	49
Mulch tiller 1 pass	198	3.3	168
Minimum till drill	92	2.7	65
Ring roll	59	8	132
			414
*Energy input/ha (M joules)			**914**

**Based on diesel energy content of 44.18 MJ/litre*

Table 6. Proportion of winter wheat crops established following ploughing (Data from Procam - Farmers Weekly 25 July 2004)

General soil type/texture	**2000**	**2003**
Light	95%	63%
Medium	90%	71%
Heavy	77%	59%

5.0 IMPACTS ON THE SOIL RESOURCE

5.1 Return of organic matter to soil

The separation of animal production in the West from arable production in the East of the UK means that in areas where cereal cropping dominates, wheat and oilseed rape straw is commonly incorporated back into soils, helping to maintain soil organic matter status and sequester carbon. However, the impact of organic amendments on soil organic matter build up is a long-term process, influenced by both current organic matter levels and management practices. Turley *et al.,* (2003) found no detectable difference in soil organic matter content where straw was either incorporated or burnt after 11 years of virtually continuous wheat cropping. However, changes in soil organic carbon (SOC) are generally slow and difficult to measure against the large background carbon content in arable soils. A more recent review of impacts of soil amendments on soil organic matter content (Bhogal *et al.,*2007) concluded that incorporation of fresh cereal straw, under English conditions, increased SOC levels by 50 (±20) kg/ha/year/t of straw applied.

5.2 Soil Erosion

Severe soil erosion is uncommon in the UK and erosion only affects a relatively small proportion of UK soils. According to the Soil Survey and Land Research Centre (SSLRC, 2000), erosion affects 17% of UK soils and results in movement of 2.2 million tonnes of soil in the UK annually. The main environmental concern (apart from loss of the soil resource) is in movement of soil to water, carrying adsorbed agrochemical and nutrients through particulate movement. The main factors affecting risk of erosion are soil structural damage caused by intensive cultivation, especially of compacted soils, or exposure of soils to heavy rain (Environment Agency, 2004). The level of risk varies according to soil type, slope, land use and timing of management practice. Areas of erosion risk have been mapped (McHugh *et al.,* 2002) and the areas of highest risk are predominantly in high-rainfall, non-cereal growing areas of the UK. An Environment Agency review (Environment Agency 2004) of the state of UK soils reported that, in situations where erosion does occur, losses of soil from cultivated land typically amounted to less than 5 t/ha.

Wind erosion normally only affects sandy and peaty soils left exposed between March and June, with areas of Yorkshire, East Midlands and East Anglia at highest risk, especially where spring cropped. Oilseeds are not common on such soils due to drought risk, but winter cereals would have a beneficial impact in reducing erosion risk.

Reducing risks

Sandy and chalky soils are most at risk from water erosion. These risks can be reduced by appropriate management in vulnerable situations (i.e. on steep or long slopes). Means of mitigation include use of soak-aways and drains to reduce runoff from concrete areas and tracks etc, maintenance of land drains, reducing unnecessary deep cultivation and avoiding production of very fine-textured seedbeds. Early planting to encourage rapid green cover re-generation is a good means of mitigating soil loss, which means winter sown cereals and oilseeds could provide benefits by helping to stabilise some vulnerable soils. Another option is to leave soil undisturbed after harvest for as long as possible.

Crop risks

Late harvested root crops and silage maize crops are more likely to pose the greatest risk of severe soil erosion in most seasons than autumn sown combinable crops. Skinner and Chambers (1996) studied soil water erosion in 17 areas of lowland England and Wales and commonly found signs of erosion in winter cereals (39% of cases), with more erosion identified in winter wheat (27% of cases) than in winter barley crops (12% of cases). In comparison, erosion in sugar beet crops accounted for 16% of cases and potatoes 8% of cases. However, Evans (1990) reviewed a number of studies and demonstrated that although erosion was commonly observed in winter cereal fields, the severity of erosion with spring crops was often about twice (potatoes and grassland) or three times (sugar beet, market garden crops) that of winter cereals. In more recent work, Evans (2002) monitored the occurrence of channel erosion in crops on a wide range of soils and derived an index of erosion risk by expressing the % incidence of observed channel erosion in a particular crop as a fraction of percentage of arable land cover by that crop (Table 7.). Although channel erosion of soil was commonly observed in cereal crops, the overall level of erosion risk was relatively small in winter cereal and oilseed crops compared to that observed with root crops and maize.

Table 7. Index of channel erosion risk in different crops. (derived from Evans (2002))

Crop	% of arable crop area/ % occurrence of observed channel erosion*
Sugar beet	4.05
Maize	4.02
Potatoes	3.28
Field vegetables	2.00
Bare soil/fallow	1.36
Spring cereals	0.83
Peas	0.76
Winter cereals	**0.69**
Field beans	0.39
Winter oilseed rape	**0.29**

* Indices of >1 indicate that erosion occurs more often than once per cropping season

6.0 IMPACTS ON EMISSIONS TO AIR

Nitrous oxide (N_20), methane (CH_4) and carbon dioxide (CO_2) are all greenhouse gases that absorb infra red radiation and contribute to global warming and the depletion of the ozone layer to varying degrees.

6.1 Carbon dioxide

According to the UK Inventory of Greenhouse Gas Emissions[4], agriculture is responsible for less than 1% of the UK's CO_2 emissions (0.77 million tonnes CO_2). So any expansion in

[4] Available to view at: via www.defra.gov.uk/environment/statistics/index.htm

arable cropping will have little impact on emissions. As noted earlier (section 4.0), changing to non-plough minimum cultivation practice can reduce fuel use and thereby further reduce CO_2 emissions. Any move to reduce fertiliser nitrogen application to cereals and oilseeds would also reduce indirect emissions of CO_2, though the gains in terms of CO_2 savings are likely to be small. Balancing these emissions, growing crops absorb CO_2, and where crop residues are ploughed back into soil carbon is sequestered (see section 5.1).

6.2 Methane

Approximately 39% of UK CH_4 emissions are derived from agriculture, largely from animal production and from the spreading of slurry and manure, less than 0.1% of UK CH_4 emissions arise from arable production (UK Inventory of Greenhouse Gas Emissions[2]).

6.3 Nitrous Oxide

Agriculture is a major source of N_20 emissions, accounting for 67% of UK emissions (UK Inventory of Greenhouse Gas Emissions). N_20 is produced in soils as an intermediate product during the microbial mediated processes of nitrification and denitrification. Though UK emissions of N_2O are relatively low compared to those of CO_2, (124,000 tonne v 0.56 billion tonne) N_2O is still an important greenhouse gas with potential impacts on a par with those of UK methane emissions. The importance of N_2O stems from the fact that it has 320 times the atmospheric impact of CO_2 (Elsayed *et al.,* 2003). As emissions have declined in other sectors, agriculture has become the major source of N_2O emissions, with arable agriculture accounting for 64% of the UK's N_2O emissions. Direct emission of N_2O from soils is affected by environmental factors including water content, temperature, aeration, ammonium and nitrate concentrations, the amount of mineralisable carbon and pH (Smith *et al*., 1998). In addition, N_2O is released during the process of fertiliser manufacturing and represents an indirect emission from agriculture.

Crop risks

Direct measurement of emission is difficult and expensive. Smith *et al*., (1998) measured N_2O emissions from agricultural soils and found that emissions from soils planted with potatoes were greater than those from spring barley or winter wheat (1.35, 0.8 and 0.3 kg N_2O-N ha^{-1} respectively) and that these were much lower than rates of loss from either grazed grassland (1.9 - 8 kg N_2O-N ha^{-1}) or cut grassland (1.5 - 3 kg N_2O-N ha^{-1}). In a comparison of maize, wheat and potatoes fertilized at recommended rates, Ruser *et al*. (2001) recorded annual N_2O-N emissions of 2.41, 3.64 and 6.93 kg ha^{-1} respectively. Ruser *et al*. (2001) also recorded emissions of 0.29 kg N_2O-N ha^{-1} from unfertilised set-aside planted with perennial grasses.

Arable crops such as cereals therefore, by comparison, make a relatively low direct contribution to UK N_2O emissions compared to root crops and grassland used by livestock.

6.4 Wider indirect contribution to greenhouse gas emissions

The development of use of crops as raw materials for biofuel production has stimulated research into the greenhouse gas balance of biofuels for comparison with that of conventional fossil-derived fuels. Such life cycle assessments (LCA) analyse fossil fuel use and emissions arising in the production of crop inputs (indirect emissions), as well as assessment of direct fossil energy inputs to the crop itself, and emissions arising from natural processes. A number of studies have attempted to assess the LCA of oilseed rape for biodiesel and wheat and sugar beet for bioethanol production, accounting for both energy use and associated greenhouse gas emissions (particularly CO_2). Unfortunately studies vary in their assumptions and in the transparency of their methodology, which makes comparisons between studies difficult. Elsayed *et al.,* (2003) recently reviewed a wide range of published reports and used these to derive best estimates of energy use and greenhouse gas emissions arising in the production of a range of biofuel crops. A summary of a sub-set of the results for arable crops of interest is given in Table 8. It should be noted that these represent modelled, estimated outputs rather than absolute figures for emission of greenhouse gasses (gaseous emissions arising from soil *etcetera* would add to such figures).

As noted in the footnotes to Table 8, despite low emissions of CH_4 and particularly N_2O from inputs to arable crop production, these molecules have a significant greenhouse gas effect that boosts the overall impact. On an equivalence basis, the estimated N_2O emissions arising from agricultural inputs more than double the impacts attributable to CO_2 output alone.

Given the difficulty in accurately assessing N_2O emissions from soils, default emission factors established by the Intergovernmental Panel on Climate Change are commonly utilised in LCA determinations, which equate to values of 1.7% N_2O emission per unit of nitrogen input, although even these are the subject of rigorous debate and discussion at present.

As might be expected from the earlier examples of energy use (section 4), nitrogen fertiliser and diesel use account for the greatest share of CO_2 and CH_4 emissions arising from arable crop inputs (Table 8). Higher outputs of CO_2 and CH_4 arising from fertiliser inputs to oilseed rape and cereals compared to sugar beet are counter-balanced by lower fuel use in the case of oilseed rape, reflecting the reduced level of mechanisation associated with combinable crops. Table 8 suggests cereals tend to have a slightly more negative impact, though it is not clear why wheat should differ so much from oilseed rape, but this probably reflects on the different sources of reference used in the calculations.

6.5 Ammonia

Ammonia reacts in the atmosphere to form particles containing ammonium which are then removed by rain. Ammonia compounds can be transported significant distances (i.e. between countries) so deposition occurs in areas some distance from emission sources. Most risk is to nutrient poor semi-natural ecosystems and conservation areas. It is reported that current levels of deposition to sensitive areas in the UK exceed critical loading levels above which such environmental impacts are anticipated (Defra 2002). Hornung *et al.* (in Defra 2002) report that sensitive habitats have exhibited shifts towards more nitrogen demanding species, which has included shifts from heather to grass, and a decrease in moss cover. Such changes have been attributed to deposition of ammonium, but it is acknowledged that other factors could also be influencing change.

Agriculture is the largest source of ammonia and increased use of nitrogen in the livestock sector has increased ammonia emissions over the last 50 years. As emissions of sulphur dioxide have declined, through control of emissions from fossil fuel burning, focus on the role of ammonia in the environment has been heightened as a cause of soil acidification. The UK is signed up to a number of international agreements to reduce ammonia emissions (UNECE

Table 8. Life cycle greenhouse gas emissions arising from production of a unit area of oilseed rape, wheat and sugar beet (from Elsayed *et al.*, 2003) (all figures kg/ha) (These figures include both direct emissions from soil or energy consumption plus indirect emissions arising from product/input manufacturing chains etc)

	CO_2	CH_4	N_2O
Oilseed rape			
N fertiliser	373 ± 54	0.706 ± 0.118	3.587 ±0.445
Other fertiliser	60 ± 9	0.002 ± -	0.003 ± -
Pesticides	14 ± 2	0.001± -	0.004 ± -
Seeds	2 ± -	-	0.005± -
Diesel	183 ± 25	0.050 ± 0.007	0.001± -
Total	**632**	**0.759**	**3.600**
Total emissions as CO_2 equivalents*	1,731± 155		
Winter wheat			
N fertiliser†	373 ± 54	0.706 ± 0.118	3.587 ± 0.445
P fertiliser	42 ± 6	0.001 ± -	-
K fertiliser	27 ± 4	0.001 ± -	0.001 ± -
Pesticides	41 ± 6	0.002 ± -	0.012 ± 0.002
Seeds	66 ± 10	-	0.120 ± 0.018
Diesel	292 ± 44	0.080 ± 0.012	0.002 ±-
Total	**741**	**0.790**	**4.563**
Total emissions as CO_2 equivalents*	2220 ± -		
Sugar beet			
N fertiliser	281 ± 41	0.531 ± 0.008	2.698 ± 0.335
P fertiliser	39± 6	0.001 ± -	0.002 ± -
K fertiliser	64 ± 10	0.003 ± -	0.001 ± -
Pesticides	6 ± 1	-	0.002 ± -
Seeds	7 ± 1	0.008 ± 0.001	0.004 ± 0.001
Diesel	230 ± 34	0.063 ± 0.009	0.002 ± -
Total	**627**	**0.606**	**2.709**
Total emissions as CO_2 equivalents*	1,438 ± 118		

* As the greenhouse gas effect of CH_4 and N_2O are significantly greater than those of CO_2, their impacts are commonly expressed in units of CO_2 equivalents, where 1 kg CH_4 = 24.35 kg CO_2 equivalent and 1 kg N_2O = 320 kg CO_2 equivalent.

† The nitrogen rate used by Elsayed *et al.*, 2003 for wheat was judged to be much too low for conventional winter wheat production and so a similar nitrogen input to oilseed rape was used (196 kg/ha N) in the above tables and a new total emissions value calculated.

Gothenberg Protocol, EC National Emissions Ceilings Directive, EC Integrated Pollution, Prevention and Control Directive).

Non-agricultural sources of ammonia emissions account for less than 20% of UK emissions. Cattle farming accounts for 44%, poultry farming 14%, pig farming 9% and use of nitrogen fertiliser accounts for 9% of the 320 kilotonnes/annum of ammonia produced in the UK from all sources (Webb *et al*., 2002). 231.6 kilotonnes of ammonia were emitted from agriculture in

2001, mostly from housing of livestock and manure spreading. Application of fertiliser to arable crops only accounted for 6.1% of ammonia emissions in 2001 (UK Inventory of Ammonia Emissions).

The risk of loss of ammonium is generally related to the rate of nitrogen fertiliser application to the crop and the efficiency of nitrogen use by the crop. In this respect cereals pose a lower risk than oilseed crops and crop rankings in terms of risk of emissions would most likely follow those associated with leaching risk (see Figure 15) which would mean that cereals pose a lower risk than most arable crops.

In terms of reducing risk, type of nitrogen fertiliser has an impact, with greater losses from use of urea compared to ammonium nitrate (estimated loss of 5-40% and 0.3-3% of N applied respectively) (Sutton and Harrison, 2002). While ammonium nitrate accounts for the bulk of nitrogen applications to UK cereal and oilseed crops, some urea is used (e.g. as a late application to milling wheat to boost grain protein content). There is ongoing debate whether this nitrogen could be more usefully utilised by application as ammonium nitrate earlier in the season, which would reduce the risk of loss.

7.0 IMPACTS ON THE WATER RESOURCE

7.1 Surface water

The Environment Agency reports that overall, there has been a substantial improvement in the biological and chemical quality of rivers since 1990[5]. In 2006**,** 68% were classed as good, in terms of chemical quality, a small increase since 2000. In terms of biological quality, 72% of rivers were classed as good quality, compared to 69% in 2000.

The improvements arise from clean up of sewage discharges and other actions to control pollution. In terms of chemical quality (a general indicator of organic pollution levels) 44% of rivers show an improvement from 1990 levels. 50% fewer rivers now exhibit high phosphate concentrations (>0.1 mg/l) than in 1990, but the number of rivers with high nitrate concentrations (>30 mg/l) has only declined slightly from 32% in 2000 to 28% in 2006.

7.2 Ground water

The loss of nitrate from agricultural soils has been linked to failure of ground-water sources of drinking water to meet the EU Drinking Water Standards. As a result 55% of England and 3% of Wales have been designated as Nitrate Vulnerable Zones, subject to restrictions on use of fertilizer and organic manures and other measures to reduce the risk of nitrate leaching.

Areas where groundwater aquifers exceed the 50mg/l EC limit for nitrate are located mainly in the south, east and centre of the country which corresponds to the main arable areas on soils underlain by chalk, limestone and sandstone. Such aquifers respond only slowly to changes in nitrate loss from agricultural soils, related to rates of infiltration through soil and parent rock etc.

[5] www.environment-agency.gov.uk Environmental facts and figures, River quality – an overview

7.3 Nutrient loss from agricultural systems - nitrate

The concentration of nitrate in groundwater depends on the balance of agriculture in the catchment area. The quantity of nitrate lost from the system will depend on the balance of inputs and recovery by crop or animal species and whether any measures are adopted to reduce leaching risk, particularly over-winter. The key problem areas arise from excessive use of fertiliser or excessive rates of animal manure or biosolid waste applications. Autumn applications of nitrogen are at particular risk, and applications to winter wheat and oilseed rape crops have declined in response to advice campaigns and revision of nitrogen recommendations that show no financial benefit arises from autumn nitrogen applications to cereals (MAFF 2000). In nitrate vulnerable zones, application of fertiliser nitrogen is not permitted between 1 September and 1 February to reduce the risk of nitrate leaching.

In general terms, cereals are relatively efficient in term of fertiliser N use (compared for example to root crops such as potatoes). Efficiency of fertiliser N use (i.e. kg of N uptake by the crop for every kg of fertiliser N applied) ranges from around 60% on medium, clay and peaty soils up to 70% on light sandy soils. Current fertiliser recommendations take account of such differences (MAFF 2000). Inevitably some of the nitrogen mineralised in soil after harvest is leached over-winter when crop uptake is low and the risk of leaching is high, but this loss is minimised where the amount of fertiliser remaining in soil at harvest is minimised. This occurs where nitrogen is applied at optimal or sub-optimal rates. In relative terms, cereals represent a relatively low risk of leaching loss, while oilseed rape represents a much higher risk relative to other arable crops in the rotation (Figure 15).

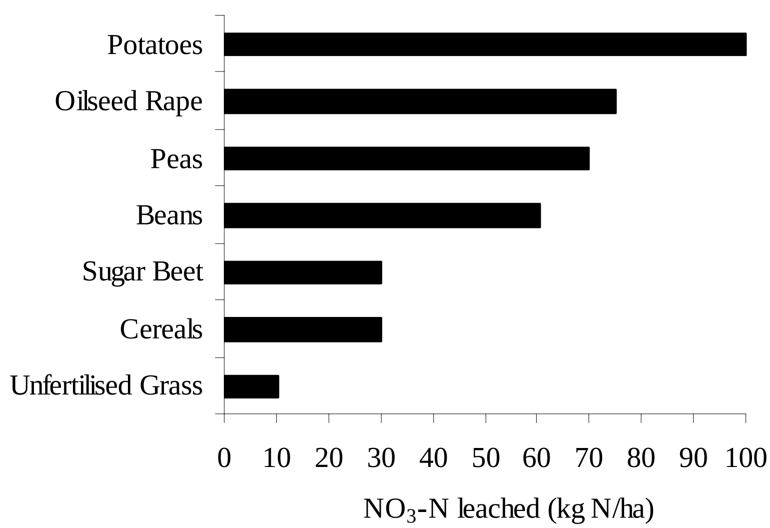


Figure 15. Nitrate leaching loss from arable crops (without manure application) (Source: MAFF, 1995)

In comparison with the above figures, nitrate leaching losses from fertilised grassland can also be significant. Nitrate losses from fertilised (400 kg/ha N) grazed permanent grassland can account for as much as 75 kg N /year, and even greater rates of loss where land is drained (MAFF 1995).

7.4 Nutrient loss from agricultural systems – Phosphate and potassium

Intensification of agriculture has been blamed for a four fold increase in phosphorus losses to water from cereal land in the period 1931-1991 (Johnes *et al.*, 2000). However, over the last 10 years, the use of organic manures and phosphate fertiliser in the UK has fallen by 21 and 30% respectively in the period between 1991 and 2001 and it appears that this is now reflected in soil water quality assessments where phosphate levels are declining (see statistics in section 7.1).

Although wastewater from sewage treatment work is the main source of phosphate input into watercourses, agricultural land is also a significant source of phosphate input (MAFF, 1999). Movement of phosphorous to water occurs through erosion of soil particles and through dissolved and particulate suspension in run-off. Chambers *et al.* (2000) estimated phosphate loss through soil erosion from 385 arable fields over 5 years. Where erosion occurred the mean soil loss per field was estimated at 17 t ha^{-1} (though the median level was 0.48 t ha^{-1}) and mean P loss per field was estimated at 14.6 kg ha^{-1}.

Potassium is applied to winter wheat and oilseed rape in quantities similar to other crops, but it is less mobile in soil. There is no information to suggest that leaching of K is currently perceived as an environmental problem.

The impacts of individual crops therefore reflect their impacts on risk of soil erosion (section 5.2).

7.5 Pesticides in water

The EU Drinking Water Directive sets a limit of 0.1µg l^{-1} for any individual pesticide and 0.5 µg l^{-1} for total pesticides. 70% of drinking water supplies are derived from surface waters. There are commonly a handful of herbicides responsible for most incidences of pesticide detection in water, with peak concentrations following winter rainfall (Edge, 1996). Agriculture is a prime source of pollution risk, but industry, sewage works and urban run off are also responsible and in some cases, discharge of pesticides occurs from manufacturing processes, under the control of Environment Agency consents.

The Environment Agency monitors pesticide levels in surface and ground waters by routine sequential monitoring on a wide range of sites. An Environmental Quality Standard (EQS) is the concentration of an individual substance which should not be exceeded in the aquatic environment, and EQS's have been set for 70 pesticides.

Surface waters

The number of EQS failures has declined markedly since 1998. Of the pesticides most probably arising from agricultural origin, the active substances most frequently occurring at levels greater than 0.1 µg l^{-1} in freshwaters are (in order of % samples exceeding the standard)

1. Diuron
2. Isoproturon
3. Mecoprop
4. MCPA
5. Chlortoluron

6. Simazine
7. 2,4-D
8. Dichloroprop
9. Atrazine

Many of these are no longer approved for use in agriculture and none of these pesticides are approved for use on oilseed rape. Only isoproturon and mecoprop are widely used on cereals, and isoproturon will be phased out of use by 30 June 2009. Although approved for use on cereals, chlortoluron is not widely used, only 4% of the wheat area and 7.5 % of the barley area was treated in 2006. Although some of the other above active substances can be legally used on cereal crops, in practice they are rarely, if ever, applied.

The industry move towards use of 100% mecoprop-P formulations (the active isomer in Mecoprop) has reduced application rates but this is not being reflected in a lower incidence of target exceedance (Figure 16). It has been surmised by the Environment Agency that amenity users of mecoprop may not have converted to use of mecoprop-p formulations, which may explain the continuing high levels of detection.

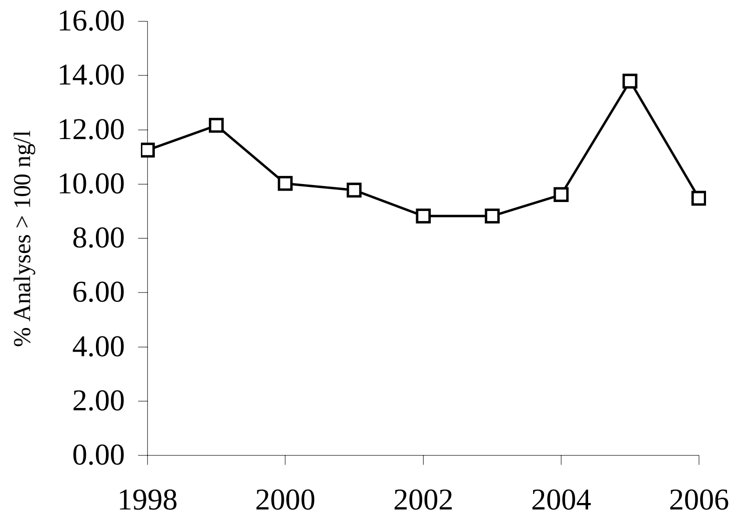


Figure 16. Trends in % of samples containing mecoprop exceeding 100 nanogrammes/litre limit in surface waters (*Derived from Environment Agency 2006*)

Ground waters

Isoproturon, at present, is detected in a small percentage of samples taken from groundwater sources (ranked 12th in occurrence). The majority of groundwater sample pesticide concentrations are below the 0.1 µg/l limit. Carbendazim residues are detected in ground waters (ranked 7th in terms of occurrence (detection) and in a very few cases exceed the 0.1 µg/l limit). Carbendazim is used on cereal and oilseed rape, but in small quantities.

8.0 IMPACTS ON BIODIVERSITY

Declines in key farmland bird species have been linked to agricultural intensification (Chamberlain *et al.,* 2000; Donald *et al.,* 2001). The balance of grassland and arable crops in agricultural systems affects biodiversity and shifts in the balance will favour some species over others. For example, replacement of cereal crops with grassland in the South Downs ESA (England) was shown to have had an adverse effect on skylark populations (Wakeham-Dawson & Aebischer, 1998).

High crop diversity is necessary to the ecological requirements of many species. For example, brown hares graze different crops at different times of year (Tapper & Barnes, 1986), while skylarks move breeding territories from one crop to another through the breeding season (Wilson *et al.,* 1997), and yellowhammers switch from one crop to another as foraging habitats change during the breeding season (Stoate *et al.,* 1998). Birds such as lapwings require cereals in which to nest and adjacent pasture on which to feed newly hatched young (Tucker *et al.,* 1994).

Pesticide applications to wheat and oilseed rape are likely to have impacts on non-target species which will include both direct effects and indirect effects through reduced food availability in the form of invertebrates and weed seeds (Boatman *et al*., 2004a). Although seed treatments decrease the risk of pesticide exposure to non-target wildlife, treated seeds may pose a small risk to seed-eating birds on arable fields.

8.1 Impacts on bird populations and links to weed flora

Birds provide good indicators of environmental change as they are easily monitored, well researched, long-lived and represent a high trophic level in the food chain. Changes in wild breeding bird populations in England form the subject of an indicator of biodiversity in the Government's Public Service Agreement 28 (2007). The farmland bird indicator shows an overall decline over the last 35 years but this is mostly accounted for by reductions in numbers of farmland specialists, with more generalist species remaining relatively stable (Figure 17) (Gregory *et al.,* 2004). The scale of effect varies between individual species with, in general, species which are ground nesting and summer insect feeders tending to fare worse (for more detailed information see Gregory *et al*, 2004 and Eaton *et al*., 2007). In contrast a few species have flourished including whitethroat, greenfinch, goldfinch, jackdaw, woodpigeon and stock dove. Decline in farmland bird populations has been linked to a number of changes in agricultural practices (Newton, 2004). Specific causes of change are well documented for grey partridge in Britain where reduced availability of invertebrates, which form a key component of chick diet, has been identified as pivotal in population declines.

The general decline in farmland bird species has also been accompanied by a decline in the diversity of weed flora on farmland. Farmland birds commonly eat weed seeds or feed on invertebrates that in turn feed on arable weeds. Species of many chicks are fed on invertebrates while adults take weed seeds. The critical periods relate to food availability in the winter and early summer. In recent years the relationships between bird species and particular weed species has been examined (Marshall *et al.,* 2003). Some of the most troublesome weeds to cereal growers such as black-grass and wild oats offer little value to arable biodiversity, while weeds such as chickweed and polygonum species (knotgrass/redshank) pose little competitive pressure in cereals but have good biodiversity value (Lutman *et al.*, 2003).

In common with the above, the main factors found to affect the importance of stubbles to bird species were identified by Vickery and Atkinson (2003) as the density of Chenopodiaceae and Polygonaceae seed and the number of agrochemicals applied to the previous crop. It was also noted that differences in levels of weed seed were more marked between fields than between crops (with skewing of the population towards more fields with relatively low seed populations (0-250 seeds m^{-2})), which demonstrates the importance of individual crop management in relation to its biodiversity value.

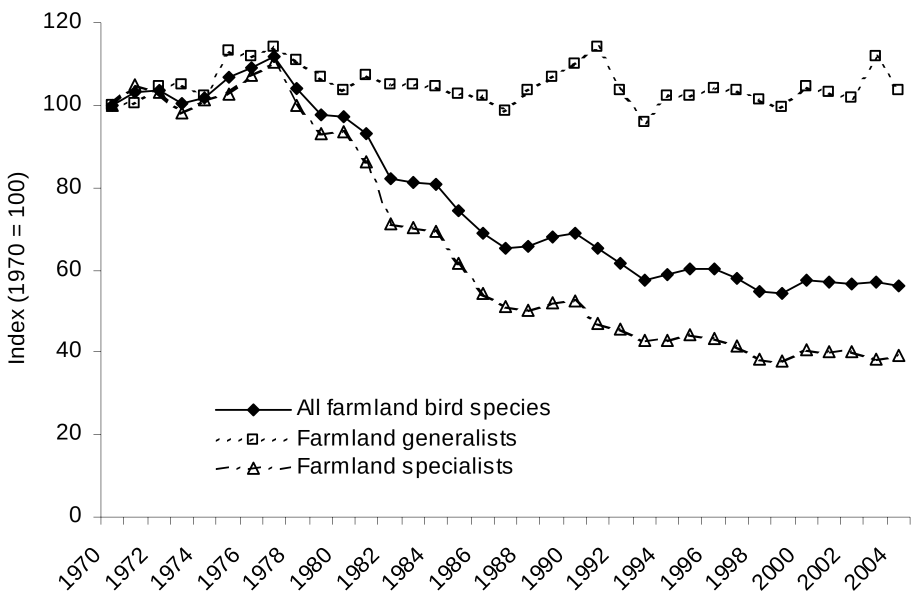


Figure 17. Index of farmland bird populations, 1970-2004 (source: BTO; RSPB).

Cereal and oilseed rape impacts

Timing of crop management actions can influence their suitability to invertebrate and bird species. Breeding lapwings and skylarks favour spring-sown cereals, in part because of their structure and less intensive management (Tucker *et al.*, 1994). Changes from spring to predominantly autumn sowing are also thought to have contributed to declines in spring-germinating components of the arable flora. For some declining farmland seed-eating birds, a reduction in the area of weedy winter stubbles is thought to have contributed to increased winter mortality (Campbell *et al.*, 1997). Weedy winter stubbles are strongly favoured as a foraging habitat by finches and buntings such as cirl buntings (Evans & Smith, 1994) and corn buntings (Donald & Evans, 1994).

Wilson *et al.* (1996) investigated field use in winter by 26 farmland bird species on mixed farmland in Oxfordshire. They found that winter cereal fields were almost universally avoided and stubbles (cereal and oilseed) were strongly preferred by seed-feeding birds.

Crocker *et al*. (2001) investigating farmland bird crop preferences found that where birds showed a preference, they almost always avoided wheat and barley in all seasons.

Research looking at the value of post-harvest crop stubbles in the Norfolk Brecklands as food resources for birds (Vickery and Atkinson, 2003) identified that weed seeds were most abundant in stubbles following sugar beet (c $500/m^2$) and oilseed rape (c $300/m^2$), which was reflected in higher number of finches and sparrows preferring such stubbles over cereal and linseed stubble. Sugar beet stubbles are not available until late in the winter when such fields are more widely used by finches and sparrows than linseed and cereal stubbles. In contrast, species such as skylarks have been shown to prefer foraging on cereal stubbles in winter (Wakeham-Dawson & Aebischer, 1998).

Oilseed rape is a preferred habitat for some bird species. In a RSPB review article (Anderson, Haskins and Nelson, 2004), is was reported that species such as skylark, yellow wagtail, sedge warbler, reed bunting and corn bunting will nest in oilseed rape crops, though the value for open-field nesting declines with age, particularly with winter-sown crops and in particular for skylarks and yellow wagtail. Rape crops are used during the breeding season by a range of bird species such as tree sparrow, reed bunting and yellow hammer. Oilseed rape is one of the most important breeding season habitats for reed bunting, and occupancy rates have been found to be four times greater than in cereals or set-aside (Gruar *et al*., 2006). Whitethroats and linnets also show a preference for hedgerow sites adjacent to oilseed rape and many other hedge species are positively encouraged.

In dense crops such as winter wheat, accessibility for nesting and foraging can be an issue, reducing the value of the crop particularly later in the season (Morris *et al*., 2004). The Sustainable Arable Farming for Improved Environment research project (SAFFIE) (see Annex 5), examined management methods of modifying vegetation architecture crops and grass/wildflower field margins to improve habitat value for biodiversity. Bird densities and territories were consistently higher (1.3 - 2.8 times) in fields with margins and undrilled patches, than in fields with a conventional crop. This response was consistent for Farmland Bird Index species and Biodiversity Action Plan species. In wheat fields with undrilled patches, skylark territory densities were higher (particularly in the late-season breeding period) and the number of skylark chicks reared was nearly 50% greater than in fields without undrilled patches (Clarke *et al*., 2007). The patches did not have a significant impact on food abundance, but increased accessibility of the crop.

In addition to skylark plots, features such as 'beetle banks', which are small raised, linear features, typically created by laying two plough furrows against each other and sown with tussock-forming native grass species, can also be used to help split large fields to help add to in-field biodiversity and field habitat. 'Conservation headlands' are regions at the edges of cereal fields where the outer few metres of the crop are managed with selective herbicides and no insecticides, to promote the growth of less competitive weeds (whilst controlling yield-damaging species) and increase the density of chick-food invertebrates. All these measures are supported as options under Entry Level Stewardship (see section 9.2)

8.2 Impacts on invertebrates

Research on the decline of farmland birds has focussed attention on the indirect effects of pesticides (Campbell *et al.*, 1997; Boatman *et al.*, 2004a). In an analysis of a long-term monitoring project in Sussex (England), Ewald and Aebischer (1999) found that spring and summer herbicide use reduced broad-leaved weed abundance and that five invertebrate groups all showed a negative relationship between abundance and the use of insecticides. Decline in populations of four invertebrate groups was also linked to use of fungicides. Pyrethroid and organophosphate insecticides have particularly strong negative effects, while none of the insect groups studied showed a negative relationship with use of the more selective insecticide pirimicarb. Broad-spectrum insecticides such as dimethoate (an organophosphate) have been reported as causing substantial damage to populations of beneficial arable invertebrates (Greig-Smith *et al.*, 1995). However there is little reliable field-based data available on rates of population recovery following use of such chemicals.

Insecticides can also have an effect on soil fauna (Bamford, 1997). Organophosphates have been shown to change the ratio of predatory mites to springtails, while carbamates are more persistent and have more broad-spectrum toxic and sub-lethal effects on soil organisms, including earthworms (Edwards, 1984; Makeschin, 1997). Dimethoate is toxic to many soil fauna (Krogh, 1994) and methiocarb is toxic to beetles, many of which perform a beneficial role (Samsoe-Petersen *et al.,* 1992).

Dimethoate is widely used on wheat (Table 3) and pyrethroid insecticides are widely used on wheat and oilseed rape (Table 3) and many other crops.

Crop impacts

In a study of the impact of different farming systems on beetles and spiders, Booij & Noorlander (1992), reported that crop type had a greater impact on populations than crop management (input use) system. Both abundance and species richness were greater under wheat than potatoes, particularly for abundance of Staphylinid beetles. Crop cover early in the growing season is a key factor affecting invertebrate populations. In similar studies of the indirect effects of pesticides, Holland *et al.* (2002) recorded fewer invertebrates (total and those included in a Chick Food Index (CFI) for grey partridge) in potatoes, sugar beet and lucerne than in winter wheat and spring barley, while peas and linseed had greater numbers of invertebrates. Booij & Noorlander, 1992 reported that Carabid beetles and Linyphiid spiders, which are useful biocontrol agents, tend to be present at higher levels in cereals and oilseed rape than in potatoes, peas and other non-cereal spring crops.

The recent fields scale evaluations (FSE) of GM crops (herbicide-tolerant) highlighted the impacts that crop type and crop management can have on both plant and invertebrate species. Comparing impacts of 59 fodder maize, 66 sugar beet and 67 spring oilseed rape crops across the UK, populations of many invertebrate species differed up to 10-fold between crops on different fields, but only two-fold between crop management regimes (GM v conventional) imposed on the same field (Hawes *et al.,* 2003). Within individual crops, invertebrate populations were shown to be linked to impacts of herbicide treatments on weed flora. In contrast, the majority of invertebrate species in the margin and field did not show treatment effects in winter oilseed rape (Bohan *et al*., 2004). Only the bees, butterflies and Collembola (springtails) showed any difference between GMHT and non-GM treatments.

One other finding of the FSE study was that when comparing the impacts of non-GM crops, spring oilseed rape crops typically contained higher numbers of invertebrates (herbivores, parasitoids, and pollinators) and dicotyledonous plants than either maize or sugar beet (Hawes *et al.,* 2003), which demonstrates the value of this crop for biodiversity.

8.3 Impacts on plants

Many species of arable flora are declining, and a number are now exceedingly rare or endangered (Wilson & King, 2003). Arable plants are the most threatened group of plants in the UK, 26 species now have Biodiversity Action Plans. Byfield & Wilson (1995) give the following list of causal factors implicated in the declines of arable flora:

- The widespread adoption of herbicides
- Efficient seed-cleaning techniques
- The increase in nitrogen fertiliser use
- The development of highly nitrogen-responsive crops
- Changes in crop rotations
- Loss of certain crop types (e.g. rye and flax)
- Loss of over-wintered stubbles and summer fallows
- Efficient field drainage
- Removal of field boundaries and loss of extensively farmed field margins.

These factors interact with the biology of the plants to determine their prospects of survival or decline.

Uncropped, cultivated margins on arable land are the most effective conservation measure (Walker *et al*., 2007), and are supported under the Entry Level Stewardship Scheme (see section 9.2).

9.0 MITIGATING THE ENVIRONMENTAL IMPACTS OF COMBINABLE CROPPING

Various field and farm scale measures are available to decrease the environmental impact of combinable cropping in the UK. These fall into categories: (i) regulatory, i.e. all farmers and growers must observe them by law; (ii) obligatory, where the holding receives subsidy payments (cross-compliance); (iii) voluntary, supported by grant payment or other incentive; (iv) voluntary, unsupported. A number of these are briefly detailed below.

9.1 Cross-compliance (Obligatory)

Cross-compliance measures are obligatory for those receiving direct payments under CAP support schemes or under certain Rural Development schemes, such as Environmental Stewardship (see below). They fall into two categories: (i) Statutory Management Requirements (SMRs), which are European legal requirements, and (ii) domestic legal requirements to keep land in Good Agricultural and Environmental Condition (GAEC). Many GAEC measures reinforce pre-existing regulatory requirements, but some are specific to cross-compliance provisions.

GAEC requirements that are particularly relevant to growers of arable crops include:

- 1: Soil protection review (to maintain soil structure and organic mater and prevent erosion, in accordance with the Cross-compliance guidance for soil management);
- 2: Post-harvest management of land (management to reduce risk of run-off or soil erosion);

- 3: Waterlogged soil (to maintain soil structure and prevent compaction of waterlogged soil);
- 4: Crop residue burning restrictions;
- 5: Environmental Impact Assessment (applies to land uncultivated for 15 years or is semi-natural);
- 11: Control of Weeds (control of specified injurious or invasive weed species);
- 12: Land which is not in agricultural production (rules for management);
- 14: Protection of hedgerows and watercourses (uncultivated, vegetated marginal zone free of pesticides and fertilisers next to boundary features);

In addition there are GAEC conditions to protect Sites of Special Scientific Interest (SSSIs), Scheduled Monuments and Public Rights of Way, and to prevent destruction of stone walls, hedgerows and trees (unless permission is granted in the case of hedges and trees).

SMRs reinforce a range of existing legislation on a variety of issues, including wild birds, ground water, sewage sludge, NVZs, habitats and species, pesticides, and a number of provisions relating to livestock.

9.2 Agri-Environment Schemes (Voluntary, supported)

Concern over the impact of agriculture on biodiversity and the landscape led to the development of agri-environment schemes, through which farmers were paid to manage land in an environmentally sensitive manner. Environmental measures under the Common Agricultural Policy (CAP) were originally supported under Regulation 797/85, article 19. In the 1992 reform of the CAP, member states were required under the accompanying measures (Regulation 2078/92) to develop agri-environment schemes, with 50% of funding provided by the European Community (75% in Objective 1 areas). Under the Agenda 2000 reform, agri-environment schemes were supported under the Rural Development Regulation 1257/1999 (Chapter VI) and were the only measure under this regulation which member states were compelled to implement, as part of their Rural Development Plan.

The fore-runner of agri-environment schemes in the UK was 1985 Broadland Grazing Marshes Conservation Scheme. This was followed in 1987 by the first tranche of Environmentally Sensitive Areas (ESAs), each supporting specific management practices directed towards the conservation of the wildlife and landscapes characteristic of the area. Eventually, 22 ESAs were established in England, covering some 10% of agricultural land. ESAs were also established in Scotland, Wales and Northern Ireland. However, there was a need for a vehicle to promote environmentally beneficial management outside ESAs, and in 1991 the Countryside Stewardship Scheme was launched in England.

Realisation of the need to extend the benefits of CSS to arable biodiversity led to the establishment of an Arable Stewardship Pilot Scheme two areas, one in East Anglia and the other in the West Midlands, leading to roll-out of many of the arable options into appropriate ESAs and, in 2002, into the CSS (Grice *et al.,* 2007).

Equivalent schemes were established by the devolved administrations in Scotland (the Countryside Premium Scheme, replaced by the Rural Stewardship Scheme in 2000), Wales (Tir Cymen, succeeded by Tir Gofal) and Northern Ireland (the Countryside Management Scheme). The ESAs were absorbed into single national schemes in Scotland, Wales and

Northern Ireland, but were retained in England until the end of 2004, when they were closed to new entrants.

In spring 2005, following a review of Defra's agri-environment schemes, Environmental Stewardship (ES) replaced the previous agri-environment schemes in England. The Policy Commission on the Future of Farming and Food (Curry, 2002) recommended a new approach, the development of a 'broad and shallow' scheme, to run alongside and complement a more demanding 'narrow and deep' scheme, similar to the existing Countryside Stewardship. The 2003 reform of the CAP, with an increased allocation of funding to environmental measures, and the opportunity to raise additional funds through modulation provided an opportunity to re-structure agri-environment schemes to encourage greater participation. Following a successful evaluation of a pilot entry Level Scheme in four areas representing arable, mixed, lowland grassland and upland farming (Boatman *et al.*, 2004b), the Curry proposals were translated into the Entry Level and Higher Level of the Environmental Stewardship scheme.

Entry Level Stewardship is open to all farmers and landowners and operates on a points allocation system: applicants can choose options from a menu, each of which is assigned a number of points per unit area, length etc. All those who reach a threshold number of points are guaranteed entry and payment of a flat rate per hectare of land entered into the scheme. Thus, for the first time, the majority of farmers will be involved in a scheme to encourage positive environmental management. The Higher Level strand is more similar to previous schemes, with selective entry, individual payment rates for each option and targeting of objectives at the level of Joint Character Area (JCA). The history of Environmental Stewardship, and the evaluation of its precursors, have been described in full by Radley (2005). An entry level scheme was also introduced in Wales in 2005, known as Tir Cynnal.

9.3 Nitrate Vulnerable Zones (Regulatory)

Nitrate Vulnerable Zones have been established to comply with EC Directive 676/1991 and EC Drinking Water Directive (80/778/EEC) (see Annex 1) to reduce water pollution caused or induced by nitrates from agricultural sources in vulnerable catchments. Over 60% of nitrate enters water from agricultural land.

The UK has designated (and this will be reviewed at least every four years) as vulnerable zones all those areas that drain into waters affected by nitrate pollution. The UK Government designated 68 Nitrate Vulnerable Zones (NVZs) in 1996 and adopted an action programme. The rules established by the action programme are compulsory for all farmers operating within the NVZs. This includes restrictions on the timing of fertiliser applications during periods of high leaching risk and limits on the total amount of inorganic and organic nitrogen that can be applied in a single application (see Annex 1).

NVZ action plans currently affect 55% of the UK agricultural area. A review of the current Nitrate Vulnerable Zones (NVZs) has shown that coverage needs to be increased from 55% to about 70% of England as nitrate levels remain high and nitrate pollution has increased in some areas of the country. Consultations are ongoing to develop further measures to stem the problem of nitrate leaching.

9.4 Alternative Farming Systems (Voluntary, unsupported)

There are a number of different farming systems that have been adopted to a greater or lesser degree in the UK to reduce the impact of arable farming.

Integrated Arable Farming Systems (IAFS)

These farming systems involve concerted measures to reduce the intensity and adverse impacts of contemporary agriculture. IAFS techniques include use of decision making, detection and monitoring aids, tools and risk assessment strategies to reduce inputs to individual crops, and to reduce inputs over the rotation as a whole by careful crop rotation and careful choice of cultivation method etc. This approach spans a wide range of levels of implementation from developmental research trials at one end of the range to approaches adopted by growers such as those linked to 'Linking Environment and Farming' (LEAF) at the other. Those involved with LEAF undertake a benchmarking audit to help identify areas for improvement in development of more sustainable farming practices.

Precision Farming Systems

The development of spatial awareness and sensor technologies and scaling down of data analysis equipment has led to the development of systems and technologies to allow growers to target inputs to parts of field in relation to need/demand. This technology has been applied predominantly in relation to application of fertilisers and to spatially map field yields in response. The aim is to reduce inputs by targeting applications to actual crop demand. This approach can be combined with the above methodologies to derive additional benefits.

Organic Farming

Only 3.5% of the UK agricultural area (excluding common grazing) is currently in organic production, or is currently in-conversion to organic production. Most of this area is represented by pasture. Only 1.7 % of UK arable land is in organic cereal production and virtually none in organic oilseed rape production.

Cereals are a mainstay of many arable organic rotations, but oilseed rape is a very difficult crop to successfully grow organically. As this report mainly deals with the impact of 'conventional' cereal and oilseed production which represents all or virtually all production in the UK, no specific attention is paid to organic production, though it is recognised that this method of farming could reduce at least some of the environmental impacts of cereal and oilseed cropping, through introduction of leys into the rotation, diversity of rotations and reduction in crop inputs, but at a cost in terms of reduced output and a requirement for added premium or other financial support. Organic systems can also be subject to significant nitrate leaching losses when fertility-building leys are ploughed out.

Impacts of alternative cropping systems

In a review of the environmental impacts of conventional, integrated and organic agriculture, Wadsworth *et al.*, 2003 concluded that the ecological impacts of different cropping systems have not been fully qualified but the assertion that fewer chemical inputs and reduced soil disturbance are beneficial to fauna and flora was substantiated in most cases. However low input and IAFS systems can be variable in their economic performance, due to the higher levels of risk incurred, for example in trying to avoid protective and prophylactic spraying by adopting a threshold and response actions.

The value of precision farming has also been questioned, while some studies show positive economic benefits, studies using more sophisticated economic analysis in Australia were less convinced of the benefits (Wadsworth *et al.,* 2003).

9.5 Quality Assurance Schemes (Voluntary, market incentive/premium payment)

Assured Combinable Crops Scheme (ACCS)

In recent years, a number of independently audited crop quality assurance schemes have been established to provide end users with confidence in the means of production and to facilitate compliance with their duty of due diligence to consumers in terms of food safety. In some cases additional environmental requirements have been added to producer protocols as a means of elevating standards and to provide marketing advantages for retailers by producing branded products. The main crop assurance scheme covering wheat and oilseed crops is the Assured Combinable Crops Scheme which ensures growers comply with legislation and take note of a number of areas (see section 2.7). This includes compliance with codes of practice for the protection of soil, air, water and safe handling and use of pesticides, ensuring that pesticides are only applied according to need and impacts on sensitive habitats are avoided or minimised. Around 85% of wheat and 92% of oilseed rape plantings are covered by ACCS[6].

Conservation grade cereals

This is a production protocol adopted by some end users using grain directly for human consumption (e.g. for cereal bars or baby food) who have specific concerns in relation to certain residues or who have other agendas to positively promote their products in the market place. Grain is grown on contract to a protocol which ensures environmental care of hedgerows, that at least 10% of land is used for nature conservations, that buffer zones are instigated around sensitive habitats/areas etc, 6m no-spray margins are adopted around field margins and certain pesticides are banned from use including

- Chlormequat
- MBC benlate
- Organophosphates
- Plant hormone products (CMPP, MCPA, MCPB)
- Trifluralin
- Methiocarb

The use of many of the above active ingredients has, or is being phased out for all cereal crops, but there would be still much to do on most farms with regard to other aspects of compliance.

10.0 CONCLUDING REMARKS

Cereals and oilseed rape are very important crops in the UK and wider EU where the bulk of UK trade is undertaken. Cereals, and in particular wheat, dominate the UK arable area and

[6] Assured Combinable Crops, personal communication

oilseed rape covers twice the area of its nearest rival break crop. Production is concentrated in the central and eastern areas of the UK, particularly for oilseed rape. Under current and future scenarios, there is nothing to suggest that there is likely to be any change in the dominance of such crops. The greatest pressures for change currently affect cash crops such as potatoes and sugar beet, where in the near future reform of the EU sugar regime is likely to reduce the UK sugar beet area by reducing returns to growers. As such cash crops tend to be grown on the better arable land, they are likely to be replaced with cereal and oil seed crops, which though reducing crop habitat diversity in the landscape and further reducing the amount of spring cropping, will reduce the amount of pesticide, phosphate, potash and fuel inputs used in UK arable agriculture. However, nitrogen use would increase, though this need not result in increased nitrate leaching as discussed earlier (section 7.3).

The current main impacts of cereal (wheat) and oilseed rape cropping can be summarised as

1) Pesticide use

- Pesticide use in oilseed rape crops is relatively low compared to that in many other arable crops. Pesticide use in wheat is similar to that in crops like sugar beet, though is much less than is applied to potatoes.

- Over that past 10 years there has been a decrease in the weight of pesticide active substance applied to wheat and a decline in pesticide application rates for all groups of pesticides, except insecticides. There has been a similar reduction in application rates applied to oilseed rape crops for all pesticides except herbicides.

- The use of organo-chlorine and organo-phosphate insecticides on wheat and oilseed rape has been largely phased out over the past decade.

- Pesticide use on cereals and oilseeds accounts for only a small and diminishing number of water quality impacts, as more problematic pesticides are removed form the market place.

2. Fertiliser use

- The efficiency of fertiliser use in wheat has been improved by plant breeding, such that increases in yield have not required increases in nitrogen fertiliser input.

- Wheat crops pose a relatively low risk of nitrate leaching loss where fertiliser applications are optimised. In contrast, oilseed rape poses a relatively higher risk due to relatively high levels of residual fertility left behind after harvest.

- Phosphate applications to both wheat and oilseed rape are declining.

- Biosolids can be applied to wheat crops. This is a useful disposal option on land for a material for which other permissible disposal options are limited.

3. Soil impacts

- There is a low risk of severe soil erosion with most cereal and oilseed crops compared to risks with root crops and other spring-sown crops where land is disturbed at critical periods on susceptible soil types.

- Phosphate loss from soils is linked to erosion and soil particulate movement. These risks are reduced if cereal and oilseed crops are established before winter on land susceptible to erosion.

- Incorporation of post-harvest cereal residues makes a valuable contribution to organic matter retention in arable soils.

3. Air impacts

- Oilseed rape and cereal production make a negligible contribution to UK CO_2 emissions.

- Combinable crops can contribute to carbon sequestration. Incorporating all cereal straw can potentially sequester 0.3 million tonnes of carbon each year.

- Agriculture is a major source of emissions of nitrous oxide, an important greenhouse gas. Cereals and oilseed rape pose less risk than root crops and fertilised grassland.

4. Water impacts

- The number of water quality failures caused by pesticides is declining. Very few pesticides used on cereals account for the small number of pesticide-related water quality failures. Very few water quality failures have been reported with the most problematic herbicide (isoproturon) in recent years. Of the pesticides most commonly associated with water quality failures, only two are currently used on oilseed rape.

- Nitrates in water continue to be a problem, but well-fertilised cereals pose a lower risk than many other arable crops.

5. Biodiversity impacts

- Weedy oilseed rape and cereal stubbles are key habitats for farmland birds. Wheat stubbles are commonly used by species like skylarks.

- Oilseed rape crops are preferred by some birds. Skylarks, yellow wagtails, sedge warblers, reed bunting and corn bunting nest in oilseed rape. During the breeding season the crop is also used by tree sparrows and yellow hammers. Hedges close to oilseed rape are preferred by whitethroats, linnets and other common hedgerow bird species.

- Wheat and oilseed rape host relatively high populations and abundance of invertebrates when compared to crops such as potatoes. Cereals in particular host many spiders and carabid beetles. Insecticide use in both cereals and oilseed rape poses a potential risk to invertebrate diversity because of non-target effects associated with products commonly used. However, this risk is minimised when applications are restricted to particular periods of the growing season.

- Molluscicide use in cereals and oilseeds is a risk to ground beetles and small mammals. Greater use of slug monitoring is required to help target use when most necessary.

At current grain prices and in light of future uncertainty over returns, all cereal and oilseed rape growers are scrutinising the value of crop inputs to justify and optimise their use which will minimise potential adverse environmental impacts. In addition, many negative effects of cropping can be moderated or mitigated by adopting different management practices, either on a whole field basis (e.g. through ICM and sustainable farming techniques or precision application of inputs) and/or through measures targeted at particular field crops (e.g. spring cropping to provide overwinter stubbles) or field margins (e.g. agri-environment schemes) to support biodiversity in farmland landscapes. Therefore, there is potential to significantly influence the environmental footprint of UK cereals and oilseed crops while maintaining a competitive farming industry.

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PART 2

ASSESSMENT OF THE POTENTIAL ENVIRONMENTAL IMPACTS ARISING FROM CULTIVATION OF WHEAT AND OILSEED RAPE FOR LIQUID BIOFUEL PRODUCTION

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SUMMARY

As part of a range of measures to reduce greenhouse-gas emissions, the UK government has set a target that 5% of UK transport fuel should be replaced by designated biofuels by 2010, using the Renewable Transport Fuels Obligation (RTFO) as a driving initiative. The European Commission has agreed further binding transport targets that 10% of transport fuel should be derived from biofuels by 2020.

The two main renewable liquid biofuels commercialised to date are biodiesel, derived from vegetable oils or animal fats, used as a diesel substitute and bioethanol (ethyl alcohol), derived from fermentation of sugar or starch feedstocks and used as a petrol substitute.

Both biodiesel derived from rape and bioethanol derived from wheat have the potential to significantly reduce both energy use in transport fuel production and reduce greenhouse-gas emissions over the full life cycle of production to point of use. However the scale of the saving depends upon how feedstocks are grown (carbon intensity/tonne of produce), how crop by-products are used (e.g. as animal feed or as fuel in the processing of biofuels) and how efficiently feedstock is converted into biofuel. Work establishing default reference values for HGCA's GHG calculator suggests that both bioethanol and biodiesel can be produced in the UK in ways that result in substantial greenhouse gas (GHG) savings compared to fossil fuel alternatives. Reductions of between 10 and 95% are reported for the production of wheat to ethanol, and reductions of 18 to 39% for biodiesel production from oilseed rape. These reductions will become increasingly important to the successful delivery of the RTFO, where biofuels will increasingly be rewarded according to their GHG savings.

Feedstock production accounts for between 50% and over 80% of the GHG emissions associated with biofuel supply and production chains. Nitrogen fertiliser and diesel fuel use represent the most significant energy inputs into wheat and oilseed rape crops, accounting for between 47 and 64% (ammonium nitrate) and 21 to 29% (diesel) of direct and indirect energy use in biofuel crop production. There is ongoing debate over the emission levels associated with nitrogen inputs, particularly arising from direct impacts of N_2O emissions from soil and other indirect impacts.

Both UK produced biodiesel and bioethanol will contribute towards the 2010 RTFO substitution target (around 2.1 million tonnes of fuel), though the infrastructure for supply of biodiesel is more advanced. This will have to compete with imports of biofuels and imported biofuel feedstocks will also be processed in the UK. Meeting the 2010 target will require a broad mix of UK derived feedstocks and commercialisation of developing so-called 'second generation' biofuel technologies to meet proposed substitution targets. Biofuels produced from UK oilseed rape and wheat feedstocks could still make a significant contribution to such targets, providing a useful additional market outlet for wheat and oilseed rape.

Competitor biofuel feedstock vegetable oils such as palm and (until very recently) soya are relatively cheap compared to rape oil, and have been widely used in EU and UK biofuel blends. Both of these oils are traded in large volumes on the world market, and represent a readily available source of feedstock. Leading exporters plan for significant expansion in palm oil plantations, to meet growing food and fuel demands. World ethanol production is increasing, by around 11-13% per annum currently. Production is dominated by Brazil and the US, which account for around 33% and 36% of world production respectively, with the

former responsible for much of the world export of ethanol. Imports of feedstocks or fuels could therefore meet a significant proportion of UK biofuel demands.

Unless steps are taken to reward production of low carbon feedstocks, it is anticipated that there will be small (for higher alcohol yielding grains) or no financial premium for production of biofuel feedstocks, as raw material cost represents a significant part of the cost of biofuel production. Significant shifts in areas devoted to wheat or oilseed production will therefore be most significantly influenced by trends in world prices, which reflect supply/demand balances. However, growers will still need to optimise returns from inputs where rewards are based on production alone. Maximising output/ha will also help minimise the area of crops required to meet biofuel targets.

With the introduction of the RTFO, reporting on green house gas (GHG) emissions associated with individual biofuel batches will become increasingly important and perhaps could help attract a financial value for reducing inputs.

Recent HGCA and Defra funded work by ADAS and others in the GREEN grain and other projects has shown that the optimum nitrogen rate for ethanol production is lower than that required for optimum grain yield (as grain nitrogen content is inversely related to ethanol yield). Individual preliminary results suggest nitrogen rates could be cut by up to 50 kg/ha to optimise ethanol production and up to 150 kg/ha to optimise GHG savings. More generally, cutting nitrogen rates by 10-12% to optimise alcohol yields is seen as feasible in return for a small premium.

The relative environmental impacts of biofuel crop feedstock production depends on whether crops grown for biofuel markets are managed differently to those destined for food and feed markets and whether the current crop area expands to meet any increased market demand. Two possible scenarios are considered.

A) Production of biofuel crops occurs by diversion of existing crops into biofuel market outlets (i.e. no change in land use)
B) Feedstock crop area increases to meet the increased feedstock demand, replacing other crops in the rotation or in the short term set-aside (the latter case will become increasingly redundant if, as anticipated, set-aside requirements are removed in future)

The supply/demand situation for oilseed rape is well balanced. In contrast, over the last five years, with the exception of the relatively poor harvest of 2007, the UK has typically produced between 8 and 13% in excess of its cereal demand, most of which is wheat. This 'surplus' cereal production (c. 1.5 to 2.6 million tonnes) has the potential to supply in the region of 1.2-2% of current UK total road transport fuel demand (by volume). In recent years around 640-720 thousand hectares of land have recently been either set-aside (which includes around 100 thousand hectares in industrial cropping) or fallowed in recent years. If planted with rape or wheat, this area has the potential to supply from 2.3-2.6% (as biodiesel) up to 4-4.5% (as ethanol) of current UK fuel demand (by volume).

Market forces will determine exactly how much of the current UK agricultural area will divert to biofuel production. Market forces will also influence levels of biofuel and feedstock imports, which will reduce pressure on home production and pressures to expand feedstock crop production

Under current market conditions it is most likely that a proportion of the conventional crop will be sold speculatively for fuel use where the price is favourable, with feedstocks supplemented by vegetable oil, oilseed, cereal or biofuel imports. While it is not clear what, if any, expansion in feedstock crop area is likely to be stimulated by future additional support measures, any expansion of the oilseed rape area is most likely to occur in areas already dominated by oilseed rape. The opportunity for expansion of the cereal acreage is more limited by its existing dominance in UK arable rotations.

The relative environmental impacts of production of feedstocks for biofuel production will depend on whether crops grown for biofuel markets are managed differently to those destined for food and feed markets and whether the current crop area expands to meet any increased market demand, replacing other crops in the process. Up until the end of the 2006/07 growing season, it was possible to produce crops for biofuel use on set-aside land (a permitted industrial use under set-aside rules), which potentially has the most significant environmental impact. The situation of set-aside is changing. In the face of tightening cereal stocks (through tightening world demand) the compulsory EU set-aside rate was set to zero for the 2007/08 cropping season and the continued use of set-aside as a supply/demand control measure is to be reviewed under the 2008 CAP health check. Therefore, irrespective of whether grown for biofuels or conventional food markets, wheat and oilseed rape cropping will expand onto former set-aside areas

CASE 1 - Oilseed rape for biodiesel replaces conventional oilseed rape crop

Managing oilseed rape for biofuel production offers little or no opportunity to reduce agrochemical or fertiliser inputs, but there is potential to reduce energy use during cultivation. Reducing the intensity of soil cultivations would reduce greenhouse-gas emissions and could contribute to reductions in nitrate leaching risk by reducing the intensity of soil disturbance and soil mineralisation of nitrogen.

CASE 2 - Wheat for bioethanol replaces conventional wheat crop

Recent HGCA and Defra-funded work, led by ADAS, looking at grain and alcohol responses to nitrogen suggests that where grain and alcohol values are equivalent, nitrogen rates can be reduced by around at least 10-12% compared to those used for feed wheat. This could be encouraged by access to a small premium of around £2-3/tonne, depending on prevailing costs. As well as improving GHG balances, reducing nitrogen application would reduce pressures on nitrate leaching. In the current absence of a UK wheat-based bioethanol processor, it is difficult to assess whether such premiums will be made available by processors, to reflect improvements in efficiency.

When compared to the UK average for wheat (which includes management for both milling and feed markets), the pool of biofuel wheat crops is likely to demonstrate small reductions in insecticide, fungicide and plant growth regulator use and reductions of up to 1-3 spray passes per annum. In addition, in the absence of premiums for alcohol content that could reduce applications further, nitrogen use will be lower than the UK average (by around 13 kg/ha N at current application rates), with benefits in terms of lower indirect energy use and green-house gas emissions, reduced risk of nitrate leaching and emission of ammonia. There may also be opportunities to reduce the intensity of cultivations with benefits in terms of savings in energy use and reduced risk of nitrate leaching and an opportunity to build up soil organic matter levels.

CASE 3 – Replacement of natural regeneration set-aside with oilseed rape

Replacing set-aside with oilseed rape increases the physical inputs of pesticides, fertilisers and energy utilisation. Impacts on nitrate leaching are not clear cut as typically set-aside has higher residual nitrogen levels that are subject to overwinter loss. It is anticipated that there could be a small increase in risks of soil erosion and phosphate loss. Overall greenhouse-gas emissions including CO_2, and N_2O would rise, largely as a result of nitrogen use. Little impact on soil water quality is expected. Replacement of set-aside with oilseed rape would reduce farmland habitat diversity (in terms of habitat, weed and invertebrate diversity) and would have a detrimental impact on some farmland birds, but other bird species of specific interest and concern that use oilseed rape as a resource in summer would benefit. However, many of these same species also use winter stubbles which may be reduced where winter sown crops replace naturally regenerating set-aside, such that overall there may be little or no beneficial impact on such species.

CASE 4 – Replacement of natural regeneration set aside with wheat

Replacing set-aside with wheat increases physical inputs of pesticides, fertilisers and energy. However, impacts on nitrate leaching are not clear-cut as typically set-aside has higher residual nitrogen levels subject to over-winter loss. There could be a small increase in the risk of soil erosion and phosphate loss. Overall greenhouse-gas emissions including CO_2, and N_2O would rise, largely as a result of nitrogen use. There could be impacts on soil water quality arising from a few specific herbicides use in cereals. Replacement of set-aside with wheat would reduce farmland diversity (in terms of habitat, weed and invertebrate diversity) and have a detrimental impact on farmland birds, but weedy wheat crop stubbles provide a valuable overwinter resource for birds if followed by spring-sown crops, which would mitigate to a limited extent losses of overwinter stubbles on set-aside.

In the case of replacement of set-aside by wheat or oilseed rape, the most significant impacts of replacing set-aside are likely to occur through reduction in diversity of habitat (which affects nesting opportunities and success) and impacts on arable flora, their associated invertebrates and knock on impacts on bird species which forage and nest on such areas.

CASE 5 – Replacement of break crops by oilseed rape

Impacts of replacing legumes with oilseed rape include an increase in fertiliser nitrogen inputs which would increase indirect energy use and overall greenhouse-gas emissions (which are typically doubled when accounting for typical rates of nitrogen applied to oilseed rape). There would also be a slightly increased risk of nitrate leaching by shifting to winter cropping/cultivations. Pesticide inputs, including carbamate insecticides and fungicide treatments, would be reduced. The main impacts on biodiversity include loss of relatively open canopy crops in the farmed landscape, favoured by birds such as lapwings and skylarks and used for foraging activity by many other species. Where break crops are spring-sown, there are benefits for overwintering birds from cereal stubbles left after harvest of the previous crop; these would be lost by replacement with winter-sown oilseed rape.

Landscape scale impacts

There have been few attempts to identify or model what the impacts might be of expansion of oilseed rape and cereal cropping at a landscape scale. Though related project experiences offer insights. Work carried out for the Defra Agricultural Change and the Environment Observatory examined the impacts in an arable landscape in Eastern England of a 21% increase in wheat area, a 69% increase in oilseed rape and a 74% reduction in set-aside. Nitrate losses were reduced slightly (where crops replaced set-aside), phosphate loss increased (by 6.3%), skylark density decreased, finches were relatively unaffected and wood pigeon increased. The increase in crop areas used in this scenario are much greater than those envisaged in meeting the 2010 biofuel targets (utilising a mix of UK cropping and import), however, such exercises help examine the potential impacts of wider expansion and highlight particular areas of concern where environmental impacts need to be carefully monitored and buffered where undesirable change is observed.

Amelioration of biodiversity impacts

Detrimental effects on biodiversity in agricultural landscapes could be mitigated to some extent by ameliorating measures along field margins and within fields. Where biofuel crops are grown, a requirement to undertake measures such as use of unsprayed crop margins, adoption of un-cropped or sown field margin treatments, use of in-field fallow patches and beetle banks to encourage flora and fauna, could mitigate against at least some of the loss of diverse habitat on farmland.

Further work

There is a need for ongoing work to screen and develop wheat cultivars with high fermentable starch contents (which equates to high alcohol yield) and reduced nitrogen demand (for both wheat and oilseed rape). This could significantly improve the performance of biofuel crops in terms of greenhouse-gas savings and reduce energy requirements which will be a significant incentive to ensure continued wide-scale use of such feedstocks. Similar work is required in oilseed rape to increase yield performance and efficiency of biofuel production and carbon savings. Areas for agronomic improvement in the environmental profile of wheat and oilseed rape biofuel crops are also identified.

All cereal and oilseed rape growers are scrutinising the value of crop inputs to justify and optimise their use to minimise any potential adverse environmental impacts. In addition, many negative effects of cropping can be moderated or mitigated by adoption of different management practices either on a whole field basis (e.g. through sustainable farming techniques or precision application of inputs) and/or through measures targeted at particular field crops (e.g. encouragement of spring cropping to provide overwinter stubbles) or field margins (e.g. prescriptions covered by agri-environment schemes) or in-field (fallow ‘skylark scrapes’) to support biodiversity in farmland landscapes. Through such means there is potential to significantly influence the environmental footprint of UK cereals and oilseed crops.

11.0 BACKGROUND

11.1 Biofuels and government targets

As a signatory to the Kyoto Protocol in 1997, the UK agreed to reduce greenhouse-gas emissions by 12.5% (compared to 1990 levels) by 2008-2012 as part of a wider EU burden sharing commitment to reduce emissions by 8% over the same period. In addition to this target, the UK committed itself further, setting a domestic target of a 20% reduction in carbon dioxide emissions on 1990 levels by 2010. The Climate Change Bill, planned to be introduced in summer 2008, will set out the UK's long term target to reduce carbon dioxide emissions by at least 60% by 2050 achieving a 26-32 % reduction by 2020.

Road transport accounts for around 25% of the UK's CO_2 emissions (DfT) with emissions directly proportional to the amount of fuel consumed. Growth in traffic and limited improvements in overall fuel efficiency[7] over recent decades means that road transport is the fastest growing source of CO_2 emissions. As part of a range of CO_2 abatement measures across a number of industries, the UK Government is committed to developing a less polluting transport system by encouraging both technical solutions to increase the efficiency of fuel use and by encouraging measures to stimulate development of liquid biofuels.

To date, Government support for biofuels has predominantly been delivered through fuel duty incentives with biofuels attracting a 20p/l lower level of duty than conventional fossil diesel and petrol. This support for biofuels is guaranteed until March 2010. The UK Government has set a target for 5% of all UK road transport fuels (by volume) to come from a renewable source by 2010, and has introduced the Renewable Transport Fuels Obligation (RTFO), to help drive the UK to meet biofuel targets. The level of obligation on fuel sales will rise beyond 5% after 2010/11 if supported by development of robust carbon and sustainability standards for biofuels. It also depends upon new fuel quality standards being adopted at EU level to cover biofuel blends greater than 5%, and that the cost to consumers is acceptable (DfT).

11.2 EU Commission directives and targets

The 2003 EU Biofuels Directive (Directive 2003/30/EC) set an indicative target that 5.75% of transport fuels should be replaced with biofuels by 2010 (in blends or as a total replacement fuel) on the basis of energy content. Following poor performance across all member states in achieving interim targets, in 2007 the EU set a binding 10% target for each Member State, for the share of biofuels to be achieved in transport fuels by 2020. This target is subject to biofuels being sustainably produced and second generation biofuels (see later) becoming available. It is estimated that achieving the 10% target, would result in 18 million ha of land in the EU being utilised for biofuel production.

11.3 Alternative renewable fuels – 'biofuels'

The two main renewable liquid biofuels commercialised to date are

- Biodiesel - derived from vegetable oils or animal fats, used as a diesel substitute.

[7] Increases in engine fuel efficiency have been negated to some extent by preference for power steering and air conditioning as well as regulated emissions, noise and safety standards (DETR).

- Ethanol (ethyl alcohol, and its derivative Ethyl Tertiary Butyl Ether (ETBE)) derived from fermentation of sugar or starch feedstocks, used as a petrol substitute or oxygenate (ETBE).

11.4. Biodiesel

Currently, biodiesel is produced from a wide range of vegetable oils, including rape oil and competitors such as soy, sunflower and palm oil. It can also be derived from animal fats, grease and tallow. The source oil or fat is trans-esterified by mixing with an alcohol (usually methanol) in the presence of a sodium or potassium catalyst. The ester produced takes its name from the source material (i.e. rape biodiesel = Rape Methyl Ester (RME)). There are some differences in technical performance between biodiesel derived from different vegetable oil and fat sources that can affect factors such as cold-flow properties (related to fatty acid chain length and saturation etc). Biodiesel can be blended with standard diesel at an inclusion rate of up to 5% without affecting current engine warranties. Through fuel blending, diesel suppliers can manage the varying quality parameters of biodiesel derived from different feedstocks, though the final blended product must meet the diesel quality standard, BS EN 590.

Biodiesel manufacturers commonly blend esters from different oilseed feedstocks to meet the required biodiesel quality requirements. As a result, availability and price of vegetable oil feedstocks world-wide will affect the level of demand for UK sourced vegetable oil.

Total EU production of biodiesel in 2006 is estimated at around 5,556 million litres, an increase in production by 54% over 2005. In the same year, 192,000 tonnes of biodiesel (218 million litres) was produced in the UK.

2nd Generation biodiesel technologies

The above feedstocks and methods are commonly referred to as '1st generation' technologies. Vegetable oil can also be fed directly into existing fossil fuel hydrocrackers, subject to hydrogenation and refining to produce diesel fuels with a specification identical to fossil diesel. As the necessary infrastructure is already available in the petrochemical industry, this is a relatively cheap means of producing biodiesel, however the carbon savings associated with this approach are lower than those that can be achieved with other more advanced methods utilising non-food feedstocks. While Government is moving to encourage such approaches, it is also mindful that it could undermine efforts to develop more costly (in terms of investment) advanced methods offering much greater carbon savings. These advanced 2nd generation methods include pyrolysis and gasification of biomass and convertion of the resulting syngas into fuel and other commodities. This approach offers much better carbon savings and produces very high quality diesel fuels than can be blended with lower quality fuel grades.

11.4.1 Biodiesel from animal sources

Used frying oils and fats (tallow) can be utilised as biodiesel feedstocks and the development of biofuels has increased the value of such waste vegetable oils. The EU Animal By-Products Directive banned the use of used frying oil from catering premises in animal feed (where it is used as a binder). Use of these feedstocks for biodiesel production and energy generation is currently the most cost-effective route of disposal.

Based on EC estimates it is calculated that 0.5 million tonnes of biofuels could be generated from used vegetable oil (ECOTEC, 2002). However industry does not foresee a potential for much more than 80,000 tonnes/annum being produced in the UK (ECOTEC, 2002).

11.4.2 Rape methyl ester yields from UK crops

Oilseed rape is the crop most likely to provide large volumes of competitively priced virgin oil for biodiesel production in the UK. UK national seed yields are typically around 3.5 tonne/ha and the UK is the third largest producer of oilseed rape in Western Europe

At current levels of efficiency of conventional mechanical and solvent extraction of oil from oilseed rape and its subsequent trans-esterification to RME, one tonne of rapeseed produces 0.415 tonne of RME (Peter Smith, Cargill). Based on an average UK rapeseed yield, this gives a current RME production potential of 1.45 tonne RME per hectare of oilseed rape.

In the longer term, national oilseed rape yields could be raised to the best yields achieved now of around 4-4.5 t/ha giving an RME yield potential of between 1.5 and 1.7 tonne per hectare of oilseed rape.

The rape meal produced as a by-product of RME production can be used in animal feed. Greater inclusion of rape meal in animal diets would reduce imports of soya meal and other protein sources, saving on energy use and emissions associated with transport of imported protein.

Glycerine is also produced as a biodiesel by-product and has uses in the fatty acid oleochemical sector. However, increasing biodiesel production is likely to swamp current markets and alternative outlets may need to be developed or the glycerine may be better recycled as a fuel in the processing plant.

11.5 Bioethanol

Bioethanol is ethanol produced from fermentation of plant carbohydrates. Total EU production of bioethanol in 2006 was 1,592 million litres, (European Bioethanol Fuel Association. World ethanol production is also increasing and major producers are looking to further develop export markets (See section 11.6).

11.5.1 Feedstocks for bioethanol production

Bioethanol can be produced commercially from sugar and starch feedstocks (1st generation technologies). Current fermentation processes rely on the use of the yeast Saccharomyces cerevisae which is only able to utilise simple sugars. Carbohydrate bearing materials therefore need to be processed to break them down to their constituent sugar units. In theory, assuming 100% efficiency, fermentation of starch should yield around 57% ethanol by weight, and sugars 54% by weight. In practice, the efficiency of fermentation is closer to 85-95% (Marrow, Coombs and Lees, 1987).

The main UK starch crops are wheat and potatoes (wheat is preferred to barley because of its higher starch yields/unit area). One tonne of wheat produces around 670 kg of fermentable sugar while one tonne of potatoes yield around 180 kg of fermentable sugar (due to low dry matter content). The rates of ethanol production per unit area of crop are very similar for wheat and potato crops (Table 9). This makes potatoes an expensive source of ethanol and favours the use of cereals on a cost of production and practicality basis. The efficiency of wheat as an ethanol feedstock, and factors affecting ethanol yield form wheat has been evaluated in HGCA funded work (Smith *et al.,* 2006).

Sugar beet feedstocks can be delivered to the distillery as beets, molasses or concentrated beet juice. Sugar beet should produce a relatively high ethanol yield per unit area (Table 9) at costs similar to that for cereal derived bioethanol.

2nd Generation bio-ethanol technologies

As with biodiesel production, there are also advanced approaches (2nd generation) in development to utilise cellulose and hemi-cellulose as ethanol feedstocks, an approach that offes access to cheap feedstocks and by-products from agricultural production.

Lignocellulose is the complex mix of lignin, cellulose and hemicellulose found in plant structures, that protects cellulose from degradation. To exploit the resource, after milling and or steam explosion, the cellulose and hemicellulose has to be hydrolysed into its constituent sugars leaving lignin as a fermentation by-product. Lignocellulose feedstocks include wastes, plant by-products (cereal straw, forestry residues) or materials specifically grown for biomass production e.g. short rotation coppice or Miscanthus grass. Developing technologies for dealing with lignocellulosic materials potentially offer the potential for low-cost high-volume production of bioethanol. The technology is currently limited to pilot-scale demonstrations and will take a few years to fully commercialise. Commercial interests involved in developing lignocelulosic ethanol production suggest the first commercial-scale plants could be in operation by 2013, using single, and relatively simple separated feedstocks.

The potential ethanol yields/ha from both 1st and 2nd generation technologies are calculated and presented in Table 9. Recent detailed analysis of the current potential of wheat as a feedstock has suggested that the potential for current ethanol production could be up to 4000 l/ha (3.14 tonnes/ha) by selection of appropriate cultivars and adoption of other best practices (Smith et al., 2006).

11.6 Potential supply of raw materials from imports

Vegetable oils

Palm oil is relatively cheap compared to other vegetable oils (Table 10) and is in plentiful supply on world markets (Table 11), though it is subject to significant annual price fluctuations. All of the main traded vegetable oils can be used as biofuel feedstocks. Palm oil is currently favoured in the UK as a biofuel feedstock based on economic competitiveness. It is commonly blended with other virgin oils, like rape or waste vegetable oils. Soya oil is used as a biodiesel feedstock in the US and increasingly, as prices of soya and rape oil have converged, in Europe.

Palm oil dominates international oil trading (Table 11), with 80% of production destined for export. Exports are also increasing, as only 18.9 Mt was exported five years ago. Across the major traded vegetable oils, oil production has increased by an average of 5% per annum over the last 10 years, with the greatest growth shown by palm oil (8.4% per annum). Growth in the industrial use of palm oil is forecast to increase by around 9% (710,000 tonnes) as Malaysia, China and the EU-25 expand their biofuel programmes (USDA, 2006).

Table 9. Tonnes of feedstock crop required to produce 1 tonne of ethanol and typical yields of ethanol per hectare of feedstock crop.

Ethanol feedstock (typical field yield)	Feedstock requirement per tonne of ethanol produced (tonne)	Estimated ethanol yield from typical UK crops (kg/ha/yr)
1. STARCH CROPS		
Potatoes (40 t./ha)	11 [a]	3600
Wheat (8 t/ha)	2.5-3.0 [a]	2600 - 3200
2 SUGAR CROPS		
Sugar beet (53 t/ha)	11-12.5 [a]	4240- 4818
3 LIGNOCELLULOSIC		
Grown		
SRC*	5.5-7.5 [b]	1,200-1,650
Miscanthus (10-12 t/ha)	5.5-7.5 [c]	1,400-2,000
Waste or co-product		
Hardwood	5.5-7.5 [b]	5-6
Softwood	6.25-9.75 [b]	3-5
Straw	4.25-6.25 [b]	750-1050

*SRC is harvested every 3-4 years; the yield indicates the equivalent annual ethanol production potential per hectare.

Source: [a] Derived from Marrow, Coombs and Lees (1987), [b] derived from Marrow and Coombs (1990).
[c] estimated based on material composition

EU rapeseed oil is currently trading at a premium for use in the food sector based on its non-GM credentials. Despite this, an increasing proportion of the UK oilseed rape crop has been grown for biofuel markets, increasing pressure on supplies. The price of all vegetable oils has increased significantly in recent years, driven by increasing demand (through population growth, increasing per-capita use and biofuel developments) and prices have converged to the point where recently soy oil has been trading at a premium over rape oil (Table 10). Such price hikes will affect investment in, and production of, biofuels over the next few years until raw material supply and demand can be better balanced.

Increasing biodiesel production in countries such as Malaysia, will result in palm oil being utilised for domestic biodiesel production, as well as export, rather than being exported as a virgin oil. US-subsidised soya-based biodiesel and bioethanol are also increasingly being exported to Europe. Such sources represent readily available supplies of competitively priced biofuels that could ease pressure and demand on UK supply of feedstocks, in the short to medium term. However, uncontrolled dumping of subsidised biofuels on the European market place, as experienced in recent so called ‘splash and dash’ episodes with US bioethanol, risks de-stabilisation of existing EU plants and undermines investor confidence.

Table 10. Average vegetable oil prices ($/tonne)

Vegetable oil	2001/02	2002/03	2003/04	2004/05	Current Rotterdam Price (2008)$^{\alpha}$
Soybean	412	534	633	545	1541
Sunflower	587	592	663	703	1870
Rapeseed	451	588	670	660	1492
Palm	329	421	481	392	1285
Coconut	388	449	630	636	1475

Source: USDA FAS (2006)

$^{\alpha}$Enagri Bioenergy Market Report, March 2008

Table 11. World production and trade in vegetable oils in 2006/07

Vegetable oil	Production (million tonnes)	Export (million tonnes)
Soybean oil	36.72	10.61
Rapeseed oil	18.42	2.04
Sunflower oil	11.17	4.17
Palm oil	37.98	30.40

Source: Oil World Annual 2007

The widespread use of imported oils in the EU will increasingly depend on whether such fuels can prove that they are produced sustainably, and not at the expense of rainforest deforestation or other land use change that would counter any greenhouse gas savings made. Over time, carbon accounting procedures in the RTFO will increasingly take account of sources and origin of raw materials and disqualify any fuels that fail to meet the minimum standards.

Ethanol production and export

World ethanol production has increased significantly in recent years (Figure 18) with 61.37 billion litres produced in 2006. Production is dominated by Brazil and the US, producing around 33% and 36% of world bio-ethanol respectively. EU production of bioethanol for fuel use is around 1.6 billion litres, with an additional 2 billion litres of production going into other industrial and potable uses.

It is suggested (Koizumi, 2004) that world exports of ethanol are likely to rise by 1.1% per annum between 2000 and 2010, while production as a whole is predicted to grow by 3% per annum to meet increasing domestic needs. By 2010, world export of around 2.65 million tonnes (2.1 billion litres) is predicted, with the EU-15 importing around 0.6 million tonnes (0.47 billion litres) per annum of ethanol.

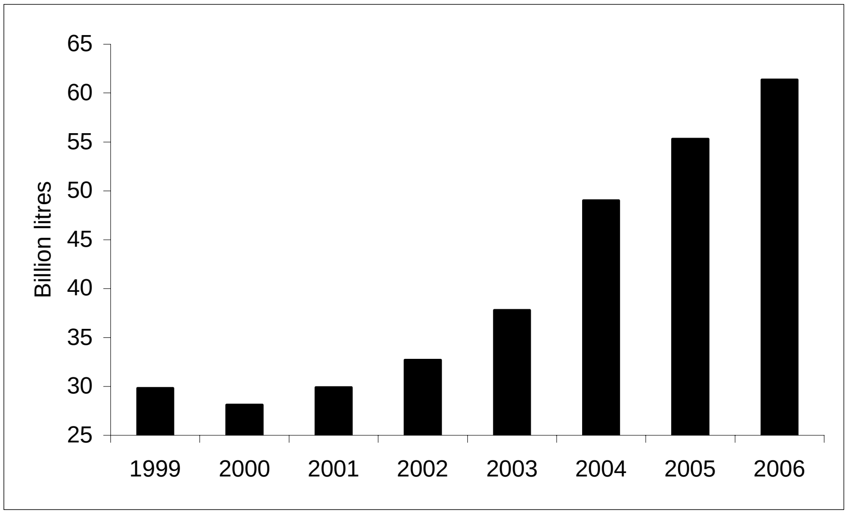

Figure 18. World Ethanol Production (billion litres) (F.O. Licht)

There is already some intra-EU trade in bioethanol to meet rising demand. In addition, under the EU's tender process for disposal of wine alcohol (which must be utilised as road fuel within the EU) batches are regularly offered for tender to biofuel manufactures, offering a cheap additional source of raw materials. Outside the EU, Brazilian bioethanol is already shipped to UK shores, duty paid, at costs below that which can be produced in the UK. Such low cost sources are likely to remain competitive even with advanced lignocellulosic ethanol production.

Raw material trade

In addition to trade in raw vegetable oils or biofuels, there is also significant intra-EU and world trade in oilseed rape and cereals which could increase to meet a higher demand for biofuel feedstocks where economic situations favour import.

The RFTO and EU 2020 targets for biofuels set standards that mean bio-fuels will have to increasingly demonstrate that they are produced sustainably in an environmentally and socially responsible manner. This applies to both domestic production and imported biofuels and feedstocks. Europe is currently working to develop agreed standards, while the UK has taken a lead with development of reporting procedures required as part of the RTFO. Over time, and as more research and analysis is undertaken on imported feedstocks, the qualifying requirements will become more stringent under the RTFO to ensure only biofuels providing agreed (and increasing) minimum 'well to wheel' greenhouse gas savings will be eligible, and that increasing proportions of feedstock should meet minimum standards and provide supporting data on feedstocks (rather than relying on default values).

11.7 EU fuel use

The EU-25 currently uses around 291 Mtoe (million tonnes oil equivalent) of fuel energy in road transport (Eurostat, 2007). Taking account of EU estimates of future growth in fuel use, this gives a biofuel energy substitution target for 2010 of around 17.4 Mtoe, rising to around 32.2 Mtoe in 2020.

Given that fuel use is approaching a 50:50 split between petrol and diesel, splitting the above targets between supply from biodiesel and bioethanol and accounting for the different energy contents of each fuel (Biodiesel (vegetable oil based) = 0.812 ktoe[8]/kt; bioethanol = 0.6 ktoe/kt), the estimated potential EU-25 biofuel demands are as shown in Table 12 *(note - there are no specific substitution targets by fuel type).*

Table 12. Estimated demand for biofuels required to meet EU-25 substitution targets based on energy content (million tonnes)

Year (and substitution target)	Biodiesel demand	Bioethanol demand
2010 (5.75%)	10.7 mt	14.5 mt
2020 (10%)	19.8 mt	26.8 mt

Based on current supply and predicted growth in supply and trade of biofuels and biofuel feedstocks, the greatest pressure in the EU is likely to occur in trying to meet targets for replacement of petroleum. However, shifting towards increased substitution of diesel market is possible in an attempt to meet targets, given appropriate market drivers and incentives. The targets for replacement are challenging. Recent (2007) EU DG-Agriculture analysis of the impacts of meeting the 10% biofuel obligation, anticipates that a proportion of feedstock demand for 2020 will have to be derived from imports (2 m tonnes of bioethanol, plus 10 m tonnes of imported oilseeds), with the remaining majority of the balance obtained from export diversion and diversion from existing domestic production.

The results of current EU member state discussions to agree individual member-state progress towards the 2010 biofuel targets will have important ramifications on market development, although all member states are bound to the 10% target in 2020, though this is dependent on biofuel technology developments and cost competitiveness.

11.8 UK fuel use

The UK Motor Spirit Trade statistics on petrol use show a continuing decline (0.9% per annum) while diesel continues to increase as a proportion of the total fuel market. Extending on current trends over the 2000-2005 period out to 2010, the market for petrol is likely to be in the region of 17.9 million tonnes per annum. For total fuel consumption, a growth of 2% per annum is assumed. Based on these forward predictions, petrol and diesel consumption in 2010 and 2020 is estimated (Table 13) (assumes any increase in fuel efficiency is offset by growth in car ownership).

[8] kilo tonnes of oil equivalent

Table 13. Estimated UK fuel consumption in 2010 and 2020 (thousand tonnes)[9]

	2010	2020
All fuels	42,139	51,367
Diesel	24,236	35,012
Petrol	17,903	16,355

The 5% biofuel target set out by the RTFO is based on substitution of overall petrol and diesel consumption, by volume (accounting for both energy substitution and impacts on fuel efficiency is difficult given the variable and limited data on effects on fuel efficiency, this is one reason why the Department for Transport currently reports figures to the EC on a volumetric sales basis.). In contrast, the 2020 10% biofuel target put forward by the EC is based on substitution of an equivalent fossil fuel energy basis. The difference in energy content of biofuels from their fossil-based alternatives is pronounced (Table 14) particularly in the case of bioethanol, making the 2020 target even more challenging.

Table 14. Gross calorific value of fossil fuel and alternative biofuels

	MJ/kg		MJ/kg
Ultra low sulphur diesel (ULSD	45.6[a]	Fatty acid methyl ester (FAME) (Biodiesel)	37.8[b]
Ultra low sulphur petrol (ULSP)	47.1[a]	Bioethanol /ethyl alcohol	29.7[b]

[a] BERR, average values (for 2006)
[b] Elsayed et al (2003)

12.0 IMPACTS OF THE SUBSTITUTION TARGETS ON POTENTIAL BIOFUEL DEMAND

2010

Based on feedstock input requirements per tonne of biofuel output (Table 9 and section 11.4.2), the feedstock requirement for production of 1000 tonnes of biofuel demand can be estimated (Table 15 - this also assumes average oilseed rape yields are raised to 4t/ha by 2010)

The estimated tonnages of biofuel required to meet the 2010 target set under the RTFO (5% substitution by volume) are shown in Table 16.

[9] Future demand of UK transport fuel does not take into account fuel efficiency/economy improvements of cars, which may occur in the years up to 2020.

Table 15. Approximate areas of crop required (at typical field yields) to produce 1000 tonnes of biofuel for a range of feedstocks at current industrial production efficiencies (see sections 11.4.2 and 11.5.1).

Biofuel/feedstock	Approximate area of crop required
Biodiesel(RME)	
Oilseed rape	666 ha
Bioethanol	
Wheat	375 ha
Wheat straw	645 ha
Sugar beet	244 ha
Wood coppice	457 ha

Table 16. Estimated tonnages of biofuel production/import required to meet the 5% substitution of UK road transport fuels in 2010 (thousand tonnes) (on an equivalent fuel tonnage basis)

	5% of predicted transport fuel consumption in 2010 ('000 tonnes) [10]	Equivalent biofuel crop feedstock area
All fuels	2,107	
Diesel	1,212	807,192 ha of oilseed rape
Petrol	895	335,625 ha of wheat or 218,380 ha of sugar beet

These targets represent both significant technical and logistical challenges. The UK could supply much of the wheat to meet the feedstock demand (approx 2.7m tonnes) for ethanol in 2010, predominantly by diverting export grain into domestic biofuel production, plus some diversion from other domestic markets and/or expansion of the cereal area to take up land released from set-aside restrictions to increase total UK supply. The development of ethanol production facilities by British Sugar and BP, utilising sugar beet as the primary feedstock offers potential to offset some of the demand on cereals. However, anticipated levels of production in this first development are limited (55,000 tonnes per annum). A further 100,000 tonnes of capacity, using wheat as a feedstock, is currently planned. There are plans for a further 1.1 m tonnes of production in the UK, mostly using cereals as a feedstock, though current economic circumstances and other uncertainties are holding up investment and development of some plants. If realised (and there are uncertainties in this) this plant capacity could meet the UK 2010 demand for ethanol production with capacity to spare (and help offset biodiesel demand). The prospects for UK wheat therefore look promising, as long as there is suitable support for industry development and expansion. It is likely that in the short to mid term at least, some of the demand will be met by a combination of increased wheat production (through reduction of the set-aside rate to zero), imports of bioethanol and/or wheat feedstocks, easing pressure on the UK wheat demand.

[10] Based on petrol and diesel both having a 50% of share of the biofuel market

Meeting biodiesel demand from domestic feedstocks in the short to medium term is a more difficult proposition. The potential feedstock demand to meet the UK's 5% substitution target dwarfs the current oilseed rape production area (471 -568 thousand hectares in recent years). While reducing the set-aside rate to zero releases an additional 440-560,000 hectares for production, to date, uptake of this for rape production has been limited, possibly due to the delay in announcing intentions for set-aside. Initial indications are that the oilseed rape area has only expanded by around 2.3% in England, while it has declined in Scotland (2007/08 season). Growers recognise the value of this new biofuel market and an increasing proportion of the UK oilseed rape crop has been directed to biofuel markets and away from other uses (Figure 19).

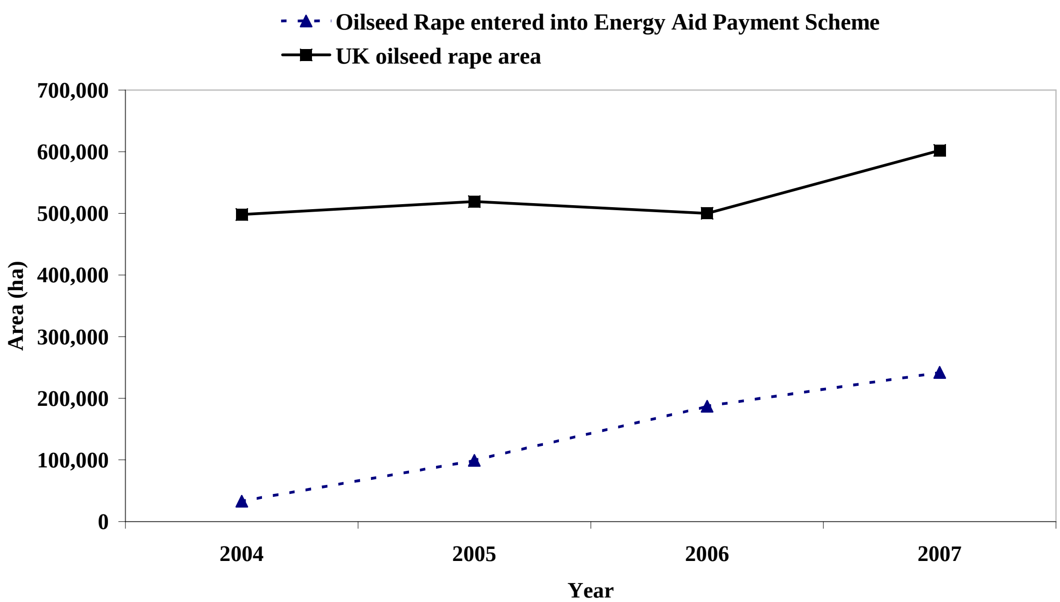

Figure 19. Oilseed rape area in its totality and oilseed rape area entered into the EU Energy Aid Payment Scheme (where use for energy generation is the intended end use)

There is currently UK capacity for production of around 0.5m tonnes of biodiesel per annum, currently utilising a range of feedstocks, including tallow, waste cooking oils, soya, palm, and rapeseed oils. Based on Figure 19, it appears that UK-produced rape currently accounts for the equivalent of less than half of the UK biodiesel industries feedstock demand (when running at full capacity). Capacity for a further 1.1 million tonnes is planned, but again concerns over investment and feedstock costs are affecting development. It is difficult to estimate how much UK oilseed will divert to biofuel production, but it will only account for a fraction of UK demand. Increasing biofuel production capacity is unlikely to drive up the area of UK oilseed rape production significantly, and this may limit development of UK biofuel production capacity much beyond that capable of delivering 5% substitution, and even this may be optimistic.

2020

The calculated targets for substitution of 10% of transport fuel energy content by 2020 are given in Table 17. As the UK is limited in the amount of first generation biofuel it can produce, (it will be difficult to go beyond the levels achieved to meet the 5% RTFO target) imports of biofuels and feedstocks will have an important role in ensuring the UK meets its EU biofuel target. However, it is assumed (by the EU) that by 2020, second generation biofuel technologies will be in place in the UK (e.g. biomass to gas, gas to liquid (biomass to liquid or BTL) for biodiesel production and lignocellulosic bioethanol production) and that these will make a significant contribution towards replacement of 10% of the UK's fuels supply. This will ensure pressure on EU produced cereals and oilseeds is reduced and limited over time, but it is likely that 1st generation biofuels will still form an important part of the market in the long-term.

Table 17. Targets for substitution of 10% of transport fuel energy content (Terra Joules) at predicted scales of transport fuel use in 2020 and estimated tonnages of biofuel production/import required to meet this energy demand

	10% of predicted transport fuel energy use in 2020 (TJ)
All fuels	236,687
Diesel use only	159,655
Petrol use only	77,032

	Equivalent biofuel tonnage ('000 tonnes)	Energy content (TJ)
Biodiesel		
Waste oil/fat	100	3,784
Vegetable methyl esther	4,120*	155,901
		159,685
Bioethanol	2,590	77,027
Total		*236,711*

*2nd generation BTL fuels have an equivalent energy content to fossil diesel and will reduce the total biodiesel demand in relation to the proportion of production they account for each year.

The area of crops in the UK dedicated to meeting the above fuel demands will be influenced by market demand, returns to growers and costs of competitor feedstocks. It is difficult to predict in any detail how the UK cereal and oilseed rape areas are likely to change, if at all, in response to any increase in biofuel use in the UK. It is therefore difficult to assess or predict the scale of any potential environmental impacts that could arise as a result of stimulating biofuel use in the UK. However, it is possible to examine the potential impacts that could occur on a unit area basis as a result of diversion of crops from food to new biofuel markets.

13.0 OPTIONS FOR FEEDSTOCK CROP PRODUCTION

The options considered to meet biofuel feedstock demand are

A) Production of biofuel crops occurs on arable land replacing the same, or other crops grown for food use.
B) Production of biofuels takes place on former set-aside or uncropped fallow.

Conventional crop feedstocks already have well developed market outlets for which supply balances have been established. Despite the increasing use of oilseed rape for biofuels, the trade supply and demand situation for oilseed rape is well balanced, with the UK showing a small net export of oilseed rape in recent years. Over the last five years, in all but 2007, the UK has typically produced between 8 and 16% in excess of its wheat demand. The recent increase in wheat plantings resulting from reduction in the set-aside rate will also increase the wheat supply from 2008. All or part of this export and increased production could be diverted towards biofuel production, given an appropriate market price, with little impact on home markets. Any stimulus to further increase production of biofuels from UK feedstocks would involve consideration of options such as bringing more land into production or substitution for other crops in the rotation.

Over the past 10 years the compulsory set-aside rate set by the EU Commission ranged from 5 to 15% of the UK arable area. In recent years this resulted in around 600 to 700 thousand hectares of bare fallow or set-aside land being left uncropped as only a relatively small proportion of the set-aside area is currently used for industrial cropping (mostly for industrial oilseed rape). However, in the face of tightening cereal stocks (through tightening world demand) the set-aside rate was set to zero for the 2007/08 cropping season. The continued use of set-aside as a supply/demand control measure is to be reviewed under the 2008 CAP health check, and it is widely anticipated that its use could be withdrawn permanently, expanding the area for arable crop production.

Set-aside, where managed appropriately, does provide some environmental benefits for important and declining farmland birds such as skylarks, grey-partridge and stone curlews as well as for plant biodiversity (particularly in the case of permanent set-aside). These benefits would be reduced or lost if converted to arable cropping. There is currently Government consultation on what measures may need to be introduced to counter the loss of such benefits.

While replacement of set-aside is included as a relevant scenario for impacts in the short-term, increasingly it will become out-dated, as irrespective of the development of biofuels, wheat and oilseed rape cropping will expand to meet the growing world demand for food.

Opportunities for oilseed rape expansion

Apart from difficulties in transporting seed to a limited number of crushing mills in the UK, the oilseed rape production area is limited by soil type and climatic factors, as oilseeds do not perform well on the lightest textured soils, or in areas subject to high annual rainfall or late harvest. Historically, the area of oilseed rape in the EU was capped by the Blair House Trade Agreement with the US. However, the move away from crop specific support schemes under recent CAP reforms has effectively removed such restrictions. Oilseed rape is already optimised in most arable rotations and an additional financial stimulus would be required by many farmers to compensate for potential risks in further intensifying oilseed rape production in rotations. Any stimulated expansion in the oilseed area is most likely to occur in areas already dominated by oilseed rape, and lead to shorter rotations between oilseed rape crops. Moves towards growing oilseed rape in a 2 in 4 rotation with wheat has already been advocated as a likely response to recent CAP reform (Farmers Weekly, 2nd-8th July 2004). It is possible to grow rape continuously (as done at ADAS High Mowthorpe in North Yorkshire for 8 years); however, yields are dependent on high inputs of herbicide and fungicide. It is questionable whether continuous rape production would be desirable.

On cropped land, any potential growth in oilseed rape area is likely to be at the expense of second wheat crops on heavy and medium textured land and other spring break crops and winter bean crops on medium-textured land. On heavier textured soils dominated by cereals, this move is likely to result in a better balance between cereal and non-cereal crops in the landscape. In such situations, minimum tillage and seed broadcasting techniques would need to be refined to ensure timely oilseed rape establishment. Displacement of winter sown beans or spring break crops would reduce crop diversity and the availability of overwinter stubbles, favoured by some key farmland bird species. Current high market prices will drive in this direction irrespective of the impact of biofuel expansion.

Expansion of oilseed rape cropping to the extent required to meet the proposed 2010 target from rape methyl ester alone would be difficult to achieve in practice, even with additional financial incentives. It is more likely that a proportion of the conventional crop will continue to be sold speculatively for fuel use where the price is favourable, with some limited expansion of the oilseed rape area (following the removal of set-aside restrictions on the cropping area) and with the balance met from imports of vegetable oil and biodiesel.

Opportunities for cereal expansion

Apart from expansion onto the land released by removal of set-aside restrictions, the options for further expansion in the cereal acreage are limited by their current dominance in UK arable rotations. Current high market prices are just as likely to drive conversion of more marginal land to cereal production as development of biofuel markets. Grain for ethanol production is therefore most likely to be derived from diversion of existing crops to industrial production.

14.0 POTENTIAL ENVIRONMENTAL IMPACTS ARISING FROM THE DEVELOPMENT OF WHEAT AND OILSEED RAPE CROPS AS BIOFUEL FEEDSTOCKS

Most crops for biofuel production will be grown in rotation as part of a mix of several crops on the farm and represent common crops in the agricultural landscape. Future developments could see increases in biomass crops such as short rotation coppice or miscanthus for ethanol production which would have a greater impact on the farmed and wider environment, particularly where such crops expanded into traditional grassland areas. However, the main concerns in this section are effects specific to wheat and oilseed rape production, representing the most likely wide-scale biofuel feedstocks in the short to medium term. Anticipated and possible impacts arising from change in land use or management practices are outlined via a number of case study assessments in the following sections. In addition to specific effects related to use of direct inputs to crops and direct, indirect and diffuse emissions arising as a result of such inputs (discussed in part 1), there are also impacts related to direct and indirect energy use and impacts on green-house gas emissions which highlight particular aspects of the crop production chain where changes in management practices are likely to have a significant impact.

14.1 Energy and greenhouse-gas emissions in biofuel production chains

Both biodiesel derived from rape and bioethanol derived from wheat have the potential to significantly reduce both energy use in transport fuel production and reduce greenhouse-gas emissions over the full life cycle of production to point of use. Compared to fossil-derived petrol, bioethanol from wheat has the potential to reduce energy inputs by 61% and total greenhouse-gas emissions by 65% for each MJ of energy created. Similarly, rape methyl ester has the potential to reduce energy inputs by 66% and total GHG emissions by 38% for each MJ of energy created when compared to fossil diesel (Table 18). The savings are even greater where waste vegetable oils are utilised via recycling schemes. Using co-products in the process can increase the savings. For example, if rape meal is used to co-fire the production plant (reducing use of fossil fuels) then the savings are even greater, the primary energy saving increases to 97%, and the overall GHG emission saving increases to 57% (Mortimer & Elsayed, 2006).

Table 18. Energy ratios and total greenhouse-gas emissions for fossil and renewable-derived transport fuel production and supply chains

	Energy input per unit of energy in product (MJ/MJ)	Total equivalent greenhouse-gas emissions for whole chain (kg eq. CO_2/MJ)
Unleaded petrol (ULSP)	1.19[a]	0.081[a]
Bioethanol from wheat	0.644±0.041[b]	0.044±0.002[b]
Diesel (ULSD)	1.26[c]	0.087[c]
Biodiesel from oilseed rape	0.54[c]	0.054[c]

[a] Mortimer, Elsayed and Horne (2004)
[b] Mortimer, Elsayed and Horne (2004) – Assumes natural gas fired boiler for heating during fermentation and grid electricity for drying (worst of 4 case studies presented, use of combined heat and power or burning straw in boilers would improve savings)
[c] derived from Mortimer & Elsayed (2006) (rape meal by-product used as animal feed in case of biodiesel, use of meal as a fuel in the esterification plant would improve savings)

Under the RTFO, biofuel suppliers will need to report on the net GHG savings and sustainability of the fuel they supply, and the Government intends to reward biofuels according to their level of GHG savings after 2010. UK farmers therefore have an opportunity to supply low GHG biofuel feedstocks. HGCA-funded work (Billins, Woods and Tipper, 2005, Woods *et al*., 2007) has developed a Biofuels Greenhouse Gas Calculator that, coupled with farm audits, paves the way for the development of an appropriate GHG accreditation procedure. Work on establishing default reference values for the GHG calculator suggests that both bioethanol and biodiesel can be produced in the UK in ways that result in substantial greenhouse gas (GHG) savings compared to fossil fuel alternatives; depending on the method of production and use of by-products etc. Reductions of between 10 and 95% are reported for the production of wheat to ethanol, and reductions of 18 to 39% for biodiesel production from oilseed rape (Woods *et al*., 2007). As conversion processes become more efficient (in terms of GHG savings) the greater the whole chain emissions savings will be from feedstock production, as processing accounts for a significant part of total emissions, particularly in the case of ethanol production (Tables 19 and 20).

Table 19. Bioethanol from wheat **-** contribution of individual steps in production and delivery chain to energy use and total greenhouse-gas emissions (as CO_2 equivalents) (from Mortimer, Elsayed and Horne, 2004)

	Energy consumption (% contribution)	Total greenhouse-gas emissions (% contribution)
N fertiliser	12.5	35.3
Diesel fuel	10.2	10.3
Other inputs	9.3	5.8
Transport	3.2	2.9
Drying	6.2	6.2
Milling, hydrolysis, fermentation and distillation	51.3	33.5
Dehydration	0.4	0.3
Plant construction	3.1	2.2
Maintenance	0.9	0.7
Distribution	2.8	2.7

Table 20. Biodiesel from oilseed rape **-** contribution of individual steps in production and delivery chain to energy use and total greenhouse-gas emissions (as CO_2 equivalents) (from Mortimer & Elsayed, 2006[11])

	Energy consumption (% contribution)	Total greenhouse-gas emissions (% contribution)
N fertiliser	16.7	14.3
Diesel fuel	4.6	5.8
Other inputs	6.0	4.4
Transport	2.6	3.1
Drying	1.6	2.0
Storage	0.1	0.1
Oil Extraction	18.7	16.4
Esterification	45.8	49.8
Plant construction	0.3	0.3
Plant maintenance	0.2	0.2
Biodiesel storage	0.9	0.8
Distribution	2.4	2.8

[11] Assuming rape meal used for animal feed

Woods *et al.* (2007) comment that feedstock production can account for between 50 to over 80% of the total GHG emissions associated with the biofuel supply chains, though this is much higher than seen in the more detailed studies presented above. Nitrogen inputs are the dominant source of GHG emissions in feedstock production. Over 90% of on-farm GHG emissions are attributed to nitrogen applications to oilseed rape and 80% in the case of nitrogen applications to wheat.

Nitrogen fertiliser and diesel fuel use represent the most significant energy inputs into wheat and oilseed rape crops, accounting for between 47 and 64% (ammonium nitrate) and 21 to 29% (diesel) of direct and indirect energy use in biofuel crop production (see section 4.0). There is ongoing debate over the emission levels associated with such inputs. A number of uncertainties exist in the calculation of GHG emissions that arise from biological soil impacts; the complexity of potential supply chains and the scientific understanding of some of the mechanisms that result in the net production of GHGs. A recent HGCA-funded review (Kindred et al, 2007a) produced in parallel to the recent development of the Biofuel GHG calculator, highlights the key areas of uncertainty involved and potential pathways towards resolving these issues.

There is clearly a need to optimise use of nitrogen for biofuel yield whilst maintaining high crop yields, unless the latter can be compensated for. There has been significant effort to look at means of reducing nitrogen applications in wheat for bioethanol production. Recent HGCA and Defra funded work by ADAS and others in the LINK-funded GREEN grain project and other HGCA-funded review work (Kindred *et al.*, 2007b) has shown that the typical optimum nitrogen rate for ethanol production from wheat is lower than that required for optimum grain yield (as grain nitrogen content is inversely related to ethanol yield). However, this depends on ethanol price and the grain:N cost breakeven ratio. At high ethanol prices (40p/l) and high breakeven ratios (5:1 (i.e. low grain price/high N fertiliser price)) there is little difference in optimum nitrogen rates for alcohol or grain yield. Initial analysis suggests nitrogen rates could be cut by around 50 kg/ha to optimise ethanol production and up to 145 kg/ha to optimise GHG savings (Sylvester-Bradley and Kindred, 2008). While such calculated optimums are dependent on a number of factors (grain value, N cost and alcohol value), it is estimated that optimising nitrogen application rate for alcohol production would require a £1-2/tonne premium to compensate for reduced yield, while compensations for optimising GHG savings would cost around £15/tonne, or £100/tonne CO_2 equivalent (Sylvester-Bradley and Kindred, 2008). The latter is much higher than the current cost of carbon credits available in the market place and therefore represents a costly route to GHG savings. The tentative initial recommendation is that where the grain and alcohol values are equivalent, nitrogen rates can be reduced by around 10% compared to those used for feed wheat (Kindred *et al.*, 2007b). Current high grain prices would increase the size of premiums required to encourage low nitrogen use. Managing for alcohol yield would also tie growers in to production for biofuel markets that could also be a disincentive.

Other ongoing HGCA-funded work is looking at means of optimising nitrogen applications for oilseed rape, but in this case there is little opportunity to exploit a difference between crops destined for biofuel or conventional outlets, unless reduced yields can be compensated for via premiums where the aim is to reduce GHG emissions.

Further savings in energy and GHG emissions may be made through minimising cultivation operations (Table 21). The above assessments of fuel use in crop production typically assume crops are established following ploughing. Though ploughing is the most common method of soil cultivation, there are signs of a move towards reducing the use of ploughing in recent years, particularly on heavy soil types (see section 4, Table 6 in part 1). Though moving from plough cultivations may not necessarily result in significant savings in energy if a number of cultivation passes or energy intensive one-pass cultivators are used, savings in energy inputs can be achieved by using appropriate cultivation equipment at the right time. Typical energy inputs for a plough based, a non-plough based (disc/tine/harrow sequence) and a minimum (or 'scratch') tillage system are presented in Table 21, which shows that energy savings of up to 75% are possible in some circumstances, significantly saving on greenhouse-gas emissions.

Table 21. Energy use in agricultural cultivation systems (MJ/ha) (Based on data from John Deere in part 1 (Table 5) and data in Richards (2000))

Plough based	Typical energy use (MJ/ha)	**Non plough based**	Typical energy use (MJ/ha)	**Minimum Till**	Typical energy use (MJ/ha)
Plough	1032	Subsoil tramlines	105	Subsoil tramlines	105
Disc x 2 pass	1032	Disc x 2 pass	1058		
Rotary harrow/drill combination	1376	Rotary harrow/drill combination	1376	Minimum cultivation/drill combination	529
Roll	280	Roll	280	Roll	280
Total	**3720**		**2819**		**914**

15.0 CASE ASSESSMENTS – EVALUATION OF IMPACTS OF CHANGES IN LAND USE

The environmental impacts of different biofuel crop production scenarios are summarised as case assessments below.

15.1 A) Diversion of crops from existing market outlets to biofuel markets

Of the land use options available for biofuel crop production, diversion of the same crops from existing market outlets to biofuel markets will have the least impact on local management practices and environmental outcomes compared to other possible options. In the absence of any significant premia for delivering greater GHG savings (by encouraging reduction in crop inputs), maintaining yield output per unit of input will remain a key aim for biofuel crops. However, the standards or management practices for biofuel feedstocks are likely to be the same for as those for food and animal feed markets. For example, mycotoxin levels will still be an issue in wheat where spent grains are used for animal feed. Optimum benchmark quality parameters for production of wheat for bioethanol have been proposed (Smith *et al*., 2006) which may lead to some future market segmentation on varietal lines delivering targets of low grain protein (11.5%), high starch (69%) and 3% sugar content. This may allow some potential for reduction in crop inputs, for example where wheat for biofuel production replaces milling and breadmaking wheats, or more importantly where premia for GHG savings are on offer.

Compared to the UK average position for crop inputs to wheat and oilseed rape, there is greater potential to reduce biofuel crop inputs in cereals than oilseed rape, in part because inputs are greater to the proportion of UK cereals destined for milling and breadmaking markets which pushes up national average inputs across the wheat area as a whole (milling wheats typically account for 28% of the UK wheat area). However, there are specific measures, such as reduced cultivations, which could be adopted to reduce reliance on fossil fuels and improve the carbon balance. Also, as described earlier, access to premia could enable reductions of up to 10% in nitrogen applications to wheat destined for biofuel markets.

Case 1 - Impacts of managing oilseed rape for biofuel production compared to conventional oilseed rape production

Inputs	
Pesticide use (based on 2006 Survey of Pesticide Usage)	No change in inputs anticipated.
Fertiliser use (based on 2006 survey of fertiliser Practice)	No change in inputs anticipated, unless premia offered for low GHG feedstocks
Energy use	Possible reduction in diesel fuel use where minimal cultivation or low till cultivations used (lowered energy input) – saving in the region of 820 MJ/ha possible and even up to 1986-2806 MJ/ha where minimum tillage possible.
Environmental impacts	
Nitrate leaching	Possible reduction where less soil disturbance created (lower levels of soil N mineralisation) where minimal cultivation or low-till cultivations used, or where lower nitrogen applications are encouraged
Phosphate movement to water	No change in impacts anticipated
Greenhouse-gas emissions	Reductions possible where minimal cultivation or low till cultivations used (lowered diesel energy input) of circa 154-224 kg CO_2 eq./ha
Ammonia emissions	No change anticipated, unless use of urea increases to reduce GHG emissions in rape for biofuel markets
Resource impacts	
Water quality	No change in impacts on water chemical quality anticipated. Potential lower risk of nitrate contamination where less intensive soil cultivations used or nitrogen application rates reduced
Soil resource	No change in impacts anticipated, though reduction in intensity of cultivation could help build soil organic matter levels.
Natural environment/biodiversity	No change in impacts anticipated.

Summary CASE 1 (oilseed rape for biodiesel replaces conventional oilseed rape crop)

Currently there is little or no driving opportunity to reduce agrochemical or fertiliser inputs to oilseed rape destined for biofuel markets, but there is potential to reduce energy use for cultivation. Reducing the intensity of soil cultivations would reduce greenhouse-gas emissions and could contribute to reduction in nitrate leaching risk, as would any driver to reward reduced GHG emissions form crop production. There will be increasing pressure to reduce GHG emissions from oilseed rape production to meet increasing biofuel GHG saving criteria. Work in a new Defra-Link project (Defra project LK0979) is designed to examine the factors affecting N use in oilseed rape to increase nitrogen use efficiency in the crop, and develop cultivars better able to exploit reduced N resources per tonne of production.

Case 2 - Impacts of managing wheat for bioethanol production as opposed to cropping for conventional food/feed outlets (average for UK wheat as a whole)

Inputs

Pesticide use (based on 2006 Survey of Pesticide Usage)	Little opportunity to reduce inputs compared to crops managed for feed markets. However likely to see reductions compared to UK wheat crop as a whole as biofuel crops will be; Less affected economically by orange blossom midge damage (requires insecticide to protect affected milling wheat crops). Less reliant on late aphicide sprays (pyrethroid) and 'ear-wash' fungicides to keep grains clear of sooty moulds and other contaminants (generally required for milling wheat market). Under less pressure to apply plant growth regulator treatments (generally required for milling wheat market with higher N use and quality requirement).
Fertiliser use (based on 2006 survey of fertiliser Practice)	Little difference compared to feed wheat crops, but current average N application rate to pool of biofuel wheat crops (c.182 kg/ha N) will be typically 13 kg/ha N lower than UK average across feed and milling wheat crops (195 kg/ha N). Optimising for ethanol yield could result in N applications to bioethanol crops being around 31 kg/ha N lower than the current wheat pool average, and more where there are premiums to optimise GHG savings. (Milling wheat cultivars have received an average of 28 kg/ha more N over the last 5 years than feed wheat to boost grain protein content[12]).
Energy use	Possible reduction in diesel fuel use where minimal cultivation or low till cultivations used (lowered energy input) – saving in the region of 820 MJ/ha possible and even up to 1986-2806 MJ/ha where minimum tillage possible.

[12] British Survey of Fertiliser Practice, 2006

	Small 13 kg/ha N reduction in fertiliser use compared to UK average wheat crop due to lower nitrogen input, indirectly saving circa 528 MJ/ha, rising to 1258 MJ/ha at 31 kg/ha N saving Small reduction in number of agrochemical spray passes (1-3) compared to UK average wheat crop due to savings in pesticide use over UK pool containing milling wheats and saving on late N applications.
Environmental impacts	
Nitrate leaching	As slightly less nitrogen would be applied to biofuel crops than UK average wheat crop, potential for risk of leaching is slightly reduced, more so where N rates are optimised for biofuel production. Reducing the intensity of autumn soil cultivations to reduce energy use could also reduce soil mineralisation of nitrogen and risk of leaching loss.
Phosphate movement to water	Risks unchanged
Greenhouse-gas emissions	Reductions possible where minimal cultivation or low till cultivations used (lowered diesel energy input) of circa 154-224 kg CO_2 eq./ha Small reduction compared to UK average wheat crop, due to 6% lower nitrogen input, of circa 87 kg CO_2 eq./ha,[13] rising to saving of 207 kg CO_2 eq/ha where optimising N application for ethanol yield Small additional savings possible due to reduced number of spray passes.
Ammonia emissions	Small reduction in risk of emissions due to slightly lower than national average nitrogen use, greater reduction in risk where optimising nitrogen for ethanol yield. Potential for increased impacts on ammonia if more urea used as alternative to ammonium nitrate to reduce GHG emissions profile
Resource impacts	
Water quality (Data sources – Environment Agency 2006)	No change in impacts on water chemical quality anticipated, but potential lower risk of nitrate contamination through lower N use and where less intensive soil cultivations used.
Soil resource	No change in impacts anticipated, though reduction in intensity of cultivation could help build soil organic matter levels.
Natural environment/biodiversity	No change in impacts anticipated.

[13] Based on emission factor of 6.69 kg CO_2 eq per kg N, as used in HGCA GHG calculator.

The above assessment for cereals is based on knowledge and experiences gained with existing cultivars grown for both carbohydrate and protein content. It is currently not clear whether cultivars specifically developed for high starch production (and low protein content) would differ in their agronomic requirements and therefore in their input requirements. Current cultivars such as Glasgow, Zebedee and Istabraq produce high ethanol yields/tonne of grain, though limited yield potential restricts alcohol production per hectare in some cases. Yield potential is the most important determinant of ethanol yield/unit area of land.

Further work is required to assess what other factors affect suitability for bioethanol production, as there are significant differences between cultivars in process efficiency, affecting viscosity of flours, level of foaming during fermentation and co-product adhesion and quality. HGCA Research review 61 'Wheat as a feedstock for alcohol production' has addressed some of the technical specification and variety selection criteria that are likely to influence ethanol production efficiency, particularly control of grain nitrogen content (Smith *et al.,* 2006). Aspects of this are being tackled in the LINK Research Project 'Genetic reduction of energy use and emissions of nitrogen through cereal production' (GREEN grain) which aims to develop high starch-yielding wheat varieties more suited to production of high yields of ethanol and with reduced requirements for fertiliser nitrogen through improvement in the amino acid balance (to reduce indigestible protein components).

Improvements in process efficiency would also bring additional improvements in the life-cycle carbon and energy balance for the bioethanol chain and once the most cost effective cultivars are identified, specific management guidelines could be developed which could offer opportunities for further input reductions.

The ability to reduce the intensity of soil cultivation to establish wheat crops and save on direct energy use in producing biofuel crops will depend on soil type and grass weed pressure, which is likely to be exacerbated by reduced cultivations and may limit the use of such options, or increase environmental pressures in other areas through increased herbicide use.

Summary CASE 2 (Wheat for bioethanol replaces conventional wheat crop)

There is currently limited opportunity to reduce inputs to wheat biofuel crops compared to typical feed wheat crops. However, when compared to the UK wheat pool, there is potential for small reductions in insecticide, fungicide and plant growth regulator use, and reductions of up to 1-3 spray passes per annum. In addition nitrogen use will be slightly lower than the UK average, with benefits in terms of lower indirect energy use and green house gas emissions, reduced risk of nitrate leaching and emission of ammonia. A drive towards rewarding GHG savings could lead to a reduction in the intensity of cultivations with benefits in terms of savings in energy use and risk of nitrate leaching and an opportunity to build up soil organic matter levels. In addition, nitrogen application rates could be cut by up to 10% to optimise ethanol yields and by up to around 50% to optimise GHG savings, with knock-on benefits in reduced nitrate leaching, reduced N_2O and ammonia emissions.

15.2 B) Expansion of biofuel crops onto set-aside land

The most significant impacts on the environment are likely to occur where fallow land is brought into cropping. However, given the reduction in the set-aside rate to zero, expansion onto set-aside will occur irrespective of the development of biofuel markets, in order to meet the growing world demand for cereals and oilseeds for food use. Any environmental impacts of such expansion should not therefore be blamed solely on the development of biofuels as the major driving cause. If, after review, set-aside is removed in its entirety by the EU, this scenario in effect becomes defunct.

The key potential impacts are detailed in the tables below in terms of impacts on inputs and risks to natural resources and farmland biodiversity. This section draws on the findings and research documented in part 1.

Case 3 - Impacts of replacement of natural regeneration set-aside with oilseed rape

Inputs

Pesticide use (based on 2006 Survey of Pesticide Usage[14])	+ *circa* extra 1.59 kg a.s./ha (typically only herbicide applied to set-aside). However, very little insecticide is applied to oilseed rape and most of increase is due to herbicide use (see Annex III). Likely to be increased demand for molluscicides.
Fertiliser use (based on 2006 survey of fertiliser Practice)	+ *circa*. 205 kg/ha N + *circa* 59 kg/ha P_2O_5
Energy use	Increase in energy use due to additional soil cultivation (circa 1884 MJ/ha as fuel) and mechanised crop management[15]. Increase in indirect inputs of energy, mainly due to fertiliser nitrogen input (circa 8324 MJ/ha).

Environmental impacts

Nitrate leaching	Overall risk is moderate. During the cropping period there is an increased risk of nitrate leaching due to addition of nitrogen fertiliser in spring, risks that are significantly increased where any nitrogen is applied in the autumn. However, nitrogen residues after oilseed rape are typically lower than those following rotational set-aside (MAFF 2000), reducing the risk of leaching post-harvest.
Phosphate movement to water	Overall risk is relatively low, but there is a relatively higher risk than with set-aside. Risk of loss to water relates to soil phosphate levels (and hence phosphate application rate) and situations where there is a risk of particulate soil movement – i.e. where soils have been disturbed and/or crop cover is sparse or patchy.
Greenhouse-gas emissions	Greenhouse-gas emissions would increase through higher energy use (by circa 144 kg CO_2/ha) directly from fossil fuel consumption and indirectly through input of fertiliser nitrogen and N_2O loss from soils (by circa 1372 kg CO_2 eq./ha).

[14] Garthwaite *et al.*, (2006)
[15] Direct energy (fuel) input to natural regeneration set-aside estimated at 922 MJ/ha (Elsayed *et al.*, 2003)

Ammonia emissions	Losses from applied fertiliser nitrogen accounts for a small proportion of ammonia emissions in the UK, and risk relates to amount of nitrogen applied (typically loss rates of 0.3-3% of N for ammonium nitrate (MAFF, 2000)), therefore risk of increase in ammonia emissions associated with 'loss' of around 0.6-6.2 kg/ha of applied fertiliser N for oilseed rape crops.
Resource impacts	
Water quality (Data sources – Environment Agency 2006)	See nitrate leaching above. Little or no impact on water chemical quality anticipated as the most commonly detected pesticides found in both surface and ground waters do not originate from application to oilseed rape. However, Carbendazim is occasionally used on oilseed rape and has appeared in ground waters at above accepted quality limits.
Soil resource	Additional soil disturbance means soil is more susceptible to risk of erosion under oilseed rape cropping. Oilseed rape is typically likely to return similar or greater quantities of organic matter to soils after harvest than rotational set-aside, which will influence long term fertility and sustainability of soils.
Natural environment/biodiversity	
Diversity of farmland habitat	Reduces diversity of habitats in the farm landscape.
Value to birds	Though oilseed rape does not support the same diversity of birds as set-aside, oilseed rape is preferred by, and therefore supports, a wide range of farmland birds and some species that have declined such as reed buntings prefer oilseed rape to set-aside (Annex II). However, loss of overwinter stubbles on set-aside land may negate the benefits.
Value to invertebrates	Oilseed rape is commonly treated with insecticides in both autumn and during the early flowering stages. However, oilseed rape typically supports more invertebrates than many spring-sown arable crops, and similar levels to cereal crops.

Summary CASE 3 – Replacement of natural regeneration set-aside with oilseed rape

Replacing set-aside with oilseed rape increases physical inputs of pesticides, fertilisers and energy utilisation. Impacts on nitrate leaching are not clear cut as typically set-aside has higher residual nitrogen rates in soil which are subject to overwinter loss. It is anticipated that there could be a small increase in the risks of soil erosion and phosphate loss. Applying fresh fertiliser nitrogen is likely to lead to increase in N_2O loss. Overall greenhouse-gas emissions will increase due to the added inputs and cultivations. Little impact on soil water quality is expected. Replacement of set-aside with oilseeds would reduce farmland habitat diversity and would have an impact on some farmland birds, but other bird species of specific interest and concern would benefit. Many of these same species also use winter stubbles which may be reduced where winter sown crops replace naturally regenerating set-aside, such that overall there may be little or no beneficial impact on such species.

Case 4 - Impacts of replacing natural regeneration set-aside with wheat

Inputs	
Pesticide use (based on 2006 Survey of Pesticide Usage)	+ *circa* extra 3.72 kg a.s./ha applied (see Annex III). Also likely to be increased demand for molluscicides.
Fertiliser use (based on 2006 survey of fertiliser Practice)	+ *circa* 182 kg/ha N + *circa* 62 kg/ha P_2O_5
Energy use	Increase in direct energy use due to additional soil cultivation (circa 2798 MJ/ha) and mechanised crop management. Increase in indirect inputs of energy mainly due to input of fertiliser nitrogen (circa 7390 MJ/ha).
Environmental impacts	
Nitrate leaching	Overall risk is relatively low. There is an increased risk of nitrate leaching during the cropping period, due to soil disturbance during crop establishment and risks associated with application of nitrogen fertiliser in spring. However after harvest, nitrogen residues following cereals are typically much lower than those following rotational set-aside (MAFF 2000), greatly reducing the risk of leaching over-winter.
Phosphate movement to water	Overall risk is relatively low, but higher than with set-aside. Risk of loss to water relates to soil phosphate levels (and hence phosphate application rate) and situations where there is a risk of particulate soil movement – i.e. where soils have been disturbed and/or crop cover is sparse or patchy.
Greenhouse-gas emissions	Greenhouse-gas emissions would increase through higher direct energy use (216 kg CO_2 eq./ha) and indirectly through input of fertiliser nitrogen and N_2O loss from soils (by circa 1218 kg CO_2 eq./ha). [Though measured N_2O levels are low in cereal crops and reported to be similar to those observed in set-aside (Dobbie *et al.*, 1999)]
Ammonia emissions	Nitrogen use accounts for a small proportion of ammonia emissions in the UK and risk relates to amount of N applied (typically ‘loss’ rates of 0.3-3% of applied N for ammonium nitrate (MAFF, 2000)), therefore risk of increase in ammonia emissions associated with ‘loss’ of around 0.54 to 54.6 kg/ha of fertiliser N for wheat crops.

Resource impacts	
Water quality (Data sources – Environment Agency 2006)	See nitrate leaching above. Low risk of increase in impacts on chemical quality of fresh water. Mecoprop is more widely used on cereals than set-aside and is responsible for a small number of water quality failures in surface water (though much of this is thought to originate from amenity use). Other pesticides used on cereals for which quality standards in surface waters have been exceeded in a small number of cases include MCPA, and chlorotoluron. However, use of such herbicides is currently very limited. Isoproturon will also soon be removed from sale and will no longer constitute a risk.
Soil resource	Though the overall risk is low, additional soil disturbance means soil is more susceptible to erosion loss under wheat cropping than where left undisturbed. Where straw is retained and incorporated into soil, a wheat crop will typically return greater quantities of organic matter to soils after harvest than rotational set-aside, which will influence the long term fertility and sustainability of soils.
Natural environment/biodiversity	
Diversity of farmland habitat	Reduces habitat diversity in the farmed landscape
Value to birds	Growing cereal crops do not support the same diversity of birds as set-aside and cereal crops are preferred by a smaller number of farmland bird species (Annex II). Cereals do support threatened birds such as grey partridge, quail and the tree sparrow (Annex II). The shed crop seed, shed weed seed and weed populations left after cereal cropping make cereal stubbles a valuable overwinter resource to many birds and this helps make set-aside so attractive to overwintering birds.
Value to invertebrates	Wheat provides good overwintering habitat for invertebrates and insecticides (pyrethroids) are only widely applied to crops during the autumn period.

Summary CASE 4 – Replacement of natural regeneration set aside with wheat

Replacing set-aside with wheat increases the physical inputs of pesticides, fertilisers and energy. However impacts on nitrate leaching are not clear cut, as typically set-aside has higher residual nitrogen rates in soil which are subject to overwinter loss. It is anticipated that there could be small impacts on risk of soil erosion and risk of phosphate loss. Applying fresh fertiliser nitrogen is likely to lead to increase in N_2O loss. Overall greenhouse-gas emissions will increase due to the added inputs and cultivations. It is possible that there could be impacts on soil water quality arising from herbicide use in cereals, but these are likely to be limited.

Replacement of set-aside with wheat would reduce farmland diversity (in terms of habitat, weed and invertebrate diversity) and have a detrimental impact on farmland birds, but weedy wheat crop stubbles provide a valuable overwinter resource for birds if followed by spring-sown crops, which would mitigate to a limited extent losses of overwinter stubbles on set-aside.

General impacts

The most significant impacts of replacing set-aside are likely to occur through reduction in diversity of habitat and the impacts of this on arable flora, their associated invertebrates and knock on impacts on bird species which forage and nest on such areas. Removal of set-aside may mean that there may be additional requirements placed on growers to mitigate the effects of loss of set-aside. Though the scale and scope of such requirements is currently under debate and review, measures such as use of unsprayed crop margins and adoption of un-cropped or sown field margin treatments to encourage flora and fauna could mitigate against at least some of the loss of diverse habitat on farmland.

15.3 C) Replacement of other crops in the rotation

Cereal production already dominates UK rotations and any significant expansion of wheat cropping is unlikely to occur at the expense of break crops, though there could be some limited substitution between cereals. In contrast, the area of oilseed rape could expand by replacement of currently less profitable crops, such as legumes and linseed. The environmental impacts are likely to be subtle. An assessment of the likely impacts of replacing winter beans with oilseed rape is presented below. The impacts of spring pea and spring linseed cropping on input requirements and environmental outputs/impacts are detailed in Annex 1, along with the impacts of set-aside and winter bean cropping.

Case 5 - Impacts of replacing winter beans with oilseed rape

Inputs

Pesticide use (based on 2006 Survey of Pesticide Usage)	*Circa* 0.28 kg/ha reduction in use of pesticide, through reductions in use of mainly fungicides. However, there would be an increased requirement for molluscicides (see Annex III).
Fertiliser use (based on 2006 survey of fertiliser Practice)	+ 205 kg/ha N P_2O_5 – no change
Energy use	Increase in indirect use of energy primarily through application of nitrogen (c. 8324 MJ/ha).

Environmental impacts

Nitrate leaching	Overall there is a small increased risk of nitrate leaching, particularly post harvest. Post harvest nitrogen residues tend to be lower after legumes than after oilseed rape (MAFF 2000) and leaching losses tend to be lower with beans (MAFF, 1995).
Phosphate movement to water	Overall risk is relatively low and unlikely to differ.

Greenhouse-gas emissions	Greenhouse-gas emissions could increase indirectly through input of fertiliser nitrogen and N_2O loss from soils (by circa 1372 kg CO_2 eq./ha). However, there is little information on comparisons between N_2O emissions from oilseed rape and legumes to confirm this.
Ammonia emissions	Though ammonia emissions from arable crops are low, there would be an increased risk of ammonia emissions through use of fertiliser N on oilseed rape of around 0.6-6.2 kg/ha of applied fertiliser N.
Resource impacts	
Water quality	See nitrate leaching above. Likely to be little overall impact on water chemical quality, through trade-offs in impacts arising from pesticide use. Simazine is widely use on beans (66% of crop area treated) and has been found to exceed surface water standards in close to 5% of cases where quality standards have been breached.
Soil resource	Likely to be little difference in impacts on soil disturbance and in return of organic crop material.
Natural environment/biodiversity	
Diversity of farmland habitat	Reduces diversity of habitats in the farmed landscape.
Value to birds	Likely to encourage a wider range of farmland birds, but losers likely to include birds which favour more open crops e.g. lapwings and skylarks.
Value to invertebrates	Likely to be beneficial due to over-winter cover provided by oilseed rape and denser canopy.

Summary CASE 5 – Replacement of break crops by oilseed rape

Impacts of replacing legumes with oilseed rape include increasing fertiliser nitrogen inputs which would increase indirect energy use and overall greenhouse-gas emissions, accompanied by an increased risk of nitrate leaching. However, pesticide inputs would be reduced, including a reduction in the use of insecticides and fungicide treatments (Annex III) The main impact on biodiversity includes loss of relatively open canopy crops in the farmed landscape which are favoured by birds such as lapwings and skylarks and for foraging by a range of species. Where break crops are spring sown, there are benefits for overwintering birds from cereal stubbles left after harvest of previous crops, these would be lost by replacement with winter-sown oilseed rape.

Linseed is a very minor crop in the UK and replacement by oilseed rape would entail an increase in nitrogen and pesticide use, though due to the small size of UK linseed crop, effects would be negligible on a national scale. The main impact on biodiversity, as with legumes, would be in terms of loss of a relatively open canopy crop in the farmed landscape and loss of overwinter stubbles for birds.

As with replacement of set-aside, detrimental effects on biodiversity in agricultural landscapes could be mitigated to some extent by ameliorating measures along field margins.

Expansion of wheat and oilseed rape biofuel crops onto set-aside, or replacement of other crops with lower nitrogen demand invariably mean that fertiliser use would be increased, indirectly increasing greenhouse-gas emissions which would be detrimental to the overall aim of introducing biofuels. In the short to medium term, the most environmentally neutral option would be to, where possible, divert existing crops towards biofuel production. This leads to a bigger question, beyond the scope of this review, as to what the wider impacts of such a move are, in terms of how any lost export from the UK (through diversion of crops to biofuel use) is replaced by production in the world market, or how deficiencies in other UK food markets are met by imports, and the method of production in originating countries. Such changes can have significant unintended environmental consequences.

15.4 The impacts of change at a landscape scale

There have been few attempts to identify or model what the impacts might be of expansion of oilseed rape and cereal cropping at a landscape scale, though there are some related project experiences that might offer insights. As part of work carried out for the Defra Agricultural Change and the Environment Observatory in 2006, a quantitative case study was developed to investigate future scenarios arising post-2005 CAP reform in an arable-dominated Joint Character Area (JCA) in East Anglia, the East Anglian Chalk JCA (Parry *et al*., 2006). This work was extended (Beulke *et al*., 2008) to consider the environmental impacts of a 'market-led' scenario, which postulated a 21% increase in wheat area and a 69% increase in oilseed rape, at the expense of a 74% reduction in set-aside, and reductions also in barley, other break crops and temporary grassland. The scenarios were compared with a 2004 baseline, which defined actual cropping at a field level. Impacts of land use change were modelled for nitrate and phosphate losses to surface water, impacts of pesticides reaching watercourses on aquatic organisms, and skylark populations, with a qualitative assessment of impacts on other bird species.

The market-led scenario led to an overall average 0.6% reduction in N losses over the three simulations, but a 6.3% increase in P loss. However, increases in N loss occurred where wheat and oilseed rape replaced other crops; the increased P loss occurred largely as a result of the replacement of set-aside and temporary grass by wheat and oilseed rape. Toxic units of pesticide entering water as a result of drainage and drift were modelled for algae and *Daphnia magna*. Overall levels of pesticide toxic units were predicted to increase by up to 66%, mainly due to an increase in the impact of pesticides entering watercourses via drains, on *Daphnia magna*. The increase resulted mainly from the increase in oilseed rape area, with the compound beta-cyfluthrin making the highest contribution. However, this pesticide is no longer approved for use.

A statistical model of skylark densities gave rise to predicted decreases in average density of 9.9%, for the market-led scenario. Mapping indicated that this predicted change was the net result of many increases and decreases in density at field level. Among seven bird species considered, negative effects were likely to be greatest for the species which have declined most (yellowhammer, skylark, and yellow wagtail), were neutral or combined both positive and negative aspects for the finch species which had shown moderate decline (linnet) or increased (greenfinch, chaffinch), and were probably positive for the species which has increased most of all, the woodpigeon. Among major crops, set-aside and/or stubbles contained the highest densities of all species except yellow wagtail, both in the breeding season and the non-breeding season. Reduced areas of this habitat were likely to have negative impacts, particularly for yellowhammer, skylark and linnet. For yellow wagtail, the reduced area of broad-leaved and spring-sown crops in the market-led scenario posed the greatest threat.

The increase in crop areas used in this scenario are much greater than those envisaged in meeting the 2010 biofuel targets, (from a mix of UK cropping and import) and as already mentioned it is difficult to foresee wheat and oilseed rape making contributions much beyond what can be achieved by meeting targets for 2010. However, such exercises help examine the potential impacts of wider expansion and highlight particular areas of concern where environmental impacts need to be carefully monitored.

16.0 TARGETS FOR FURTHER IMPROVEMENT IN THE ENVIRONMENTAL PROFILE OF BIOFUEL CROPS.

1) Pesticide Use

- Over that past 10 years there has been a decrease in the weight of pesticide active substance applied to wheat, but not in oilseed rape, though application rates for most groups of pesticides show a decline as actives effective at lower doses have been introduced. The use of organo-chlorine and organo-phosphate insecticides on wheat and oilseed rape has been largely phased out over the last decade. Pesticide use on oilseed rape has increased without significant increase in average yield, and this must be seen as an area for improvement, as it is in all crops to optimise and rationalise the use of pesticides

2. Fertiliser use

- The efficiency of nitrogen fertiliser use in wheat has been improved with crop breeding, such that increases in yield have not required increases in nitrogen fertiliser input, though there are concerns that limits on such efficiency have been reached and that recommended nitrogen application rates need re-examining in the light of current varietal yield potential. Further action is required to optimise the efficiency of fertiliser use by crops and for biofuels to specifically develop low grain N, high starch content wheat cultivars for the biofuel market, and means of predicting alcohol yield to help optimise nitrogen application rates for biofuel crops.

- Wheat crops pose a relatively low risk of nitrate leaching loss where fertiliser applications are optimised. In contrast, oilseed rape poses a relatively higher risk due to relatively high levels of residual fertility left behind after harvest. Work is required to reduce the risks by optimising nitrogen use in oilseed rape, an area of research HGCA and Defra is currently funding (Defra project LK0979).

- Wheat crops are a useful means of disposing of biosolids to land at a time when alternative forms of disposal are becoming increasingly limited. Development of biofuel crops is a useful and environmentally desirable means of disposing of such wastes and would improve the GHG balance of biofuel crops utilising nutrients in such waste products.

3. Air impacts

- Oilseed rape and cereal production make a negligible contribution to overall UK CO_2 emissions. However, combinable crops can make a contribution towards carbon sequestration. It has been estimated that incorporating cereal straw can increase soil organic carbon levels by 30-70 kg carbon per hectare per year, for each tonne of straw incorporated. The validity and value of such contributions needs further study. Alternatively, straw could be burnt for electricity production or converted into ethanol to reduce burning of fossil fuels and improve the overall GHG balance of biofuels. The impacts of such options also need to be evaluated to determine the management practices having the most significant impacts in improving the GHG balance of biofuels.

- Agriculture is a major source of emissions of nitrous oxide, an important greenhouse gas. Cereals and oilseed rape pose less risk than root crops and fertilised grassland. But work is required to better quantify emission rates, the impacts on overall GHG balance, and means of reducing emission rates where possible.

4. Water impacts

- A very limited number of pesticides used on cereals and oilseed rape do cause occasional pesticide-related water quality failures. Continuing work and review is required to continually improve performance and reduce the incidence of detection.

- Nitrates in water continue to be a problem, but well-fertilised cereals pose a lower risk than many other arable crops. Improving nitrogen use efficiency and work to reduce overall nitrogen requirement should help reduce such risks.

5. Biodiversity impacts

- Continuing work and actions are required to develop costs-effective means of reducing the detrimental impacts of cereals and oilseeds on biodiversity, which primarily arise as a result of the scale of cropping in the UK. Further work is required to assess and model the impacts of large scale landscape change.

- Molluscicide use in cereals and oilseed rape is a risk to ground beetles and small mammals. Greater use of slug monitoring is required to help target use when most necessary.

6. Energy use in the biofuel supply chain

- Energy use and greenhouse gas emissions associated with crop production represent a significant proportion of the total energy demand and emissions for biofuel production using current technologies. Work to reduce the use of nitrogen (see section 17) and diesel use, through reducing cultivation operations can help improve the overall energy balance of liquid biofuels. However this needs to be balanced against consequences for grass weed build-up under reduced levels of tillage and soil inversion that leads to increased pesticide use and possible increased risks to water. The balance of risk need to be evaluated to provide the best advice to growers.

Many negative effects of cropping can be moderated or mitigated by adoption of different management practices either on a whole field basis (e.g. through sustainable farming techniques or precision application of inputs) and/or through measures targeted at particular field crops (e.g. encouragement of spring cropping to provide overwinter stubbles) or field margins (e.g. prescriptions covered by agri-environment schemes) or to increase diversity in field crops through establishment of features such as fallow areas as ‘bird scrapes’ or ‘beetle banks’ to support additional biodiversity in farmland landscapes. Through such means there is potential to significantly influence the environmental footprint of UK cereals and oilseed crops.

17.0 AREAS FOR FURTHER RESEARCH AND DEVELOPMENT OF BIOFUELS

There are opportunities for crop breeders to develop specific varieties of wheat and oilseed rape for the production of biofuels. This may be through improving feedstock quality (e.g. improving alcohol yield of wheat) or through reducing inputs (e.g. nitrogen fertiliser) whilst maintaining feedstock yields. With the Government intending to reward the use of biofuels related to their GHG savings after 2010, there is a need to develop appropriate accreditation procedures that allow a greater value to be attributed to those feedstocks that have a low GHG intensity. There has been much activity in this area, although further work is required.

R&D to improve biofuel feedstock quality

HGCA Research Review No.61 (Final report of project 3108) suggested ideal specifications for wheat for alcohol production. As bioethanol production is limited by the amount of grain going through the process, the higher the alcohol yield, the more bioethanol is produced from the same energy input into the process, with GHG cost per unit of biofuel reduced. The impact of crop management, specifically strategies to reduce N fertiliser input while increasing alcohol yield has also been assessed (HGCA project 3335. Final report 417) and the potential for developing suitable low protein cultivars is being investigated under the GREEN grain project (Defra project LK0959). It has been recognised that although low grain protein is important, there are other aspects to maximising alcohol yield per tonne of grain. Work is ongoing to investigate what factors are most important although non-starch polysaccharides (NSPs) in grain have already been identified as requiring study. NSPs cause undesirable levels of viscosity during processing which may hamper processing efficiency.

Opportunities are currently being identified for biorefining processes to extract added value from grain (HGCA project 3176). This may mean that grain quality aspects may come to be considered differently depending on the value of the different grain components once fractionated.

In terms of oilseed development, Woods *et al.* (2007) noted that breeders improved the oil content of OSR seed back in the 1990s to around 44% but that there has been little increase since, suggesting that the scope for improvement may be limited. It is also suggested that breeding efforts to improve oil quality have reached a similar stage. Any further improvements are therefore only likely to yield small improvements in GHG intensity through decreased energy use in processing. More significant impacts would be achieved by reducing inputs and improving the overall yield and oil yield.

R&D to optimise nitrogen use in biofuel feedstocks

With increasing emphasis on carbon accounting for biofuel markets, there will be increasing need for growers to optimise nitrogen inputs to optimise biofuel yields while minimising associated GHG emissions. Ongoing LINK work (Defra project LK0979) has shown that some oilseed rape cultivars require less N to achieve high yields than others, with candidate traits identified which correlate with increased yields and decreased nitrogen demand. The LINK project GREEN GRAIN aims to reduce the fertiliser requirement of wheat, identifying 'nitrogen stores' in the crop and seeking genotypes with reduced stores. However, work is likely to be required beyond these projects to capitalise on the findings and to stimulate appropriate crop breeding programmes.

The timing of N applications and type of fertiliser used may also prove important in reducing overall GHG emissions. The effect of N timing on wheat for biofuels market is currently being investigated as an extension to HGCA project 3084 (optimising fertiliser nitrogen levels for modern cereal crops). Similar approaches are currently underway looking at the nitrogen timings of oilseed rape (HGCA project 3277) to improve yields (e.g. canopy management approach)

Further work is required to investigate the implications of N fertiliser reduction on GHG balances and further economic analysis to better understand the balance between GHG savings and profitability at different grain costs, to help identify the levels of premium required to help drive down nitrogen use where reduced nitrogen use comes at the cost of a yield penalty.

R&D to improve biofuel GHG balance assessments

Further work is necessary to address a number of uncertainties surrounding the calculation of biofuel GHG balances. Technical issues regarding GHG emissions from N fertiliser manufacture and in-field N_2O emissions (see below) are the most important issues to be resolved. These and issues regarding the diversity of approaches relating to how and where biofuel feedstocks and resulting fuels are produced are important to the further development of carbon reporting.

There is growing interest in comparing the life cycle analyses (LCA's) of imported competitor feedstocks and biofuels derived from tropical oils with those of UK origin, but there are currently few readily available reference resources to allow such comparisons. Clearly clearance of forests to plant palm plantations would rank very poorly in environmental terms. Some competitors to UK feedstocks have better LCA profiles, such as Brazilian sugar cane ethanol. Canadian oilseed rape is currently excluded from many European food market outlets because of actual or perceived risk of GM contamination, which is depressing Canadian prices. However, Canadian oilseed rape has the advantage that it is spring sown using minimum tillage and uses less nitrogen than the majority of the UK oilseed area. It is beyond the scope of this report to draw up a detailed comparison, but it is clear that the credentials of some competitor feedstocks may be better than those of UK-derived stocks in some cases. Work is required in the UK to identify where there are likely to be potential problems with LCA's for imported produce or biofuels given that the end product is marketed to the consumer based on its environmental credentials.

Further work is required to assess the impacts of blends of biofuels and mineral fuels on fuel economy, and also on resultant emissions while ensuring fair and comparable test conditions. The prospects for biofuel blends at low levels of inclusion with fossil fuels should be positive, given their additional lubricating or oxygenating effects. However, the current literature is sparse, contradictory, and lacks rigorous test conditions in many cases, particularly where blended fuels are involved and clear concise work is required. The current work by CRed (Carbon Reduction Programme) at The University of East Anglia should provide a useful starting point to assess where further work is required.

There is considerable debate and uncertainty regarding emissions of N_2O from soils arising as a result of natural soil processes affecting the fate of applied nitrogen fertilisers. However the potent green-house gas impacts of N_2O mean that even small discrepancies have significant impacts on the overall assessment of greenhouse gas savings, and in the worst case scenarios, can wipe out any greenhouse gas savings made through use of biofuels. The studies quoted in this paper make use of Inter-Governmental Panel on Climate Change (IPCC) accepted methodologies and figures for indirect N_2O emissions resulting from use of ammonium nitrate fertiliser. However, these are standardised figures and as shown in earlier sections, N_2O emissions can vary widely. Recent papers have also highlighted other approaches to measure emissions, leading to question whether the IPCC figures are too low (Crutzen *at al*., 2007). However such claims have yet to be widely accepted by peer review. Further work is required in this area to ensure that any biofuel does indeed deliver what it promises and that benefits are not outweighed by connected indirect impacts on GHG emissions associated with unintended land use change, or through diffuse environmental pollution impacts associated with inputs to biofuel crops.

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Annex 1

Annex 1 – Summary of inputs to and environmental outputs/impacts of set-aside and non-cereal break crops.

Set-aside

Inputs	**Impact**
Pesticide use (based on 2006 Survey of Pesticide Usage)	Typically 1.0 kg a.s./ha applied per annum (mostly herbicide).
Fertiliser use (based on 2006 Survey of Fertiliser Practice)	No inorganic fertiliser applied.
Energy use	Limited to direct expenditure of energy on cutting of cover and application of agrochemicals (assumes energy associated with cultivation of set-aside is allocated to following crop)
Environmental impacts	
Nitrate leaching	Minimal risk during set-aside phase, but increasing risk after crop cover ploughed in which releases nitrogen.
Phosphate movement to water	Risk relates mainly to particulate movement to water. Minimal risk in set-aside due to lack of soil disturbance, maintenance of green cover and absence of fertiliser application.
Greenhouse-gas emissions	Minimised – direct measured emission of N_2O from soils is very low (around 0.29 kg/ha (Dobbie *et al*., 1999)) which is similar to that of cereal cropping
Ammonia emissions	Minimised through absence of fertiliser nitrogen application.
Resource impacts	
Water quality	Minimised – some risk from leaching of nitrogen from mineralised crop residue, but depends how quickly following crops are established to accumulate the mineralised nitrogen. Minimal risk to water quality. Mecoprop is used on a limited area of set-aside. Mecoprop is responsible for a small number of water quality failures in both surface and ground waters (though much of this is thought to originate from amenity use).
Soil resource	Minimal risk of soil erosion in autumn due to soil being left undisturbed, but risk also relates to level of green cover achieved. Ploughing-in of set-aside returns organic matter to soils to help maintain soil health, structure and fertility.
Natural environment/biodiversity	
Diversity of farmland habitat	Adds to diversity of habitats on farm.

Value to flora	Mostly dominated by common arable weeds, but allows other annuals, including rare species, to flourish where present in seedbank.
Value to birds	Valuable resource for seed and insect feeding birds, particularly overwinter and during the early breeding period, which is important for a number of farmland bird indicator species and threatened species (see Annex II).
Value to invertebrates	High value but depends on quality and diversity of crop cover.

Winter beans

Inputs	**Impact**
Pesticide use (based on 2006 Survey of Pesticide Usage)	Typically 2.87 kg a.s./ha applied per annum.
Fertiliser use (based on 2006 Survey of Fertiliser Practice)	Typically no nitrogen applied. c. 57 kg/ha P_2O_5.
Energy use	Main expenditure of energy associated with cultivation and crop management.
Environmental impacts	
Nitrate leaching	Main risks limited to post harvest loss and speed with which following crops are established – similar level of impact to oilseed rape.
Phosphate movement to water	Overall risk is relatively low. Risk of loss to water relates to soil phosphate levels (and hence phosphate application rate) and situations where there is a risk of particulate soil movement – i.e. where soils have been disturbed and/or crop cover is sparse or patchy.
Greenhouse-gas emissions	Greenhouse-gas emissions are relatively low in arable systems (Smith et al., 1998) and in bean crops are minimised through absence of use of nitrogen fertiliser. CO_2 and other greenhouse-gasses are emitted through burning fossil fuels during cultivation etc, but these are typically half the total emissions produced by oilseed and cereal crops which rely on high inputs of nitrogen, which indirectly results in significant emissions of greenhouse-gasses.
Ammonia emissions	Minimised through absence of fertiliser nitrogen application.
Resource impacts	
Water quality	Similar levels of leaching loss to oilseed rape, but higher risk than with cereal crops. Simazine is widely use on beans and has been found to be responsible for 4-5% of cases where pesticides exceeded surface water quality standards. It is also

	found in groundwater at around 15% of groundwater monitoring sites, though rarely at levels above 0.1ug/l
Soil resource	Low risk of soil erosion in autumn due to soil disturbance, but risk depends on speed of crop establishment. Ploughing-in of bean straw residue returns organic matter to soils to help maintain soil health, structure and fertility. Legumes help to build and retain organic nitrogen levels in soil.
Natural environment/biodiversity	
Diversity of farmland habitat	Relatively minor crop in UK which adds to crop diversity.
Value to birds	Bean crops are open crops and therefore are less favoured by many species, though they encourage lapwings and skylarks which prefer such open crops.
Value to invertebrates	Beans are commonly treated with an insecticide (up to 40% of bean area) on occasions between April and June. However, pirimicarb is commonly used on the crop (approx. 29% of insecticide treated area) which reduces impacts on non-target species. Crop cover levels are low early in the season reducing its value to invertebrates.

Spring peas (combinable dried peas – animal feed)

Inputs	*Impacts*
Pesticide use (based on 2006 Survey of Pesticide Usage)	Typically 3.52 kg a.s./ha applied per annum.
Fertiliser use (based on 2006 Survey of Fertiliser Practice)	No fertiliser nitrogen applied. Typically 87 kg/ha P_2O_5 applied.
Energy use	Main expenditure of energy associated with cultivation and crop management.
Environmental impacts	
Nitrate leaching	Main risks limited to post harvest loss and speed with which following crops are established – similar level of impact to oilseed rape.
Phosphate movement to water	Overall risk is relatively low. Risk of loss to water relates to soil phosphate levels (and hence phosphate application rate) and situations where there is a risk of particulate soil movement – i.e. where soils have been disturbed and/or crop cover is sparse or patchy.
Greenhouse-gas emissions	Greenhouse-gas emissions are relatively low in arable systems (Smith et al., 1998), and in pea crops are minimised through absence of use of nitrogen fertiliser. CO_2 and other greenhouse-gasses are emitted through burning fossil fuels during cultivation etc, but these are typically half the total emissions produced by oilseed and cereal crops

	which rely on high inputs of nitrogen, which indirectly results in significant emissions of greenhouse-gasses.
Ammonia emissions	Minimised losses through absence of fertiliser nitrogen application.
Resource impacts	
Water quality	Similar levels of nitrate leaching loss to oilseed rape, but higher risk than with cereal crops. In general low risk to freshwater, but bentazone is widely used on pea crops and bentazone accounts for a small number of samples exceeding pesticide tolerance in ground waters, though detected in less than 5% of monitoring sites.
Soil resource	Low risk of soil erosion in autumn where soil is left undisturbed. Ploughing-in of pea crop residues returns organic matter to soils to help maintain soil health, structure and fertility. Legumes help to build and retain organic nitrogen levels in soil.
Natural environment/biodiversity	
Diversity of farmland habitat	Relatively minor crop in UK which adds to crop and habitat diversity.
Value to birds	Significant part of value lies in uncultivated overwinter stubbles being left before pea cropping. Access to crop is increasingly restricted as it matures.
Value to invertebrates	Peas are commonly treated with an insecticide late in the growing season (June). However, pirimicarb is widely used on this crop (52% of insecticide treated area) which reduces impact on non-target species. Crop cover levels are low early in the season which reduces its value to invertebrates. Non-cereal spring-sown crops tend to host smaller populations than winter sown crops.

Spring-sown linseed

Inputs	*Impacts*
Pesticide use (based on 2002 Survey of Pesticide Usage)	Low use of pesticides – typically 1.99 kg a.s./ha
Fertiliser use (based on 2002 Survey of Fertiliser Practice)	Low use of nitrogen - 84 kg/ha N and phosphate – 71 kg/ha P_2O_5.
Energy use	Main expenditure of energy associated with cultivation and crop management, plus indirect energy associated with use of fertiliser nitrogen (though much less than cereals and oilseed rape at 3411 MJ/ha).

Environmental impacts	
Nitrate leaching	Relatively low use of nitrogen in linseed crops – but little information on risk of leaching loss.
Phosphate movement to water	Overall risk is relatively low. Risk of loss to water relates to soil phosphate levels (and hence phosphate application rate – which is relatively low for linseed) and situations where there is a risk of particulate soil movement – i.e. where soils have been disturbed and/or crop cover is sparse or patchy. As a spring sown crop such risk is low.
Greenhouse-gas emissions	Greenhouse-gas emissions are relatively low in arable systems (Smith et al., 1998). In linseed, indirect emissions are limited through relatively low use of nitrogen fertiliser (562 kg CO_2 eq/ha). Direct emissions of CO_2 through burning of fossil fuels during cultivation etc, are likely to be similar to those of other combinable crops.
Ammonia emissions	Nitrogen use accounts for a small proportion of ammonia emissions in the UK and risk relates to amount of N applied (typically 'loss' rates of 0.3-3% of applied N for ammonium nitrate (MAFF, 2000)), therefore risk of increase in ammonia emissions associated with 'loss' of around 0.223 to 2.31 kg of fertiliser N/ha for linseed crops.
Resource impacts	
Water quality	Nitrogen application rates are low, but little information on risk of nitrate leaching loss. None of the pesticides used on linseed are commonly encountered as problems in surface and ground water sources.
Soil resource	Low risk of soil erosion in autumn where soil is left undisturbed. Ploughing-in of linseed crop residues returns relatively small amounts of organic matter to soils to help maintain soil health, structure and fertility.
Natural environment/biodiversity	
Diversity of farmland habitat	Very minor crop in UK which adds to crop and habitat diversity on farmland.
Value to birds	Significant part of value lies in uncultivated over-winter stubbles being left before cropping. Preferred by species which require open crop habitats.
Value to invertebrates	Insecticide use is low (except where flea beetle is a problem, where insecticide is applied in April/May) Typically only 33% of the crop receives insecticide. This enhances its value to invertebrates, however, crop cover levels are relatively low which reduces its habitat value to invertebrates.

Annex 2. Preference or avoidance of crop types by farmland birds of conservation concern. (B = breeding period, W = winter, ++ = strong preference, + = preference, - = avoidance, 0 = neutral, s = stubbles; h = harvested; ns= newly-sown). (Turley *et al.*, 2002) (BAP = Listed as target species in UK Biodiversity Action Plan)

Species	Farmland Bird index	Red list	Amber list	BAP	Habitats: Set-aside		Rape		Wheat		Potatoes		Sugar beet		SRC	
					B	W	B	W	B	W	B	W	B	W	B	W
Kestrel	*		*		+?	+?	-	-	+?	+?						0
Grey partridge	*	*		*	+/-	+	+	+	+	-/+			-		+	+
Quail		*							+				-		-	
Stone-curlew		*		*	+				-				+?			
Lapwing	*		*		+		-	-	-	+/-	+h	-?		-?	-	-
Woodpigeon	*				+		+	++	-	-/+ns				+	-	-
Stock dove	*		*		+		0		0	+?			+		-	-
Turtle dove	*	*			+		-		-		-		-			
Barn owl	*				+	+										
Skylark	*	*		*	++	++	+/-	-/+	-/+/0	--	+?	+s	+?	-/+	-	-
Yellow wagtail	*		*		-/+		-		-		+		+		-	
Dunnock			*		+	0	+		-	-				+	-	+
Mistle Thrush			*		+				-							0
Song Thrush		*		*	+	0/-	+	+	-/+?	-					+	+
Whitethroat	*				+/-		+/-		-		+		+		+	
Starling	*	*						-	-	-					-	0
Jackdaw	*				+			-		-		+		-		0
Rook	*				+	+?	-	+?	-	-	+	+		-		-
House sparrow		*					+		+?							
Tree sparrow	*	*		*	+	0	+	0	+	0				+	-	+?
Greenfinch	*				+	+	+	0	+?/-	-/+s					+	+
Goldfinch	*				+	+	+	+s	-	-			0	-	-	-
Linnet	*	*		*	+	+	++	+	-	-	-		-	+	+	-
Bullfinch		*		*	0		+		0				0			+
Yellowhammer	*	*			+	+	+/-	-/+s	-/+	-	+		0	-/+	+	+
Cirl bunting		*		*	+	+		0		-						
Reed bunting	*	*		*		+	++	0	-	-	-			+	+	+
Corn bunting	*	*		*	+	+	-/+	+s	-/+				-		-	

Annex 3 – Impacts of changing crop land use on pesticide input per hectare of crop grown

Change in pesticide input (active substance) per hectare of crop replaced (kg a.s./ha) (based on average weight of active ingredient applied on each ha of crop grown in 2006)
Derived from Garthwaite *et al.* 2006

	Replacing set-aside with winter wheat	Replacing set-aside with winter oilseed rape	Replacing beans with winter oilseed rape
Insecticides	+0.07	+0.02	-0.01
Carbamates	0	0	-0.02
Organophosphate	+0.05	0	0
Pyrethroid	+0.01	+0.03	+0.01
Fungicide	+1.05	+0.30	-0.59
Herbicide	+1.24	+0.97	+0.06
Molluscicide	+0.04	+0.16	+0.19
All pesticides*	+3.72	+1.59	-0.28

*Includes seed treatments, plant growth regulators and crop desiccants.

Annex 4. CURRENT LEGISLATION AFFECTING UK CROPPING SYSTEMS

Water protection legislation

The Ground Water Directive

The Ground Water Directive (EEC Directive 68/1980) attempts to regulate the emission of dangerous substances into the water. It has been implemented in the UK by the Ground Water Regulations (SI 2346/1998). Neither of these instruments are specific to agriculture, they are general instruments for the protection of ground water resources. The Ground Water Directive defines substances not to be discharged into ground water (List I) and substances that can be discharged up to a certain limit (List II). Authorisation by the competent authority in the Member State is required for the latter subject to a previous investigation on the effects of the discharge and must be renewed at least every four years. The Environment Agency is responsible for enforcing these Regulations.

The Ground Water Directive is expected to be replaced over coming years by a new Ground Water Directive, to be made pursuant to Article 17 of the Water Framework Directive

The Local Environment Risk Assessments for Pesticides (LERAPs)

Introduced in 1999, LERAPs were introduced to protect water courses from pesticides that carry the greatest risk to water ecosystems. The LERAP Scheme requires farmers to establish no-spray areas near watercourses. The major benefit of LERAP is that it allows individual farmers to determine their optimal no-spray area in relation to the pesticide in question and risk to water body concerned. Pesticide labels carry details of the LERAPs category for the active substance and mandatory requirements that apply in relation to establishment of the buffer zone and record keeping for inspection.

The Water Framework Directive 2000/60/EC

This recently introduced legislation is designed to update existing water legislation and introduce a co-coordinated approach to water management. The Directive introduces statutory water analysis and planning for river basins.

The main aims of the Directive affecting agriculture are to

1. Prevent further deterioration and to protect and enhance the status of aquatic ecosystems and associated wetlands

2. To reduce pollution of water

The overall aim is to achieve ‘good ecological and good chemical status’ by 2015. The Environment Agency is responsible for implementation of the Directive in England and Wales. The longer term impacts on UK agriculture will depend on the findings of monitoring programmes.

Nitrate legislation

Nitrate directive - EC Directive 676/1991

The main aim of EC Directive 676/1991 is to reduce water pollution caused or induced by nitrates from agricultural sources. Waters that are or could be affected by pollution have to be identified. For surface freshwaters the limit is set by EC Directive 440/1975 and for ground waters the limit is set to 50 mg/l. In order to accomplish the reduction of nitrate pollution Member States have to designate (to be reviewed at least every four years) as vulnerable zones all those areas that drain into waters affected by pollution and establish action programmes and codes of good agricultural practice for the protection of all waters. The UK Government designated 66 Nitrate Vulnerable Zones (NVZs) in 1996 that covered an area equivalent to 8% of England and adopted an action programme. The rules established by the action programme are compulsory for farmers operating within the NVZs. The Environmental Agency is responsible for their enforcement. A further 47% of England was designated as NVZs in October 2002. In the areas controlled by action programmes, the following rules apply:

1. Organic fertilizer applications are limited to crop requirement after allowing fully for residues in soil and form other sources.

2. The use of manufactured nitrogen fertilisers is banned between 15 September and 1 February for fields in grass, and between 1 September and 1 February for fields not in grass.

3. On an individual farm, base application of organic manure should not exceed 250 kg/ha of total nitrogen each year averaged over the area of grass on the farm, and 170 kg/ha of total nitrogen each year averaged over the area of the farm not in grass.

4. On a field base organic manure should not be applied at a rate that would result in the total nitrogen exceeding 250 kg/ha in any 12 month period. The use of organic manures is banned within 10 metres of surface water.

5. All new, substantially reconstructed or enlarged installations for the containment of slurry and silage must conform to the Control of Pollution Regulations 1991 (amended 1997).

6. All farms must keep adequate records relating to livestock numbers and the use of inorganic nitrogen fertiliser and organic manures. The records must be retained for at least five years.

In 2007 a review was undertaken to investigate how the Nitrate Directive has been implemented and looked at the current extent of NVZs and the effectiveness of the current Action Plan. The review highlighted the need for further action and indicated that coverage of NVZs need to increase to about 70% of England. A consultation was launched inviting views on proposals to improve action programme measures to control pollution caused by nitrogen from agricultural pollution, and whether these measures should be applied to discrete NVZs or to England as a whole. A summary report of Defra’s analysis of the consultation is expected early in 2008.

Pesticide legislation

FEPA

In 1985 Part III of the Food and Environment Protection Act (FEPA) came into force in order to protect human and animal health, plants and the environment and to make pesticide use safer. Its main aims are: to protect the health of human beings, creatures and plants; to safeguard the environment; and to secure safe, efficient and humane methods of controlling pests. Contravening the FEPA Regulations is an offence punishable by a fine not exceeding £5,000 or six months imprisonment.

The Control of Pesticides Regulations 1986 (as amended)

The COPR prohibit the advertisement, sale, supply, storage and use of pesticides unless approval and consent have been obtained. Approval can be in the form of an experimental permit, a provisional approval or a full approval. Approval can also be subject to conditions imposed when approval is given or amendments can be applied subsequently in light of new research or findings. These Regulations also impose training requirements for pesticide users.

EC Directive 414/1991 (as amended)

This Directive is a step towards harmonisation of pesticide regulatory systems within the EU. It is a two-stage process. The first stage concerns the inclusion of an active substance into Annex 4, the second stage is the authorisation to use given by each Member State to Plant Protection Products (PPP) containing the listed active substance. This Directive also introduced a system of mutual recognition of PPP authorisation between Member States. It has been implemented in the UK through the Plant Protection Products Regulations (PPPR). All existing pesticides used in Europe are being re-evaluated (reviewed) according to standards set out in relevant EU directives.

The Plant Protection Products Regulations 1995, 1997 (as amended)

A PPP cannot be placed on the market without specific approval (special conditions apply for the purpose of research and development). Approval is provided for up to 10 years provided the PPP is sufficiently effective, has no unacceptable effects on plants or plants products, has no unacceptable effects on human or animal health or the environment and can be used in such a way that residues do not exceed the established maximum levels. Contravention is punishable by a fine.

The Pesticides (MRL) Regulations (as amended)

The aim of these Regulations is to establish a Maximum Residues Levels (milligrams per kilo) in plants and plants products. MRLs are based on Good Agricultural Practice – the proper use of the product. They are therefore not safety limits and so residues in excess of an MDL do not necessarily constitute a risk to health. Non compliance constitutes an offence punishable by a fine.

Soil protection legislation

Sludge (use in Agriculture) regulations 1989 – (UK implementation of EU Directive 86/278)

These regulations contain provisions designed to prevent harm to humans, animals, plants or soil microorganisms from heavy metals or pathogens present in sludge while maintaining soil fertility and crop yields. The regulations must be followed by anyone applying sludge to land. The regulations place a burden on the user to

1. Sample and analyse soils before application
2. Restrict applications where there are high levels of metal present in soil (with limits related to soil pH)
3. Restrict use to defined situations and crops
4. Requirement to incorporate into soil as soon as possible

Air protection legislation

Environmental Protection Act 1990, Part III.
The Local Authority Environmental Health Department is responsible for enforcing this legislation, which covers nuisance arising from odours and smoke. Abatement orders are served on offenders, to prohibit or restrict occurrence or recurrence of the problem. Non compliance constitutes an offence punishable by a fine.

Crop Residues (burning) regulations 1993

Prohibits the field burning of all crop harvest residues (except linseed) in all but a few very restricted circumstances.

Other legislation affecting intensive livestock units

There is additional legislation covering emissions from intensive livestock enterprises (pig and poultry houses) including the Integrated Pollution Prevention and Control (IPPC) regulations 2000 (IPPC Directive 96/61/EC), designed to reduce emissions form such establishments to soil air and water.

Annex 5. Recent and ongoing relevant research.

1. DEFRA FUNDED RESEARCH

National ammonia reduction strategy evaluation system (NARSES) (AM0101)

Description:
Objective is to develop a national-scale model to estimate the magnitude, spatial distribution and time course of agricultural ammonia (NH_3) emissions and the potential applicability of abatement measures and associated costs.

From: 01/04/01
To: 31/03/04
Cost: £507k
Contractor / Funded Organisations: ADAS Consulting Ltd

Scoping study of potential impacts of climate change on nutrient pollution (of water) from agriculture (CC0378)

Description:
Much contemporary DEFRA-funded research has focused on developing the understanding of, and modelling capability for, diffuse nutrient losses from agricultural land. This proposed study aims to explore how contemporary models used for policy support might be modified and applied to assess the impact of climate change scenarios on nutrient losses from agriculture to water courses.

From: 01/04/02 to 16/02/04
Cost: £65k
Contractor / Funded Organisations: ADAS Consulting Ltd

EUROHARP (UK) - Evaluating national methods for quantifying diffuse nutrient losses from land to water bodies (ES0102)

Description:
The primary objectives of EUROHARP are to provide end-users (environmental policy makers, implementers and evaluators at national and international level) with a thorough scientific evaluation of contemporary quantification tools (models) and their ability to estimate diffuse nutrient (N, P) losses to surface freshwater systems and coastal waters, and thereby support reporting obligations (EC) and the planned implementation of the new Water Framework Directive.

From: 01/01/02 to 31/12/05
Cost: £240k
Contractor / Funded Organisations: ADAS Consulting Ltd

Brimstone-NPS: Integrated land use & manure management systems to control diffuse nutrient loss from drained clay soils (ES0106)

Description:

The objective is to develop integrated land use and manure management practices to reduce diffuse nitrogen (N) and phosphorus (P) losses from drained clay soils under arable and grassland farming systems. The study will be carried out on drained clay soils of the Denchworth Association at the existing Brimstone Farm experimental facility in Oxfordshire.

From: 01/08/01 to 31/03/06
Cost: £995k
Contractor / Funded Organisations: ADAS Consulting Ltd

Environmental benchmarks - arable (ES0112)

Description:
The main objective is to quantify the current and possible future environmental burdens of arable crop production systems, as well as the crop outputs, in the different farming systems and regions throughout England and Wales. This project will help quantify aspects of current economic and environmental performance and what changes in practices can be made to improve both. The results will help inform policy makers and the farming industry about where arable agriculture stands now in terms of the environmental burdens and how improvements may be made.

From: 01/04/02 to 31/03/04
Cost: £70k
Contractor / Funded Organisations: Silsoe Research Institute (BBSRC)

Agricultural futures and their implications for the environment (CTE0206) (IS0209)

Description:
The overall aim of the project is to provide information on possible agricultural futures in England and Wales in order to support decision making on environmental policy. The project focuses on the link between agriculture and environment over the next 50 years. This recognises the influence of limits imposed by the physical and natural circumstances of farming in England and Wales, but also of constraints and opportunities arising from a range of possible future economic, social, technological and political conditions, as well as social preferences which find expression in policy.

From: 01/01/03 to 31/12/04
Cost: £159k
Contractor / Funded Organisations: University - Cranfield

Communication methods to persuade agricultural land managers to adopt practices to benefit environmental protection (KT0107)

Description:
The project will assess the activities and communication methods used by MAFF and other organisations that have sought to persuade farmers to adopt practices that will enhance protection of the environment and conservation management. Existing methods will be assessed and an integrated, cost-effective approach for future MAFF sponsored activities will be recommended. The use of creative, attractive, non-traditional approaches will be specifically considered by partner Town & Country Communications Group Ltd who have experience both within and without the agricultural industry.

From: 01/06/01 to 30/11/01
Cost: £67k
Contractor / Funded Organisations: ADAS Consulting Ltd

Best methods of influencing farmers & other land managers on environmental issues: barriers & means of overcoming them (KT0108)

Description:
The project specifically examines what communication approaches are most suited to relaying information on environmental protection and conservation matters to farmers and other land managers. Identifies the barriers to the uptake of advice and research messages, and indicates how such barriers may be overcome from an informed psychological and market research perspective.

From: 15/08/01 to 31/10/01
Cost: £18k
Contractor / Funded Organisations: Jordia UK Trading Ltd

Nutrient management decision support system (PLANET) (KT0113)

Description:
The objective is to produce an electronic nutrient management decision support system (running title PLANET) for use by farmers and their advisers. The PLANET decision support system (DSS) will be developed as a practical tool that is easy to use, so farmers will want to use it for their own economic benefit and to protect the environment.

From: 01/05/03 to 31/07/05
Cost: £493k
Contractor / Funded Organisations: ADAS Consulting Ltd

Assessment of P leaching losses from arable land (NT1046)

Description:
The research is designed to assessing the contribution of agricultural practices to P loss and to enable the control of P inputs from agriculture to surface and underground waters by assessing;.

1. Annual losses of soil and fertilizer P from UK arable land (on a kg/ha basis) by subsurface flow (i.e. leaching) to surface and ground waters.
2. The relative magnitude of P loss by this pathway compared to losses from erosion and surface flow.
3. P concentrations in arable UK soils above which there is a significant risk of P loss down the soil profile by leaching.

From: 01/04/00 to 31/03/03
Cost: £194k
Contractor / Funded Organisations: Rothamsted Research (BBSRC)

Documenting soil erosion rates on agricultural land in England and Wales (SP0411)

Description:
There is a lack of reliable information on rates of soil loss from agricultural land in the UK for use in the development, calibration and validation of national scale models for predicting soil loss and sediment delivery from agricultural land. To address this deficiency, there is an urgent need to assemble empirical information on rates of soil loss from a representative range of soil types and terrain types under different land use and land management in England and Wales. The use of environmental radio-nuclides and more particularly caesium-137 (Cs-137) offers an effective alternative means of assembling such data. The Cs-137 approach has now been validated and extensively used by the applicant in studies in both the UK and overseas and offers a unique means of assembling retrospective information on longer-term average erosion rates (i.e. 40 years) on the basis of a single site visit. This project is phase one of a two phase project (see below) and aims to develop, test and validate sampling and data processing protocols for using Cs-137 measurements in a reconnaissance mode and commence the assembly of a national database on soil erosion rates by producing a database specifically for Southern England

From: 01/07/03 to 30/06/05
Cost: £214k
Contractor / Funded Organisations: University of Exeter

Documenting soil erosion rates on agricultural land in England and Wales – Part 2 (SP0413)

Description:
This project follows on from Project SP0411. It aims to complete the assembly of a national database on soil erosion rates, which commenced during phase one and uses the same approach to collect information on rates of both gross and net erosion on a number of fields throughout England and Wales, representative of a wide range of physiographic and land use conditions. The project will help identify key controls on rates of soil loss at the national scale and will provide a basis for developing prediction models and indicator tools that can be used to extrapolate the data collected and therefore provide the basis for a national inventory or assessment of soil erosion and its associated off site and on site problems. The inventory or assessment can contribute to a number of

national initiatives linked to soil protection and the sustainable management of agricultural soils, catchment sensitive farming, the reduction of diffuse pollution, catchment management and the development of river basin strategies.

From: 01/07/05 to 15/08/08
Cost: £414k
Contractor/ Funded Organisations: University of Exeter

Effects of fertiliser nitrogen additions on soil quality and fertility (SP0504)

Description:
Medium-term effects of addition of inorganic N fertilisers on soil quality and sustainability will be investigated, with particular emphasis on impact of N fertiliser on returns and turnover of organic C and N.

From: 01/04/98 to 31/03/03
Cost: £217k
Contractor / Funded Organisations: ADAS Consulting Ltd

Leachable N levels after fertilising high yielding wheat varieties (IS0223)

Description:
Assessment of the extent to which increased use of fertiliser N on crops with high yields will lead to increases in potentially leachable nitrogen. This work follows six industry-funded fertiliser experiments conducted in 2005, 2006 and 2007 with ghost trails to assess effects of the N fertiliser on residual and potentially polluting soil N in the succeeding seasons.

From: 01/08/05 to 31/03/09
Cost: £180k
Contractor/Funded Organisations: ADAS UK Ltd

Organic manure and Crop Organic Carbon Returns – Effects on Soil Quality (Soil-QC) (SP0530)

Description:
Building upon the previous research conducted in Defra projects SP0501 and SP0504, which evaluated the effects of `medium-term farm manure and fertiliser nitrogen (N) additions on soil quality and fertility" and utilising a network of seven sites, this project seeks to develop an improved understanding of the processes and linkages through which OC additions influence soil quality and fertility, and sustainable crop production. Additionally, at the four farm manure sites, green waste compost and paper waste additions will be introduced as new treatments. An important aspect of the study will be to assess how soil properties will change over time, both in the short and long-term, which will be achieved through a combination of field measurements and modelling.

From: 01/04/04 to 31/03/09
Cost: £988k
Contractor/ Funded Organisations: ADAS UK Ltd

The effect of crop rotation and rotational position on soil structure and structural resilience (SP0510)

Description:
There is currently great concern about the sustainability of UK soils: i.e. are current management practices maintaining/improving soil health or are we causing long-term damage. The project will look at soil physical condition and structural resilience. The aim of the project is to compare the effects of rotational position (in 2 conventional farms and one organic farm) on the physical resilience of soils in arable rotations, and to identify the key factors responsible for soil structural resilience.

From: 01/08/01 to 31/03/05
Cost: £353k
Contractor / Funded Organisations: ADAS Consulting Ltd

Development of economically & environmentally sustainable methods of C sequestration in agricultural soils (CTE0205) (SP0523)

Description:
The objective is to provide a quantified assessment of likely carbon sequestration in soils from practical management options, together with the consequential effects in respect to their ecological implications and the impacts on the farm business. The project includes an assessment of carbon sequestration, direct and indirect energy use, and environmental and economic consequences for the range of practical management practices which are likely to result in an increase in the retention of organic matter in the soil.

From: 01/06/02 to 30/04/03
Cost: £30k
Contractor / Funded Organisations: ADAS Consulting Ltd

Framework to evaluate farm practices to meet multiple environmental objectives: CTE9901. (WA0801)

Description:
The objectives are to provide a consistent and integrated modelling framework to help farmers and other stakeholders achieve multiple environmental objectives in a cost-effective way, and to demonstrate the impact on the environment of current farming practice and alternative approaches. To initiate an active forum on the environmental impacts of farming systems for all stakeholders, to shape review and disseminate the insights of this project.

From: 19/07/99 to 18/07/02
Cost: £350k
Contractor / Funded Organisations:
Rothamsted Research (BBSRC),
Silsoe Research Institute (BBSRC)

Market mechanisms for reducing GHG emissions from agriculture, forestry and land management (SFF 0602)

Description:
The Agriculture, Forestry and Land Management (AFLM) sector is responsible for emitting three major GHGs; carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), but it is also responsible for sequestering large quantities of carbon in forestry, interacting with large stores of carbon in the soil and vegetation, and assists in reducing overall UK emissions through energy production from biomass. The purpose of this project is to assess data needs, feasibility as well as options for delivery and provide an initial cost benefit analysis of market mechanisms to facilitate trading to reduce direct GHG emissions from agricultural enterprises.

From: 03/07 to 08/07
Cost: unknown
Contractor/ Funded Organisations: NERA Economic Consulting

2. LINK FUNDED RESEARCH WITH CO-FUNDING FROM HGCA

3D Farming - making biodiversity work for the farmer. (Increasing beneficial insect numbers and diversity in field margins for aphid control.) - LK0915

(HGCA project number 2238)

Description:
The main aim is to manage field margins in order to increase the abundance, diversity and impact of beneficial predatory and parasitic insects and spiders for aphid control in cereals and break crops, whilst simultaneously enhancing biodiversity on farmland. Existing margin management options, including options promoted in arable stewardship schemes for increasing biodiversity, will be evaluated for their influence on the predatory and parasitic fauna within fields.

From: May 00 for 4 years
Partners: IACR Rothamsted; Game Conservancy Trust; IACR Long Ashton; CSL; SAC; HGCA; CWS; Dow Agrosciences; UAP; Unilever Research; Tesco; HDC; PGRO; Potato Processors Assoc
Total project cost: £1.1m
Contact: Dr W Powell, IACR-Rothamsted. e-mail: wilf.powell@bbsrc.ac.uk

Sustainable Arable Farming for an Improved Environment (SAFFIE) - LK0926

(HGCA project number 2617)

Description:
The overall aim is to enhance farmland biodiversity by integrating novel habitat management approaches, in the crop and non-cropped margins, to develop more sustainable farming. Improved understanding of interactions will lead to increases in invertebrate and weed seed abundance, and their availability, will be of particular benefit to farmland birds.

Date: Jan 2002 for 5 years
Sponsor: DEFRA, SEERAD and ENGLISH NATURE
Participants: ADAS Consulting Ltd, British Potato Council, British Trust for Ornithology, Central Science Laboratory, Crop Protection Association, The Game Conservancy Trust, Jonathan Tipples, Linking Environment And Farming, Natural Environment Research Council, Royal Society for the Protection of Birds, Safeway Stores plc, Sainsbury's Supermarkets Ltd., Syngenta , The Home-Grown Cereals Authority, The National Trust, and CAER, University of Reading,
Total project cost: £3.5M
Contact: Jeremy Wiltshire, ADAS Boxworth, e-mail Jeremy.Wiltshire@adas.co.uk

Components of Resistance to Diseases in Winter Oilseed Rape Cultivars (OREGIN, LK0956)

(HGCA project number 2951)

Description:
The problem of resistance to stem canker and light leaf spot operates at different stages in epidemics between sowing and harvest. Resistance ratings to these diseases and major components of merit ratings to select cultivars for HGCA Recommended Lists are currently based on visual disease assessments once per season with no epidemiological assessments in the autumn. Breeders

are concerned about variability in disease and yield loss results from different sites. This project aims to understand components of resistance to these diseases and improve accuracy of winter oilseed rape cultivar resistance ratings.

Date: 01 April 2004 to 31 March 2008
Sponsor: Defra, HGCA
Participants: ADAS, National Institute of Agricultural Botany, Scottish Agricultural College, Saaten-Union, CPB Twyford, Nickersons, Elsoms Seeds, Syngenta, Monsanto
Total project cost: £910,452
Contact: Prof Bruce Fitt, Rothamsted Research

Improved Resistance to Septoria in Superior Varieties (IMPRESSIV, LK0945)

(HGCA project number 2956)

Description:
Septoria tritici blotch has been consistently the major disease of wheat in Britain for more than a decade. It is the principle target for foliar fungicides but control with strobilurins has recently become much more difficult because of the emergence of resistance to these fungicides, while there is little flexible in the timing of application of triazole fungicides. There is therefore an urgent need to increase the availability of wheat varieties, which combine good resistance to septoria with excellent yield and quality. This project aims to apply new knowledge of the genetics of resistance to septoria to improve methods of selecting wheat varieties with greater resistance to septoria, enabling wheat breeders to improve the effectiveness of breeding for resistance to septoria tritici blotch. This will lead to the production of a steady supply of wheat varieties which have good resistance to septoria and are well-adapted to UK conditions.

Date: 01 October 2004 to 30 September 2009
Sponsor: HGCA part funded
Participants: John Innes Centre, Advanta Seeds, Elsoms Seeds, New Farm Crops, Nickersons, Semundo, Sejet Planteforaedling, Defra
Total project cost: £1,470,000
Contact: Dr James Brown, John Innes Centre

Identification of genetic markers for lodging resistance in wheat (LK0958)

(HGCA project number 2976)

Description:
Modern wheat varieties are approaching the minimum height that is compatible with high yields. Therefore new ways of reducing lodging risk must be sought to prevent resource productivity declining and PGR usage increasing. Exploiting the large genetic variation in stem and anchorage strength would significantly increase lodging resistance, but breeders have not improved these characters because they are very time-consuming to measure. Their selection would be greatly assisted by genetic markers, but these have never been investigated in wheat. This project aims to identify QTLs (Quantitative Trait Loci) for stem and anchorage strength, which breeders could use to effect a step improvement in lodging resistance.

Date: 01 June 2004 to 31 May 2008
Sponsor: Defra, HGCA, Advanta Seeds UK Ltd
Participants: ADAS, Advanta Seeds UK Ltd
Total project cost: £686,157
Contact: Dr Pete Berry, ADAS High Mowthorpe

Genetic reduction of energy use and emissions of nitrogen in cereal production (GREEN grain) (LK0959)

(HGCA project number 2979)

Description:
This project has the combined aims of genetically reducing the nitrogen emissions and growing costs of wheat production whilst enhancing the value of wheat grain for the bioethanol and grain distilling industries, for pigs and poultry and for other markets. The project seeks to achieve these goals by identifying wheat genotypes with minimal nitrogen storage in the stems, and reduced gliadin protein in the grain.

Date: 01 July 2004 to 30 June 2009
Sponser: Defra, SEERAD and HGCA
Participants: ADAS, Scottish Crop Research Institute, Syngenta Seeds, Scotch Whisky Research Institute, Wessex Grain, Grampian Country Food Group, Foss UK Ltd,
Total project cost: £2.4m
Contact: Dr Roger Sylvester-Bradley, ADAS

Breeding oilseed rape with a low requirement for nitrogen fertiliser (LK0979)

(HGCA project number 3116)

Description:
Oilseed rape receives more nitrogen fertiliser than almost any other arable crop, but the amount of nitrogen removed in the seed is relatively small. The high fertiliser requirement represents a large growing cost and, because of the high energy input and by-products produced during its manufacture, it causes significant green house gas emissions to be associated with growing the crop. This project aims to improve the viability of UK oilseed rape for biodiesel and food production by reducing green house gas emissions, nitrate leaching and financial costs associated with growing the crop.

Date: 01 July 2006 to 30 June 2011
Sponser: Defra and HGCA
Particpants: ADAS, BASF plc, BP Oil International Ltd, Elsoms Seeds Ltd, HGCA, Northest Biofuels Ltd, Nickerson UK Ltd, Syngenta Seeds Ltd, Saaton Union UK Ltd, Terra Nitrogen UK Ltd, University of Nottingham, University of Warwick
Total project cost: £968,830
Contact: Dr Pete Berry, ADAS UK Ltd

<u>Weed Management Support System (WMSS)</u>

(HGCA Project number 2286)

Description: To produce a usable and robust system to improve weed management in winter wheat which will promote environmentally sound decision making to enhance crop profitability and the biodiversity of farmland. To establish user requirements and design a WMSS to meet these requirements. This will include specification of herbicide efficacy requirements, weed biology information requirements, cultural and rotational information requirements and identification of new data requirements. Construction of biological and decision models to create DESSAC compatible WMSS software. Validation and delivery of the WMSS.

Date: 01 October 2000 to 30 September 2004
Sponsor: Defra, HGCA
Participants: ADAS Boxworth, Rothamsted Research, Scottish Agricultural College, Silsoe Research Institute
Total project cost: £1,960,070
Contact: Mrs Lynn Tatnell, ADAS Boxworth

3. OTHER RELEVANT RECENT AND ONGOING HGCA-FUNDED RESEARCH

Improving yields of oilseed rape with late nitrogen applications

Project number 3277

Lead scientist ADAS UK Ltd.
Partners GrowHow UK, Bayer CropScience
Start Date 01 March 2006 **End date** December 2006
HGCA funding Unknown **Total cost** Unknown

Triticale – opportunities as a low input cereal for bioethanol production

Project number 3348

Lead scientist Richard Weightman, ADAS UK Ltd.
Partners Senova Limited
Start Date 01 July 2007 **End date** 31 March 2008
HGCA funding £15,000 **Total cost** £20,000

Project aims: To quantify the performance of modern triticale varieties under UK conditions and assess their value for the bioethanol market.

Approach: Quantify the agronomic performance and alcohol processing yield of triticale. Assess the residue viscosity of triticale fermented at lab scale and compare to that from wheat. Laboratory measurements of starch, protein and alcohol processing yield will be made on triticale samples grown under UK conditions and compared to yields of wheat grain of similar protein contents. Evaluate the potential greenhouse gas savings of UK grown triticale compared to other cereals and inform the industry of the value of triticale as a feedstock for bioethanol production.

Optimising nitrogen applications for wheat grown for the biofuels market

HGCA project number 3335

Lead scientist Dr Daniel Kindred, ADAS
Start Date January 2007 End date August 2007
HGCA funding £18,000 Total cost £18,000

Project Aims: To assess the potential for growing wheat for bioethanol production at lower N rates than those used for feed wheat production.

Approach: Analysis of over 100 sets of N response data to investigate the extent to which the optimum N rate for bioethanol production differs from that for grain production for the feed market

Maximising bioethanol processing yield of UK wheat: Effects of non starch polysaccharides in grain

HGCA Project number 3314

Lead scientist	Dr Richard Weightman, ADAS		
Partners	Scottish Whisky Research Institute (SWRI)		
	Green Spirit Fuels Ltd		
	Danisco Animal Nutrition		
	Frontier Agriculture Ltd		
Start Date	01 April 2007	End date	01 September 2009
Total cost	£136, 306		

Project Aims: With a UK government target of 5% of transport fuels from renewable sources by 2010, a significant market for biofuels is emerging and wheat will be the principal feedstock. To optimise production, there is a need to quantify bioethanol yield and understand the contribution of grain constituents on yields. Currently the importance of NSP's to variation in bioethanol yield is not yet understood and the yield of alcohol from wheat is assessed using a method designed for potable alcohol production.

Approach: Establish a bioethanol processing laboratory. Study the impact of 1B1R wheats and non starch polysaccharides (NSP) on bioethanol yield and variation in grain composition over a range of grain N contents. Compare bioethanol processing yields of feed varieties at a fixed protein content. Conduct a desk review of the impact of enzymes on the bioethanol process and an assessment of enzymes on performance of feed wheats for bioethanol production.

Maximising the yield of high value components from wheat by fractionation

HGCA Project number 3176

Lead scientist	Richard Weightman, ADAS UK Ltd		
Partners	Nickerson-Advanta Ltd.		
	University of Manchester		
Start Date	01 May 2007	End date	31 October 2008
HGCA funding	£79,901	Total cost £84,901	

Project Aims: To define the variation in yields, purity and value of bran and starch-rich fractions from a range of wheat germplasm in order to inform the industry of the feedstock specification to optimise high value components for cereal biorefineries.

Approach: Study debranning technology for production of starch rich endosperm and clean bran. Determine how grain size and shape affects debranning and fractionation. Quantify starch and protein content of individual cereal fractions. Quantify the arabinoxylan content of different cereal fractions. Identity opportunities for the biorefining processing industry to extract added value from grain.

Optimising fertiliser nitrogen levels for modern cereal crops

HGCA Project number 3084

Lead scientist	Prof Roger Sylvester-Bradley, ADAS		
Partners	Scottish Agricultural College, Kemira, GrowHow		
Start Date	01 August 2004	End date 31 January 2008	
HGCA funding	£174,207	Total cost £201,207	

Project Aims: To provide evidence of the extent to which optimum amounts of fertiliser N for new, high-yielding varieties of winter wheat and spring barley differ from those for the lower yielding varieties used in the 1980s to develop national fertiliser recommendations (e.g. in RB209).

Approach: To set up a series of N response experiments in typical conditions (soils & locations) for winter wheat and spring barley. To establish amounts of N fertiliser as the main treatment difference in experiments on winter wheat and spring barley.

Managing nitrogen applications to new Group 1 and 2 wheat varieties

HGCA Project number 2700

Lead scientist	Mr Peter Dampney, ADAS		
Partners	ADAS Consulting Ltd		
Start Date	01 September 2002	End date	31 January 2006
Total cost	£114,264		

Project Aims: To develop optimum nitrogen fertiliser application practices for realising the high yield potential of modern Group 1 and 2 wheat varieties whilst also meeting the grain protein and Alveograph quality requirements set by both home and export markets.

Approach: To test if modern high yielding wheat varieties have different nitrogen requirements for achieving their yield potential, compared to older lower yielding varieties which form the scientific underpinning basis of current national standard fertiliser recommendations. To identify optimal methods for applying extra N in addition to that required for yield in order to achieve large increases in grain protein concentration, and to investigate the effect of different nitrogen management approaches on grain Alveograph values.

Nitrogen management in spring malting barley for optimum yield and quality

HGCA Project number 2660

Lead scientist	Mr Richard Overthrow, The Arable Group	
Partners	The Arable Group, Scottish Agricultural College Commercial Ltd	
Start Date	01 February 2002	End date 31 January 2005
HGCA funding	£124,063	

Project Aims: With an increasing requirement for higher grain nitrogen in malting barley caused by a move to lager production, traditional husbandry methods for spring barley are no longer appropriate. The project aims are therefore to identify the husbandry guidelines for spring malting barley grown under high levels of applied nitrogen fertiliser.

Approach: Determination of the relationship between increased nitrogen usage and plant growth regulator programmes on the yield and quality characteristics of spring barley. Exploration of the influence of seed rate under higher nitrogen and plant growth regulator programmes on both grain yield and grain quality characteristics, and determination whether nitrogen timing has an important influence on grain yield and grain quality characteristics when higher levels of nitrogen are used in the presence of plant growth regulators.

Adaptive optimization of spatial sampling: methods which could be used in automated mapping of soil

HGCA Project number 2453

Lead scientist	Dr R Murray Lark, Silsoe Research Institute		
Partners	Silsoe Research Institute		
Start Date	01 January 2002	End date	31 December 2004
HGCA funding	£25,173	Total cost	£167,812

Project Aims: The development of precision agriculture for extensively grown field crops is limited by the availability of adequate data on spatially variable properties of the soil, because of the substantial costs of field sampling and laboratory analysis. The aim of this project is to develop, test and demonstrate strategies to control automated field sampling and measurement of soil properties by means which minimize the sampling effort required to obtain soil information at required levels of precision.

Approach: Development of sampling schemes in which growing knowledge about the spatial variability of the variable being mapped is used to adapt the sampling so as to obtain information of adequate precision with high efficiency. To test these schemes using simulated data sets with realistic spatial properties and demonstrate schemes to prepare the ground for future application of emerging sensor technology within the industry that will enable cost-effective and reliable mapping of soil properties, resulting in reduced labour costs.

Integrated control of slugs in arable crops

HGCA Project number 2436

Lead scientist	Dr David M Glen, Styloma (*formerly Rothamsted Research*)		
Partners	Styloma, Rothamsted Research, ADAS Consulting Ltd, University of Newcastle-upon-Tyne		
Start Date	01 September 2001	End date	31 August 2005
HGCA funding	£178,074	Total cost	£443,548

Project Aims: Slugs cause serious damage to winter cereals and oilseed rape at establishment particularly where reduced cultivation and direct drilling are used. Current control relies mainly on baits, which is expensive and can cause collateral damage to other wildlife. Areas prone to slug damage are often treated prophylactically and can receive several applications where damage is prolonged. There is a need to improve the efficiency and targeting of current control methods. The aim of this project is to devise a rational risk assessment system for the integrated control of slugs in arable crops.

Approach: Assessment and quantification of the impact of key factors such as soil, weather and agronomic conditions, including the timing and method of pellet application, on control efficacy. Quantification of the relationships between slug populations and conditions in the previous crop to evaluate their use as a damage indicator in the succeeding crop. Development of a trapping system that is a reliable predictor of crop damage.

Revised thresholds for cabbage stem flea beetle

HGCA Project number 3023

Lead scientist	Dr Jon Oakley, ADAS		
Start Date	01 August 2004	End date	31 October 2007
HGCA funding	£66,044		

Project Aims: Threshold levels for pests are rarely exceeded in oilseed rape crops but pesticide usage remains high with 87% of crops treated in the autumn and 55% treated in the spring. Much of the insecticide usage targeted on cabbage stem flea beetle is disproportionate to the likely risk of attack due to difficulties in assessing risk in time to take action. The aim of this work is to reducing insecticide usage in oilseed rape to the minimum amount required to protect the crop.

Approach: To establish the relationships between water and sticky trap catches and the incidence of adult feeding damage and larval numbers and to determine whether the results from the monitoring for adult cabbage stem flea beetles and plant damage at early crop growth stages (GS 1,1-1,2) can be reliably and easily used to determine the need for autumn treatment with a pyrethroid insecticide.

Appropriate doses network: new fungicide performance information for wheat growers

HGCA Project number 2497

Lead scientist	Neil Paveley, ADAS		
Partners	ADAS High Mowthorpe, Rothamsted Research, The Arable Group, Scottish Agricultural College		
Start Date	01 May 2001	End date	31 May 2005
HGCA funding	£371,699	Total cost	£371,699

Project Aims: Recent work has established HGCA as the key source of independent fungicide performance information. Comparative eradicant and protectant dose-response curves, and interpretation, have been communicated to the industry through the HGCA Wheat Disease Management Guide, and updates. The main aim of this current project is to keep fungicide dose-response information for HGCA members 'live' and up to date, by quantifying:

1. the biological and economic performance of novel active ingredients, and
2. changes in the dose of established products required to achieve effective control, due to shifts in pathogen sensitivity.

Approach: To test whether the addition of strobilurin to a triazole based treatment is economically justified by yield/quality responses to (i) control of remaining sensitive Septoria tritici strains, (ii) control of rusts, and (iii) physiological benefits to canopy light interception and duration. Where strobilurin treatment is justified, to quantify at what dose. To test alternative and novel active ingredients, currently in the pipeline, to: (i) broaden the mode of action base of disease control to reduce the risk of further resistance problems threatening disease management, and (ii) identify those new products which demonstrate improved performance. To check the extent to which dose-response curves (and hence appropriate doses) for important triazole fungicides may have shifted due to quantitative resistance and to act as an early warning for shifts in other mode of action groups.

Pest and disease mAnagement System for Supporting Winter Oilseed Rape Decisions (PASSWORD)

HGCA Project number 2155

Lead scientist	Dr Peter Gladders, ADAS		
Partners	ADAS Consulting Ltd, Central Science Laboratory, Rothamsted Research, Scottish Agricultural College		
Start Date	01 October 2000	End date	30 September 2005
HGCA funding	£148,546	Total cost	£478,092

Project Aims: Crop losses from diseases of oilseed rape are significant, despite a large investment in fungicides. Stem canker and light leaf spot are serious problems for the industry. Seasonal, regional and within farm variation is known to occur and this provides a major challenge when deciding on appropriate fungicide inputs. The project aim is to construct a decision support system for management of diseases and pests in autumn on winter oilseed rape.

Approach: Development of regional forecasts of risk for stem canker in England and for light leaf spot in Scotland. Development of crop-specific forecasts of risk of stem canker and light leaf spot epidemics. Production of a system to guide autumn disease management, integrated with pest management. To test disease forecasts and assessments of yield loss in field experiments and through user appraisal to reduce unnecessary use of pesticides.

Development of a risk assessment method to identify wheat crops at risk from eyespot

HGCA Project number 2382

Lead scientist	Dr Fiona Burnett, Scottish Agricultural College		
Partners	Scottish Agricultural College, Central Science Laboratory, Scottish Agronomy Research Ltd (SAC), Velcourt Ltd		
Start Date	01 August 2000	End date 29 February 2004	
HGCA funding	£241,055	Total cost	£252,305

The Problem

Project Aims: Identifying which crops will benefit from fungicide applications at stem extension to control eyespot is difficult. The currently recommended disease threshold for treatment of eyespot is widely known to be of limited use, so an alternative method with built-in predictive capability is required. The aim of this project is to provide growers with a rationale for deciding which crops will give a cost effective response to fungicide treatment based on an assessment of disease risk.

Approach: The factors that influence the development of eyespot in the crop will be assessed and a risk weighting applied to each factor. The relative importance of these factors will be assessed for different geographical area and cropping situations. The data will be utilised to produce an accurate eyespot risk forecast, which will be validated using data from independent field trials and survey data.