Land Use Policy Group

The UK statutory conservation, countryside and environment agencies

Exploring the Concept of Sustainable Intensification

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www.lupg.org.uk

Environment Agency
Cyngor Cefn Gwlad Cymru Countryside Council for Wales
Natural England
SEPA Scottish Environment Protection Agency
Scottish Natural Heritage All of nature for all of Scotland
NIEA Northern Ireland Environment Agency www.ni-environment.gov.uk

LUPG

LUPG comprises the Countryside Council for Wales, Natural England, Environment Agency, Northern Ireland Environment Agency, Joint Nature Conservation Committee, Scottish Environment Protection Agency and Scottish Natural Heritage.

LUPG provides independent evidence and analysis to Government on matters of common concern related to agriculture, woodlands and other rural land uses. It seeks to develop a common understanding of the pros and cons of policy mechanisms related to land use, particularly farming and forestry.

www.lupg.org.uk

Countryside Council for Wales

The Countryside Council for Wales champions the environment and landscapes of Wales and its coastal waters as sources of natural and cultural riches, as a foundation for economic and social activity, and as a place for leisure and learning opportunities. It aims to make the environment a valued part of everyone's life in Wales.

From 1 April 2013, Natural Resources Wales will take over the functions currently carried out by the Countryside Council for Wales, Environment Agency Wales and Forestry Commission Wales.

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www.snh.org.uk

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The Environment Agency (EA) is the leading public organisation for protecting and improving the environment in England and Wales. The EA achieves this by regulating industry, waste and water quality; managing flood risk and water resources, and improving wildlife habitats in addition to many other activities. The EA also monitors the environment, and makes the information that it collects widely available.

www.environment-agency.gov.uk

Northern Ireland Environment Agency

The Northern Ireland Environment Agency takes the lead in advising on, and in implementing, the Government's environmental policy and strategy in Northern Ireland. The Agency carries out a range of activities, which promote the Government's key themes of sustainable development, biodiversity and climate change. Our overall aims are to protect and conserve Northern Ireland's natural heritage and built environment, to control pollution and to promote the wider appreciation of the environment and best environmental practices.

www.ni-environment.gov.uk

The Scottish Environment Protection Agency

The Scottish Environment Protection Agency (SEPA) is Scotland's environmental regulator. SEPA's main role is to protect and improve the environment, and it does so by regulating activities that can cause pollution, and by monitoring the quality of Scotland's air, land and water. SEPA reports on the state of Scotland's environment and publishes a wide range of environmental data and information.

www.sepa.org.uk

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Website: www.lupg.org.uk

Foreword

Hunger and food insecurity affect growing numbers of people worldwide. Although at present these things can largely be attributed to inequalities in purchasing power and failures in distribution, the predicted rise in the global population will inevitably increase the global demand for food. Meanwhile, the nature of the demand is changing, as emerging economies shift to higher-protein diets. These pressures on our productive capacity are likely to be exacerbated by a rise in global temperatures, changing weather patterns, and competition for land, energy and water. They will affect not only the global food system, but also the other ecosystem services which underpin agricultural production or are associated with it[1].

A previous LUPG report considered various aspects of food security and its link to environmental security - including the requirement for food production in Europe, reducing the environmental footprint, the application of new technology, and changing patterns of land use[2]. This work was the starting point for the present study.

The Foresight report on the Future of Food and Farming, describes sustainable intensification as *"simultaneously raising yields, increasing the efficiency with which inputs are being used and reducing the negative environmental effects of food production"*[3]. In embarking on this project, we were mindful that the debate about food security involves many strands -reductions in waste, healthier diets, improvements in distribution and the affordability of basic foodstuffs are all critically important. From LUPG's viewpoint, however, we need a better understanding of the land-use issues involved, both for the UK and for Europe[4,5].

This report presents evidence from twenty case-studies of farms in GB, about how far farmers have been able to increase yields while, as a direct outcome, reducing negative impacts on the environment. It also highlights cases where farmers have gone further – improving biodiversity and landscape quality, and reducing emissions to air and water at the same time as increasing food production. The sample as a whole shows a considerable capacity for innovation among the farmers involved.

From these case studies we also wanted to know how the results were achieved - did the successful farmers encounter particular obstacles, for instance? Most of the farms are in agri-environment schemes, but do other rural development measures play an important part? If so, what are the implications for the next round of Rural Development Programmes?

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[1] *Agriculture at a Crossroads*. International assessment of agricultural knowledge, science and technology for development (IAASTD): Global report 2009. Accessible at: http://www.agassessment.org/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Global%20Report%20(English).pdf

[2] *Scoping the development of the Environmentally Sustainable Production Agenda, IEEP report for LUPG. 2010. Accessible at: http://www.ieep.eu/topics/agriculture-and-land-management/*

[3] *Foresight. The Future of Food and Farming (2011) Final Project Report. The Government Office for Science, London*

[4] *Proposal for a Regulation of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD). 12th October 2011. See Article 61 – European Innovation Partnership for agricultural productivity and sustainability. Accessible at: http://ec.europa.eu/agriculture/cap-post-2013/legal-proposals/com627/627_en.pdf*

[5] *The Natural Choice; Securing the Value of Nature. Natural Environment White Paper, June 2011. The commitment to 'look at ways of reconciling the objectives for increased food production and better protection of the environment ...' has now been taken forward under the Green Food Project report, Defra, July 2012.*

Since the case studies included only twenty farms the initial findings from the project were tested against a wider range of opportunities and experience in three focus groups.

Clearly, further evidence is required to improve our understanding of the opportunities for sustainable intensification and of its limits. This study is best viewed as an exploratory one. We hope others will use it to inform further research and other approaches. An obvious first step would be to examine a wider range of indicators, representing a wider range of farming systems and practices over a longer period.

Peter Pitkin
Scottish Natural Heritage
Chair of Land Use Policy Group

Acknowledgements

None of the work described in this report would have been possible without the co-operation of the case study farmers, who not only made their own records available, but were prepared to discuss them in detail with the members of the research team. We would also like to thank all of those who participated in the three farmer focus groups and who allowed us an insight into their business objectives as well as their individual perspectives on the sustainable intensification concept.

We are also very grateful to all those who commented on the initial project findings during the pre-publication seminar that took place on 20th September 2012. In particular we would like to thank Ali Cargill (Director of Case Study Farm A2); Andrea Graham (National Farmers Union); Dr Tara Garnett (Food Climate Research Network); Professor Alan Buckwell (Institute for European Environmental Policy); Lee McDonough (Department for Environment, Food and Rural Affairs); Professor Ian Crute (Agriculture and Horticulture Development Board) and Professor Jules Pretty (University of Essex).

The two principal authors of the report, John Elliott (ADAS) and Professor Les Firbank (Firbank Ecosystems Ltd) developed the methodology and carried out the overall analysis whilst being ably supported by a team of farm advisors from ADAS who worked on the individual case studies. Finally, Margaret Griffiths and Bryn Thomas (Welsh Government) contributed valuable insights throughout the process as did the rest of the LUPG Steering Group comprising James Petts and Graeme Kerr (Natural England) alongside Maria de la Torre and Cécile Smith (Scottish Natural Heritage).

Brian Pawson
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LUPG Project Steering Group

Executive Summary

The concept of 'sustainable intensification' (SI) of global agriculture, in which yields are increased without adverse environmental impact and without the cultivation of more land, was promoted by the Royal Society, against the backdrop of increasing future demand for food, whilst needing to safeguard the ecosystem services underpinning agricultural production. The concept was developed in more detail by a highly influential Foresight report in 2011.

In broad terms, the relationship between food production and levels of other ecosystem services is essentially inverse within contemporary British agriculture, as shown in Fig. 1. SI of an individual farm, as defined by the Royal Society, would result in it increasing its agricultural yield, with no additional impacts on the environment, i.e. arrow **a** in Fig. 1. Some authors consider that SI should involve a win-win, with increases in both food production and the flow of ecosystem services (e.g. Firbank (2009), Pretty et al. (2011)), i.e. arrow **b**. SI would also include farms that have made environmental improvements and minor increases in yield (arrow **c**). Arrows **a** and **c** therefore represent the limits of SI as defined by the Royal Society and by this study. Arrow **d** represents the situation where the environment has been improved and food production has stayed constant; this is not regarded as SI in this study, though it is recognised that it represents an improvement over the *status quo ante*.

Sustainable intensification also applies to those situations where the land is performing below its potential, i.e. falls below the line in Fig 1. In this study we have focused on progressive farms, so that we expect them to be at or close to the production / ecosystem services frontier.

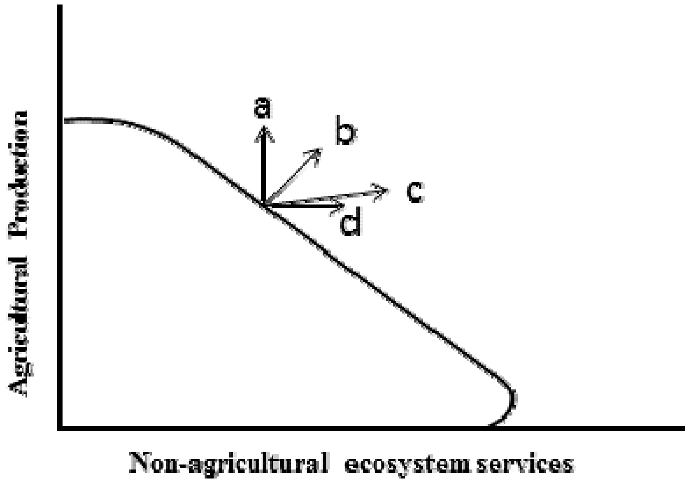


Figure 1: Conceptualisation of sustainable intensification of farms within a UK context

The purpose of this study is to provide quantified evidence, using farm level case studies, of the environmental and production gains occurring in situations where farm management is thought to be consistent with a "*sustainable intensification approach*".

Methodology

Our approach was to identify a sample of farms that appeared to be adopting sustainable intensification, quantify changes over time across a suite of ecosystem services (including food production) and then to see if these findings could be validated by using focus groups made up of other farmers more typical of the industry as a whole.

Case study farms were selected on the basis that they were considered to be innovative by their peers and with a view to capturing a range of different production approaches. The chosen farms were also required to represent the major farm types across the three GB countries. Our assessment period comprised the last five years, generally from 2005-06 to 2010-11, taking two snapshots of performance in the baseline and latest year in order to gauge the extent of any changes.

We focused on five major categories of ecosystem services that have been highlighted during the UK National Ecosystems Assessment, namely agricultural production, biodiversity, climate regulation, landscape and regulation of water quality. Other aspects such as the extent of water use or changes in other ecosystem services strongly linked to food production have been noted in the narrative component of the case studies, but not quantified.

Three focus groups were held to provide a broader perspective on the sustainable intensification concept, each representing a discrete farm type, namely arable, dairy and LFA livestock. Participating farmers were presented with information on the SI concept as well as headline results from the cases studies in order to explore their awareness of the topic, its relevance to their business and their responses to the main findings of the project.

Metrics

A key methodological issue was the selection of suitable indicators for this study. All of the area-based indicators take account of land on the farm not being used for food production (this contributes to other ecosystem services) as well as any land used off farm, for example to generate purchased animal feed etc.

For food production, we used a measure of gross energy per hectare of land in order to aggregate the output of all commodities on the farm, from crops to meat, milk and eggs. This approach uses readily available output volume data (net produce sold) but has limitations in that it cannot differentiate between animal and crop protein, nor does it allow for absolute nutritional value or the market attributes of produce (such as organic) to be taken into account. The alternative was to use the aggregate economic value of produce sales but this tends to reflect market demand and is less relevant to quantifying the volume of food production, which lies at the heart of the food security debate.

For environmental indicators we have taken farm data on livestock numbers, cultivated area and inputs (fuel, fertilisers etc.) and used published values for environmental impact and existing models (FARMSCOPER[6] and CALM[7]) to convert these into the levels of pollutants and carbon footprints. These values are again presented on a per hectare basis, although we have also presented data on carbon footprints per unit of gross energy produced to highlight changes in emissions intensity.

Biodiversity and landscape quality could not be assessed directly from farm records, so we followed the UK Biodiversity Indicators programme and collected data such as presence of habitats, and membership of agri-environmental schemes to indicate the potential for changes in biodiversity and landscape quality. Therefore the scores for these indicators do

[6] FARMSCOPER is a decision support tool that can be used to assess diffuse agricultural pollutant loads on a farm and quantify the impacts of farm mitigation methods on these pollutants. It also determines potential additional consequences of mitigation method implementation for biodiversity, water use and energy use.

[7] CALM is a free web-based calculator designed by the CLA to help land managers work out the balance of greenhouse gases emitted by farming businesses, i.e. emissions from energy and fuel use, livestock, cultivation and land-use change and the application of nitrogen fertilisers, set against the carbon stored in their trees and soil.

not capture habitat quality, species abundance/ conservation value or landscape character. In addition, the landscape and biodiversity scores were highly correlated and so we focused on the biodiversity scores at the whole farm level.

Overview of case study farms

An overview of the farms studied is given below in Table 1.

Table 1: Distribution of case study farms by type and country

	England	Scotland	Wales	Total
Arable	5	2	-	**7**
Mixed	2	2	-	**4**
Dairy	1	1	2	**4**
LFA Livestock	1	1	3	**5**
Total	**9**	**6**	**5**	**20**

Farms range in size from 102 – 1821 ha. Crops include sugar beet and potatoes, cereals and oilseeds, as well as soft fruit and field vegetables. Livestock enterprises include dairy cattle, beef cattle, sheep, pigs and poultry. Two farms were in organic production. Seventeen of the twenty farms were participating in an agri-environment scheme in 2011 and fourteen had installed on-farm renewable energy schemes or were planning to do so.

Inter-relationships between food production and environmental variables

Food production per unit area at baseline varied greatly between farm types, ranging from a mean of 8 GJ ha^{-1} for the upland farms, 30 GJ ha^{-1} for dairy, 52 GJ ha^{-1} for mixed farms, and around 100 GJ ha^{-1} for arable farms. This variation by sector reflects the chosen metric, gross energy, and plainly favours crops over livestock. For example, whilst meat has an energy value of 5-6 GJ $tonne^{-1}$, the figure for cereals is three times greater. In addition only a proportion of each animal (between one and two thirds of live weight) is actually consumed. As meat production is the only available form of sustainable production over much of upland GB, where land quality also limits food production per unit area, it is important to focus on the change in the indicator rather than its absolute value. Many upland farms also have significant stocks of other ecosystem services such as carbon storage, landscape and cultural capital and would be expected to be to the right-hand-side of the graphic at Fig 1.

No decreases in production over the study period were seen among dairy farms. All other farm types exhibited both production increases and decreases. In some instances these were related to genuine productivity gains whilst for other farms the picture was obscured by changes in the enterprise mix and seasonal effects on yields.

For environmental pollution, the indicators were based on high level variables such as the number of livestock, area under cultivation and inputs used. In a technologically static context, any changes in these indicators would provide a good measure of how farms were tackling pollution pressures; however, many of the case study farms were implementing relatively novel practices to mitigate environmental impact and the indicators and models that we used were not capable of capturing this. Examples from the arable case studies include the use of precision farming to match inputs to crop requirements, investment in energy efficient equipment, the use of buffer strips and reduced tillage. For livestock systems, the focus was largely on managing manures to avoid nutrient losses and maintaining or improving animal health productivity.

The biodiversity indicator measured the stock in the baseline year as well as change over time. The stock scores favoured farms with several types of habitat, whilst the change scores emphasised actions designed to enhance habitat diversity on farm, rather than to maintain existing high quality habitats.

Whilst the overall baseline relationship between food production and other ecosystem services was negative, the exact nature of this relationship differed between farm types (see Figure 2).

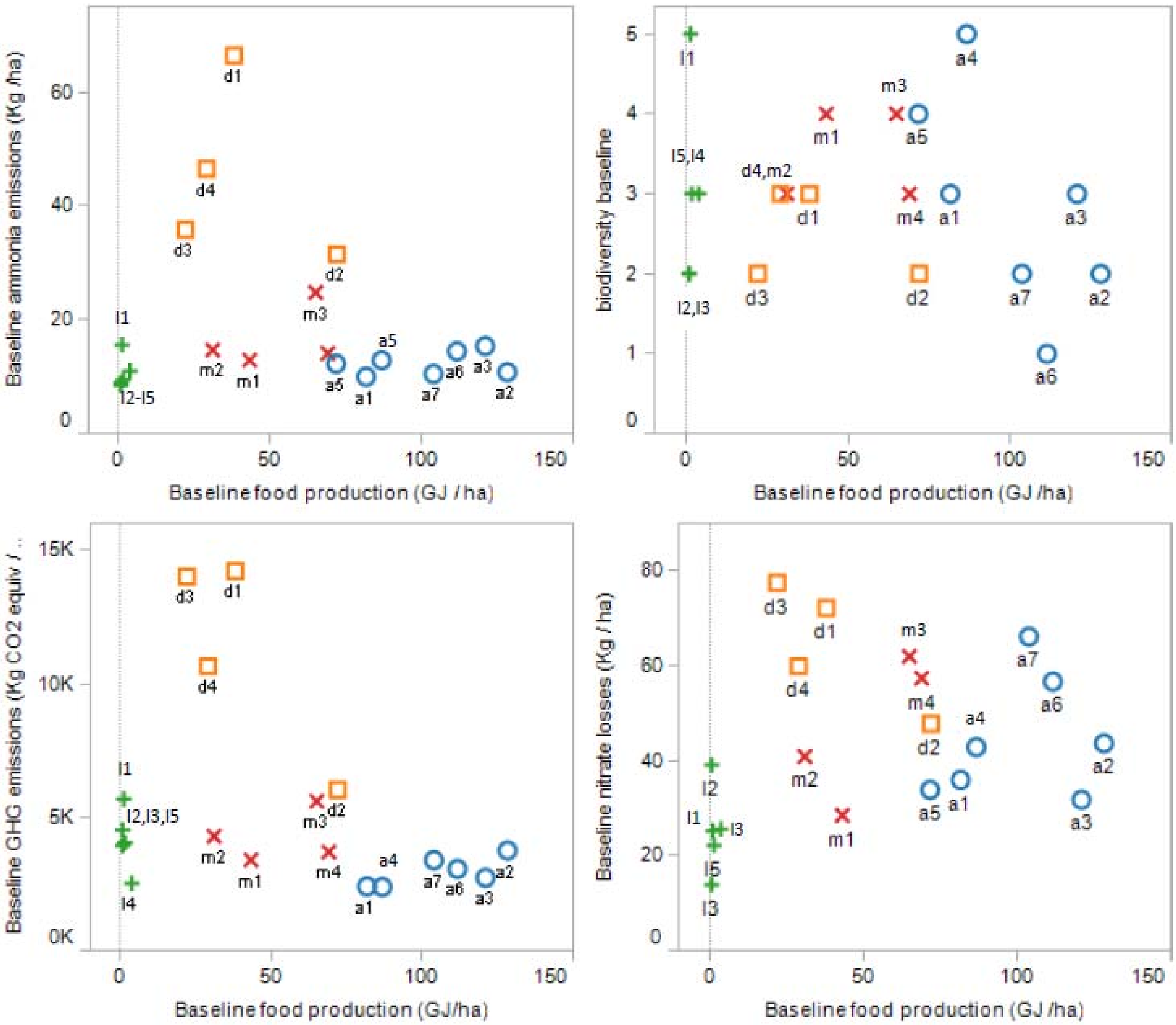


Figure 2: Relationships among baseline environmental variables and food production

The units are: Ammonia and nitrate emissions are Kg ha-1; Biodiversity is a score; carbon footprint is kg CO2 equiv/ha; food is GJ /ha. Individual farms are shown, labelled where space allows, grouped into farm type by colour and symbol: Arable farms shown with blue circles, coded A: Dairy farms shown with orange squares, coded D: LFA livestock farms shown with green crosses, coded L and Mixed farms shown with red cross, coded M.

In general terms, dairy farms exhibited the highest levels of ammonia and GHG emissions, whilst nitrate emissions were lowest among the upland livestock farms, and were often highest among the dairy farms. Biodiversity scores showed a great deal of variation both within and between all of the sectors.

How food production and environmental performance changes over time

Evidence for sustainable intensification comes from those farms that have enhanced both food production and environmental quality since the baseline. Of the twenty farms studied, the best evidence for sustainable intensification comes from four examples; two arable, one mixed and an LFA farm. In these cases, food production has increased by 10% or more;

losses of ammonia, nitrates and GHGs have been held static or reduced and biodiversity has been enhanced (Figure 3).

Again, there are differences between the various farm types. The three dairy farms that increased production also increased pollution levels per unit area, but emissions intensity (GHG per unit of gross energy produced) declined. Also, some farms adopted strategies where the impacts were not well captured by our approach; for example case study A3 operates a “no-till” system which has significantly increased soil organic matter and enhanced soil fauna, supporting wider biodiversity as well as improving soil moisture retention.

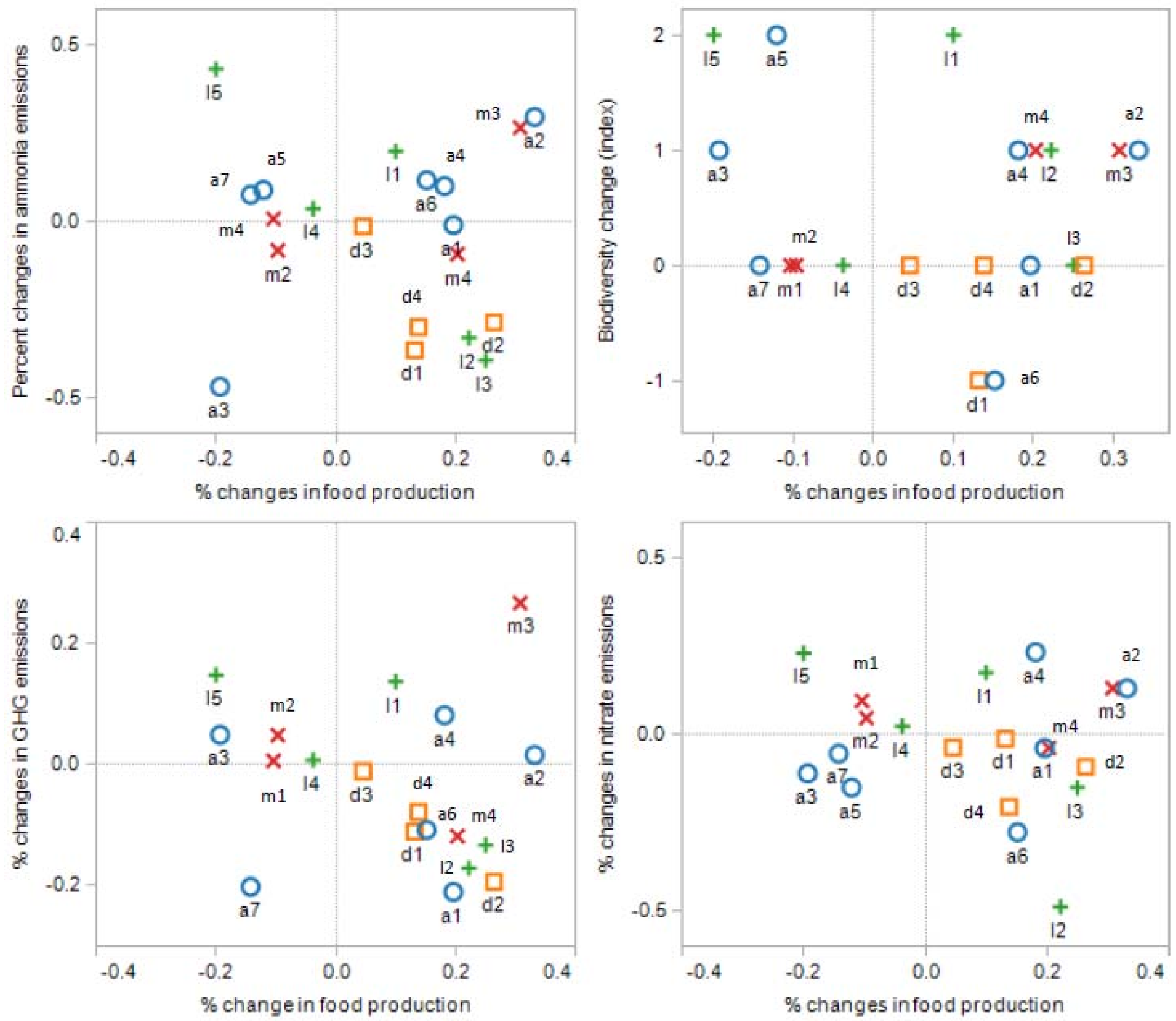


Figure 3: Changes in environmental variables and food production for individual farms

In each case, the top right quadrant represents improvements in both food production and environment bottom left a reduction in both. Percent changes in emissions and food production are provided; emissions are re-signed so that an increase in emissions is shown as negative. Biodiversity changes are scores. See Fig 2 for labelling. Farms A2, A4, M3 and L1 are consistently in the top right quadrants, giving evidence that these farms have undergone sustainable intensification.

There was consensus among both case study farms and participants in focus groups that enhancements to biodiversity were best done on less productive land (a land sparing approach) but this is reliant on financial support in the form of agri-environment schemes or other means.

Farms strategies adopted by case study farms

It is important to consider what strategies were used by those farms that did achieve SI. Key components for the four farms that achieved SI are:

- Farm A2 worked closely with the supply chain to increase yields and reduce environmental impacts, with significant investment in technology to improve input efficiency.
- Farm A4 used a twin approach, taking poorer land out of production and focusing on resource efficient farming (minimum tillage, precision farming etc) on the remainder.
- Farm M3 used enterprise change, notably increasing the crop area at the expense of livestock numbers, alongside renewable energy and precision farming; agri-environment schemes were used on poorer land.
- Farm L1 made system changes, reducing livestock numbers but improving productivity through breed change, alongside a strong focus on conservation supported by agri-environment schemes.

Several farms increased food production at the expense of environmental quality per unit land. This was particularly noticeable among those farms that have sought to increase milk and meat production, i.e. dairy farms D1, D2 and D4, and the LFA farms L2 and L3. Despite investments to increase the efficiency of resource use, increased outputs tended to be highly associated with emissions of ammonia, nitrate and GHGs per unit area, although losses per unit of production were much more stable.

One farm (L5) was in the process of conversion to organic status and demonstrated environmental enhancement in combination with a decline in food production.

Finally, several farms (A3, A5, A7 M1, M2, D3 and L4) achieved neither significant yield increases nor environmental improvements between the two points in time. This is often affected by enterprise change or seasonal factors, or a combination of both.

Key findings

1. *This project can be viewed as a pilot study, identifying some of the principal issues involved in designing and implementing a system for collecting and interpreting the kinds of farm-level data needed to quantify the strategic changes taking place within UK agriculture, including sustainable intensification.*
2. *This project has not revealed an overall negative relationship between food production and other ecosystem services among the case study farms, although only a minority of farms have increased both parameters simultaneously. This may be because the set of variables was too limited. Ideally, a wider set of ecosystem services should be included, alongside measures of critical natural capital, e.g. soil carbon, water use and the presence of rare species and habitats. Any quantification of ecosystem services from individual farms is highly sensitive to the selection of indicators, how they are measured and over what timescale, and how they are weighted. It may be appropriate to restrict comparisons to within farm types.*
3. *It is possible to assess the sustainable intensification of individual farms using data already available to them, in ways that can distinguish farms and farm types in terms of strategy and outcomes. It is preferable to use a series of observations over time rather than just two discrete snapshots.*
4. *This project provides evidence that sustainable intensification has been practised by some farms in the UK in recent years. This evidence was most consistent in the area of*

reduction in pollution. However, a number of farms which increased food production also saw an adverse impact on environmental quality, indicating a trade-off between the two.

5. *The major driver of farm strategy is profitability, often alongside an ambition to improve the environmental performance of the farm: farmers engage to some extent with the concept of SI, albeit unknowingly. Using new technology and innovative practices to reduce pollution can add to profitability and environmental quality through improving the efficiency of utilisation of increasingly expensive inputs of nutrients and energy. Improved environmental performance may also be part of securing better market access or premium prices.*

6. *Different farm types and farming systems have different possibilities for sustainable intensification. In particular, dairy systems have relatively high levels of environmental impact linked to methane and the pollutants in manures. The results suggest that there may be limitations in terms of the SI concept for the livestock industry, where increased productivity is likely to be associated with higher input intensity (though not exclusively) and higher emissions per unit land (but not per unit of food production) given current farming methods and application of technologies. For example, SI may not be an appropriate strategy in the uplands, where other ecosystem functions such as water quality, carbon storage, landscape and biodiversity may have a greater social value than increases in food production.*

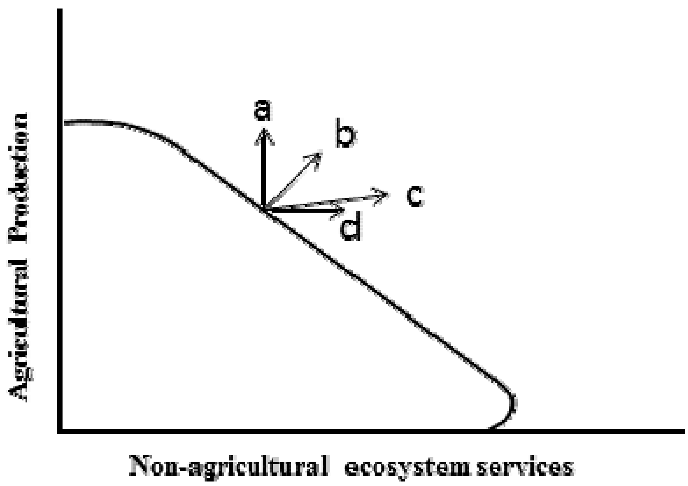
7. *Actions to enhance and maintain biodiversity are largely a cost to the farm business, and often require external financial support (such as agri-environment schemes) for their continued maintenance, even where the farmers concerned value biodiversity for its own sake. The default approach appears to involve the use of the least productive land on the basis of least cost to the business, rather than decisions being informed by the best possible environmental outcome in return for the payments being made; this issue is particularly relevant to AES design. As well as the need for ongoing support payments to underpin the provision of public environmental goods and services, such as biodiversity and landscape, there is a case for increased support in the form of information provision, advice and associated research programmes if the process of sustainable intensification is to be supported.*

Crynodeb Gweithredol

Mae 'dwysáu cynaliadwy' yn golygu cynhyrchu mwy o gnydau heb gael effaith amgylcheddol niweidiol a heb drin rhagor o dir. Cafodd y cysyniad hwn o 'ddwysáu cynaliadwy' ym maes amaethyddiaeth fyd-eang ei hybu gan y Gymdeithas Frenhinol mewn cyd-destun o fwy a mwy o alw am fwyd yn y dyfodol, ar yr un pryd â'r angen i ddiogelu'r gwasanaethau ecosystem sy'n sail i gynhyrchu amaethyddol. Cafodd y cysyniad ei ddatblygu'n fanylach mewn adroddiad Foresight dylanwadol iawn yn 2011.

Yn gyffredinol, mae'r berthynas rhwng cynhyrchu bwyd a lefelau gwasanaethau ecosystem eraill yn mynd yn groes i'w gilydd mewn amaethyddiaeth gyfoes ym Mhrydain, fel y gwelir yn Ffigur 1. Yn ôl diffiniad y Gymdeithas Frenhinol byddai defnyddio dwysáu cynaliadwy mewn un fferm yn arwain at gynyddu ei chnwd amaethyddol, heb effeithiau ychwanegol ar yr amgylchedd, hy saeth **a** yn Ffigur 1. Mae rhai awduron yn credu y dylai dwysáu cynaliadwy olygu enillion i'r naill ochr a'r llall, gyda chynnydd yn faint o fwyd sy'n cael ei gynhyrchu a llif gwasanaethau ecosystem (ee Firbank (2009), Pretty et al. (2011)), hy saeth **b**. Byddai dwysáu cynaliadwy hefyd yn cynnwys ffermydd sydd wedi gwneud gwelliannau amgylcheddol ac sy'n gweld cynnydd bach yn eu cnwd (saeth **c**). Felly mae saethau **a** ac **c** yn cynrychioli cyfyngiadau dwysáu cynaliadwy fel y caiff ei ddiffinio gan y Gymdeithas Frenhinol a gan yr astudiaeth hon. Mae saeth **d** yn cynrychioli'r sefyllfa lle mae'r amgylchedd wedi gwella ac mae cynhyrchu bwyd wedi aros ar yr un lefel; ni chaiff hyn ei ystyried fel dwysáu cynaliadwy yn yr astudiaeth hon, er cydnabyddir bod hyn yn golygu bod y sefyllfa gyfredol wedi gwella.

Mae dwysáu cynaliadwy hefyd yn berthnasol i'r sefyllfaoedd hynny pan na fydd y tir yn gwneud cystal â'i botensial, hy bydd yn disgyn o dan y llinell yn Ffigur 1. Yn yr astudiaeth hon rydym wedi canolbwyntio ar ffermydd blaengar, felly rydym yn disgwyl iddynt fod ar y blaen neu'n agos at y blaen o ran cynhyrchu / gwasanaethau ecosystem.



Ffigur 1: Cysyniad dwysáu cynaliadwy ffermydd yng nghyd-destun y DU

Drwy ddefnyddio astudiaethau achos lefel fferm, diben yr astudiaeth hon yw rhoi tystiolaeth wedi'i meintoli o'r enillion o ran yr amgylchedd ac o ran cynhyrchu a geir mewn sefyllfaoedd pan ystyrir bod rheoli'r fferm yn cyd-fynd â "dull gweithredu dwysáu cynaliadwy".

Methodoleg

Ein dull gweithredu oedd dod o hyd i sampl o ffermydd a oedd yn ymddangos fel petaent yn mabwysiadu dwysáu cynaliadwy, mesur y newidiadau dros amser ar draws cyfres o wasanaethau ecosystem (gan gynnwys cynhyrchu bwyd) ac wedyn gweld a oedd modd dilysu'r canfyddiadau hyn drwy ddefnyddio grwpiau ffocws a oedd yn cynnwys ffermwyr eraill a oedd yn fwy nodweddiadol o'r diwydiant drwyddo draw.

Cafodd ffermydd yr astudiaethau achos eu dewis ar y sail eu bod eu cymheiriaid yn eu hystyried fel rhai arloesol, a gyda'r bwriad o gofnodi amrywiaeth o ddulliau cynhyrchu gwahanol. Roedd gofyn i'r ffermydd dan sylw hefyd gynrychioli'r prif fathau o ffermydd ar draws tair gwlad Prydain Fawr. Roedd cyfnod ein hasesiad yn edrych dros y pum mlynedd diwethaf, yn gyffredinol rhwng 2005-06 a 2010-11, gan edrych ar ddau gipolwg o berfformiad; un yn y waelodlin ac un yn y flwyddyn ddiweddaraf er mwyn mesur unrhyw newidiadau.

Roeddem wedi canolbwyntio ar bum prif gategori o wasanaethau ecosystem a amlygwyd yn ystod Asesiad Ecosystemau Cenedlaethol y DU, sef cynhyrchu amaethyddol, bioamrywiaeth, rheoleiddio hinsawdd, tirwedd a rheoleiddio ansawdd dŵr. Mae adrannau naratif yr astudiaethau achos yn cynnwys gwybodaeth am agweddau eraill fel faint o ddŵr a oedd yn cael ei ddefnyddio neu newidiadau mewn gwasanaethau ecosystem eraill sydd â chysylltiad cryf â chynhyrchu bwyd, ond ni chafodd yr agweddau hyn eu mesur.

Cynhaliwyd tri grŵp ffocws i roi persbectif ehangach ar y cysyniad o ddwysáu cynaliadwy, roedd pob un yn cynrychioli math penodol o fferm, sef âr, llaeth a da byw ALFf. Cafodd y ffermydd a oedd yn cymryd rhan wybodaeth am y cysyniad o ddwysáu cynaliadwy yn ogystal â'r prif ganlyniadau o'r astudiaethau achos er mwyn edrych ar eu hymwybyddiaeth o'r pwnc, pa mor berthnasol ydyw i'w busnesau a'u hymatebion i brif ganfyddiadau'r prosiect.

Metreg

Un mater methodolegol allweddol arall oedd dewis dangosyddion addas ar gyfer yr astudiaeth hon. Mae'r holl ddangosyddion sy'n seiliedig ar ardal yn ystyried tir ar y fferm nad yw'n cael ei ddefnyddio i gynhyrchu bwyd (mae hyn yn cyfrannu at wasanaethau ecosystem eraill) yn ogystal ag unrhyw dir a ddefnyddid oddi ar y fferm, er enghraifft i gynhyrchu porthiant anifeiliaid a oedd yn cael ei brynu ac ati.

Ar gyfer cynhyrchu bwyd, roeddem wedi defnyddio mesuriad ynni crynswth fesul hectar o dir er mwyn cronni allbwn holl nwyddau'r fferm, o gnydau i gig, llaeth ac wyau. Mae'r dull gweithredu hwn yn defnyddio data swmp allbwn sydd ar gael yn hawdd (cynnyrch net a werthir) ond mae ganddo gyfyngiadau gan nad yw'n gallu gwahaniaethu rhwng protein cnydau ac anifeiliaid, ac nid yw'n ystyried caniatáu ar gyfer gwerth maethol absoliwt chwaith na phriodoleddau marchnad y cynnyrch (fel organig). Y dewis arall oedd defnyddio gwerth economaidd cronnus gwerthiant cynnyrch ond mae hyn yn tueddu i adlewyrchu'r galw yn y farchnad ac mae'n llai perthnasol i fesur swmp y bwyd a gynhyrchir, sydd wrth galon y ddadl diogelwch bwyd.

Ar gyfer dangosyddion amgylcheddol rydym wedi cymryd data fferm ar niferoedd da byw, ardaloedd wedi'u trin a mewnbynnau (tanwydd, gwrtaith ac ati) ac rydym wedi defnyddio gwerthoedd wedi'u cyhoeddi ar gyfer yr effaith amgylcheddol a modelau sydd eisoes yn bodoli (FARMSCOPER[8] a CALM[9]) i drosi'r rhain i lefelau llygryddion ac ôl troed carbon. Caiff y gwerthoedd hyn eu cyflwyno unwaith eto ar sail fesul hectar, er ein bod hefyd wedi

[8] Mae FARMSCOPER yn declyn i helpu i wneud penderfyniadau. Mae modd ei ddefnyddio i asesu llwythi llygredd amgylcheddol gwasgaredig ar fferm a mesur effeithiau dulliau lliniaru ffermydd ar y llygryddion hyn. Mae hefyd yn pennu canlyniadau ychwanegol posibl gweithredu dulliau lliniaru ar gyfer bioamrywiaeth, defnyddio dŵr a defnyddio ynni.

[9] Mae CALM yn gyfrifiannell sydd ar gael am ddim ar y we. Cafodd ei dylunio gan Gymdeithas Tir a Busnes Cefn Gwlad i helpu rheolwyr tir i gyfrifo'r cydbwysedd o nwyon tŷ gwydr sy'n cael eu hallyrru gan fusnesau ffermio, hy allyriadau o ddefnyddio ynni a thanwydd, da byw, trin y tir a newid defnydd tir a rhoi gwrteithiau nitrogen, drwy gymharu hynny â'r carbon sydd wedi'i storio yn eu coed a'u pridd.

cyflwyno data ar ôl troed carbon fesul uned o ynni crynswth a gynhyrchir i ddangos y newidiadau mewn dwysedd allyriadau.

Nid oedd modd asesu ansawdd tirwedd a bioamrywiaeth yn uniongyrchol o gofnodion ffermydd, felly roeddem wedi dilyn rhaglen Dangosyddion Bioamrywiaeth y DU a chasglu data fel presenoldeb cynefinoedd ac aelodaeth o gynlluniau amaeth-amgylcheddol i ddynodi'r potensial am newidiadau mewn ansawdd tirwedd a bioamrywiaeth. Felly nid yw'r sgoriau ar gyfer y dangosyddion hyn yn cofnodi ansawdd cynefin, amlygrwydd rhywogaeth/gwerth cadwraeth na chymeriad tirwedd. Ar ben hynny roedd perthynas agos iawn rhwng y sgoriau tirwedd a bioamrywiaeth felly roeddem wedi canolbwyntio ar y sgoriau bioamrywiaeth ar lefel y fferm gyfan.

Golwg gyffredinol o ffermydd yr astudiaethau achos

Mae Tabl 1 isod yn cynnwys golwg gyffredinol o'r ffermydd a astudiwyd.

Tabl 1: Dosbarthiad ffermydd yr astudiaethau achos fesul math a gwlad

	Lloegr	**Yr Alban**	**Cymru**	**Cyfanswm**
Âr	5	2	-	**7**
Cymysg	2	2	-	**4**
Llaeth	1	1	2	**4**
Da Byw ALFf	1	1	3	**5**
Cyfanswm	**9**	**6**	**5**	**20**

Roedd y ffermydd yn amrywio o ran maint o 102 ha i 1821 ha. Mae cnydau'n cynnwys betys siwgr a thatws, grawnfwyd a hadau olew, yn ogystal â ffrwythau meddal a llysiau'r maes. Roedd mentrau da byw yn cynnwys gwartheg llaeth, gwartheg eidion, defaid, moch a dofednod. Roedd dwy o'r ffermydd yn organig. Roedd un deg saith fferm o'r dau ddeg yn cymryd rhan mewn cynllun amaeth-amgylcheddol yn 2011 ac roedd un deg pedwar wedi gosod cynlluniau ynni adnewyddadwy ar y fferm neu'n bwriadu gwneud hynny.

Y cysylltiadau rhwng cynhyrchu bwyd a newidynnau amgylcheddol

Ar y waelodlin roedd cynhyrchu bwyd fesul ardal uned yn amrywio'n sylweddol rhwng gwahanol fathau o ffermydd, gan amrywio o gymedr o 8 GJ ha^{-1} ar gyfer ffermydd yr ucheldir, 30 GJ ha^{-1} ar gyfer llaeth, 52 GJ ha^{-1} ar gyfer ffermydd cymysg, ac oddeutu 100 GJ ha^{-1} ar gyfer ffermydd âr. Mae'r amrywiad hwn rhwng sectorau'n adlewyrchu'r metreg dan sylw, ynni crynswth, ac mae'n amlwg yn ffafrio cnydau ar draul da byw. Er enghraifft, er bod gan gig werth ynni o 5-6 GJ $tunnell^{-1}$, mae'r ffigur ar gyfer grawnfwydydd dair gwaith yn fwy. Ar ben hynny, dim ond cyfran o bob anifail (rhwng un a dwy ran o dair o'r pwysau byw) sy'n cael ei defnyddio mewn gwirionedd. Gan mai cynhyrchu cig yw'r unig fath o gynhyrchu cynaliadwy sy'n bosibl ar lawer o ucheldiroedd Prydain Fawr, lle mae ansawdd y tir hefyd yn cyfyngu ar gynhyrchu bwyd fesul ardal uned, mae'n bwysig canolbwyntio ar y newid yn y dangosydd yn hytrach na'i werth absoliwt. Mae gan nifer o ffermydd ucheldir lawer o wasanaethau ecosystem eraill hefyd fel storio carbon, tirwedd a chyfalaf diwylliannol a byddai disgwyl iddynt fod ar ochr dde'r graffigyn yn Ffigur 1.

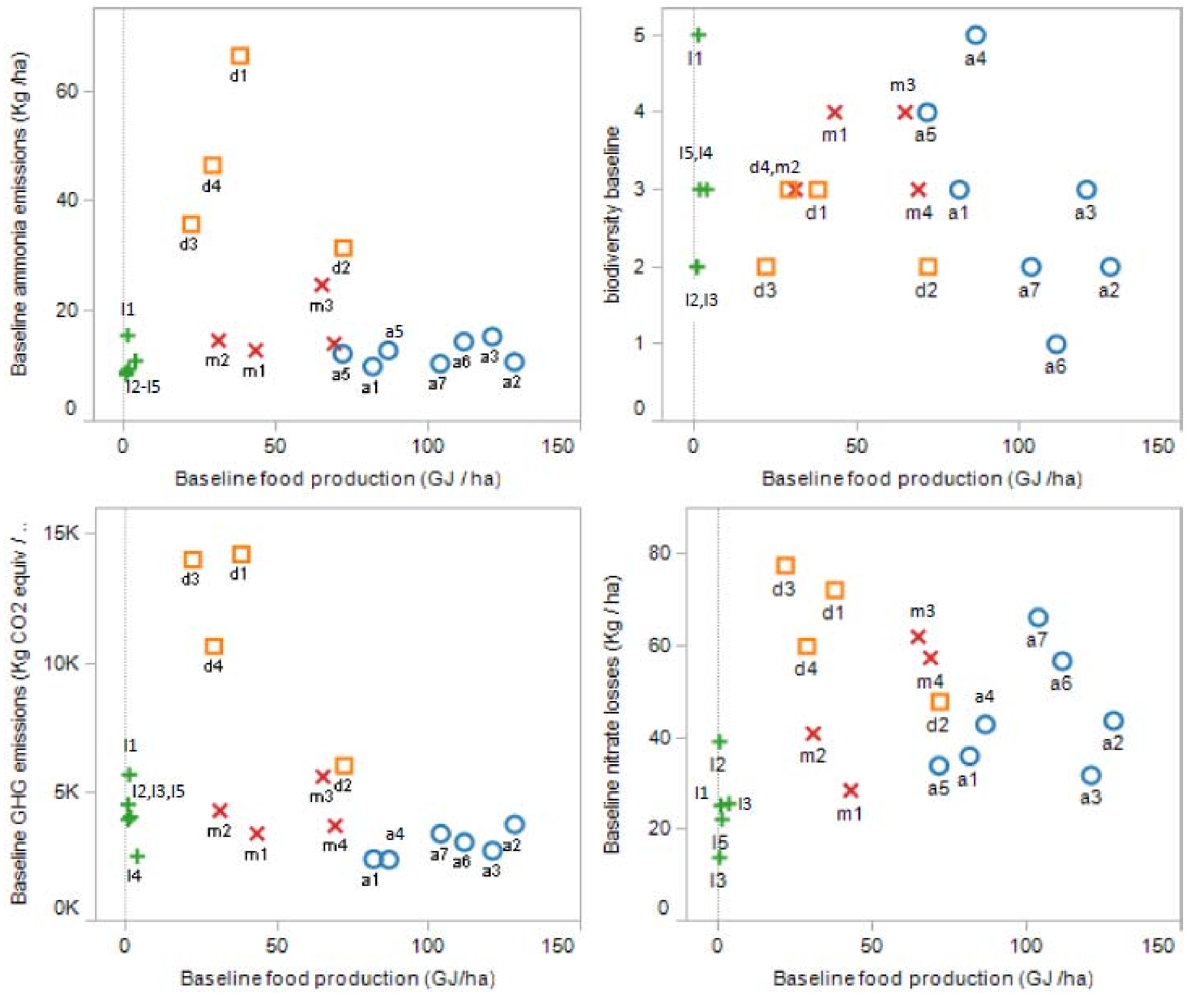
Ni welwyd dim gostyngiad mewn cynhyrchu ymysg ffermydd llaeth dros gyfnod yr astudiaeth. Roedd pob math arall o fferm wedi dangos cynnydd a gostyngiad mewn cynhyrchu. Mewn rhai achosion roedd y rhain yn ymwneud ag enillion go iawn mewn cynhyrchu ond ar gyfer ffermydd eraill roedd y darlun yn aneglur oherwydd y gymysgedd yn y fenter ac effeithiau tymhorol ar gnydau.

Ar gyfer llygredd amgylcheddol, roedd y dangosyddion yn seiliedig ar newidynnau lefel uchel fel nifer y da byw, yr ardal sy'n cael ei thrin a'r mewnbynnau a oedd yn cael eu defnyddio.

Mewn cyd-destun sy'n dechnegol statig, byddai unrhyw newid yn y dangosyddion hyn yn rhoi mesur da o sut roedd ffermydd yn mynd i'r afael â phwysau llygredd; fodd bynnag, roedd nifer o ffermydd yr astudiaethau achos yn gweithredu arferion cymharol newydd i liniaru effaith amgylcheddol ac nid oedd y dangosyddion na'r modelau roeddem yn eu defnyddio yn gallu cofnodi hyn. Mae enghreifftiau o'r astudiaethau achos âr yn cynnwys defnyddio ffermio manwl i gyfateb mewnbynnau i ofynion cnwd, buddsoddi mewn offer ynni effeithlon, defnyddio lleiniau clustogi a thrin llai. Ar gyfer systemau da byw, roedd y ffocws ar reoli tail yn bennaf er mwyn osgoi colli maethynnau a chynnal neu wella cynhyrchiant iechyd anifeiliaid.

Roedd y dangosydd bioamrywiaeth yn mesur y stoc yn y flwyddyn gwaelodlin yn ogystal â'r newid dros amser. Roedd y sgoriau stoc yn ffafrio ffermydd gyda sawl math o gynefin, ac roedd y sgoriau newid yn pwysleisio camau gweithredu a oedd wedi'u dylunio i wella amrywiaeth cynefinoedd ar fferm, yn hytrach na chynnal y cynefinoedd o ansawdd uchel a oedd eisoes yn bodoli.

Er bod y berthynas waelodlin gyffredinol rhwng cynhyrchu bwyd a gwasanaethau ecosystem eraill yn negyddol, roedd union natur y berthynas hon yn amrywio rhwng gwahanol fathau o ffermydd (gweler Ffigur 2).



Ffigur 2: Y berthynas rhwng newidynnau amgylcheddol a chynhyrchu bwyd y waelodlin

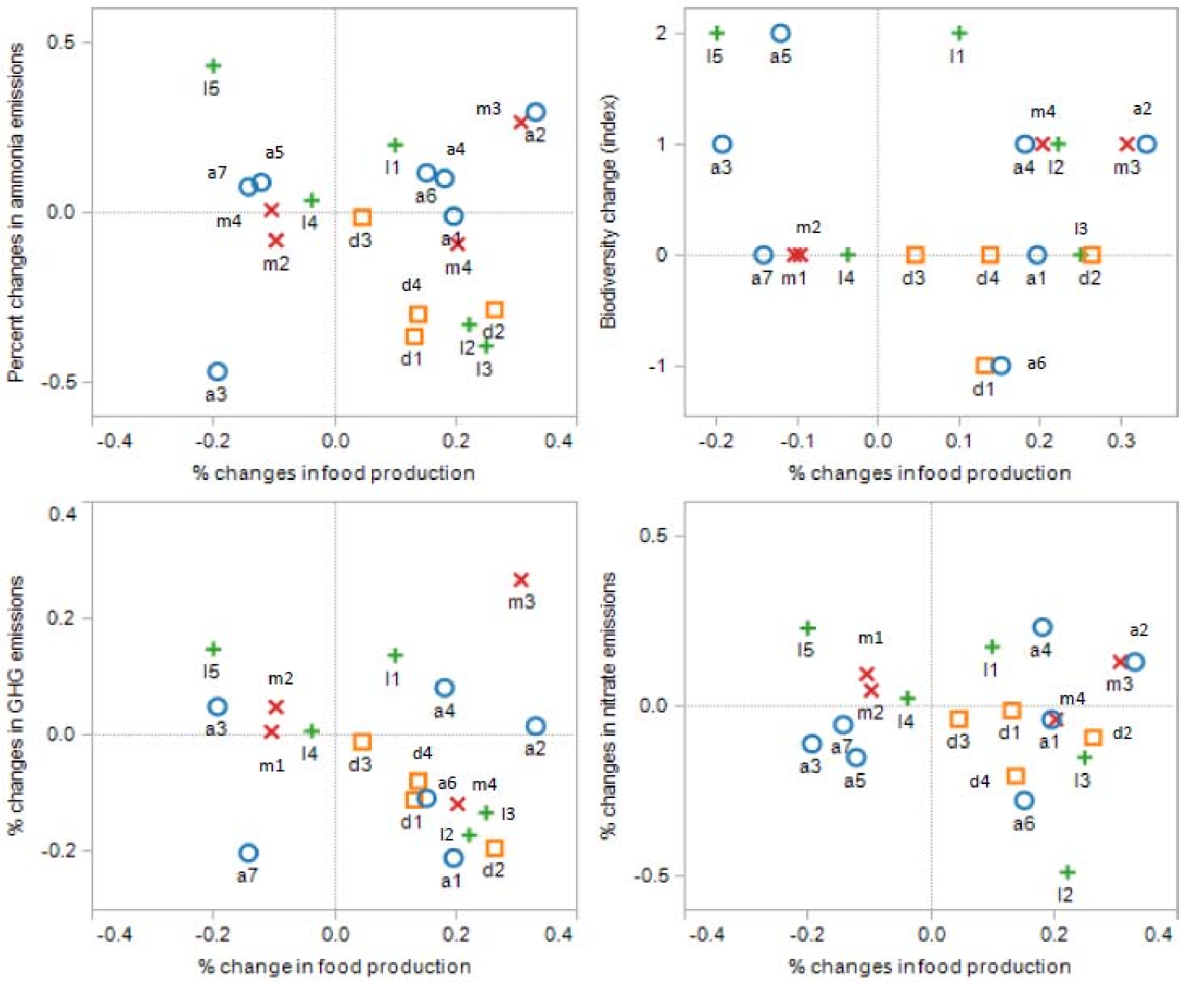
Dyma'r unedau: Mae allyriadau amonia a nitradau yn Kg ha^{-1}; Mae bioamrywiaeth yn sgôr; mae ôl troed carbon yn kg CO2 cyfystyr â/ha; mae bwyd yn GJ /ha. Caiff ffermydd unigol eu dangos, eu labelu os oes lle ar gael, eu grwpio yn ôl math o fferm gyda lliwiau a symbolau: Dangosir ffermydd âr â chylchoedd glas, cod A: Dangosir ffermydd llaeth â sgwariau oren, cod D: Dangosir ffermydd da byw ALFf â chroes wyrdd, cod L a dangosir Ffermydd cymysg â chroes goch, cod M.

Yn gyffredinol, roedd y ffermydd llaeth yn dangos y lefelau uchaf o allyriadau nwyon tŷ gwydr ac amonia, ac roedd yr allyriadau nitradau ar eu hisaf yn y ffermydd da byw ar yr ucheldir, ac yn aml roeddent ar eu huchaf yn y ffermydd llaeth. Roedd sgoriau bioamrywiaeth yn amrywio'n sylweddol yn y sectorau a rhwng yr holl sectorau.

Sut mae cynhyrchu bwyd a pherfformiad amgylcheddol yn newid dros amser

Daw tystiolaeth ar gyfer dwysáu cynaliadwy o'r ffermydd hynny sydd wedi gwella o ran cynhyrchu bwyd ac ansawdd amgylcheddol ers y waelodlin. O'r dau ddeg fferm yn yr astudiaeth, daw'r dystiolaeth orau ar gyfer dwysáu cynaliadwy o bedair enghraifft: dwy âr, un gymysg ac un fferm ALFf. Yn yr achosion hyn, roedd cynhyrchu bwyd wedi codi 10% neu ragor; roedd colledion amonia, nitradau a nwyon tŷ gwydr wedi aros yn statig neu wedi gostwng ac roedd bioamrywiaeth wedi cael ei gwella (Ffigur 3).

Unwaith eto, ceir gwahaniaethau rhwng y gwahanol fathau o ffermydd. Roedd y tair fferm laeth a oedd yn cynhyrchu mwy hefyd wedi cynyddu eu lefelau llygredd fesul ardal uned, ond roedd dwysedd yr allyriadau (nwyon tŷ gwydr fesul uned ynni crynswth a gynhyrchwyd) wedi disgyn. Hefyd, roedd rhai ffermydd wedi mabwysiadu strategaethau a oedd yn golygu nad oedd ein dull gweithredu ni'n cofnodi'r effeithiau'n dda; er enghraifft mae gan astudiaeth achos A3 system "dim trin" sydd wedi cynyddu faint o ddeunydd organig sydd yn y pridd yn sylweddol ac mae wedi gwella ffawna'r pridd, gan gefnogi'r fioamrywiaeth ehangach yn ogystal â gallu'r pridd i ddal gwlybaniaeth.



Ffigur 3: Newidiadau mewn newidynnau amgylcheddol a chynhyrchu bwyd ar gyfer ffermydd unigol

Ym mhob achos, mae'r cwadrant uchaf ar y dde yn cynrychioli gwelliannau o ran cynhyrchu bwyd a'r amgylchedd a'r chwith ar y gwaelod yn golygu gostyngiad yn y ddau. Rhoddir y newidiadau canrannol mewn allyriadau a chynhyrchu bwyd; mae arwydd ar gyfer yr allyriadau er mwyn dangos cynnydd mewn allyriadau fel negatif. Mae newidiadau bioamrywiaeth yn sgoriau. Edrychwch ar Ffigur 2 i weld y labeli. Mae ffermydd A2, A4, M3 a L1 yn gyson yn y cwadrantau de uchaf, sy'n rhoi tystiolaeth bod y ffermydd hyn wedi mynd drwy ddwysáu cynaliadwy.

Roedd consenswS ymysg ffermydd yr astudiaethau achos a'r rheini a gymerodd ran mewn grwpiau ffocws bod gwelliannau i fioamrywiaeth yn well ar dir llai cynhyrchiol (dull gweithredu cynilo tir) ond mae hyn yn dibynnu ar gymorth ariannol ar ffurf cynlluniau amaeth-amgylcheddol neu ddulliau eraill.

Strategaethau fferm wedi'u mabwysiadu gan ffermydd astudiaeth achos

Mae'n bwysig ystyried pa strategaethau a ddefnyddiodd y ffermydd hynny a oedd wedi cyflawni dwysáu cynaliadwy. Dyma brif gydrannau'r pedair fferm a oedd wedi cyflawni dwysáu cynaliadwy:

- Roedd Fferm A2 yn gweithio'n agos gyda'r gadwyn cyflenwi i gynyddu cnydau a lleihau effeithiau amgylcheddol, gan fuddsoddi'n drwm mewn technoleg i wella effeithlonrwydd mewnbynnau.
- Roedd Fferm A4 wedi defnyddio dau ddull, rhoi'r gorau i gynhyrchu ar dir salach a chanolbwyntio ar ffermio sy'n defnyddio adnoddau'n effeithlon (llai o drin, ffermio manwl ac ati) ar y gweddill.
- Roedd Fferm M3 wedi defnyddio newid menter, sef cynyddu'r ardal ar gyfer cnydau ar draul niferoedd da byw, ochr yn ochr ag ynni adnewyddadwy a ffermio manwl; roedd cynlluniau amaeth-amgylcheddol yn cael eu defnyddio ar dir salach.
- Roedd Fferm L1 wedi gwneud newidiadau system, gan leihau niferoedd y da byw ond gwella'r cynhyrchiant drwy newid bridiau, ynghyd â chanolbwyntio'n gryf ar gadwraeth wedi'i gefnogi gan gynlluniau amaeth-amgylcheddol.

Roedd nifer o ffermydd wedi cynyddu faint o fwyd roeddent yn ei gynhyrchu ar draul ansawdd amgylcheddol fesul uned dir. Roedd hyn yn arbennig o amlwg ymysg y ffermydd hynny sydd wedi ceisio cynhyrchu mwy o laeth a chig, hy ffermydd llaeth D1, D2 a D4, a'r ffermydd ALFf L2 a L3. Er gwaethaf buddsoddi i ddefnyddio adnoddau'n fwy effeithlon, roedd mwy o allbynnau'n tueddu i fod yn gysylltiedig ag allyriadau amonia, nitradau a nwyon tŷ gwydr fesul ardal uned, er bod colledion fesul uned cynhyrchu yn fwy sefydlog o lawer.

Roedd un fferm (L5) wrthi'n trosi i fod yn fferm organig ac roedd wedi dangos gwelliannau amgylcheddol ar y cyd â gostyngiad o ran cynhyrchu bwyd.

Yn olaf, roedd nifer o ffermydd (A3, A5, A7, M1, M2, D3 ac L4) wedi methu cyflawni cynnydd sylweddol mewn cnydau na gwelliannau amgylcheddol rhwng y ddau bwynt mesur. Mae newidiadau mewn menter, neu ffactorau tymhorol, neu gyfuniad o'r naill a'r llall, yn aml yn effeithio ar hyn.

Prif ganfyddiadau

1. *Mae modd ystyried y prosiect hwn fel astudiaeth beilot, sy'n dynodi rhai o'r prif faterion sy'n ymwneud â dylunio a gweithredu system ar gyfer casglu a dehongli'r mathau o ddata lefel fferm y mae ei angen i fesur y newidiadau strategol sy'n digwydd mewn amaethyddiaeth yn y DU, gan gynnwys dwysáu cynaliadwy.*
2. *Nid yw'r prosiect hwn wedi datgelu perthynas negyddol gyffredinol rhwng cynhyrchu bwyd a gwasanaethau ecosystem eraill ymysg ffermydd yr astudiaethau achos, er mai*

dim ond lleiafrif o'r ffermydd sydd wedi cynyddu'r ddau baramedr ar yr un pryd. Efallai mai'r rheswm dros hyn oedd bod y set o newidynnau'n rhy gyfyngedig. Yn ddelfrydol, dylid cynnwys set ehangach o wasanaethau ecosystem, ochr yn ochr â mesurau o gyfalaf natur critigol, ee carbon pridd, defnyddio dŵr a phresenoldeb cynefinoedd a rhywogaethau prin. Mae mesur gwasanaethau ecosystem o ffermydd unigol yn sensitif iawn i ddewis dangosyddion, sut cânt eu mesur a dros ba gyfnod, a sut cânt eu pwysoli. Gall fod yn briodol dim ond cymharu'r un mathau o ffermydd.

3. *Mae'n bosibl asesu dwysáu cynaliadwy ffermydd unigol drwy ddefnyddio data sydd eisoes ar gael iddynt, mewn ffyrdd sy'n gallu gwahaniaethu rhwng ffermydd a mathau o ffermydd o ran strategaeth a chanlyniadau. Mae'n well defnyddio cyfres o arsylwadau dros amser yn hytrach na dim ond dau gipolwg ar wahân.*

4. *Mae'r prosiect hwn yn rhoi tystiolaeth bod dwysáu cynaliadwy wedi cael ei wneud gan rai ffermydd yn y DU dros y blynyddoedd diwethaf. Roedd y dystiolaeth hon fwyaf cyson ym maes lleihau llygredd. Fodd bynnag, roedd nifer o ffermydd a oedd wedi cynhyrchu rhagor o fwyd hefyd wedi gweld effaith andwyol ar ansawdd amgylcheddol, gan ddynodi bod un yn cymryd lle'r llall.*

5. *Proffidioldeb yw'r prif beth sy'n gyrru strategaeth fferm, ac mae hynny'n aml ochr yn ochr â'r dyhead i wella perfformiad amgylcheddol y fferm: mae ffermwyr yn ymwneud i ryw raddau â'r cysyniad o ddwysáu cynaliadwy, er nad ydynt efallai'n ymwybodol o hynny. Mae defnyddio technoleg newydd ac arferion arloesol i leihau llygredd yn gallu ychwanegu at broffidioldeb ac ansawdd amgylcheddol drwy wella effeithlonrwydd a defnyddio mewnbynnau maethynnau ac ynni sy'n dod yn ddrutach. Gall perfformiad amgylcheddol gwell hefyd fod yn rhan o sicrhau gwell mynediad yn y farchnad neu brisiau uwch.*

6. *Mae gan wahanol fathau o ffermydd a systemau ffermio bosibiliadau gwahanol ar gyfer dwysáu cynaliadwy. Yn benodol, mae gan systemau llaeth lefelau cymharol uchel o effaith amgylcheddol sy'n gysylltiedig â methan a llygryddion mewn gwrteithi. Mae'r canlyniadau'n awgrymu efallai fod cyfyngiadau o ran y cysyniad o ddwysáu cynaliadwy ar gyfer y diwydiant da byw, lle mae cynnydd mewn cynhyrchiant yn debyg o fod yn gysylltiedig â dwysedd mewnbwn uwch (er nid yn llwyr) ac allyriadau uwch fesul uned o dir (ond nid fesul uned cynhyrchu bwyd) ac ystyried y dulliau ffermio a sut caiff technolegau eu defnyddio ar hyn o bryd. Er enghraifft, efallai na fydd dwysáu cynaliadwy yn strategaeth briodol yn yr ucheldiroedd, lle mae gan swyddogaethau ecosystem eraill fel ansawdd dŵr, storio carbon, tirwedd a bioamrywiaeth mwy o werth cymdeithasol na chynnydd mewn cynhyrchu bwyd efallai.*

7. *Mae camau i gynnal a gwella bioamrywiaeth yn gost i'r busnes fferm gan fwyaf, ac yn aml maent yn gofyn am gymorth ariannol allanol (fel cynlluniau amaeth-amgylcheddol) er mwyn parhau i'w cynnal, hyd yn oed pan fydd y ffermwyr dan sylw yn gwerthfawrogi bioamrywiaeth yn ei rinwedd ei hun. Mae'n ymddangos mai'r dull diofyn yw defnyddio'r tir lleiaf cynhyrchiol ar sail y gost isaf i'r busnes, yn hytrach na gwneud penderfyniadau ar sail y canlyniad amgylcheddol gorau posibl yn gyfnewid am y taliadau sy'n cael eu gwneud; mae'r mater hwn yn arbennig o berthnasol i ddylunio cynlluniau amaeth-amgylcheddol. Yn ogystal â'r angen am daliadau cymorth parhaus yn sail i ddarparu nwyddau a gwasanaethau amgylcheddol cyhoeddus, fel bioamrywiaeth a thirwedd, ceir achos dros ragor o gymorth ar ffurf darparu gwybodaeth, cyngor a rhaglenni ymchwil cysylltiedig er mwyn cefnogi'r broses o ddwysáu cynaliadwy.*

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1. Introduction

During the second half of the 20th century, global agricultural production increased at rates that were enough to keep pace with demands. Concerns about global food security focussed on issues of equity and distribution, rather than worries about the total amount of food available around the world (McIntyre et al. 2009). Meanwhile, awareness grew about the environmental implications of increased levels of agricultural production. Initially, these were expressed largely in terms of negative impacts on biodiversity (Carson 1962), but awareness grew about the importance of agriculture on a wide range of public goods, many of which are highly valued by society. In the UK, the post-War period of rapid growth in agricultural production was followed in the 1980s by a period of maintaining production levels, whilst enhancing the environmental quality of farmland, not least to attempt to put right some of the harm caused during the earlier period of intensification (Firbank et al. 2011).

The emphasis on the environmental quality of farmland initially addressed biodiversity and landscape, in particular through incentive-based agri-environmental schemes. The focus has since widened, as it became increasingly clear just how strongly public goods from agricultural land have been adversely affected by the increase in agricultural production at global, European and national scales (MA 2005, UKNEA 2011). Regulation has also been important, for example water quality improvement is governed under a number of European directives, notably the Nitrates Directive (Nitrates Action Plan) and Water Framework Directive (WFD), with actions supported by information, advice and grants. Since 2005, farmers have to keep their land in Good Agricultural and Environmental Condition (GAEC) in order to qualify for single payments (cross-compliance) and agri-environment schemes.

Self-regulation by the farming industry to achieve environmental goals, such as the Voluntary Initiative promoting responsible pesticide use[10] is increasingly important while farm assurance schemes have extended beyond food safety issues to encompass environmental impacts, for example LEAF Marque[11]. Further examples include the industry-led Greenhouse Gas (GHG) Action Plan Framework for Action (2010), that has targets for how agriculture can reduce its GHG emissions and the sector specific Welsh Red Meat Roadmap[12].

The global spike in food prices in 2007-08 changed perceptions markedly, and brought attention to the fact that global demand for food was starting to rise faster than supply. The Royal Society addressed the challenge of how food availability might be increased without repeating the environmental damage of the mid 20th Century, and promulgated the concept of 'sustainable intensification' (SI) of global agriculture, in which yields are increased without adverse environmental impact and without the cultivation of more land (Royal Society 2009). This concept was developed in more detail by an highly influential Foresight report in 2011 (Foresight 2011).

The UK government responded positively to the Foresight report, promising to '*work in partnership with our whole food chain including consumers to ensure the UK leads the way on sustainable intensification of agriculture*'[13]. As part of this and following a commitment in the Natural Environment White Paper to '*bring together government, industry and environmental partners to reconcile how we will achieve our goals of*

[10] http://www.voluntaryinitiative.org.uk/default.aspx
[11] http://www.leafuk.org/leaf/consumers/theLEAFmarquecons.eb
[12] A Sustainable Future: The Welsh Red Meat Roadmap www.hccmpw.org.uk
[13] Defra press release, 24 January 2011, http://www.defra.gov.uk/news/2011/01/24/food-shortages/

improving the environment and increasing food production' Defra established 'The Green Food Project', a joint initiative between Government, industry and environmental partners. The project has now reported and made conclusions across a range of topics, including research and technology, knowledge exchange, future workforce, investment, building effective structures, valuing ecosystem services, land management, consumption and waste. Recommendations are being taken forward.

Previous work commissioned by LUPG[14] considered the sustainability challenge for agriculture and forestry in Europe. This study aims to build on that work and the emerging policy interest in the concept of sustainable intensification by testing the concept using case study farms. This study seeks to scope a methodology for assessing sustainable intensification, to use this method to seek evidence that some British farms have been practising sustainable intensification, to consider how this has fitted into their business model, and what the potential barriers are to wider uptake by other farms.

Our approach was to seek out innovative, commercial farmers that may already be practising sustainable intensification for case studies.

Key questions for the study are:

- *How can we recognise SI?*

  There are currently no standard methods for assessing SI at the level of the individual farm. This project represents an important first step in developing a quantified approach to sustainable intensification, using data readily available to farmers to inform relevant indicators.

- *Are there already examples of sustainable intensification among British farmers?*

  The best publicised examples of how farming can seek to positively manage both environment and agricultural production are exemplar farms, such as the RSPB's Hope Farm[15] and the Allerton Project of the Game and Wildlife Conservation Trust[16] (Firbank et al. 2011). Whether such farms are achieving SI or not, it can be perceived that they are special cases. This project therefore seeks to identify case studies of sustainable intensification among commercial farms, including arable, dairy, mixed and upland livestock.

- *Does the evidence support farmers' perceptions of successfully delivering SI?*

  The project seeks to collect evidence from case study farms, to see to what extent evidence of enhanced agricultural and environmental performance supports farmers' perceptions.

- *If so, what strategies are the farmers adopting, and why?*

  There are many potential ways of delivering SI. This project seeks to use both the case study farms and focus groups to tease out which strategies are being adopted by different types of farm, how they fit in to the farming businesses and how applicable they are more widely.

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[14] Scoping the development of the Environmentally Sustainable Production Agenda, IEEP report for LUPG. 2010. Report accessible at: *http://www.ieep.eu/topics/agriculture-and-land-management /*
[15] http://www.rspb.org.uk/ourwork/farming/hopefarm/
[16] http://www.gwct.org.uk/research__surveys/the_allerton_project/default.asp

- *What has been the role of current Rural Development Programme (RDP) measures in supporting sustainable intensification and what challenges does the concept present for existing agri-environment schemes?*

  Ideally, agricultural support measures should facilitate SI, given the Government support for this approach. However, these measures are only part of a wider regulatory and policy mix. The study will test the extent to which this is actually the case currently, and explore what changes are needed. The study will address this issue through interaction with innovative farmers through the case studies and also with a wider cross-section of farmers in focus groups.

2. Sustainable intensification

2.1 Defining sustainable intensification

All ecosystems provide a range of goods and services that are important for human well-being. British farmland is managed largely to deliver the ecosystem service[17] of producing food, but also has an important role in many other ecosystem services, including supporting biodiversity; providing landscapes for leisure, access, beauty and sense of place; regulating water and air quality; and contributing to climate regulation through the production of GHGs and the sequestration and release of carbon. The UK National Ecosystem Assessment considered, in very broad terms, how farmland management has impacted on major ecosystem services in recent decades. These impacts are summarised in Table 1.

Table 1: National trends in ecosystem services affected by agricultural land management

Final ecosystem service	Impact of farmland on service	Comments
Crops, livestock, fish etc	++	Farmland is managed largely for food production
Trees, standing vegetation, peat	-	The uplands are major stores of peat, which has been subject to losses through drainage, erosion and removal.
Climate regulation	--	Strong negative score due to emissions of greenhouse gases and soil carbon
Water quality	+/-	Important to capture rain water; potential for flood risk mitigation often compromised by management
Hazard regulation	--	Negative impact on sediment losses to watercourses
Waste breakdown and detoxification	--/+	Negative score due to diffuse pollution of water courses; positive score due to potential to help manage wastes through composting, anaerobic digestion etc
Wild species diversity including microbes	--	Negative impacts: status of microbes unknown
Socially valued landscapes	++	Farm management is largely responsible for the landscapes that many people cherish

Compiled from Firbank et al. (2011) and Van der Wal 2011).

[17] Ecosystem services are defined as ‘Ecosystem services are the benefits people obtain from ecosystems’. These include provisioning services such as food, water, timber, and fibre; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling’ (Millennnium Ecosystem Assessment 2005).

In very general terms, the relationship between food production and levels of other ecosystem services is considered to be essentially inverse in contemporary British agriculture (Firbank et al. 2011). This relationship can be visualised as a graph in which food production is on the vertical axis and other ecosystem services are integrated together along the horizontal axis. Farms are arranged along or below the line that indicates the levels of ecosystem services (including food) produced by commercial farms at any time. The line is not a constant, as it can change as new technologies and farming practices are introduced. It will also change with external factors, such as climate change or the costs of energy. The line curves at high levels of non-agricultural ecosystem services, recognising that low levels of agricultural production can enhance the environment. Also, the line levels off at high levels of agricultural production, as there is a point at which environmental quality can be reduced without any increase in agricultural yield, for example through use of excess fertiliser (Fig 1). The actual location of an individual farm on this graph depends on the biophysical context of the farm, its climate, and the extent of use of technologies and knowledge (Firbank 2012b).

Sustainable Intensification (SI), as defined by the Royal Society, of an individual farm would result in it increasing its agricultural yield, with no additional impacts on the environment, i.e. arrow **a** in Fig. 1. Some authors consider that SI should involve a win-win, with increases in both food production and the flow of ecosystem services (e.g. Firbank (2009), Pretty et al. (2011)), i.e. arrow **b**. This is the preferable situation: indeed, in our assessments of individual farms we define sustainable intensification as *the increase of both agricultural production and of other ecosystem services from an individual farm.* SI would also include farms that have made environmental improvements and minor increases in yield (arrow **c**). Arrows **a** and **c** therefore represent the limits of SI as defined by the Royal Society and by this study. Arrow **d** represents the situation where the environment has been improved and food production has stayed constant; this is not regarded as SI in this study, though it is recognised that it represents an improvement over the *status quo ante*.

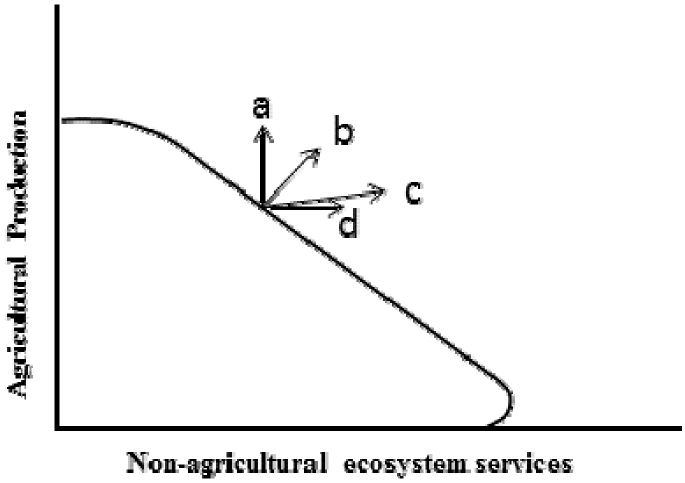


Figure 1: Visualisation of sustainable intensification of individual farms.

*The line indicates the joint production of food and other ecosystem services among well-run farms at a given area and time; farms can be located along or below the line according to their delivery of agricultural production and other ecosystem services at a given time. Sustainable intensification involves increasing the yield still further, with no environmental degradation (**a**) or with environmental enhancement and minor yield increases (**c**), or any point between (**b**). Environmental improvements not accompanied by yield increases (**d**) are not regarded as sustainable intensification in this study.*

Arrows **a, b** and **c** would be appropriate to farms that are already productive in terms of food production and other ecosystem services compared with their peers. SI also applies to those situations where the land is performing below these levels, i.e. falls below the line in Fig 1, perhaps because of poor uptake of current knowledge and technologies: for example, there are many cases in Africa where increases in yield have been associated with improved environmental practices, such as improved management of highly degraded soils (Pretty et al. 2011).

Note that there is no explicit social or economic dimension to this analysis (cf Barnes 2012), as we consider that while these dimensions are essential to the delivery of both agricultural production and other ecosystem services, they are not actual measures of SI in themselves. Also note that this analysis does not assume that SI is an appropriate goal for all farms in the UK; perhaps some farms should not seek to increase food production, but rather specialise in production of other ecosystem services, for example in the Scottish uplands (Barnes 2012). Finally, this analysis addresses only the flows of ecosystem services from the farms, and does not address the stocks, the natural capital of soils, biodiversity and landscape, of the individual farms.

In this project, we are seeking evidence that individual farms have increased both agricultural production and the delivery of other ecosystem services (**b** and **c** in Fig 1) and also of farms that have enhanced food production without impacting on other ecosystem services (**a** in Fig 1). We are focussing on progressive commercial farms, so that we expect them to be at or close to the boundary line in Fig 1.

2.2 Strategies of sustainable intensification

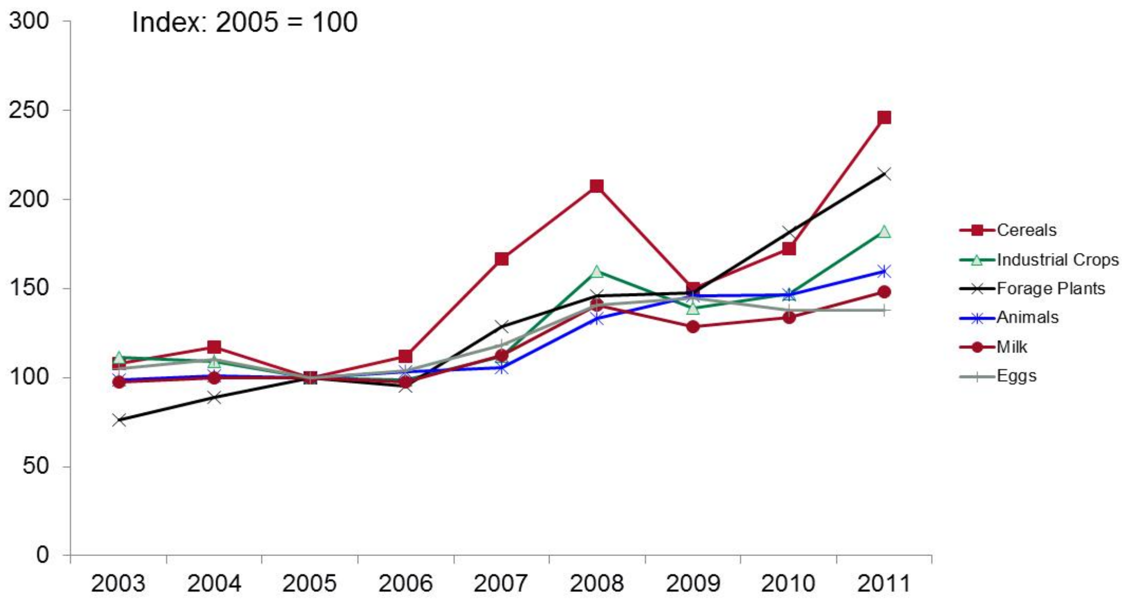
Sustainable intensification may be a desirable policy goal, but will only be delivered by individual farms if it fits in with their business objectives and model. It is helpful to separate three types of innovation that may lead to sustainable intensification; the enhancement of agricultural yield, the reduction of pollution and the positive enhancement of the environment. These have different drivers and require different approaches.

Enhancing agricultural productivity

The main driver for increasing agricultural production is the commercial incentive provided by markets. Farm-gate prices for food have increased substantially since 2006 (Fig 2), making increased food production a potential way of increasing farm profitability.

Several management responses are available to increase food production on a farm. One is to increase levels of inputs such as fertilisers, or to increase stocking densities, though these incur environmental costs. However, it is recognised that the underlying driver for increased farm commodity prices is in fact the sharp increase in oil price in 2008. This also drove up the cost of many farm inputs, notably fertilisers, agrochemicals, feed and fuel so that the most economic response to higher farm commodity prices is often not simply to use more inputs. Instead, the focus is productivity gain, that is, improving the amount of food produced relative to inputs used in doing so.

Production increases achieved through productivity gains, i.e. generating more output per unit of input is also likely to have a lesser negative environmental impact. Approaches available to farmers to achieve higher productivity include adoption of new practices, technologies and systems such as improved breeds and varieties with enhanced genetic yield potential, and / or with more precise use of inputs, whether through precision application of fertilisers and pesticides, a more precise match between animal nutritional requirements and the feedstuffs made available to them, or less wastage though losses to disease.

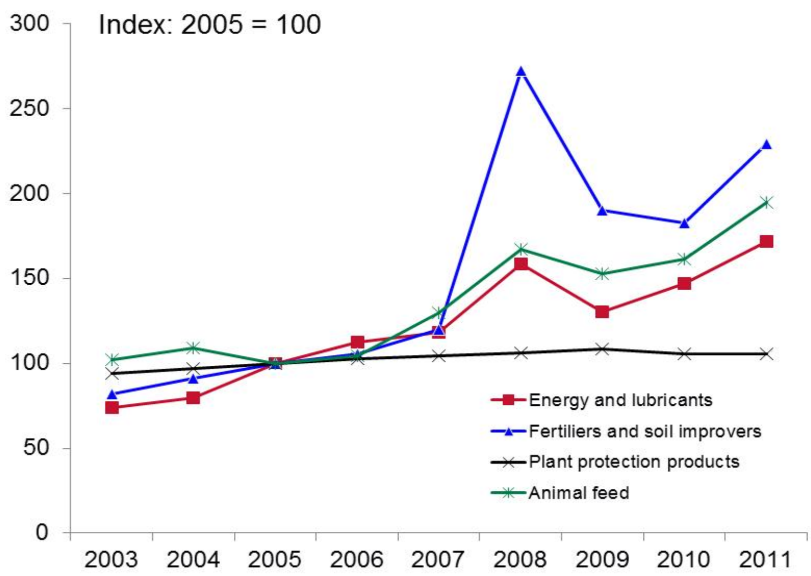


Source: Defra http://www.defra.gov.uk/statistics/foodfarm/farmgate/agripriceindex.

Figure 2: Trends in farm gate prices for major foodstuffs in the UK

Reducing environmental pollution

The reduction of pollution has a positive impact on ecosystem services including water quality, air quality and greenhouse gas regulation. There are two major drivers to encourage reduced pollution. The first is regulation in terms of the Water Framework Directive and resulting national legislation; the second is that much pollution reflects wasted inputs and as the price of inputs has increased substantially in recent years (Fig. 3), the pressure on farms to cut costs by using resources such as energy, water and nutrients more efficiently has increased.



Source: Defra http://www.defra.gov.uk/statistics/foodfarm/farmgate/agripriceindex/

Figure 3: The rising costs of agricultural inputs to UK farming

Technologies available to reduce emissions of greenhouse gases (GHGs) include more efficient use of energy, e.g. with new energy-efficient machinery, larger machines requiring fewer tractor passes, heat exchange systems etc or the adoption of farming practices which are inherently less energy-demanding such as reduced tillage cultivation. A separate but linked approach is generation of renewable energy, whether with anaerobic digestion or an abiotic approach such as solar or wind turbines.

Losses of ammonia to the air and losses of nitrates, phosphates, sediments and other pollutants to watercourses can be reduced by more efficient use of inputs, the use of slurries and manures as fertilisers, changes to tillage and grazing regimes and the use of well-designed slurry and manure storage systems and buffer strips. Water costs and availability can be managed using reservoirs or drip irrigation. For livestock systems, technological advances in breeding and nutrition and in the management of animal health also offer opportunities for reducing input use per unit of output or in absolute terms.

Enhancing the farmed environment

The reduction of pollution reduces the negative environmental impact of agriculture; there are also many ways of positively enhancing the farmed environment through conservation measures and environmental land management. Such actions include increasing levels of wildlife, enhancing the farm landscape and creating public access. Such positive actions often build upon existing interest by the farmer (including commercial interests, such as game shooting) and the availability of support, largely through agri-environment schemes[18]. The attractiveness of such support is a function of the net income that would be foregone, which depends on the agricultural potential of the land to be used, the market conditions at the time, and the costs of any actions that are required. Options within agri-environment schemes can deliver important ecosystem services on farmland, even when they had not been intentionally designed to do so (FERA 2012).

It is more difficult for intensive agriculture and biodiversity to coexist and most commonly land is either explicitly managed for environmental outcomes at the expense of being farmed (land sparing[19]) or is managed extensively so that both objectives can be realised together (land sharing). Land sparing is often concentrated on the least productive land while land sharing is more often a whole farm approach, for example in integrated farming systems or organic agriculture. In these cases the net income lost from reduced food production is often offset through agri-environment or organic payments.

[18] Technically organic payments are not the same as AES payments as they have a different intervention logic under EC Regulations. Organic payments relate to the costs of conversion (during which reduced levels of production are not compensated for by increased market premiums) or relate to organic maintenance (during which the same argument may apply as during conversion).
[19] Land sparing was originally defined in terms of sparing natural habitats in one location by increasing food production in another. Here land sparing is applied to areas of land within the farm.

2.3 Assessing sustainable intensification

There is no agreed operational definition of sustainable intensification[20]; indeed, there is no agreed operational definition of either 'sustainable' or 'intensification' in the context of agriculture. 'Intensification' is a process, and can only be assessed by following changes over time.

The UK National Ecosystem Assessment (UKNEA 2011) provides a classification of ecosystem services that need to be accounted for in the context of sustainable intensification, which is based on the Millennium Ecosystem Assessment (MA). The UKNEA also pulls together those national datasets that exist on many of these ecosystem services, and how they have changed over time[21], showing the range of ecosystem services that can be delivered from British farms, as well as potential indicators of these services ((UKNEA 2011). The UKNEA of enclosed farmland focussed especially on production of food and energy, including the socio-economic benefits; the regulation of climate, atmosphere and water quality and quantity; and cultural services, notably landscape management and the provision of habitats for biodiversity; major surrogate indicators included crop yields, nationally and per unit area, along with trends in biodiversity, water quality and GHG emissions (Firbank et al. 2011).

Such data on ecosystem services and their indicators are typically published at a national or regional scale, or using some form of spatial grid. The majority of farm-scale ecosystem studies have addressed one or two ecosystem services, usually agricultural production and one other, such as biodiversity or GHG emissions (Firbank et al. 2011). Farm scale models of 'sustainability' have typically been achieved using downscaled national values (e.g. Glendenning et al. (2009) and Del Prado et al. (2011)). There are very few examples published where multiple ecosystem services have actually been measured at the farm scale over time. The studies most relevant to this one were conducted by Pretty et al. (2008a, b) and by Barnes (2012), using indicators set around agronomic, economic and social function, rather than ecosystem services. Barnes (2012) took agricultural production farm-scale data from the Farm Accounts Survey and data on land use and cover to infer other ecosystem services.

Any overall assessment of sustainability involves considering gains and losses among a wide range of parameters that are very different in nature. Sometimes, this consideration involves qualitative judgement (as was the case for the research of Pretty (2008a, b)), sometimes aided by graphical data representations, such as radar diagrams (e.g. Del Prado et al (2011), Barnes (2012)). In other cases, the variables are integrated into a common unit, often monetary[22]. Indeed, the UKNEA approach is to seek to ascribe monetary values to different ecosystem services to improve their management (UKNEA 2011), using techniques such as willingness to pay. Other approaches are possible; Cobb et al (1999) used levels of agri-environment scheme payments to value different environmental benefits.

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[20] Although there is a lot of work in this area at the moment, some being developed by individual supermarkets
[21] While the UK has much data on environmental change, data on how these changes have translated into ecosystem services is much sparser.
[22] Such integration is assumed for Fig 1.

3. Methods

3.1 Overall approach

Our approach was to quantify changes in a suitable range of ecosystem services, including food production, over a fixed period of time for individual farms considered more likely than most to be adopting SI, and then to help validate these findings using focus groups of other farmers. We did not attempt to assess the environmental or economic sustainability of the farms in absolute terms at any particular time.

Our case study farmers were selected not at random, but according to whether they were considered to be innovative by their peers. They were selected to represent the major farm types, and also the three countries of England, Scotland and Wales. Data are presented by farm type (Arable, Dairy, Mixed and Less Favoured Area (LFA) Livestock), to take account of the large differences in the environmental context and capability for food production between these situations.

We focused on five major categories of ecosystem services that have been highlighted during the UK National Ecosystem Assessment (UKNEA 2011), namely agricultural production, biodiversity, landscape, climate regulation, and regulation of water and air quality. We did not quantify water quantity directly in this study although it is recognised as an increasing issue in future (Environment Agency 2011). However, changes in water use or in other services strongly linked to food production have been noted in the narrative component of the case studies.

Our assessment period was from the baseline of 2005-06 to the latest year for which complete data were available, usually 2011. The baseline was chosen as it was before the recent rapid rises in global food prices. The evidence relied on data and commentaries obtained during farm visits and interviews; we did not attempt to collect data not already held by the farmers.

Our approach was to select for analysis a single, high level indicator from each of the major groups of ecosystem service, with additional data made available in the case study reports. The indicators are presented per unit area, where the area includes land on the farm not used for food production, and also land off-farm needed to generate animal feed used on farm. The use of land area as the basis for measurement reflects the fact that additional land is unlikely to become available for food production and the emphasis for SI should be the balance of and interaction between food and other ecosystem services per unit area.

Food production was converted into the single unit of gross energy and expressed per unit of land area (GJ ha^{-1}). This unit was chosen because it can be applied to all food types in a transparent way. It is recognised that gross energy production may not align with commercial business objectives as this ignores variation in the financial value of different foodstuffs, for example milling wheat or malting barley yields are often lower than where yield only objectives are pursued for a feed market. The analysis also discriminates against meat production systems in that animal protein has a particular nutritional value recognised in markets but not captured by the indicator. Inevitably, food production varies between farm types, reflecting the large differences in productivity of land between the arable areas of the lowlands and the extensive grazing in the uplands. However, the indicator is required to measure changes within a system on a given farm (over time) rather than between farms; as such these limitations do not present major problems for the analysis unless there are substantive changes within the farm system.

We used existing published values and existing models to convert farm data into the levels of GHGs, potential losses of diffuse pollution to watercourses and releases of ammonia to the air, indicators of regulation of climate, air and water quality. These published values are taken largely from national data, and so do not capture the impacts of particular farm practices, for example the use of buffer strips or zero tillage. The method accounts for energy generation (e.g. using solar power) but does not account for any carbon sequestration taking place.

Very few farms have data on biodiversity and landscape, so instead we followed the UK Biodiversity Indicators programme (Defra 2012) and collected data on land characteristics and management that could be used to indicate the potential for biodiversity and landscape quality, rather than a meaningful assessment of biodiversity stock in terms of species of habitats, or landscape character in terms of visual quality or consistency with the cultural character of the area. Data are reported at the whole farm level (as opposed to per unit hectare, or per unit of food production), including land area not on the farm, in particular land needed to grow animal feed.

We ran three focus groups among different groups of farmers, subsequent to collection of the case study data, to explore both awareness of the concept of sustainable intensification and the applicability of the findings from the case study farms. This also provided an independent and more broadly-based view by the farming community of the wider applicability of the concept, strategies being used and barriers to uptake.

A fuller account of the metrics used is given at section 3.4 and at Appendix 3.

3.2 Case study farms

We considered that we were more likely to find evidence of sustainable intensification from the more innovative farms, rather than from farms that were in some sense representative of the wider industry. Rather than conducting a random survey of farms, we therefore contacted farmers that were recognised as innovative, and concerned with both agricultural productivity and environmental management. We also excluded farms that have increased production or environmental performance from an unusually low baseline, as we wanted to reflect the potential for sustainable intensification near the boundary visualised in Fig 1.

Our selection criteria for individual farms were:

- Each farmer is a known innovator and perhaps leader in food production and/or resource and environmental management;
- The farmer had to be prepared to tell their story and share their data, subject to confidentially (farms are identified to sector only), regardless of the outcome of the assessment;
- The farm had to be a mainstream commercial operation, not supported primarily from other sources of income, and not owned by a charity or research organisation, so that are findings are seen to be relevant to the industry;
- The farm had to be a single unit, in order to establish a clear set of farm-scale metrics (or part of a wider business with multiple holdings, as long as the study farm could be treated as a separate unit).

We required a sample of at least 20 farms, presenting a range of farm strategies and environmental conditions. This we achieved by imposing conditions on the overall sample of farms. Our essential criteria for the sample were:

- 20 farms, with no more than 4 reserves;

- No fewer than 4 geographically distributed farms in each of four sectors, as represented by Defra robust farm types, i.e. arable (RT1 Cereals and RT2 General Cropping), dairy (RT6 Dairy), Less Favoured Area (LFA) cattle and sheep (RT7 LFA Grazing Livestock) and, finally, mixed lowland (RT9 Mixed). Intensive pig and chicken enterprises were not included, because of their reduced footprint of land at unit level; this also applied for specialist horticulture.
- We sought farms that displayed an overall range of strategies in relation to sustainable intensification, including the use of new technologies and genetics, changes to farming systems, organic systems and participation in agri-environment schemes.

Each farm received a half-day visit from a consultant to gather quantitative data and qualitative comments to provide the necessary context for interpretation. While there was an opportunity to check and clarify data by phone and email post-visit, we asked for a considerable amount of information and there are necessarily some data gaps and limitations. All participating farmers have had the opportunity to read and comment on their case study write-ups to ensure factual robustness and to allow them to respond to the analysis.

We used face-to-face interviews with all farmers, based on a structured questionnaire, with follow-up phone calls to capture missing or unclear data. The interviews focussed on both quantitative data on land management and performance, as well on qualitative data on the business model and objectives.

We sought data for two separate years, the baseline year and the most recent year for which complete records were available. In most cases, the baseline year was 2005-2006, and the most recent year was 2010-11, but there were some exceptions (see individual case studies). We did not attempt to make any corrections for differences in years for the overall analyses.

In terms of reporting, a common format has been used to ensure consistency, using the following principles:

- Each case study report starts with an overall assessment of SI on the farm and a summary of the indicators and approach; this is followed by a more in-depth description of the farm and farming system, the approach to sustainable intensification, farm performance against indicators and finally a short conclusion.
- Anonymity is protected though avoiding reference to country-specific organisations or programmes e.g. agri-environment schemes are referred to as entry level or higher level AES, rather than Glastir Entry etc;
- Cropping and stocking changes and tables of indicator change use a common format
- The achievement of SI is premised on indicator change between the baseline and latest year in absolute terms but with caveats where this is not a reliable basis for assessment. SI indicators are presented along with percentage change and the latter coded using a traffic-light approach (green where positive direction and scale of change; red where negative); where the scale of change is modest (less than +/-10%), it is highlighted in grey and does not influence the overall assessment of SI.

3.3 Focus groups

Three focus groups were held to provide a broader perspective on the sustainable intensification concept, each representing a discrete farm type, namely arable, dairy and LFA livestock.

The aim was to secure eight or more farmers at each group meeting in order to secure a wide section of perspectives and generate a debate. A pragmatic approach to securing delegates was adopted, using existing sector-based groups where there is an established routine of coming together for talks and discussion, where individuals know each other and can contribute openly and where there was a group organiser who could assist setting up the event.

Key elements of the focus group agenda were:

- Welcome and introductions: As means of an ice breaker, during the introduction process, each participant was also asked to describe what they enjoyed about farming;
- An individual exercise capturing awareness and knowledge of the sustainable intensification concept;
- Presentation of project aims and introduction of SI concept: Revisit awareness and knowledge exercise
- Strategies for achieving SI: Individual exercise to capture strategies currently adopted or which farmers planned to adopt;
- Drivers for SI: Complete individually and then re-group to discuss;
- Presentation of case study results: Discussion of strategies, indicators and challenges;
- Policy discussion: Exercise to highlight barriers to uptake of SI.

Details of the event locations, attendance and discussion at each focus group are summarised in the results section (4.4) and detailed at Appendix 5.

3.4 Selection of metrics of sustainable intensification

Here we present summary methods only: more details are available in Appendix 3.

Agricultural production

Data were collected on food production by the whole farm area, including uncropped land and estimates of the land required to produce any animal feed imported onto the farm. In order to avoid double counting, we excluded crops grown to feed the farmer's own animals. In order to generate a single measure of food production, we condensed the available data into gross energy per unit area, i.e. GJ ha^{-1}, using published values.

Climate regulation

Greenhouse gas emissions (GHGs) were estimated for the farms using two distinct approaches (detailed at Appendix 3):

(i) Emissions of methane and nitrous oxide were calculated using the Farmscoper tool. This used data from the case study farms on cropping, soil type and rainfall, livestock numbers, fertiliser use and housing to estimate gross emissions for each gas in kg ha^{-1};

(ii) Carbon dioxide emissions (CO_2) were calculated separately using the CALM tool; this allows for energy use and land use change, including elements of agri-environment schemes. Methane and nitrous oxide emissions were then converted into Global Warming Potential (GWP) in CO2 equivalents and combined with the carbon dioxide emissions to give a total GWP or carbon footprint.

While there are significant limitations in terms of the accuracy of the coefficients used across all the farms, given the different geoclimatic conditions, the approach should provide a good estimate of climate regulation impacts of individual farms based on system change. The tools do not allow for variation in farm practices, for example how and when fertiliser is applied, but focus instead on the amount of fertiliser used.

Water and Air quality

The Farmscoper tool was also used to calculate losses of nitrate, phosphate, sediment, pesticides and ammonia. Again, the estimates take account of soil and rainfall, cropping and stocking, and level of inputs used. As with GHGs, the tool was not used to allow for the use of technologies or farm practices to mitigate against pollutant loss, such as GPS placement of fertilisers or the use of buffer strips to protect against water pollution[23]. As with the other indicators, it is important therefore to consider the indicator scores at individual farm level rather than across farms and to use the scores to reflect changes in the direction and scale of pollutants rather than as an absolute measure of impact. Losses of nitrate and ammonia are used as high level indicators of water and air quality respectively (see Appendix 4 for details).

Biodiversity

Few of the farmers had their own biodiversity data, so it was not possible to use data relating to the presence or absence of particular species. We therefore sought data on the protection goals supported by UK policy and enshrined in the UK Biodiversity Indicators (Defra 2012), in terms of the habitats and resources available to wildlife, and the extent to which they were supported through agri-environment schemes or legal protection. Thus we collected data on agri-environment and farm assurance scheme membership and options, the presence of Priority Habitats and rare breeds, and improvements to habitat area and condition. We also considered broader aspects of farm management known to have major impacts on farmland birds, including changes to the diversity of crops, the diversity and area of non-cropped habitats (Butler et al. (2007, 2009)).

Scores for biodiversity 'stock' and 'change' were compiled from the range of responses to indicate the diversity and protection of habitats at the baseline, and the efforts being made to improve the farm for biodiversity since, including the connection of areas of semi-natural grassland. These were used to create 5 point indices for use in the diagrams: biodiversity stock ranged from 1 to 5 (no farm can have zero or negative biodiversity) but change scores ranged from -2 to +2, depending on whether conditions for wildlife had been made worse or better. These scores are not additive, so data are not presented on biodiversity stock in the most recent year. This procedure gives high baseline scores to those farms with a diversity of habitats and a broad range of activities under agri-environment schemes, and high change scores to farms that have added to, or actively managed, the habitat features on their farm, or have changed their overall farming system in ways considered to be wildlife-friendly.

[23] The tool contains a library of approximately 100 mitigation methods, mostly indentified in the 'User Guide' of mitigation methods (Newell-Price et al., 2011); these cover some but not all technologies / practices used in this study.

Such scores are helpful when considering change on a farm or group of farms, but are not sufficiently well related to actual numbers and diversity of wildlife to be regarded as useful for comparing absolute levels of biodiversity between different groups of farms (not least upland vs. lowland).

Landscape

Our approach was similar to that for biodiversity, in that we considered features present on the land, designations (including presence in a designated area) and support for landscape features. In practice, there was much overlap with the biodiversity scores, as the majority of 'landscape' features were also habitat features, such as hedgerows. The main additional element was the presence of historic buildings and landscape elements. While the biodiversity value of a particular feature can be regarded in the same across the country, the same is not true of the landscape character; it depends much more on the local context. Landscape is also not sensitive to small changes: a change in hedgerow length of 10% may be significant for biodiversity but may have little influence on visual character. Equally, changes may take a long time to affect landscape character; it takes time for tree planting to mature into woodlands.

We considered cross-checking landscape change against Landscape Character Area definitions. However, we found that the definitions of landscape character were really too broad to allow a considered assessment of landscape quality from the data we collected. The landscape scores were therefore very closely correlated to the biodiversity scores, and did not capture the distinctive aspects of landscape quality. On this basis, whilst landscape scores are presented in the case studies, they are excluded from the quantitative data shown in the results section of the main report.

3.5 Data interpretation and analysis

For each farm (excluding A5, for which complete information was not available), data are presented in the main report for each of the high level indicators, with more information in the case study reports. Also, a composite ecosystem service score was compiled. For this, emissions of nitrate, ammonia and GHG gases were all scored as negative, and biodiversity as positive. For each variable, a score was derived by dividing the value for each farm by the overall average for the variable, so the average score for each of the three polluting impacts was -1, and the average for biodiversity was +1. The scores were simply added, weighting them equally, and giving an average ecosystem services score across all farms as -2 (three average scores of -1 and one average score of +1).

Note that the comparisons between baselines and current values for individual farms are subject to various levels of uncertainty, partly from the values given by farmers and models used by ourselves, but mainly because of year-on-year variations in weather and market conditions. We are not able to ascribe formal levels of statistical significance to the changes; instead, we have used results within +/-10% of the baseline values as indicating no significant change.

4. Results

4.1 Engagement of farmers with the project

As set out in the methodology, the case study farmers were selected on the basis of their profile as innovators or early adopters of technology and perceived performance in terms of high production intensity and/or a positive approach towards sustainability. Nominations were received from the project steering group but also industry organisations including AHDB and from within the consultant team.

While nominees were generally cooperative, there were some problems securing engagement across the sample and in particular from the dairy sector. These appeared to arise simply because we were dealing with very busy individuals and a busy time of year (spring) in an unusual season (high temperatures in March and record rainfall in April). Given this backdrop, we are most grateful to the twenty farmers who did participate and for their perseverance in terms of providing data and background information.

The set of case study farms comprised seven arable, four mixed, four dairy and five LFA Livestock farms distributed across GB as set out in Table 2.

Table 2: Distribution of case study farms by type and country

	England	Scotland	Wales	Total
Arable	5	2	-	**7**
Mixed	2	2	-	**4**
Dairy	1	1	2	**4**
LFA Livestock	1	1	3	**5**
Total	**9**	**6**	**5**	**20**

The farming systems, as described by the farmers themselves, included intensive, semi-intensive, organic; profit maximisation, intensive farming on the good land and managing the poor land for biodiversity, and a total no-till system. Details of the individual farms are given in the case study write ups in Appendix 4

This was very much a participative study and the farmers who took part in the three focus groups also made valuable contributions. Again there were challenges in securing access to groups at a busy time of year and in difficult weather conditions, when fieldwork days were hard to anticipate but very precious. Again, we are most grateful to those farmers who did attend the three focus group events and to those who helped organise them. A synopsis of the study findings was sent to participating farmers via the contact for each group.

4.2 Analysis of indicators of food production and environment

Here we focus on the single indicators representing each ecosystem service of provision of food, regulation of air and water quality and of climate, and biodiversity, which delivers cultural, regulating, supporting and provisioning services. A summary of the headline indicators scores for the case study farms is shown in Table 3 with all of the raw data and indicators located in the case study reports (Appendix 4).

Food production

Not surprisingly, the food production per unit area varied greatly between farm types, ranging from a mean of just over 1 GJ ha^{-1} for the upland farms, 25 GJ ha^{-1} for dairy, 42 GJ ha^{-1} for mixed farming, and around 100 GJ ha^{-1} for arable farms. These differences reflect the productive potential of the different farms due to altitude, land quality and climatic conditions but also vary significantly because of the differences in gross energy content between different forms of agricultural production. These differences mean that the various farm types tend to be clustered in the graphs, with arable farms showing high levels of food production, LFA showing low levels and mixed and dairy farms intermediate.

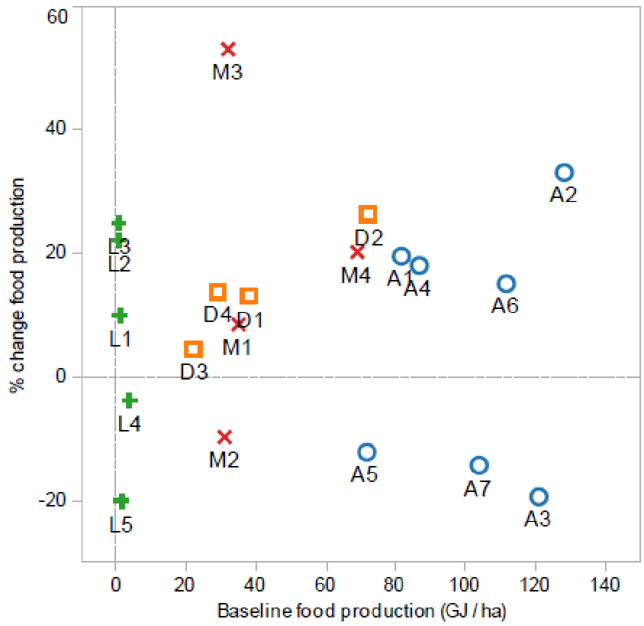

Figure 4: Agricultural production of case study farms, and how it has changed over time.

Baseline production is in units of energy per unit area (see text for details); percent change refers to changes between baseline and latest data. Individual farms are shown, labelled where space allows, grouped into farm type by colour and symbol (arable – blue circles, farms coded A: dairy, orange squares, farms coded D: LFA farms shown with green crosses, coded L and mixed, shown with red X, coded M).

All four dairy farms increased food production per unit area, of which farm D2 (the most productive at baseline) achieved the greatest increase. By contrast, arable, mixed and LFA farms displayed both increases and decreases in food production (Table 3), with no apparent relationship with baseline values (see Figure 3 and the case studies reports at Appendix 4).

The largest increases in yield were achieved by farms of all types where the pattern of farming has changed; M3 increased the area of arable cropping, reduced livestock numbers and increased arable crop yields; A2 obtained a large increase in potato yield, attributed to a variety change; D2 increased yields of both milk per cow and arable crops per area, and increased cattle numbers, while L3 increased numbers of cattle and sheep, although their sale weights have remained largely unchanged.

Several farms showed a reduction in food production since baseline. For two of the farms, this reduction was a consequence of a change in farming system; L5 is in a period of transition to organic status, and has increased the farm area but not livestock numbers, while A7 has switched land away from cereals to fruit and vegetables, with lower energy contents. In all other cases, yield reductions can be explained by annual variation, often of weather: the slight drop in productivity of L4 can be explained by the reduction in size of the suckler herd, a response to the poor spring of 2010, with less silage and more expensive straw: the slight decline in production by the organic mixed farm M2 can also be explained by a reduced area of crops and increased feed purchases for fewer lambs while A3 had a greater proportion of spring sown crops because of poor autumn weather and A5 had reduced yields for winter wheat and oilseed rape due to dry conditions in the latest year.

Table 3: Synthesis of changes in SI Indicator scores for each case study farm

		Food Production	Carbon Footprint	Nitrate losses to water	Ammonia losses to air	Biodiversity
		GJ /ha	kg CO2equiv/ha	kg/ha	Kg/ha	Index
Arable	A1	20%	21%	4%	1%	0
	A2	33%	-2%	-13%	-30%	1
	A3	-19%	-5%	11%	46%	1
	A4	18%	-8%	-23%	-10%	2
	A5	-14%	-	15%	-9%	2
	A6	15%	11%	28%	-12%	-1
	A7	-14%	2%	5%	-7%	0
Mixed	M1	10%	-1%	-3%	0%	0
	M2	-11%	-5%	-5%	8%	0
	M3	52%	-27%	-13%	-27%	1
	M4	20%	4%	4%	9%	1
Dairy	D1	14%	11%	1%	36%	-1
	D2	26%	19%	9%	29%	0
	D3	5%	1%	4%	1%	0
	D4	11%	8%	21%	30%	0
Livestock	L1	10%	-14%	-18%	-20%	2
	L2	5%	17%	49%	33%	1
	L3	35%	13%	15%	39%	0
	L4	-3%	-1%	-2%	-4%	0
	L5	-18%	-15%	-23%	-43%	2

The results are colour coded: green is an enhancement (an increase in food production and biodiversity score, a reduction in emissions); red is a deterioration. A grey colour indicates that change is within 10 % for numerical data, and 0 for biodiversity; these are interpreted as little or no significant change.

Baseline relationships between food production and environmental variables

There were differences between farm types in their relationships between levels of food production and the individual environmental variables (all expressed per unit area) at baseline (Fig 4).

In general terms, there was no clear overall relationship in terms of individual environmental variables and levels of food production between farm types. The only suggestion of such a relationship within a farm type was for the dairy sector, where the data in Fig. 5 hint at negative relationships between food production and emissions of nitrate and GHGs. Emissions of ammonia and GHGs were highest amongst dairy farms, but were otherwise not closely related to levels of food production (note that no carbon data were available for farm A5). Nitrate emissions were lowest among the LFA livestock farms and on two of the dairy farms, although there was much variation (Fig 5). Note also that the baseline scores for GHG emissions do not take account of carbon stocks present on the farm, either in vegetation or in the soil.

Baseline biodiversity scores were variable for all farm sectors, and no obvious relationship with food production was detected. It must be remembered here that the scores for biodiversity reflect particularly the diversity of habitats and features (such as hedgerows and ponds) and engagement with agri-environment schemes, rather than actual levels of biodiversity and the conservation value of wildlife on the farm. This approach reflects feedback from farmers on their approach to biodiversity; as one of the case study farmers said, "… *biodiversity is important, but it must complement the existing farming system*". Typically agri-environment schemes were used to improve the management of less productive areas. Two of the farms that achieved high baseline scores for biodiversity, farms A5 and M1, have game bird shoots.

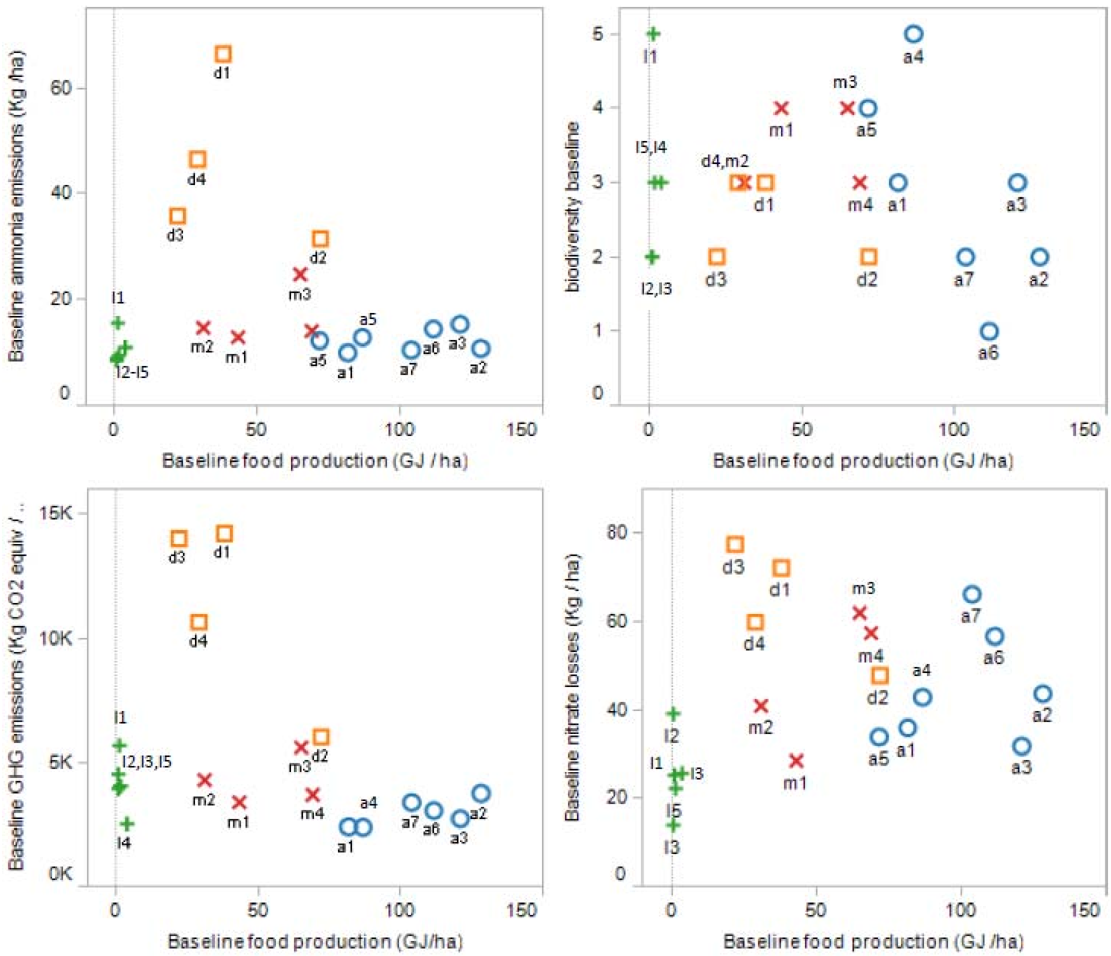

Figure 5: Relationships among baseline environmental variables and food production

The units are: Ammonia and nitrate emissions are Kg ha-1; Biodiversity is a score; carbon footprint is kg CO2 equiv/ha; food is GJ /ha. Farms are coded as Figure 4, with individual farms showed where space allows.

It is possible to integrate different environmental variables into a single score representing a range of ecosystem services and relate them to food production. Here, we have weighted four measures of ecosystem services equally, after standardising them to account for the very different ranges of values. The ecosystem service scores are inevitably negative given the way they have been calculated, as they comprise three negative impacts (ammonia emissions, GHG emissions and nitrate losses) and only one positive impact (biodiversity score) . Further information is available in section 3.5.

The data show a very different pattern to the inverse function anticipated within Figure 1 (note that within both Fig 1 and Fig 6, but not the other graphs, food production is on the vertical axis and other ecosystem services along the horizontal). Rather than an overall negative relationship between food production and other ecosystem services, our data shows a clustering of the different farm types, with arable farms having the highest levels of food production and dairy farms showing the lowest levels of ecosystem services (Fig 6a). The data hint at a negative relationship between food production and ecosystem services for arable farms. The equivalent plot i.e. including the emissions of ammonia, nitrate and GHGs but excluding biodiversity, (Fig 6b) makes it clear that the LFA livestock, arable and most of the mixed farms have similar levels of pollution per unit area, and are separated in the graph more by differences in food production. The dairy farms show higher levels of pollution than the other farm types.

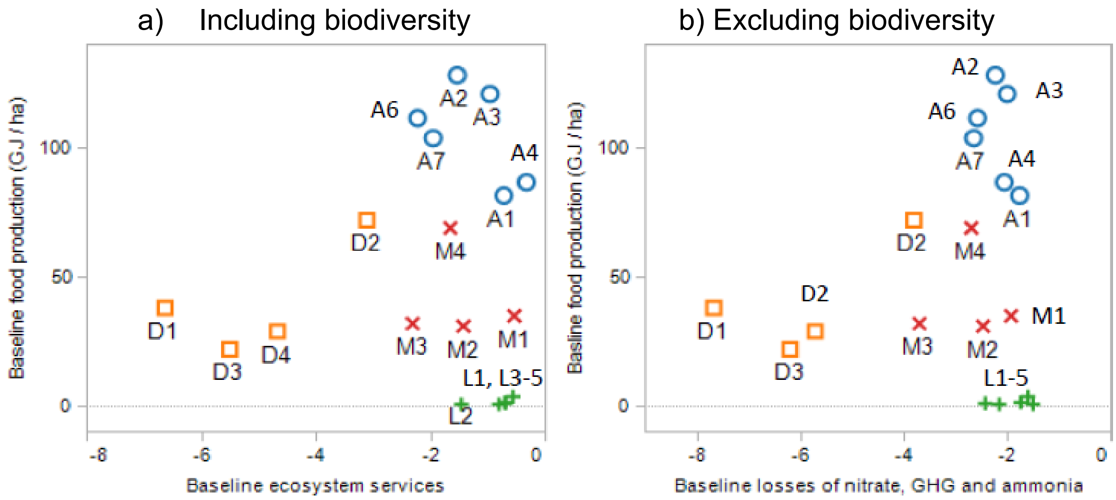

Figure 6: Relationships among food production and other ecosystem services at baseline

The baseline ecosystem services is a composite score per unit area, integrating equally-weighted data on ammonia, GHG and nitrate emissions, each given a negative value, and biodiversity, which has a positive score. The data are shown (a) including and (b) excluding biodiversity, i.e. addressing the losses of ammonia, GHGs and nitrates, also per unit area. See text for details. Farms are coded as Figure 4. Note the LFA Livestock farms are not identified individually as they are clustered too closely together.

Rather than seeing an overall negative relationship between food production and other ecosystem services, our data shows a clustering of the different farm types, with arable farms having the highest levels of food production and dairy farms showing the lowest levels of ecosystem services (Fig 6a). The equivalent plot i.e. including the emissions of ammonia, nitrate and GHGs but excluding biodiversity (Fig 6b), makes it clear that the LFA livestock, arable and most of the mixed farms have similar levels of pollution per unit area, and are separated in the graph more by differences in food production. The dairy farms show higher levels of pollution than the other farm types.

Changes in food production and environmental variables

Changes in food production and environmental indicators are visualised in Figure 7 and summarised in Table 3 (page 17). Changes are expressed in percentages of baseline scores, with environmental improvements (i.e. positive biodiversity change scores and reductions in ammonia, GHG and nitrate emissions) shown in the right hand quadrants of the graphs, and increases in food production at the top quadrants. Points in the top right quadrants therefore represent outcomes consistent with SI.

In general terms, arable farms were able to increase food production while reducing ammonia emissions, often with increased biodiversity scores and (usually) little change or slight improvement to carbon footprints. Nitrate losses often worsened, however. Changes to food production and ammonia emissions were positively correlated among the farm types that included livestock. The mixed farms showed a range of changes, with one displaying both increased food production and improved environmental outcomes. The performance of the LFA Livestock farms was also very variable, with just one farm showing increased food production and improved environmental outcomes. All of the Dairy farms increased food production at the expense of worsening carbon footprint and nitrate and ammonia losses, with little change to biodiversity scores.

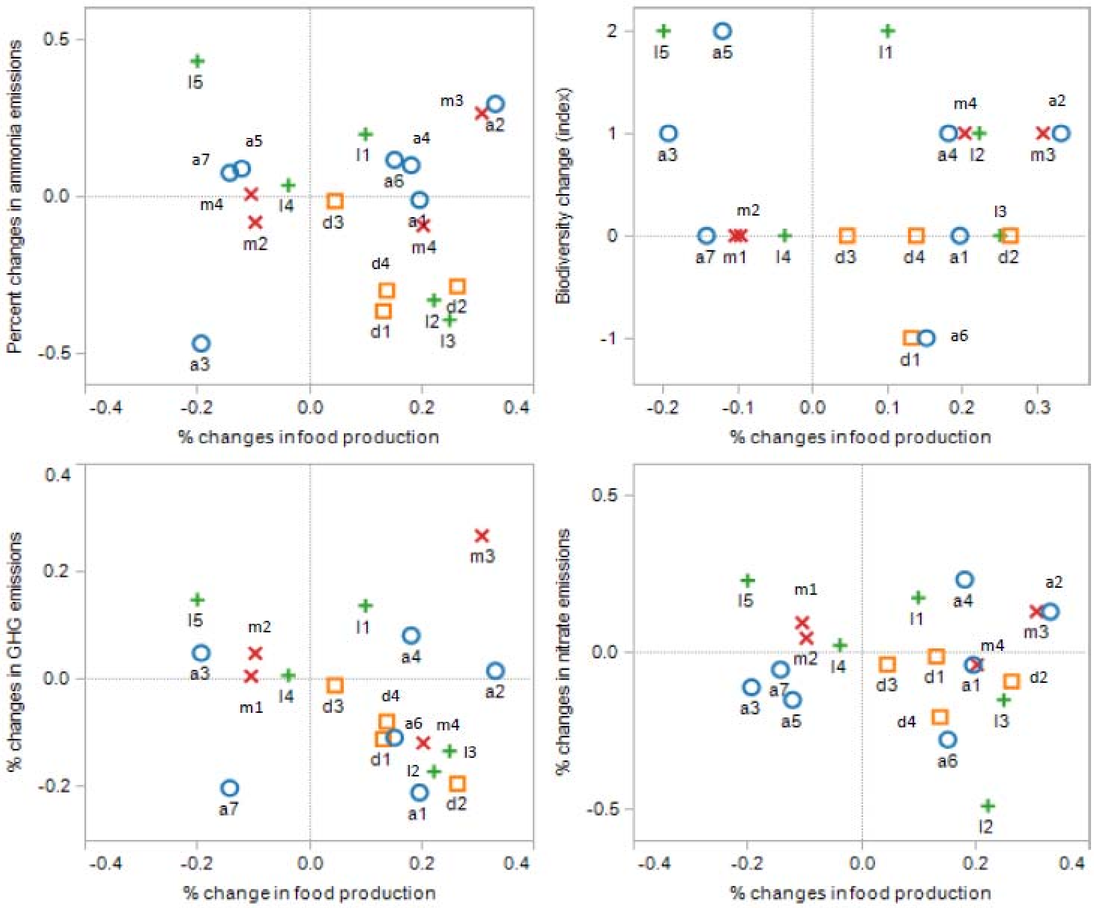

Figure 7: Changes in food production related to other environmental variables

Changes in food production are the differences between baseline and the most recent year, expressed in percentage terms. Changes in biodiversity are changes in score rather than stock. Changes in nitrate, ammonia and GHG emissions are percentage differences, but with the axes reversed so that any increases in emissions fall below the line of no change (shown as 0). In all cases, farms in the top right hand quadrant display an increase in food production and an improvement in environmental quality. All individual farms are coded as in Figure 4.

Changes in emissions per unit energy production in food

It can be useful to present information relating to the provision of ecosystem services in terms of the amount of food produced rather than per ha; indeed, carbon footprints are now typically presented in this way (Fig 8). Here, data on changing levels of ammonia, GHG emissions and nitrate are presented per unit of energy production in food. Such an analysis is not appropriate for the biodiversity data, which are whole farm scores.

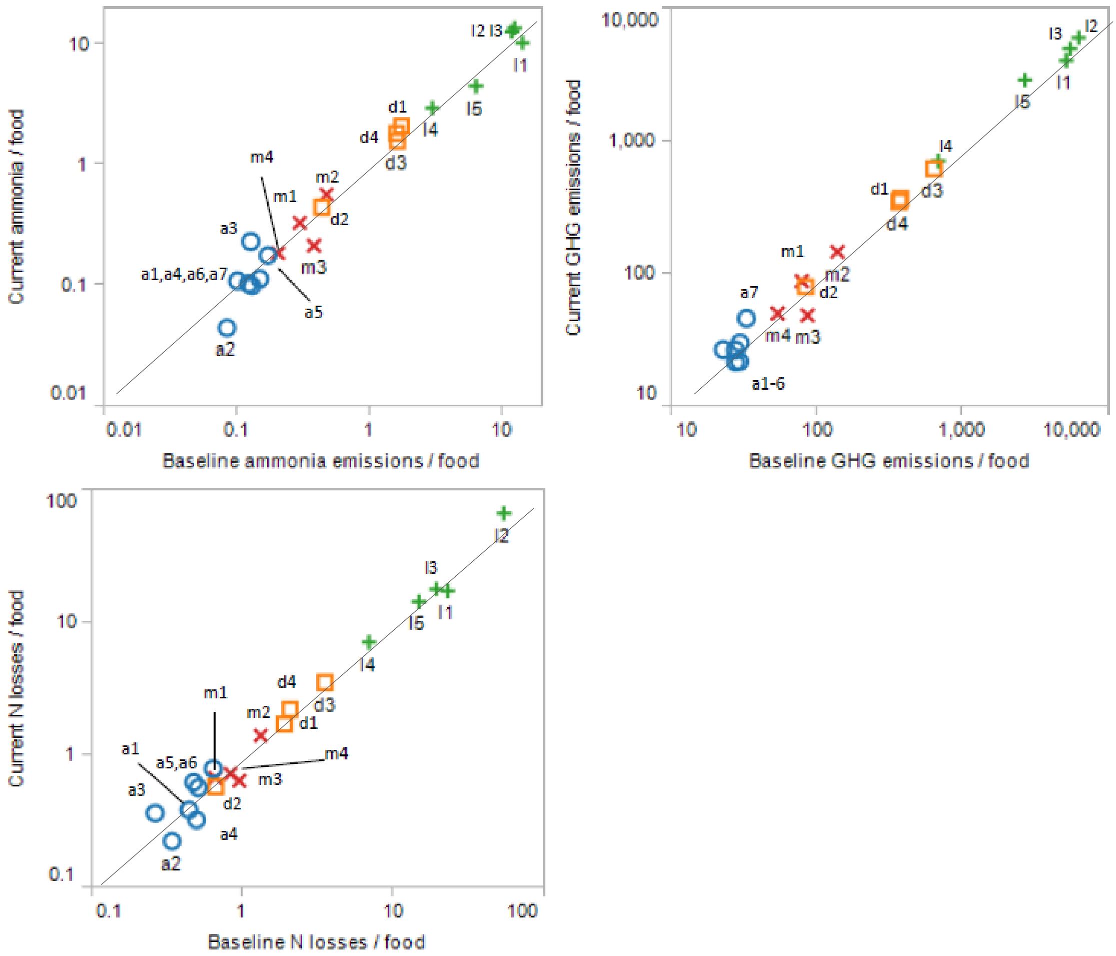

Figure 8: Changes in levels of emissions per unit of energy in food production

Data are presented for emissions of ammonia, GHG and losses of nitrate, per energy content of food produced at the time of the emissions. The sloped lines represent no change in emissions per unit food energy. Log scales are used to cope with the very wide of emissions over the farm types. Farms are coded as Figure 5.

Not surprisingly, the range of values varies greatly between the sectors, with emissions from the LFA sector being several orders of magnitude greater than from arable due to the low divisor value. Points below the line of equality indicate a reduced level of emissions per unit food energy, while points above the line represent increases. The scales are logarithmic to encompass the very wide range of values.

Fig. 8 indicates that changes in food production and levels of pollution have changed little between baseline year and latest year for dairy units; farms in the other sectors have shown more variation. Farms A2 and M3 reduced losses of all pollutants per unit food produced. Farm A2 has introduced technologies such as more fuel-efficient machinery, better insulation and more efficient use of fertilisers, in part related to releasing the poorer land from production. The baseline figures for farm M3 were high for the sector (unlike farm A2, which was much more typical), and the reductions in pollutants were driven partly by scaling back the livestock enterprise and partly by resource efficiencies such as the installation of wind turbines and greater use of precision farming techniques.

By contrast, farm A3 showed increases in all pollutants per unit food. This is largely due to a change in the farming system (the introduction of a chicken enterprise) which has masked environmental improvements. Fertiliser applications to arable crops have fallen and the farm has adopted a no-tillage regime; the models currently available do not capture the potential benefits of this system to carbon budgets and biodiversity.

Changes in carbon footprint per hectare and per GJ of food produced are shown in table 4 for additional emphasis. This shows that where absolute carbon footprint per unit area has increased (or only fallen marginally), this is often associated with a non-significant increase or a reduction in carbon footprint of each unit of food produced, reflecting increased food production per unit area. The exception is farm A7 where the carbon footprint has increased both per ha and per unit of food produced.

In other cases, for example for A3, a fall in food production per unit area has resulted in an increase in carbon intensity per unit of food production between the baseline and current year. Only Farm L3 showed a substantial increase in carbon footprint per unit area, but a substantial decrease per unit of food; this reflects a significant increase in food production, albeit at the expense of an absolute increase in GHG emissions.

Table 4: Percentage changes in carbon footprint per unit area and food production.

	Carbon footprint per unit area (% change)	Carbon footprint per unit food (% change)
A1	21	1
A2	-2	-26
A3	-5	18
A4	-8	-22
A5	Missing data	
A6	11	-4
A7	2	19
M1	-1	16
M2	-5	7
M3	-27	-46
M4	4	-13
D1	11	-3
D2	19	-6
D3	1	-4
D4	8	-3
L1	-14	-21
L2	17	12
L3	13	-16
L4	-1	2
L5	-15	4

The results are colour coded: green is a reduction in carbon footprint, red is an increase, grey that change is within 10 %.

4.3 Evidence for sustainable intensification

The objective of this study was to determine whether sustainable intensification (SI) has been achieved by individual farms, by seeking evidence of increases in food production without adverse environmental effects (ideally, environmental enhancements) according to the selected indicators. Farms that had increased food production per unit area without decreases in any of the environmental indicators, and ideally increases in at least some of them, were characterised as displaying SI according to the definition given in Section 2.1.

The changes in food production and environmental performance are summarised in Table 3 and visualised in Figure 7. We cannot give uncertainty measures for individual data points (we have no measure of statistical variation in how farmers report the data we have used), and so regard changes between +/-10% (shown grey in Table 3) as not indicating genuine change.

Farms that have achieved SI

Table 3 suggests that several farms have increased food production and shown no decreases in any ecosystem services, and so have achieved SI; two of the arable farms (A2 and A4) and one mixed farm, M3. One of the LFA farms (L1) has achieved environment improvements and a yield increase at 10%, at the border of what is here regarded as significant, and is also considered to have achieved SI.

Farm A2 has deliberately sought to establish a sustainable business model, working closely with the supply chain to increase yields and reduce environmental impacts, notably carbon footprint. This has relied on engagement of staff, a combination of technology to improve resource efficiency, monitoring of performance and putting less productive land into grassland, buffers, hedgerows and woodland. The farm is also seeking to reduce its current high demand for water so as to become self-sufficient.

Farm A4 is using higher level AES funding to take poorer land out of production to enable easier and more cost-effective farming with no impact on income. The farm has also focused on resource efficient farming, using variable rate fertiliser applications, integrated pest management, minimum tillage and precision farming. Energy consumption has also reduced due to installation of solar panels and reduced fuel use as a result of minimum tillage.

Farm M3 has also delivered sustainable intensification. The farm has changed a great deal since the baseline of 2006, with economic output doubled, enterprise change and an investment in wind turbines; an increase in cropping at the expense of livestock numbers has inflated the change in the food production indicator. There has also been investment in precision farming techniques, and agri-environment schemes on the poorer land.

Farm L1 has also made system changes, moving from a focus on hill sheep by increasing the proportion of more prolific cross-bred ewes, and improving grassland management to reduce inputs of both fertilisers and concentrates. The farm achieved maximum biodiversity scores for both stock and change, with diversity of habitats as well as the presence of native breeds of sheep and cattle.

The arable farm A1 might have demonstrated SI but for a large increase in GHG emissions. This relates to investments in new potato and vegetable stores and the running of new haulage lorries which were not in the baseline assessment; thus the farm scores therefore now include operations that were previously outsourced. Had carbon emissions across the whole food chain been taken into account, this farm may well have achieved SI.

Farms that have increased yields with reductions in ecosystem services

Several farms have increased food production at the expense of environmental quality per hectare of land. This was particularly noticeable among those farms that have sought to increase meat and dairy production, i.e. dairy farms D1, D2 and D4, and the LFA farms L2 and L3. All of these farms have made investments to increase the efficiency of resource use but increased outputs of livestock tend to be highly associated with emissions of ammonia, nitrate and GHGs per unit area, although losses per unit of production were reduced, albeit not by a significant amount.

Farm A6 achieved an increase in yield, due largely to an increase in areas of wheat and potatoes and higher yields for spring barley and oilseed rape. The increase of crops with higher demand for nitrogen has increased pollution pressures, as has the new practice of buying in poultry manure. The reversion of set-aside to crops has resulted in the negative score for biodiversity change.

The increase in food production for farm M4 was also due to changes in crop yields, rather than in the overall approach to farm management. The farm has increased its suckler herd, increasing its carbon footprint.

Farms that have increased ecosystem services without an increase in food production

One farm (farm L5) improved all aspects of environmental performance in combination with a decline in food production. This decline was associated with the process of conversion to organic status and an increase in farm area; further increase in stock numbers is constrained by additional commitments to agri-environment schemes. The environmental improvements of this farm were explained by buying new machinery, adopting precision farming, improving resource use efficiency, reducing inputs and reducing overall livestock density in accordance with the agri-environment schemes that support the system.

Farms that have shown no increases in food production or ecosystem services

Finally, several farms achieved neither significant yield increases nor environmental improvements between the two points in time. This is often affected by enterprise change or seasonal factors, or a combination of both, as follows:

- Changes in cropping and the introduction of a poultry enterprise has resulted in reduced food production and increased emissions from Farm A3.
- The decline in food production from Farm A5 was associated with drought, and the increase in nitrate pollution is the result of moving some land from cropping to fruit production.
- Farm A7 transferred land from arable to fruit, with the resulting loss of food production in terms of energy per unit area, while the importation of hen litter has increased GHG emissions.
- The mixed farm M1 has also seen yield reductions due to drought
- The organic farm M2 had more land down to grass in the latest year as part of the rotation.
- The relatively extensive dairy farm D3 has increased its size, rather than performance per unit area;
- The LFA farm L4 has seen little overall change in performance.

It is hard to discern a common thread separating those farms that have achieved SI from the others. One probable reason is that sustainable intensification is a process, and cannot always be observed using just two points in time, especially given the substantial differences between years in terms of both food production and environmental variables. This is most relevant to those farms in the ‘grey’ zone where changes in the indicators are insufficient to meet our criteria for SI (M1, D3 and L4). It is also clear from the narrative, that some of those farms which had a reduction in food produced such as A3 or had increased environmental impacts between baseline and the most recent year (A1) are practising inherently sustainable systems.

There are perhaps two key findings in this respect. The first is that some farms have been more effective in using technology and system change to deliver SI while others have experienced a trade-off between increasing intensity of production and environmental impacts. Using different years or even different metrics might have affected the number of farms demonstrating SI but it might still be expected that this would only be a minority of farms. The second relates to the fact that some of these farms are operating quite intensively at the baseline position and sometimes with limited scope to increase production and reduce environmental impacts, for example the dairy farms. This raises a question over the extent to which the concept of SI should be universally applied.

4.4 Results from the focus groups

Following on from the in-depth case studies a series of sector specific focus groups was held. The main purpose of these was to test:

(i) Recognition of the concept: Test the level of understanding of Sustainable Intensification - at both an abstract and practical level - amongst a wider body of farmers

(ii) Extent of uptake: Identify what proportion of farmers in these groups consider themselves to be practicing SI on their farms

(iii) Applicability of case study strategies: Gain a wider understanding of the strategies and underlying drivers for the implementation of SI

(iv) Policy perspectives: Explore views on the impact of current agricultural policy in encouraging and/or enabling SI.

The focus group format was designed to be informal and highly interactive, to ensure that participants felt at ease and free to voice their opinions. All responses were treated anonymously. A series of exercises and presentations were used to help guide discussions.

Focus Group Summary

Approximately half of all focus group farmers were aware of the concept of SI; knowledge was highest in the arable sector and lowest in the dairy sector. There also appeared to be a correlation between the level of knowledge about the concept in these sectors and the ease with which they considered it was possible to implement it. This is reflected in higher existing and proposed uptake in the arable sector relative to the dairy sector.

There was a general feeling that it is harder to achieve SI in dairying, in part because of the current market climate with rising costs and falling milk prices. In contrast the market returns for other sectors have been more buoyant during 2012, and this may be reflected in a more positive attitude towards accommodating improved environmental outcomes. The perception of the dairy focus group, that SI is harder to implement in their sector, is backed up by the case study findings, whereby those dairy farms that achieved a significant increase in food production were unable to do so without a simultaneous increase in losses of nitrate and ammonia. Similar trends were also found in the other systems which included livestock.

All focus groups favoured the use of latest technologies to achieve productivity gains, reducing inputs without affecting outputs where possible. However, there were some differences between groups, for example the dairy group did not favour land sparing as much as the others.

However, when stripped back to the underlying drivers, again we see commonality across all sectors, and between the case studies and focus group results i.e. the primary underlying driver is financial return.

Similar views were expressed across all focus groups regarding the effects of EC, UK and national agricultural policy, notably around the extent to which the Single Payment Scheme deflects from the drive for efficiency and adds to costs. There was also consensus on the need for access to more R&D and help with investment in new technologies.

5. Discussion

5.1 Nature of the evidence

The results have shown that it is possible to distinguish between farms that are implementing different strategies, which might contribute to sustainable intensification, using data already in the possession of the farmer. We have successfully quantified food production, carbon footprint and losses of nitrates and ammonia; we have also developed an index of biodiversity change. The index of landscape and landscape change has been the least successful, as it proved impractical to develop indicators of landscape quality on the basis of the data available. This approach would need to be re-thought for future work. Other variables, for example water use and natural capital, could also be considered in the future. Animal welfare should also be considered, even though it is not strictly relevant to the measurement of food production or environmental quality.

This project has revealed several issues impinging on the quality of data interpretation:

- *We lack data on statistical variation of the parameters at the farm scale:* Sustainable intensification is best regarded as a strategy, yet farm management also involves tactical responses to variation in weather and markets. More data are required from *more* farms, over complete time series, to establish how to separate the signals of sustainable intensification from the noise of year to year variation in cropping, and the use of inputs and energy.
- *The chosen variables are derived from farm actions, rather than farm outputs:* The indicator data arise from what the farmer has done, for example input use or agri-environment options, rather than on direct measurements of the changing environment. This is particularly obvious for biodiversity, but is also true of the other measures.
- *The disadvantage of only using farmers' own data is that baseline data on stocks of natural capital are not collected*. Ideally, field surveys should be conducted, although some can be inferred from national databases of biodiversity, soil type etc.
- *The chosen variables are derived in ways that do not capture all actions at the farm scale:* We lack good models to establish the impact of farm-scale mitigation actions on the environment. A particularly good example is farm A3. The farmer noted the following results from his introduction of zero tillage "*We produce, if anything, more food than before as well as a fantastic increase in biodiversity. The changes in soil life have been particularly significant. Increased worm activity and micro-flora has improved soil structure and P and K indices, requiring less inputs*". These benefits were not captured by our models as there is insufficient data

available for us to be able to calculate the environmental impacts of zero tillage systems with any precision.

- *It is difficult to address the impacts of any consequential land use changes taking place off-farm.* While we have estimated the areas of land needed to produce animal feed, these estimates do not account for the impact of indirect land use change, affecting biodiversity outside of GB, for example.
- It may never be possible to devise low cost approaches to quantifying the environmental performance of individual farms to a high level of accuracy. However, it should be possible to develop a suite of indicators and protocols that enable better precision and more robust comparisons.

Key finding 1: This project can be viewed as a pilot study, identifying some of the principal issues involved in designing and implementing a system for collecting and interpreting the kinds of farm-level data needed to quantify the strategic changes taking place within UK agriculture, including sustainable intensification.

5.2 Implications of the evidence

What is the nature of the relationship between food production and other ecosystem services?

In this study, we hypothesised that the relationship between food production and other ecosystem services was essentially negative, along a boundary condition (Figure 1). Such a relationship was not seen consistently among the case study farms (Figure 6), where there was evidence of positive relationships (synergies) as well as negative ones (trade-offs).

The relationship between food production and ecosystem services is, of course, highly sensitive to which services are measured, over what timescales and how they are weighted. In this study, three types of services were measured at baseline; food production, pollutants and biodiversity. Food production was recorded in terms of food energy output per unit area of land, and so was inevitably highest in lowland arable farms and lowest on extensive upland livestock farms. Pollution was measured in terms of losses of ammonia, GHGs and nitrate, per unit of land area; all are associated with intensive livestock and arable farming. Biodiversity was assessed using a scoring system based on the diversity of habitats and the extent to which environmentally beneficial farming practices had been deployed, rather than directly measuring the presence and abundance of particular species. This approach favoured farms with a wide range of habitats and those engaged in agri-environment schemes.

The lack of a clear pattern in the relationships between food production and other ecosystem services seen in Fig. 6 therefore reflect the selection of variables and of the units used. A different set of variables (addressing, for example, water regulation, financial value of the crop, landscapes that attract tourists and presence of rare species and habitats) would no doubt have generated very different findings for these farms. Moreover, because the study focussed on change using farmers' own data, there was little attempt to quantify the natural capital of the farm, in terms of carbon stocks in the soil, landscape structure or the presence of particular species. Changes in these can take a long time to detect, unless there is major land use change or disturbance.

The weightings applied to each of the ecosystem services also have a powerful influence on the findings. In this study, we have selected a small number of variables and presented data on them separately. A more holistic approach would be to seek to ascribe values for each ecosystem service, allowing a more integrated view of the overall outputs from a particular farm over time (UKNEA 2011); however, such valuation is in its infancy and may suffer from a lack of transparency.

Finally, it is necessary to consider the issue of long-term sustainability of any changes measured. Thus ongoing increases in food production per unit of land, as distinct from productivity, which relies on the efficiency of use of all inputs (not just land), may not consistently and predictably demonstrate SI over time as resources such as energy, water etc may become limited. It might therefore be pertinent to capture productivity change as well as production change per unit area.

Key Finding 2: This project has not revealed an overall negative relationship between food production and other ecosystem services among the case study farms, although only a minority of farms have increased both parameters simultaneously. This may be because the set of variables was too limited. Ideally, a wider set of ecosystem services should be included, alongside measures of critical natural capital, e.g. soil carbon, water use and the presence of rare species and habitats. Any quantification of ecosystem services from individual farms is highly sensitive to the selection of indicators, how they are measured and over what timescale, and how they are weighted. It may be appropriate to restrict comparisons to within farm types.

How can we recognise sustainable intensification?

This project has shown that it is possible to use data already held by farmers to characterise changes in environmental performance and food production on individual farms over time in ways that reveal whether or not SI has been taking place, and in what form. The evidence is strongest for food production and emissions; evidence for changes in biodiversity is much less direct, and changes to landscape have proved very difficult to assess. The evidence is much easier to interpret when accompanied by narratives from the farmers themselves.

Temporal factors are also of great importance. In this study, we collected data as close to 2006 and 2011 as possible. The use of two discrete years may have disguised underlying progress towards SI, in that some farms had reduced yields in 2011 because of poor weather. Also, the farms best placed to show evidence of SI were those that had completed any changes to their system between the baseline and the latest year; farms in transition (such as A3 and L5) scored less well than those farms that had retained the same farming system. A related problem is that of variation in starting levels. SI is likely to be seen more easily among farms with initially low performance; this may be true for farm M3. These problems would be overcome by making a series of observations over time rather than just using two discrete snapshots.

Key Finding 3: It is possible to assess the sustainable intensification of individual farms using data already available to them, in ways that can distinguish farms and farm types in terms of strategy and outcomes. It is preferable to use a series of observations over time rather than just two discrete snapshots.

Are there already examples of sustainable intensification among British farmers?

In this project, we visualised sustainable intensification as vectors describing change from the potential present states at and under a curve, relating current levels of food production and other ecosystem services (Fig 1). It is clear that we have examples of a wide range of trajectories of change; some farms (arable, mixed and livestock) have increased food production and environmental quality simultaneously as a result of changes to farming practices or systems, while others are in transition and may well demonstrate SI over a longer time period. This project has, for the first time, provided evidence that individual farms in GB have been practising sustainable intensification, simultaneously enhancing food production and environmental quality, especially through reductions in pollution.

It is important to recognise that other farms demonstrated a trade-off between food production and environmental quality. This represents a risk for a broad policy of increasing food production.

Key Finding 4: This project provides evidence that sustainable intensification has been practised by some farms in the UK in recent years. This evidence was most consistent in the area of reduction in pollution. However, a number of farms which increased food production also saw an adverse impact on environmental quality, indicating a trade-off between the two.

What strategies were the farmers adopting, and why?

The major driver for change among the case study farmers has been the desire to enhance profitability in the context of making the business model more sustainable. This highlights a limitation of using food energy as a metric in this context, as it may be more profitable to grow lower volumes of higher quality food or switch to enterprises which have inherently lower energy values. This applies to farm A7, which has increased production of fruit and vegetables; L1, where there has been a conscious decision to reduce livestock stocking densities (reflecting the changing support away from headage payments), and L5, where yields have fallen as part of the process of converting to organic.

Beyond changes in farming system and the balance of crops and livestock, farmers have also used technology to increase agricultural outputs, for example through improved genetics or precision farming. For many, the focus has been on improving productivity rather than increasing outputs per se. This most farms of the case study farms have installed, or wish to adopt, technologies and techniques that will help them to reduce input costs. Many of these will also deliver environmental benefits, such as a lower carbon footprint. Approaches include precision farming, more efficient machinery, zero tillage and improved water management. Several of the case study farmers have installed solar panels or wind turbines to provide another income stream, again simultaneously reducing energy consumption as well as improving the farms carbon footprint. In general, the enhancement of ecosystem services through reducing pollution makes good business sense as the impact of rising input costs (Figure 3) can be reduced. Such changes are likely to continue.

The farmer focus groups largely confirmed the case study findings and suggested that early adopters and mainstream farmers have also engaged to some extent with sustainable intensification. However, this is by no means a conscious strategy but rather it reflects responses to economic drivers, including resource efficiency, payment for ecosystem services through agri-environment schemes, as well as social drivers such as improving the farm environment for the future.

Key finding 5: The major driver of farm strategy is profitability, often alongside an ambition to improve the environmental performance of the farm: farmers engage to some extent with the concept of SI, albeit unknowingly. Using new technology and innovative practices to reduce pollution can add to profitability

and environmental quality through improving the efficiency of utilisation of increasingly expensive inputs of nutrients and energy. Improved environmental performance may also be part of securing better market access or premium prices.

In our study, the various farm sectors performed very differently. To some extent, the grouping of the farm types reflects the metrics used, notably in terms of energy content of food per unit area (which resulted in very large differences between sectors) but it also suggests that certain sectors face particular challenges in seeking to identify opportunities for sustainable intensification per unit area (which resulted in very large differences between sectors); it also suggests that certain sectors face particular challenges in seeking to identify opportunities for sustainable intensification.

Our study only looked at four dairy farms and these were not selected at random. It is therefore inappropriate to focus too much on the performance of this sector. Yet it is striking that no dairy farm achieved sustainable intensification; levels of pollution rose in proportion with increasing yield, even though new technologies were being installed. This finding was supported by the dairy focus group. Similarly, levels of pollution per unit area were high for all farms that included livestock, even extensive LFA farms. It is also telling that of all the farms that achieved increases in gross energy by increasing production from livestock (D1, D2, D4, M3, M4, L2, L3), only one farm managed to do so without increasing levels of GHG emissions and/or nitrate and ammonia losses per unit land area (although not per unit food production), and this was from a modest starting position (M3). It is not clear that SI, as defined by this project, is currently a viable option for all sectors of the livestock industry, and may not be an appropriate strategy in the uplands where other ecosystem functions may be valued more highly than increases in food production (e.g. water quality, carbon storage, landscape quality).

Key finding 6: Different farm types and farming systems have different possibilities for sustainable intensification. In particular, dairy systems have relatively high levels of environmental impact linked to methane and the pollutants in manures. The results suggest that there may be limitations in terms of the SI concept for the livestock industry, where increased productivity is likely to be associated with higher input intensity (though not exclusively) and higher emissions per unit land (but not per unit of food production) given current farming methods and application of technologies. For example, SI may not be an appropriate strategy in the uplands, where other ecosystem functions such as water quality, carbon storage, landscape and biodiversity may have a greater social value than increases in food production.

What is the role of current support measures in facilitating sustainable intensification?

Many of the farms have made some improvements to their land with the objective of enhancing biodiversity, sometimes with the intention of '*passing on more than was acquired*'; sometimes to enhance game shoots. But in most cases, these actions were seen as being separate from the business of farming, and best located on unproductive land, with support from agri-environment payments; this view was also held by Farm L5, which is undergoing conversion to organic. One farmer explained that he is "*unsure how (his approach to biodiversity) will change. Want to maintain biodiversity but primary focus is production*". Another one explained that the '*big decisions hinge on policy changes when the (agri-environment) agreement is up for renewal in 2016*".

There was little awareness of landscape issues among the farmers; landscape enhancement was seen as being achieved through very localised actions such as planting hedgerows or trees, or maintaining historic features.

The focus groups commented on the role of the Single Payment Scheme and the Rural Development Programme. The SPS was seen as being helpful in general terms, given how reliant the farming industry is on it, but there was a sense that it does not encourage sustainable intensification, as it "*rewards scale and risk-averse attitudes, and props up the less efficient farmers.*" Agri-environment schemes were generally viewed more favourably, but the most intensive arable farmers, farming on grade I land, felt that the existing schemes had little value or appeal to them; "*We need a 'high end'* stewardship *model for high intensity, high land value areas."*

There was strong consensus on the need for increased dialogue between farmers and policy makers for sustainable intensification to be adopted successfully: "*Regulations need to be justified more to the recipient. They need to be more evidence based / the evidence needs to be better communicated to farmers,"* and "*Policymakers need to be more grounded and have a working knowledge of farming*."

Key finding 7: Actions to enhance and maintain biodiversity are largely a cost to the farm business, and often require external financial support (such as agri-environment schemes) for their continued maintenance, even where the farmers concerned value biodiversity for its own sake. The default approach appears to involve the use of the least productive land on the basis of least cost to the business, rather than decisions being informed by the best possible environmental outcome in return for the payments being made; this issue is particularly relevant to AES design. As well as the need for ongoing support payments to underpin the provision of public environmental goods and services, such as biodiversity and landscape, there is a case for increased support in the form of information provision, advice and associated research programmes if the process of sustainable intensification is to be supported.

6. Conclusions

This study demonstrates that it is possible to evaluate the success (or otherwise) of individual farms across a range of sectors in delivering increased levels of food etc. Whilst we have identified a number farms that appear to have achieved sustainable intensification, not all farm strategies involve win-wins and it is important to recognise that increased food production often involves trade off's in terms of the impact on other ecosystem services.

While our approach of using only data available to farmers restricts how well certain environmental variables can be addressed, it does mean that it is possible to build on this work to develop a tool for individual farms to feed back their performance, both to themselves and to others. Further work is needed to develop or refine the tools available so as to accurately translate farm data into reliable indicators of ES performance. Crucially a time series of data is necessary to allow for the natural variations across seasons which afflict the farming sector and to capture the direction and scale of change.

This study also demonstrates that engagement with innovators and early-adopters in the farming community can help identify both opportunities and barriers to policy ambitions such as sustainable intensification. This learning can be of considerable value in designing future support schemes under the CAP as well as informing wider policy-making. It also provides credibility for policy initiatives in terms of the wider industry.

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Appendix 2: Farm Questionnaire

Telephone call to seek (confirmation of) participation in the SI project

"Good morning/afternoon/evening, my name is [INTERVIEWER NAME] from ADAS/SAOS, an independent consultancy/organisation. We are carrying out a study on behalf of the **Countryside Council for Wales / Natural England / Scottish Natural Heritage and others** to explore the concept of sustainable intensification. Sustainable intensification means simultaneously raising yields, increasing the efficiency with which inputs are used and reducing the negative environmental effects of food production.

The project will use case study farms to test the principle and will be used to inform public policy on initiatives to improve both food security and the environmental impacts of agriculture, through for example, farm advice and grants or agri-environment schemes.

We will require you to provide the following:

- **Your time** for an on-farm meeting to talk with you and collect data about your farm and farming system. We will meet with you at your convenience; any follow-up queries will be by telephone or email.
- **Your data** to enable us to measure food production and environmental inputs and impacts. We will require both current (2010/2011) and historical (5 years previous) data for your farm (where there have been changes).
- **Your views** on why you have chosen the approach to farming, the challenges faced and outcomes you have seen (both positive and negative).

The responses you provide will be held, together with your details, by ADAS for the duration of the study and will be destroyed when the project has reported later in the year. The data provided to the project will be presented anonymously in a final report to the Countryside Council for Wales. You will have the opportunity to read and approve the case study write up with steps taken to ensure confidential data is not released and that case study farms are not identified without your prior written consent. This data will be used for research purposes only.

Can you please confirm that you are happy to be involved in the project and provide information of food production and environmental impacts?"

YES

NO

Farm Details

Farm ID	
Consultant Name	

		Enter data or tick
Country	Wales	
	Scotland	
	England	
Robust Farm Type	Cereals	
	General cropping	
	Horticulture	
	Dairy	
	Grazing livestock (LFA)	
	Grazing livestock (lowland)	
	Mixed	
Farmed area* (ha)	Owned	
	Full tenancy	
	Short term tenancy (FBT or equivalent)	
	Other rented	
	Contract farmed	
	Joint Venture	
	Seasonally rented in land	
	Other	
	Other	
	Seasonally let out land	
	LFA* (ha)	
	Area of moorland (ha)	
	Area of improved grazing (ha)	
	Area of in-bye (ha)	
	Non-farmed habitats - woodland, wetland etc** (ha)	
	Average Annual Rainfall (mm)	
RB209 Soil Type**	Light sand soils	
	Shallow soils	
	Medium soils	
	Deep clayey soils	
	Deep silty soils	
	Organic soils	
	Peat soils	
Soil Permeability**	Free Draining	
	Impermeable	
	Arable Soils Drained (%)	
	Grassland Soils Drained (%)	

* Based on SPS claim

** If there is more than one widespread type, give rough percentages

	Start Date	**End Date**
Dataset No. 1: **Baseline**		
Dataset No. 2: **Last Year**		

The start and end months should be the same for both years (e.g. Apr 06 - Mar 07 and Apr 10 - Mar 11)

Farm policy and motivations

What is your role on the farm?

Sole trader

Director

Business partner

Farm Manager

Other………………..

Which of these age brackets do you fit into?

Under 34 years 35-44yrs 45-54yrs 55-64yrs 65-74yrs 75yrs+

Business model and philosophy

What are you trying to achieve on your farm in terms of food production and environment and how?

Farming system

Description of system (intensive, extensive, machinery, specifics)

Inputs

Seed (purchased, farm saved), fertiliser/manures (use of planning tools, manure system), pesticides, feed (compound, farm mix etc). Use of buying groups.

Production and markets

Yields and quality, target/specialist markets, how is output sold

Farm labour

Labour (family/manager, labour, contractors etc)

Farm management

Business planning and tools

Farm financial sustainability

Profitability level (high/medium/low) – farmers own perspective but capture efficiency benchmarks if available

Environmental management

Overview of current and planned implementation, initiatives and results

Innovation and technology

Current and planned implementation, initiatives and results

Route to market and added value

Sell their produce direct to consumers, on contract to a manufacturer or retailer e.g. through a farmers' cooperative (e.g. CamGrain) or selling group. Use of local markets etc.

Cropping and Outputs

Crop (separate line for grain, straw etc)	Baseline			Last Year			Reason for change (area / yield)
	Area (ha)	Quantity Sold* (tonnes)	DM (%)	Area (ha)	Quantity Sold* (tonnes)	DM (%)	

This data is only required where crop products (grain, straw etc.) are moved / sold off the farm.
Enter Dry matter (DM) if known.

Livestock numbers

Type	Baseline			Last year			Reason for change (area / yield)
	Average no. (Head)	Duration on Farm (Months)	Details e.g. breed, weight (kg) etc	Average no. (Head)	Duration on Farm (Months)	Details e.g. breed, weight (kg) etc	
Dairy Cows and Heifers							
Dairy Heifers in Calf 2 yrs +							
Dairy Heifers in Calf < 2 yrs							
Bulls 2 yrs +							
Beef Cows and Heifers							
Beef Heifers in Calf 2 yrs +							
Beef Heifers in Calf < 2 yrs							
Other Cattle 2 yrs +							
Other Cattle (1 - 2 yrs)							
Other Cattle <1 yr & Calves							
Sheep							
Replacements 1-2 yrs							
Lambs < 1 yr							
Sows in Pig & Other Sows							
Gilts in Pig & Barren Sows							
Gilts Not Yet in Pig							
Boars							
Other Pigs (> 110kg)							
Other Pigs (80 - 110kg)							
Other Pigs (50 - 80kg)							
Other Pigs (20 - 50kg)							
Other Pigs (< 20kg)							
Layers (Caged)							
Layers (Not caged)							
Pullet							
Broilers							
Turkeys							
Breeding Birds							
Other Poultry							
Other							

Livestock Output

Type	Baseline					Last year					Reason for change (no/weight/yield)
	Numbers In	Weight In	Numbers Out	Weight Out	Total Milk / Wool Volume	Numbers In	Weight In	Numbers Out	Weight Out	Total Milk / Wool Volume	
	(Head)	(kg)	(Head)	(kg)	(litres/kg)	(Head)	(kg)	(Head)	(kg)	(litres/kg)	
Dairy cows											
Suckler cows											
Replacements											
Beef cattle											
Calves											
Breeding sheep											
Replacements											
Lambs											
Breeding sows											
Replacements											
Finished pigs											
Broilers											
Laying hens											

Purchased Feed

Feed Type	Baseline (if different)	Last Year	Reason for change
	Quantity Purchased (t)	Quantity Purchased (t)	

Fertiliser Use

Crop	**Area (ha) or assume areas as section 3)**	**Baseline (if different)**		**Last Year**		**Reason for change**
		Fertiliser Rates		Fertiliser Rates		
		N (kg/ha)	P_2O_5 (kg/ha)	N (kg/ha)	P_2O_5 (kg/ha)	

The same crop can be entered multiple times to represent different purposes (e.g. Milling Wheat and Feed Wheat) of different fields.
Fertiliser rates refer to manufactured fertiliser only.

Livestock Housing

Type	Baseline (if different)				Last year				Reason for change
	% time grazing	% time in yards (outdoor)	% time housed (indoor)	% as slurry	% time grazing	% time in yards (outdoor)	% time housed (indoor)	% as slurry	
Dairy cows									
Suckler cows									
Replacements									
Beef cattle									
Calves									
Breeding sheep									
Replacements									
Lambs									
Breeding sows									
Replacements									
Finished pigs									
Broilers									
Laying hens									

Purchased Straw & Bedding

Type	Baseline (if different)	Last Year	Reason for change
	Quantity Purchased (t)	Quantity Purchased (t)	
Straw			
Wood Shavings			
Gypsum Mixed With Sawdust			
Lime			
Sand			
Other			

If 'Other' is selected, please indicate somewhere what 'Other' refers to.

Manure storage

		Baseline (if different)	Last Year	Management, changes and comments
All FYM	FYM stored (%)			
	Typical location of FYM heap			
	Is it covered?			

		Baseline (if different)	Last Year	Management, changes and comments
All Slurry	Slurry stored (%)			
	Slurry store type			
	Is it covered?			

	Baseline (if different)	Last Year	Management, changes and comments
Dirty water collected and sent to slurry store (%)			
Dirty water collected and sent to a dirty water store (%)			

Manure Purchased /Sold

Type	Nutrient contents (%)*			Purchased (P)or Sold (S)	Baseline	Last Year	Policy and reason for changes
	N	P	DM		Quantity (t)	Quantity (t)	
Cattle FYM – fresh							
Cattle FYM – old							
Pig FYM – fresh							
Pig FYM – old							
Sheep FYM – fresh							
Sheep FYM – old							
Duck FYM – fresh							
Duck FYM – old							
Layer manure							
Broiler / Turkey litter							
Cattle slurry							
Pig slurry							
Cattle slurry, strainer box liquid							
Cattle slurry, weeping wall liquid							
Cattle slurry, mechanically separated liquid							
Cattle slurry, separated solids							
Pig slurry, separated liquid							
Pig slurry, separated solids							
Dirty water							
Biosolids, liquid digested							
Biosolids, digested cake							
Biosolids, thermally dried							
Biosolids, lime stabilised							
Biosolids, composted							
Biosolids, thermally hydrolysed							
Green compost							
Green / Food compost							
Paper crumble, chemically / physically treated							
Paper crumble, biologically treated							
Other							

* N, P contents and Dry Matter contents if known

Manure Applications

Crop	Area (ha)	Baseline				Last Year				Reason for change
		Manure Type	Manure Rate (t/ha or m^3/ha)	Application Method*	Incorporation Delay**	Manure Type	Manure Rate (t/ha or m^3/ha)	Application Method*	Incorporation Delay**	

* Discharge spreader
Broadcast spreader
Deep injection
Shallow injection
Band spreader – trailing hose

** <2 hours
2-4 hours
4-6 hours
6-12 hours
12-24 hours
1-2 days
3-5 days
6-12 days
12-32 days
>32 days
Not incorporated

Fuel and Power

Fuel / Power Item	Measurement Units	Baseline (if different) Total Volume	Last Year Total Volume	Management of inputs and reason for change
Electricity and fuels for heating	kW			
Oil	litres			
Diesel	litres			
White diesel	litres			
Petrol	litres			

Please include entries for all fuel, electricity, gas, diesel, etc.
Measurement units include kilo watt hours (kWh), gallons, cubic feet, etc.

Agri-environment schemes

Agri-environment scheme membership	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Membership of ‘entry-level’ or whole farm scheme (tick)								
Membership of ‘higher-level’ scheme (tick)								
Total area of land under scheme (including arable margins)								
Options implemented and scale of uptake (ha / m etc)								
PROMPT: Boundary features								
PROMPT: Trees & woodland								
PROMPT: Historic & landscape features								
PROMPT: Buffer strips & margins								
PROMPT: Options for arable								
PROMPT: Options to protect soils								
PROMPT: Options for grass outside SDAs								
PROMPT: Option for mixed stocking on grass								
PROMPT: Options for SDAs								
PROMPT: Other								
Other environmental schemes or initiatives - Organic (e.g. Soil Association, Organic Farmers and Growers, etc.); - Leaf MARQUE, rather than Leaf; - GLOBAL GAP; - Red Tractor/Assured Food Standards umbrella scheme; - Conservation Grade; - Retailers / processors schemes (e.g. Tesco's Nature's Choice, Waitrose Wildcare etc);								

Approach to biodiversity

	Commentary
Can you provide a commentary about your approach to biodiversity (e.g. conservation management, land sparing etc.) on the farm form 2005 – now	
Can you explain how your management of farmland biodiversity is likely to change in the next 5 years, and why?	
List any accreditations or status you have achieved for management of biodiversity	
What has been the impact of **biodiversity management** practices on food production?	

Biodiversity – evidence of change

Do you have biodiversity records for your farm over time, ideally since 2005? If so, please provide details	Yes	No	Details or comments
Birds			
Game birds			
Butterflies			
Plants			

For the following farm management options, have they changed since 2005?	Increased	About the Same	Decreased	Comments
Autumn vs. spring sowing				
Silage / early grass cuts vs. hay				
Area non-cropped habitats				
Drained land				
Livestock density (stocking and breed/weight of animals)				
Diversity of crops (including grassland)				
Diversity of non-cropped habitats (including ponds, woodlands)				

Biodiversity – priority habitats

Details for all of the stated habitats that are found on your farm	**Present (Y/N)**	**Since 2005 . . .**						
		Has area / length/ number increased?	Has area / length/ number decreased?	Has condition improved?	Has condition deteriorated ?	Have you increased grazing intensity on this habitat?	Have you reduced grazing intensity on this habitat?	What actions have you undertaken on this habitat?
Chalk rivers								
Coastal and floodplain grazing marsh								
Hedgerows								
Lowland calcareous grassland								
Lowland dry acid grassland								
Lowland meadows								
Machair								
Mountain heath and willow scrub								
Ponds								
Purple moor grass and rush pasture								
Traditional orchards								
Upland calcareous grassland								
Upland flushes, fens and swamps								
Upland hay meadow								
Wood pasture and parkland								

Comments:

Biodiversity – SSSIs / Neutral Grassland

SSSI sites on the farm	Reason for designation	Habitat type	Most recent condition assessment	Date of assessment	Actions in place as a result of most recent assessment
Site no 1					
Site no 2					
Etc					

Semi-natural grassland*	Yes	No	Comments
Do you have species-rich, nutrient rich grassland on your farm (e.g. hay and water meadows)			
If yes, have you created more grassland to connect land parcels that were separate in 2005?			
If yes, have you fragmented land parcels that were present in 2005?			

*Neutral Grassland (Lowland meadows/Upland hay meadows); Acid Grassland; Calcareous Grassland; Fen, Marsh and Swamp; Purple moor grass and rush pastures

Biodiversity – native breeds

4	**Details of any native breeds of sheep and cattle on the farm**	**Have numbers increased since 2005?**	**Have numbers decreased since 2005?**	**Comments**
4.1	a - please give breed name			
4.2	b etc, as required			

Approach to landscape

	Commentary
Can you provide a commentary about your approach to **landscape management** on the farm from 2005 – now	
Can you explain how your **management of landscape** is likely to change in the next 5 years, and why?	
List any accreditations or status you have achieved for **management of landscape**	
What has been the impact of **landscape management** practices on food production?	

Approach to water quality

	Commentary
Can you provide a commentary about your approach to **limiting impacts on water quality** on the farm form 2005 – now	
Can you explain how your approach to **limiting impacts on water quality** is likely to change in the next 5 years, and why?	
List any initiatives you have joined / been supported by to **limit impacts on water quality**	
What has been the impact of approach to **limiting impacts on water quality** practices on food production?	

Limiting climate change impacts

	Commentary
Can you provide a commentary about your approach to **limiting impacts on climate change** on the farm form 2005 – now	
Can you explain how your approach to **limiting impacts on climate change** is likely to change in the next 5 years, and why?	
List any analysis or data you have done for **limiting impacts on climate change** such as carbon footprinting	
What has been the impact of your approach to **limiting impacts on climate change** practices on food production?	

Climate change adaptation

	Commentary
Can you provide a commentary about your approach to **adapting to climate change** (including extreme weather, disease/pest risk,) on the farm form 2005 – now	PROMPTS: Planting trees and agro-forestry; Improved drainage systems; Buffer strips; Create wetlands, ponds and water meadows; Increase water storage; Improve manure storage; Improve irrigation efficiency and precision farming; Collect and store water run-off; Keep livestock away from watercourses; Restore natural river profiles; Use land for flood storage;
Can you explain how your approach to **adapting to climate change** is likely to change in the next 5 years, and why?	
List any analysis or data you have done for **adapting to climate change** such as carbon footprinting	
What has been the impact of your approach to **adapting to climate change** practices on food production?	

Producing renewable energy

	Commentary
What renewable energy do you generate on-farm (wind / solar / hydro power, biomass, anaerobic digestion), and how much renewable energy do you **generate** on-farm? i.e. how many kWhrs do you sell back to the national grid, what weight of biomass do you grow per annum?	
How much renewable energy do you **use** on-farm? i.e. number of kWhrs, tonnes of biomass,	
What are your motivations behind generating and/or using renewable energy on-farm? (where applicable)	
What has been the impact of your approach to **generating renewable energy** on food production?	

Other environmental impacts

Reducing Pesticide Use / Ecotoxicity	Yes	No	Commentary
Have you implemented an integrated pest management (IPM) programme?			
Do you minimise pesticide use, avoid more toxic chemicals or use biopesticides?			
Do you minimise medicine use in animals?			
Do you participate in the catchment sensitive farming programme or the voluntary initiative?			
Have you undertaken any other initiatives to reduce pesticide use / medicine use?			

Reducing Water / Land Use Issues	Yes	No	Commentary
Do you collect rainwater for use as drinking water or for irrigation purposes?			
Have you completed a water footprint for the farm? (If so, capture outputs)			
Do you use latest technology / application methods for crop irrigation to reduce evaporation			
Have you undertaken any other initiatives to reduce water use?			

Appendix 3: Sustainable Intensification Metrics

Food Production

Rationale

One of the cross-cutting priorities from the Foresight Project was that we should work on the assumption that there is little new land for agriculture. Following from this, food production in this study is measured on a per hectare basis so that the 'intensity' of production per unit area is a key driver. The ambition was to find a single metric for measuring the quantity of food production across a range of crop and livestock production systems. The gross energy (GE) content of food provides a common basis for quantifying production and the indicator used is gross energy per hectare of land (gigajoules per hectare). Additionally, it is necessary to apply a set of rules to allow for unfarmed land / land used for feed inputs and the element of produce which is available for human consumption.

For land area we have not attempted to normalise each hectare n the basis of its productive capacity as the main requirement is to quantify change over time across a common unit of production (the farm). This means that the food production indicator can only be compared over time within a farm unit and is not comparable across farms.

As farms will be assessed on the basis of environmental indicators as well as food production, the method assumes that all land on the farm, including land not used for agriculture such as wetland and woodland should be included as these can represent an element of land sparing or land sharing.

The aim is to capture all land associated with production so that any feed imported onto a farm, notably for livestock production, should be accounted for. In most cases, this feed is in a compound form and is a formulation of commodities such as wheat, barley and protein crops (field beans or peas) and by-products from other food processes such as soya bean or other oilseed meals, and sugar, cereal or distillery by-products. By-products have been excluded from the calculation of land use on the basis that the land has already been allocated to a primary food commodity. For cereals and protein crops, we have used a generic compound formulation (see Table 5) to estimate the quantity used and UK average yields to convert these to land area. This area has then been added to the farmland area before calculating food production intensity. This puts farms importing feeds on a common basis with those growing their own feed, for which land area is accounted.

Table 5: Generic compound formulations for estimating commodity use

	Inclusion rates in compound feeds				
	Dairy	Beef	Sheep	Fattening pigs	Poultry
Wheat	15		10	45	45
Barley	20	40	22	20	20
Wheat and other cereals	20	21	15	9	9
Oilseed rape meal	20	20	10	11	11
Soybean cake and meal	5		5	7	7
Sunflower cake and meal			5		
Field beans	5		10		
Sugar beet feed, dried molassed	8	12	15	3	3

The unit of output (gross energy) should be quantified on a common basis as the balance between commodities might change over time on the same production unit. There are a number of sources of data for the calorific value of food, but we have used the UK Nutrient Databank, maintained by the Food Standards Agency (FSA), which contains extensive information on the nutrient content of foods commonly consumed in the UK and is based on the McCance and Widdowson's *The Composition of Foods* (CoF) series of publications. Table 6 sets out the gross energy values for key food commodities.

In terms of non-edible components of farm produce, the main issue lies with livestock which first need to be adjusted from a liveweight basis to carcass weight and subsequently adjusted further for bone and other elements. Thus while the gross energy content of meat is high relative to crops, this relates to the consumable component only; we need to account for the 'non consumable' component of livestock which does not contribute. EBLEX provided data on the relative proportions of consumable products (Kempster et al 1985; BPEX 2012; EBLEX 2012).

Table 6: Energy content of meat and milk

		Energy content
Beef (average, trimmed lean, raw)	(GJ/tonne FW)	5.7
Lamb (average, trimmed, lean, raw)	(GJ/tonne FW)	6.5
Pork (average, trimmed, lean, raw)	(GJ/tonne FW)	5.2
Poultry (average, trimmed, lean, raw)	(GJ/tonne FW)	5.2
Milk	(GJ/1,000 litres FW)	2.8
Cereals (wheat)	(GJ/tonne DM)	18.4
Field beans	(GJ/tonne DM)	18.6
Sugar beet	(GJ/tonne DM)	14.0
Potatoes	(GJ/tonne DM)	13.0
Vegetables	(GJ/tonne DM)	6.0
Soft fruit	(GJ/tonne DM)	7.1

Source: Chan et al (1995); The Dairy Council (undated); US FDA (undated)

Water, Air Quality and Climate Regulation Assessments

Rationale

The Farmscoper model[24] was used to calculate changes in the emissions of greenhouse gases (GHGs) and water pollutants across the 20 case study farms assessed for sustainable intensification. This model is a decision support tool that uses farm level input data to determine diffuse agricultural pollutant loads on a farm. The model was applied to two snapshots in time, a base year (pre-intensification) and a latest year (post-intensification) for each of the farms assessed.

[24] The Farmscoper model was developed under Defra project WQ0106(3) and refined under Defra Project FF0204

Farmscoper model

Farmscoper determines pollutant losses using a smart export coefficient based system. A series of different pollutant models were applied across the whole of England and Wales to a range of farm management practices. The results of the modelled simulations were area weighted to determine the losses for different soil types and climates, reflective of the broad scale variations across the country. The results were expressed in terms of units applied (export coefficients), so that the results could be readily scaled with the inputs of the farming system. For example, the loss of phosphorus per kg of phosphorus applied in fertiliser; the loss of methane per kg of excreta from dairy animals whilst grazing; the loss of ammonia per kg of manure applied.

Farmscoper outputs

Farmscoper predicts the emissions of the following pollutants:

- Nitrates
- Phosphorus
- Sediment
- Ammonia
- Methane
- Nitrous Oxide
- Pesticides

Pollutant losses are expressed as both absolute loads (kg) and as footprints (kg ha^{-1}). For nitrate, phosphorus and sediment, losses can also be expressed in terms of concentrations in water leaving the farm (mg l^{-1}).

Farmscoper inputs

The input data to Farmscoper consists of rainfall, composition of crop area, fertiliser application rates, quantities of manure purchased and the crops to which manure is applied. Additional data was entered into the model for those farms with livestock such as livestock type and numbers, duration of on-farm occupancy and the proportion of time spent grazing and how manure is managed. These inputs affect the different pollutants as listed in Table 7.

Table 7: Impacts of survey data on pollutants predicted by Farmscoper

Input Data	Nitrates	Phosphorus	Sediment	Ammonia	Methane	Nitrous Oxide	Pesticides
Annual Rainfall	Yes	Yes	Yes	-	-	Yes	Yes
Soil Type	Yes	Yes	Yes	-	-	Yes	Yes
Cropping	Yes	Yes	Yes	Yes	-	Yes	Yes
Fertiliser Applied	Yes	Yes	-	Yes		Yes	-
Manure Applied	Yes	Yes	-	Yes	Yes	Yes	-
Livestock type, number and weight	Yes	Yes	-	Yes	Yes	Yes	-
Duration of animals on-farm	Yes	Yes	-	Yes	Yes	Yes	-
Manure Management	Yes	Yes	-	Yes	Yes	Yes	-
Proportion of time animals housed	Yes	Yes	-	Yes	Yes	Yes	-

Limitations of using the Farmscoper model to measure sustainable intensification

While the basic output of Farmscoper is suitable for an overall assessment of sustainable intensification based on system change, there are some caveats as listed below:

- Does not take into account the spatial location of applications of fertiliser and manure i.e. whether applications are near to watercourses.
- Does not differentiate between conventional manure application methods and manure/slurry injection.
- Does not differentiate between conventional fertiliser application methods and the latest methods such as precision application using GPS technology.
- Does not differentiate between different manure and fertiliser application timings (based on averages for different manure types / crop types in England and Wales)
- Assumes a default length of the grazing period for compaction and poaching of the soil, and excreta at grazing is spread throughout this window, no matter the actual extent that livestock are assumed to graze.

Some of these caveats are dealt with by the second part of the Farmscoper model (the 'Evaluate' worksheet), which determines the impacts of a range of different mitigation methods (approximately 100 methods), such as some of the items listed above and most of which are indentified in the 'User Guide' of mitigation methods (Newell-Price et al., 2011). This functionality was not used in this study due to limitations of the data available (method definition) and incomplete coverage of technologies and practices.

Carbon dioxide emissions

GHG emissions from agriculture are mainly in the form of methane from livestock and manure, and nitrous oxide from fertiliser use. However, direct emissions of carbon dioxide (CO_2) are also important; these arise from the use of energy and fuel together with emissions from land use, land-use change and forestry (LULUCF). While Farmscoper estimates methane and nitrous oxide emissions from case study farms, it does not calculate carbon dioxide emissions. For this reason we used a commonly available carbon-footprinting tool CALM (Carbon Accounting for Land Managers[25]). CALM calculates the annual emissions of the key GHGs and carbon sequestration associated, and measures emissions of carbon dioxide, methane and nitrous oxide from a land-management business and any carbon which is stored in soil and trees. The calculator also assesses the impact of Environmental Stewardship options.

CALM has been used to estimate the emissions from energy and fuel use, and cultivation and land-use change only. The total is then combined with the carbon dioxide equivalent (CO_2e) emissions from methane and nitrous oxide to estimate the total global-warming potential (GWP)[26]. Factors used to convert methane and nitrous oxide emissions in to GWP are:

- CO_2 1
- Methane 21
- Nitrous Oxide 310

[25] http://www.calm.cla.org.uk/

[26] Global Warming Potentials (GWPs) are used to compare the impact of the emission of equivalent masses of different GHGs relative to carbon dioxide. For example, it is estimated that the emission of 1 kilogram of methane will have the same warming impact 1 as 21 kilograms of carbon dioxide. Therefore the GWP of methane is 21. The GWP of carbon dioxide is, by definition, 1. http://archive.defra.gov.uk/environment/business/reporting/pdf/110707-guidelines-ghg-conversion-factors.pdf

Biodiversity

Rationale

The main challenge of scoring biodiversity is that there is a vast range of potential measures of the quantity and quality of the many aspects of biodiversity, few of which are recorded by individual farms. This challenge has been addressed by the UK Government by establishing a new set of biodiversity indicators. These indicators contain a mix of actual biodiversity records and actions by land managers and by Government that are assumed to be positively related to biodiversity (Table 8).

Our approach has been to adopt these national indicators, and where possible match them to data available to individual farmers without the need for additional field assessments and without access to population records of individual species. We therefore designed a questionnaire data to provide information about the potential support for biodiversity on the farm at the baseline, and how it has changed.

Our approach was therefore to seek evidence of structures and activities known to enhance biodiversity, and not to seek data on actual outcomes in terms of species diversity and abundance. The presence of each activity or structure adds to the total 'biodiversity score'. The resulting scores for the farm at baseline, and for what changes have been made since, are sensitive enough to detect potential biodiversity changes over time, and whether they are from a high or low starting point. They are unable to distinguish the quality of biodiversity that may be present (e.g. the presence or rare species) or to capture the differences between farming systems (e.g. arable vs. upland).

Table 8: UK biodiversity indicators most relevant to farmland and current trends

Indicator number	Indicator title	Individual measures	Current trend
1(a)	Populations of selected species (birds)	Breeding farmland birds	↓
		Breeding water and wetland birds	↓
1(b)	Populations of selected species (butterflies)	Generalist butterflies	↔
2	Plant diversity	Arable and horticultural land	↑
4	UK Priority Habitats		↔
5	Genetic diversity	Native sheep breeds	↔
		Native cattle breeds	↑
6	Protected areas	Condition of A/SSSIs	↑
8	Agri-environment land	Higher level, targeted schemes	↑
		Entry type schemes	↑
14	Habitat connectivity	Neutral grassland	?

Source: Biodiversity in your Pocket 2011

We also sought commentaries from the farmers about their approach to biodiversity and how it is likely to change in the future.

Data collection

1 & 2 Status of particular taxa

Very few farmers collect data on individual taxa. However, we did give one point each for membership of a farm assurance scheme, a farm environment scheme and the existence of biodiversity records (including game counts), for both baseline and latest years.

We also took into account major land management changes that are known to influence species richness and abundance across birds, mammals, butterflies, bumblebees and arable plants (Butler et al 2007, Firbank et al 2008, Butler et al 2009). For the following, we recorded what had changed between baseline and latest year: changes in directions noted were all given +3 points; no change = 0 points; changes in the reverse direction were given -3 points:

- More spring sowing and less autumn sowing
- More hay and less silage
- Increased area of non-cropped habitats
- Less drained land
- Reduced livestock density
- Increased crop diversity
- Increased diversity of non-cropped habitats

The loss of set-aside to productive agricultural land was also given -3 points, following Firbank et al (2003).

4 UK Priority Habitats

UK Priority Habitats for nature conservation tend to be localised and small by their nature. Many of these are likely to be found on farmland. We asked which of these habitats were present on the farm at baseline, with one point for each habitat. We then asked whether the habitat had increased in size, and in condition: each such answer added one point to the biodiversity change score. Note that the farmers' assessment of improvement in condition may well not reflect the assessment of an independent expert.

The habitats were:

Arable field margins, Chalk rivers, Coastal and floodplain grazing marsh, Hedgerows, Lowland calcareous grassland, Lowland dry acid grassland, Lowland heathland, Lowland meadows, Machair, Mountain heath and willow scrub, Ponds, Purple moor grass and rush pasture, Traditional orchards, Upland calcareous grassland, Upland flushes, fens and swamps, Upland hay meadow, Wood pasture and parkland

5 Native sheep and cattle breeds

The farmer was given one point for each native breed of sheep or cattle, and a change point for if numbers had increased or decreased since.

6 Condition of A/SSSIs

For this, we simply noted the presence of SSSIs on farm, one point for each.

8 Higher level, targeted schemes and entry-type schemes

The farmers were asked the same questions for the baseline and latest year. Support through a baseline agri-environment scheme scored one point, of a higher level scheme scored three. One point was also scored for each of the following if supported by the scheme: boundary features, trees and woodland, buffer strips and margins, arable options, options to protect soils, grass outside SDAs (Severely Disadvantaged Area), mixed stocking on grass, SDAs and other.

14 Connectivity of neutral grassland

We extended the issue of connectivity of neutral grassland to include all grasslands. We asked if species-rich grassland was present in the baseline year, and gave a change score of +2 if connectivity had increased since, and -1 if had been reduced.

Scaling of scores

The final biodiversity scores were rescaled into an index with a simple 5 point scale that better reflected the overall precision of the data being collected. Scores for initial biodiversity were recalculated as follows; note, the lowest index value was 1, as all farms are considered to have *some* biodiversity.

Point score	Biodiversity index
0	1
1-5	2
6-10	3
11-15	4
>16	5

Indices for biodiversity change were as follows, and included positive and negative values: note that these scores cannot be added to baseline biodiversity scores to give current values.

Point score	Biodiversity change index
<-11	-2
-10 to -3	-1
-2 to +2	0
3 to 10	1
>10	2

Note on quality of responses

It was clear that farm responses varied in quality, presumably in terms of their interest in biodiversity. It was not always easy to tell whether an answer referred to baseline or current values. While it's not clear that all farmers recognised the same habitats in the same way, nor changes in condition, the text responses suggests that the farming community is in general well informed about biodiversity and its management, giving an assurance that the data is essentially sound, albeit with a potential error of several points for each farm.

Landscape

Rationale

Landscape has high cultural value. An important part of this value is local distinctiveness; an action that may improve a landscape in one area may be detrimental in another area. The UK is a signatory to the European Landscape Convention, and so is required to (a) to recognise landscapes in law as an essential component of people's surroundings: (b) to establish and implement landscape policies aimed at landscape protection, management and planning; (c) to integrate landscape into its planning policies and in its cultural, environmental, agricultural, social and economic policies. There is no single UK landscape strategy; rather each devolved administration has its own approach, which has a strong regional element through designated and landscape character areas.

Here we are concerned with actions at the farm scale that may impact on landscape quality. We have decided not to give an initial assessment of the landscape quality of the farm; this is not possible without a detailed field survey. Rather, we have opted to collect data on the resources of the farm and the recent actions of the farmer. We have chosen to focus on categories of actions that can be gain financial support through agri-environment schemes or rural development programmes in England (Higher Level Stewardship), Scotland (the Safeguarding and Enhancing the Landscape package of the Scotland Rural Development Programme[27]) or Wales (Glastir), focussing on those not restricted to individual regions or areas. These are presented in Table 1; the questions to farmers are based on this table.

UK activities considered to enhance at least some farmed landscapes, because they win support from England, Scotland Rural Development Programme or from Wales, have been used to build an indicator score for landscape (Table 9). These are high level activities, and may include several specific measures. The indicator numbers given here are purely for internal reference within this project. Many actions also aimed at enhancing biodiversity (e.g. hedgerow management) are excluded to avoid duplication.

Table 9: Landscape indicator components

Indicator number	Measure	England	Scotland	Wales
	Create and manage public access to the land	x	x	
	Create and manage attractive viewpoints		x	
	Repair vernacular buildings		x	X
	Restore existing stone boundary features or historic built structures	x	x	X
	Improve the management of archaeological sites	x	x	X
	Manage and enhance single and small groups of trees	x	x	X
	Corridors, boundaries, buffer strips and areas	x	x	X
	Conversion and maintenance of organic farming	x	x	X

Scoring system

The questions sought to identify those features that are relevant to landscape quality on the farm. The farmer was asked whether there was any accreditation (e.g. being within an AONB, or some form of landscape awards); whether there were agri-environment scheme options to cover boundary features, trees and woodland and historic features and landscape (one point for each at baseline, one point for change if they had increased in size or condition). We also scored points for the presence of the following priority habitats at

[27] http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/Packages/SafeguardingandEnhance

baseline: grazing marsh, hedgerows, lowland meadows, machair, mountain heath, willow and scrub, ponds, traditional orchards, upland hay meadow and wood pasture and parkland; improvements in extent and condition to each of these generated a point for the change score.

As for biodiversity, the values were rescaled to give the indices reported in the case studies, as follows. For initial landscape value, the recalibration was:

Point score	Landscape index
0-1	1
2-3	2
4-5	3
6-7	4
>8	5

And for change:

Point score	Landscape change index
< -6	-2
-5 to -2	-1
-1 to 1	0
2 to 5	1
>6	2

Comment on quality of the responses

The landscape scores were largely a subset of biodiversity scores. We looked into relating them to landscape character (for example to determine whether woodland planting was in character or not), but found the character descriptions too vague to be of use in this regard. The farmers' comments showed no appreciation of the local landscape character in determining the current landscape quality or plans for the future.

Appendix 4: Case Study write ups

Arable Farm A1

Summary

This 1840ha arable farm has increased food production by 20% while there has been little change in biodiversity, or in losses of nitrates and ammonia. While GHG emissions per unit area have increased by over 20% per unit area, at least some of this is due to new sources of carbon emissions onto the farm that would have previously have been outside the business. Therefore it is difficult to be sure whether or not the farm has achieved sustainable intensification.

Case study A1 is a part-owned, part-tenanted, arable farm of 1840ha, growing combinable crops, potatoes, sugar beet, and field vegetables and including 70ha of broadleaf woodland. A system of 'land swapping' with local neighbours is employed to ensure sufficient clean land for potatoes and, similarly, a small portion of land is seasonally rented in for growing carrots. The average rainfall for the area is 700mm, although actual levels have been much lower over the last two years. The soils range in texture from light sands, to medium and deep clayey soils, with approximately one third of the land coming under each category.

This family run business has a defined set of 'ethics and morals' which it adheres to. These include: protection of farm landscape features and balancing intensity of land use with environmental sustainability. Customers are also chosen for their fit with these factors. The aim is to be 'innovators and early adopters of new technologies, with a proactive approach to both market and environmental trends, including climate change'.

Table 10 below shows that the farm has been successful in increasing its level of food production without causing any negative impacts to landscape and biodiversity. The increase in nitrogen losses to air and water are not significant at less than 5%. The carbon footprint per unit area has increased substantially, associated with investment in additional potato / vegetable stores and the running of two haulage lorries (previously these operations were out-sourced and therefore would not have registered on the farm's carbon footprint).

Table 10: Farm A1 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	82	98	Medium	20%
Carbon footprint	kg CO2equiv/ha	2407	2913	High	21%
Nitrate loss to water	kg/ha	36	37	High	4%
Ammonia loss to air	Kg/ha	10	10	Medium	1%
Biodiversity	index	3		Medium	0
Landscape	index	2		Medium	0

* Specific to sector

Overview of the farm and farming system

This is a family owned business, with three brothers as farm managers and active directors. The farm is a long standing local employer and where additional seasonal staff are required a local agency is used.

Combinable crops make up approximately forty five percent of the arable area, with the remaining fifty five percent being used for potatoes, sugar beet, carrots, onions and parsnips. A range of early, main-crop and over-wintered carrots and onions are grown to spread supply for the customer. The farm is at the northern limit for growing market grade carrots and onions, so rather than producing a sub-standard product for the fresh market, it has specialised in producing a high quality product for the processing market. Potatoes are grown on a long rotation of seven to eight years, compared with the average of four to five. Requirements for clean land for root crops is fulfilled by a combination of seasonal renting, 'land swapping' with neighbours and using temporary pasture, fallow, and break crops (such as stubble turnips) in the rotation.

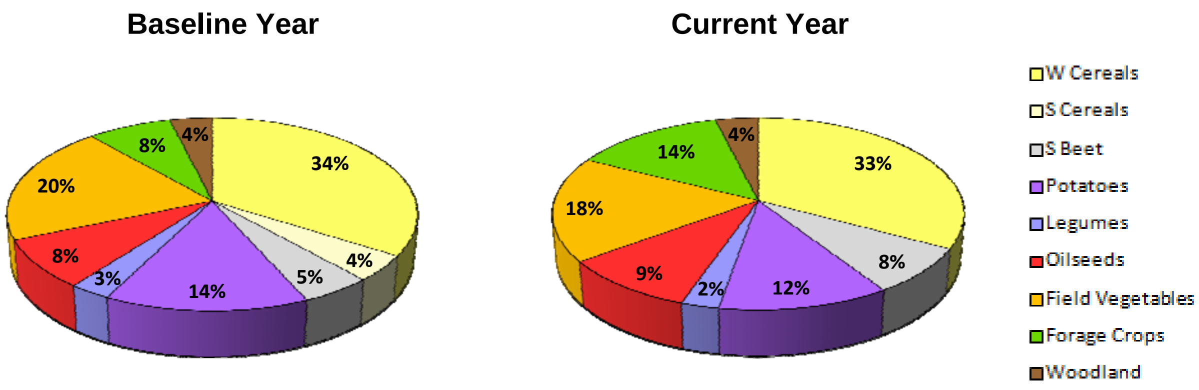

Figure 9: Farm A1 - Changes in cropping from 2005-06 to 2010-11

Cropping has remained largely the same from the baseline year to the latest year, with the following exceptions:

- The area of strawed carrots has been reduced owing to cavity spot problems. Carrots are now harvested earlier to overcome this issue.
- Onions are now supplied twelve months of the year, and the overall production has increased. This has largely been met by growing more onion sets, which give the most reliable crop.
- The area of sugar beet was reduced over the period of 'tight profitability margins'; this will be increased in future as the margins are better again now.
- Beetroot was trialled for a short period, as less sugar beet was grown, but was not continued due to lack of customer support.
- The area of fallow land has been reduced since the abolition of set-aside.

Most seed is purchased, but the farm business has shares in the seed companies it uses in order to provide some control and consistency throughout the whole supply chain. Buying groups and cooperatives are used minimally, with best market prices being sought first. The farm is also used for potato variety trials to help determine the best choices for local conditions.

Approach to sustainable intensification

The approach to farming is described as 'conscientiously intensive'. A land sparing approach was tried in terms of taking land out of production as field margins but this did not fit with farming practices and has been discontinued; instead a general land sharing approach of '*being as kind to the land as possible within the bounds of best practice conventional farming'* is practiced along with effective management of woodland and other features.

The directors set a baseline of morals and ethics which are implemented across the whole business, including choice of customers and suppliers. The business has evolved an innovative approach to finding market niches, which enables the production of crops best suited to the farm environment, thus yielding high quality and high margin outputs. Customer relations are of strategic importance to this overall approach. The farm's natural landscape and biodiversity are highly regarded and underpin cropping and rotation choices. Although the holding is in an entry level agri-environment scheme, this is not considered the main driver for environmental improvement, '*it can be dangerous to link changing your environment with money'.*

The business's vision for environmental management is asserted as '*going beyond legislation'.* New and innovative technologies are used where deemed appropriate, that is, after careful cost benefit analysis. Business planning and strategy tools are used in the financial management of the enterprise.

Farm performance

<u>Food production</u>

Food production is relatively intensive, with absolute output (expressed in gross energy per unit of land area) at 98GJ per hectare. This is 20% higher than five years previously and is attributable to increases in yields of potatoes, sugar beet, onions, carrots and oil seed rape. The most significant increases are in carrots and onions and in both cases are due to increased levels of experience and favourable weather conditions for the latest year. The increase in potato yield, of nearly twelve tonnes a hectare, is accounted for by varietal changes and agronomic improvements, which has also enabled reduced nitrogen application. In contrast to the overall trend, yields of winter wheat in the latest year have not improved from the baseline. The consecutive very wet autumn of 2010 and dry spring on 2011 in this region did not favour bumper wheat yields.

<u>Climate change mitigation and adaptation</u>

Table 11 shows that there has been a dramatic increase in carbon emissions since the baseline year. This is attributable to the expansion of the business, rather than a decrease in efficiency. Notably, the farm now has two haulage lorries and has built a number of new vegetable and potato stores, thus increasing the farm's requirement for diesel, electricity and gas. Whilst bringing these operations onto the farm business has increased the farm's carbon footprint, it has not necessarily added to carbon emissions globally as these operations were already taking place. Indeed it is possible that these operations are being carried out at a lower carbon cost overall, as the farm is using modern, efficient equipment and technologies and is likely to reduce total food miles for its produce.

Whilst nitrous oxide emissions have also increased, the change is modest.

Table 11: Farm A1 - Greenhouse gas emissions, per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO_2e kg/ha)	381	869	489	129%
Methane loss CO_2e (kg/ha)	0	0	0	
Nitrous Oxide loss CO_2e (kg/ha)	2026	2044	18	1%
Carbon footprint per unit land CO_2e (kg/ha)	**2407**	**2913**	**507**	**21%**
Carbon footprint per unit food CO_2e (kg/GJ)	**29.5**	**29.8**	**0.4**	**1%**

Much interest is taken in 'future proofing' the business under uncertain climate change scenarios. A carbon footprint and subsequent carbon management plan has been implemented for potatoes owing to a customers' request. Although focussed on a specific crop, it is still largely significant for the whole farm. In 2011 further climate change mitigation and adaptation work was carried out under PACT (pathways for carbon transition). This involved business level assessment, analysis, bench marking and setting of targets for future performance. Water security was identified as the biggest challenge.

New technologies are also being implemented including:

- a solar PV array project has just gone active, with 50 panels installed so far and another 50 planned;
- plans for a new irrigation reservoir and;
- a strategic move away from diesel to electric irrigation pumps (which have a higher level of efficiency).

Water and air quality

The cultivation and harvesting of root crops requires significantly more movement of soil than for combinable crops, therefore the inherent risk of pollutant losses to water and air is higher. Whilst results remain reasonably static, with the exception of a small increase in nitrate loss, in respect of the increased area and intensity of root crop production since the baseline year, these figures still represent a positive achievement.

Table 12: Farm A1 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	36.0	37.4	1.4	4%
Phosphorus loss (kg/ha)	0.1	0.1	0.0	-3%
Sediment loss (kg/ha)	19.7	19.6	-0.1	0%
Pesticide loss (kg/ha)	0.1	0.1	0.0	7%
Ammonia loss (kg/ha)	10.0	10.1	0.1	1%

Maintaining pollutant losses at a reasonably steady state, whilst increasing productivity can be attributed to the approach to land management, including the use of break crops, overwintered stubbles, fallow and extended rotations along with a whole farm approach to soil management and protection.

Biodiversity

Biodiversity stock: 3 Change: 0

The biodiversity stock arises from engagement with an entry-level agri-environment scheme and participation in LEAF and the RSPB voluntary initiative. Records are taken of game birds in support of the managed shoot on farm. There are no priority habitats here. Set-aside land was kept out of production. The approach is land sparing, with intensive management of crop producing areas and patches of woodlands, including a SSSI: this has remained unchanged over the period of interest and is unlikely to change in the near future.

Landscape

Landscape stock: 2 Change: 0

The farm contains a scheduled ancient monument, for which agri-environment support has been gained, as well as woodland. The landscape is managed for greening and aesthetics; it has remained unchanged over the period of interest and is unlikely to change in the future, subject to changes in CAP.

Other ecosystem services

Extreme and uncertain weather conditions are currently the greatest concern for the farm; the subsequent impact on water security has the potential to be a significant issue. Overall, climate change is viewed as an opportunity rather than a threat. Temperature rise could make it possible for the production of high quality onions, suitable for non-processing markets. If climate change was to result in more favourable growing conditions, it is recognised that increased production potential will need to be balanced with the protection of the farm's ecosystem services.

Conclusions

Overall this farm has increased its level of food production whilst maintaining its biodiversity and landscape value. Although the data shows a large increase in carbon footprint, the actual significance of this is difficult to determine as the operations through which these extra emissions arise were previously carried out off farm with a possibly higher carbon impact. The investment in high efficiency modern technology and on-farm renewable energy generation indicates the potential for carbon reductions going forward.

The farm is run very professionally and is delivering high levels of food production, while aiming to minimise environmental impacts in a holistic approach. It is largely achieving the latter through attention to management and use of technology. Critically, a sustainable approach is explicitly seen as important in maintaining client relations and market access for high quality, niche products. Awareness of production and environmental risks is high and research has been carried out into climate change adaptation with an ambition to remain a robust, sustainable business going forward. Key challenges identified include water security and reliance on energy but overall climate change is viewed as an opportunity rather than a risk.

Arable Farm A2

Summary

This 494ha arable farm has achieved a substantial increase in food production in conjunction with a fall in nitrate and ammonia emissions and some improvements to biodiversity. Based on these indicators the farm has demonstrated sustainable intensification over the period.

Case study A2 is an owned arable unit of 494ha, comprising combinable crops and roots with a small area of permanent grass (Figure 1). Approximately 30ha of land is seasonally rented to ensure enough clean ground for growing potatoes. The holding is situated in a low rainfall area and is on free draining soils. Part of the farm is within a coastal AONB. The main crops are winter wheat, potatoes and sugar beet.

The approach to SI is based on making enough profit to be able to invest in the environment as well as in infrastructure. The strategy includes land sparing, investment in technology for production, processing and storage and detailed financial monitoring and planning with plans for generation of renewable energy in future.

The farm appears to have achieved sustainable intensification with improvements in five of the dimensions considered (see Table 13). Gross energy of output per unit area has increased by 33 %, while emissions to air and water and carbon footprint fell. The biodiversity score increased over the period.

Table 13: Farm A2 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	128	171	High	33%
Carbon footprint	kg CO2equiv/ha	3754	3694	Medium	-2%
Nitrate loss to water	kg/ha	44	38	High	-13%
Ammonia loss to air	Kg/ha	11	8	Medium	-30%
Biodiversity	index	2		Medium	1
Landscape	index	2		Medium	0

* Specific to sector

Overview of the farm and farming system

Case study A2 is an owned arable unit of 494 ha, largely comprising combinable crops and roots with a small area of permanent grass (Figure 1). Approximately 30ha of land is seasonally rented to ensure enough clean ground for growing potatoes. A further 1266ha of cereals and general cropping land are contract farmed; while this land is entirely separate from the business (and outside this analysis), the additional scale of operation and returns has allowed investment in modern equipment, with benefits for the main farm. In addition to the farmer-director, the farm employs a farm manager, eight full time staff and additional seasonal staff: no contractors are used.

The holding itself is on free draining soils, largely medium textured (90%), situated in a low rainfall area. Part of the farm is in a coastal AONB and most of the land lies within an NVZ. Since 2005-06, set aside (6% of land use) has gone but a similar area of land is left out of agricultural production. The area of winter wheat and sugar beet has increased at the expense of both winter and spring barley.

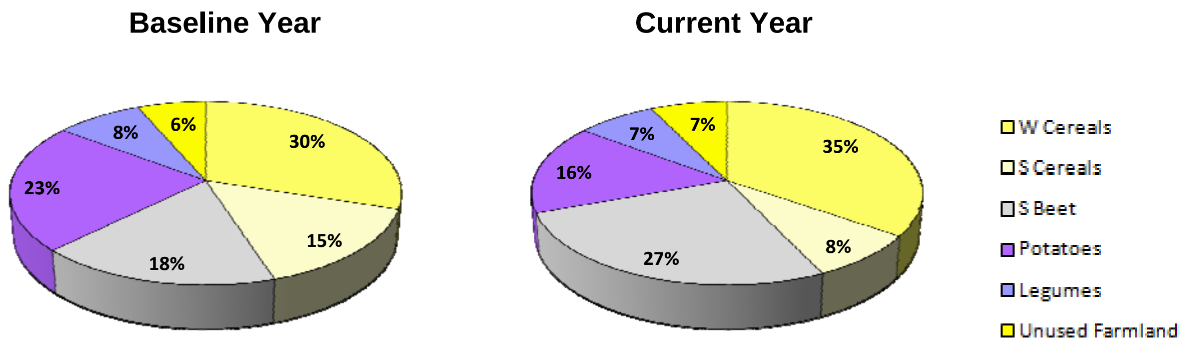

Figure 10: Farm A2 - Changes in cropping from 2005-06 to 2010-11

Approach to sustainable intensification

The farm's approach to sustainable intensification is described as follows: '*We are trying to develop a* sustainable *agricultural model based on margin over fixed costs, on a multi-year contract basis, which gives us the ability to invest in the environment as well as re-invest in infrastructure*'. The director notes that "*Improvement to environmental performance has only been possible with the engagement and cooperation of all farm staff*".

The main mechanisms which are being used to achieve these aims are:

- Land sparing: the farm has put unproductive land, (including former set-aside) into permanent grassland and created grass buffers, hedgerows and woodland.
- Use of technology to improve energy and resource use efficiency, including GPS, humidification and adiabatic cooling[28] of potato stores, modernised irrigation system, and new tractors. Nutrient recommendations from an independent agronomist are tailored specifically on a field by field basis. The director notes that "*the ability to invest in new, improved technologies is reliant on economies of scale and therefore this has only been possible due to the contract farming enterprise*".
- Monitoring of performance using 'Gate Keeper' software for farm records and nutrient management planning, and Farmplan for forward business planning and group benchmarking.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) is very high, at 171 GJ per hectare. This is 33% higher than five years previously, and is very much due to a large increase in potato yield from 36 tha^{-1} in 2006 to 55 t ha^{-1} in 2011, based mainly on variety change, and a smaller increase in sugar beet yield from 76 t ha^{-1} to 92 t ha^{-1}. Fertiliser

[28] Adiabatic cooling this refers to the humidification of air under adiabatic (isocaloric) conditions, so that energy is neither added nor removed. The heat necessary for evaporation is taken from the air, which consequently cools down.

use has fallen, except for N on potatoes. Improved storage has also had a significant impact on output by reducing losses from stores.

Climate change mitigation and adaptation

Significant consideration has been given to ensuring that the farm system continues to be robust under future climate change scenarios, whilst reducing its climate change impact. Furthermore, one of the farm's major customers for potatoes (a multi-national food and drinks company) has required its suppliers to conduct a carbon footprint and implement a carbon reduction plan for the five years following 2012. The carbon footprint analysis for this study indicates a significant reduction in greenhouse gas emission intensity (Table 14).

Table 14: Farm A2 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	1165	1,271	106	9%
Methane loss CO2e (kg/ha)	0.00	0.00	0	
Nitrous Oxide loss CO2e (kg/ha)	2,589	2,423	-167	-6%
Carbon footprint per unit land CO2e (kg/ha)	**3754**	**3694**	**-60**	**-2%**
Carbon footprint per unit food CO2e (kg/GJ)	**29.3**	**21.6**	**-7.6**	**-26%**

The absence of methane losses reflects the absence of livestock. The reduction in N_20 emissions results from increased nitrogen use efficiencies. The increase in carbon dioxide emissions has been limited by changing to more fuel efficient machinery, investing in machinery that can perform multiple tasks simultaneously, mapping out the most direct routes between fields and stores and updating stores with extra insulation and fitting invertors to fans.

Water and air quality

The farm has shown an overall reduction in pollutant pressure, with nitrogen-based emissions declining, and losses of pesticides, phosphorus and sediment held constant[29] (see Table 15). These represent more significant declines per unit of production. Success can partly be attributed to more efficient application of resources, and partly to the farm's approach to land sparing, whereby more marginal land, and land adjacent to watercourses is taken out of arable production.

Table 15: Farm A2 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	43.7	38.0	-5.8	-13%
Phosphorus loss (kg/ha)	0.1	0.1	0.0	0%
Sediment loss (kg/ha)	19.8	19.7	-0.1	-1%
Pesticide loss (kg/ha)	0.1	0.1	0.0	-3%
Ammonia loss (kg/ha)	10.8	7.6	-3.2	-30%

[29] The method of analysis may underestimate the actual reductions in losses, as they do not include some of the measures adopted by this farm, e.g. GPS and precision spraying to reduce pesticide losses, and the use of buffer strips to reduce losses of sediment.

Biodiversity

Biodiversity stock: 2 Change: 1

The biodiversity stock comes from the presence of hedgerows and meadows, along with taking biodiversity records from the RSPB volunteer and farmer alliance survey in 2005 and 2011. The score is low in part because none of the farm is in an agri-environment scheme. The positive changes have arisen through broad changes in farm management; greater habitat diversity (cropped and non-cropped) and greater use of hay; however, set-aside has been lost. These scores probably undervalue the biodiversity benefits of this farm, where un-productive land was put into permanent pasture in 2005 (i.e. before our baseline) and there has been a 'major push' on hedges and woodlands.

Landscape

Landscape stock: 2 Change: 0

The stock is based on hedgerows and meadows; the lengths of hedgerows have increased. The approach to landscape is to visually improve hedgerows and trees, placing boundary oaks on bleak skylines. The farmer would like to plant more hedges, which is dependent on government grants, but is looking towards planting more woodland and shelter trees.

Other ecosystem services

For an arable farm in a low rainfall area, use of freshwater is a critical issue. The farm has a high demand for water, partly because water used for washing potatoes must be potable, and partly for irrigation. Thus irrigating last year's crop twice produced a very significant yield increase at 9t/ha, whilst sugar beet and potatoes have also benefited from improvements in irrigation. The farm is aiming to be self sufficient in water, through the use of efficient irrigation systems, and through increasing rainwater storage through roof harvesting, expanding reservoirs and creating wetlands, ponds and water meadows.

Conclusions

This farm has achieved a significant increase in food production per unit of land and in most of the environmental impact indicators. This has largely been accomplished by a combination of production technology uptake, land sparing to use resources more efficiently and targeted environmental action. Attention to detail in variety selection, cultivation techniques, crop husbandry and storage practices along with agronomic management have been key. The business is also conscious of the production and environmental risks, notably pressures on water availability and is taking action to become more self-sufficient.

The business plan is to continue to improve environmental performance through technology uptake, including possible investment in a bio digester for waste potatoes, installing photovoltaics, and using waste oil through a bio-diesel plant.

Arable Farm A3

Summary

This 250ha arable farm has pursued a sustainable production approach based on zero tillage for the last ten years and has seen crop yields increase and inputs reduce, with a significant improvement in soil carbon and fauna. However, due to changes in the cropping pattern between the baseline and latest year, food production in gross energy terms is lower than in 2006 (a high base). The introduction of a free range egg enterprise will make the farm self-sufficient in P & K but has led to an increase in nitrate and ammonia losses (from a low base). There has been a positive change in biodiversity based on increased soil fauna. While we cannot say this farm is demonstrating sustainable intensification on the basis of the indicators used in this study, it is clear that this reflects the limitations of a static analysis and the metrics used, rather than the performance of the farm.

Case study A3 is a fully owned family business farming approximately 250ha in a low rainfall area on mainly medium soils with some deep clays and organic soils. The primary enterprise is arable, comprising winter and spring cereals, sugar beet, oilseed rape and beans. The whole of the arable enterprise has been managed under a complete 'zero tillage' system for the last 10 years. The business has recently set up an outdoor egg production enterprise.

Table 16 shows a reduced level of food production in 2011 relative to 2006; the data largely reflects the discontinuation of sugar beet and an increased area of spring cropping in the latest year due to difficult weather conditions in autumn 2010. While the move to zero tillage ten years ago did initially lead to some yield loss, after a period, yields recovered and are now higher than before the change. It is also important to recognise that the farm is actually practicing a sustainable approach through avoiding annual cultivation – both in terms of losses of carbon and nutrients – but also in terms of improved soil structure and fauna. The egg enterprise further reduces reliance on imported nutrients.

Table 16: Farm A3 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	121	98	High	-19%
Carbon footprint	kg CO2equiv/ha	2731	2596	Low	-5%
Nitrate loss to water	kg/ha	32	35	Low	11%
Ammonia loss to air	Kg/ha	15	23	Medium	47%
Biodiversity	index	3		Medium	1
Landscape	index	3		Medium	0

* Specific to sector

This case study highlights the limitations of a static analysis and of the available metrics in reflecting what is clearly a highly productive and environmentally-led system. Indeed the zero till approach would appear to have much to offer in terms of delivering sustainable intensification.

Overview of the farm and farming system

The family business partnership employs one full time farm worker. Standard computer-based nutrient and business planning tools are used along with input from an independent agronomist and in-house strategic planning.

Figure 4 highlights the cropping changes between the baseline and latest year, with a significantly higher area of spring sown cereals and legumes. The discontinuation of sugar beet growing is also notable in terms of gross energy yield.

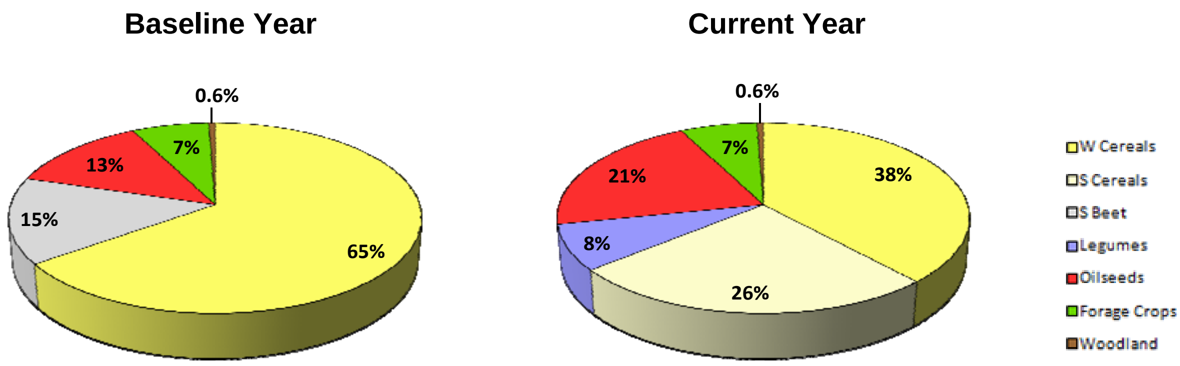

Figure 11: Farm A3 - Changes in cropping from 2005-06 to 2010-11

Approximately 50% of the cereals are sold to a local co-op and the rest to an independent merchant. On average, half of the annual seed requirement comes from farm saved seed. Other farm inputs are purchased from independent suppliers and, with the installation of the laying hen enterprise, all P and K requirements will be met by the poultry manure produced on farm.

The full zero tillage system has saved considerably on input costs, particularly fuel, and more recently P and K, although this is not captured by the analysis as the system was present in the baseline year. Crop yields decreased during the first three years of conversion, but have increased throughout the last five year period.

Approach to sustainable intensification

The whole approach to sustainable intensification on this farm centres round the concept of No-till. No-till uses a specialist drill which cuts slots into the ground, into which the seed is placed, importantly resulting in minimum disturbance to the soil; hence the term 'no-till' or 'zero tillage'. The residue of the previous crop remains largely undisturbed on the soil surface and forms a thick mulch. No-till is unique from other systems of direct drilling such as minimum tillage, which use tines and/or coulters and result in significant amounts of soil movement and, in some cases, even shallow inversion. In principle, a no-till system increases the amount of water and organic matter (nutrients) in the soil and decreases erosion. It increases the amount and variety of life in and on the soil but may require herbicide usage.

This farmer describes his approach as: "*a total no-till system, to the degree that, to see whether a field has been drilled one has to kneel down*". The particularly long stubble is due to the use of a stripper header on the combine. This only removes the ears from the corn, leaving long stems to provide extra mulch. "*In practical terms the no-till system means the whole farm is in perpetual stubble; the effect on environmental issues has been dramatic.*"

The philosophy underpinning this system can be summarised as: "*to maximise food production whilst reducing inputs (fertiliser, fuel and agrochemicals) as well as improving wildlife habitats*" and future ambitions include: To continue to learn to manage a no-till system, integrate the poultry enterprise into the system, and investigate producing diesel fuel from OSR.

Farm performance

Food production

The overall level of food production, has decreased by 19% over the period from a high base of 121GJ/ ha. This is largely due to an increase in spring-sown crops in 2010/11 (beans, oats and barley) due to difficult autumn planting conditions. Yields of all crops grown in both years increased over the period (winter wheat from 8.5 to 9.1 tonnes per hectare and winter oilseed rape from 3.4 to 4.1 tonnes per hectare), despite the very wet autumn and dry spring. This compares favourably to arable case studies where there were yield reductions under these weather conditions.

Climate change mitigation and adaptation

No-till farming delivers benefits for both climate change mitigation and adaptation. With reference to greenhouse gas emissions (Table 17), the level of carbon dioxide has been reduced by 38%. This is largely attributable to a reduction in fuel use for field operations of over 50% (from an average of 91 to 43 litres per ha) and an increase in soil carbon to a current level of 4.6% (farm data), which is over twice the median level for soils with a clay content of 35%.

Table 17: Farm A3 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO_2e kg/ha)	312	194	-118	-38%
Methane loss CO_2e (kg/ha)	84	111	27	32%
Nitrous Oxide loss CO_2e (kg/ha)	2334	2291	-43	-2%
Carbon footprint per unit land CO_2e (kg/ha)	**2731**	**2596**	**-135**	**-5%**
Carbon footprint per unit food CO_2e (kg/GJ)	**22.6**	**26.6**	**4.0**	**18%**

Under the no-till system, the soil is perpetually covered with stubble/residues/growing crops. This helps to protect the soil from wind and water erosion, particularly important on the black organic soils. The increased soil organic carbon content also helps to improve both the water holding and drainage capacity and benefits soil fauna and aeration. All these factors will help to make the farming system more robust under future climate change where there is likely to be an increase in the number of extreme weather events.

Water and air quality

The estimated increase in nitrate and ammonia losses in Table 18 relate to the introduction of a 16,000 bird free-range poultry enterprise rather than changes in fertiliser use on the arable system. Indeed nitrogen use on winter wheat and winter oilseed rape has reduced by 7% since the baseline year.

Water quality was the original driver underpinning the farmer's decision to change to a no-till system. The farmer owns another holding which is in a catchment sensitive farming area and, as part of this initiative, was trying to reduce the level of pollutant losses to water, particularly phosphate[30]. Switching to no-till cultivations to help maintain soil structure and reduce run off by keeping applied nutrients and crop residue near the surface. Unfortunately the tools available for calculating losses of nutrients do not capture this effect and as such nitrate losses to water are likely to be overstated.

Table 18: Farm A3 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	31.8	35.3	3.5	11%
Phosphorus loss (kg/ha)	0.1	0.1	0.0	23%
Sediment loss (kg/ha)	20.2	19.5	-0.8	-4%
Pesticide loss (kg/ha)	0.1	0.1	0.0	-13%
Ammonia loss (kg/ha)	15.4	22.6	7.2	46%

While higher ammonia losses are associated with the poultry enterprise, a multi-tier system[31] was installed principally because of the reduced emissions status. The egg enterprise will allow the unit to be self sufficient in fertiliser P & K once fully established. This is consistent with the considered approach to farm policy across the business.

<u>Biodiversity</u>

Biodiversity stock: 3 Change: 1

The biodiversity stock arises from hedgerows, ponds, buffer strips, boundary features, trees and woodland, supported by ELS where appropriate. The change results from increased area of non-cropped habitats and diversity of both crops and non-crop habitats. However, this scoring system does not capture the main change to biodiversity as perceived by the farmer, which is the introduction of no-till across this arable farm. "*No till gives a huge boost to biodiversity, in winter anything that can walk or fly comes onto our farm for food and cover. This is the effect of having 100% overwinter stubble*".

This is a win-win with food production: "*We produce, if anything, more food than before as well as a fantastic increase in biodiversity. The changes in soil life have been particularly significant. Increased worm activity and micro-flora has improved soil structure and P and K indices- less inputs*". The farmer expects the biodiversity benefits to accumulate: "*With the system established we expect the bird population to continue to increase with the increasing number of worms. The population of birds that eat the birds, that eat the birds, that eat the worms, continues to grow (birds of prey)*".

<u>Landscape</u>

Landscape Stock: 3 Change: 0

The landscape stock arises from the presence of ponds, hedges and trees. The approach is aimed more at management for biodiversity than for landscape per se: "*Use of agri-*

[30] Based on CSF research, the whole farm was mapped using GPS equipment, taking one sample per hectare (consisting of 16 cores per sample). The maps showed the levels of phosphate, potash, magnesium and pH of each field varied considerably, with some indices quite high. This information was transferred to a Calibrator Uniq Controller on a BogballeM2Wvariable-rate fertiliser spreader.
[31] Flat deck systems are cleaned out once a year and have considerably higher emissions than the multi-tier system used on this farm.

environment schemes to encourage wildlife"; these schemes were in place before the baseline. This approach will continue, and is not expected to impact on food production.

Other ecosystem services

Interestingly, the farmer has noticed that some of his fields comprised of black organic soils, have started to accumulate additional top-soil from adjacent fields owned by other farms. When dry, organic peaty soils are especially prone to wind erosion. During the autumn / winter when the majority of adjacent fields are bare, the soil is readily picked up and carried by the wind. In contrast, the fields on this farm, which are perpetually covered by stubble / mulch / crops, not only protect soils from this risk but also act as soil traps.

Conclusions

The farm has not scored well on the SI assessment but arguably has one of the most considered and sympathetic approaches to food production. If a different year were chosen to take a snapshot of performance, a very different set of scores might apply. The farmer's own perspective is that the no-till system is delivering both on increased food production and reduced environmental impact and this is supported by the experience of others and by some research studies. Overall the measures implemented under no-till have *'made food production cheaper, more efficient and more robust'.*

The key conclusion for our study is that care needs to be taken in a static approach to measuring sustainable intensification. While we have discounted smaller changes in indicators (less than 10%) as insufficient to affect our overall assessment, it is clear than in some cases, seasonal factors and enterprise change can deliver larger impacts. Much also depends on the starting position (this farm had the second highest gross energy production in the study) and the ability of our assessment tools to capture the effect of management practices. Thus we accounted for the absence of cultivation and reduction in fuel use in the calculation of carbon dioxide loss but did not account for other no-till effects on retention of nutrients and water or on biodiversity.

Arable Farm A4

Summary

This 300ha arable farm has increased food production and reduced nitrate losses whilst enhancing both landscape and biodiversity. On the basis of these indicators, the farm has clearly demonstrated sustainable intensification.

This arable farm of approximately 300 hectares is in a low rainfall area (600mm per alum) and has predominately free-draining medium textured soils, with a small percentage of impermeable clays. Major crops include cereals, oil seed rape and sugar beet, with some vining peas also grown. The approach to food production is commercially driven but with a deliberate attempt to secure environmental improvements and avoid risks. The farm has adopted a land sparing approach, producing food on the more productive land and using technology and knowledge to increase yields, while setting marginal land aside for conservation.

The farm manager has a strong interest in wildlife conservation and manages the land to enhance biodiversity. This is largely achieved through an HLS agreement which has been in place since 2005. This approach is complementary and seems to fit well with the overall philosophy.

Table 19 below shows that overall the farm appears to be achieving sustainable intensification. Improvements have been made in each indicator area, resulting in a simultaneous increase in food production and reduction in environmental harm / improvement in environmental good.

Table 19: Farm A4 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	87	102	Medium	18%
Carbon footprint	kg CO2equiv/ha	2385	2190	Medium	-8%
Nitrate loss to water	kg/ha	43	33	High	-23%
Ammonia loss to air	Kg/ha	13	12	Medium	-10%
Biodiversity	Index	5		High	2
Landscape	Index	4		High	1

* Specific to sector

Overview of the farm and farming system

This farm employs a farm manager and one full time member of staff. Contractors are used for pea and sugar beet production and some labour exchange takes place with a neighbour on an informal basis. Machinery, including a self propelled sprayer and combine, is part owned and shared with the neighbour; this has enabled the purchase of higher specification equipment.

PLANET software is used for nutrient management planning, along with additional advice from an independent agronomist, who also purchases all crop protection products for the farm. The farm does not belong to any buying groups, and instead there is focus on the timeliness of purchase of inputs to secure cost savings. Most grains are sold through a grain co-operative, although malting barley may subsequently be sold to local maltsters. Wheat is mainly produced for the feed market, with a focus on yield. Future and strategic planning is considered difficult as "*farming tends to be reactive, depending on global market* *fluctuations*". A system of minimum tillage has been implemented in recent years, and where possible, other energy saving measures are being sought.

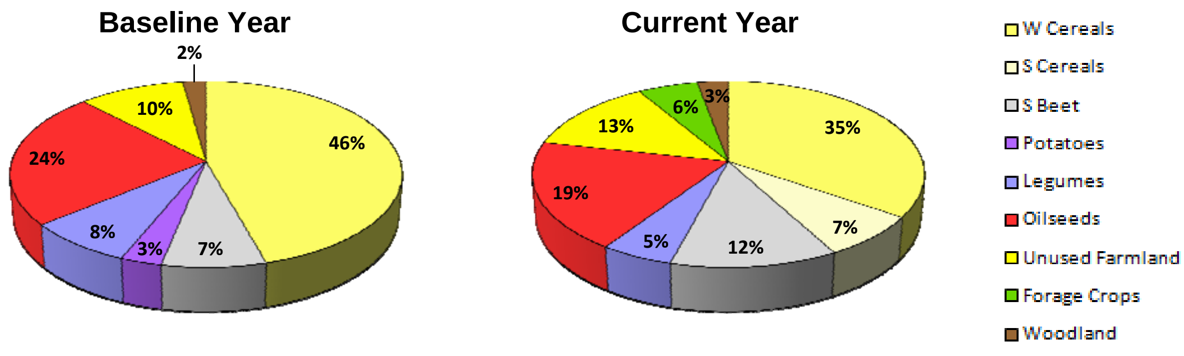

Figure 12: Farm A4 - Changes in cropping from 2005-06 to 2010-11

Approach to sustainable intensification

The farm uses both a land sparing approach whereby the aim is to be as intensive as possible on the productive land, and use more marginal areas for nature conservation. The farm manager's philosophy is "*to achieve a level of farm outputs which is, at least, equal to that before environmental enhancement, but with no detriment to food production*".

A higher level agri-environment scheme is central to this approach as it has enabled low yielding areas to be taken out of production without impacting on income. It allows a more targeted approach than previous systems of set aside or environmental agreements and has enabled easier and more cost effective farming. Changes under the agri-environment scheme include pasture management, including creation of wet meadows, hedge and woodland management and the creation of game covers and pollen and nectar mixes.

The farm has just started to use variable rate fertiliser applications, which, together with cropping changes, has already achieved a 50% reduction in fertiliser usage. The incorporation of other cost effective and environmentally friendly technologies is planned in future, including a headland management kit for the sprayer and basic precision farming tools.

Farm performance

<u>Food production</u>

Total baseline food production expressed in energy output per unit area is moderate for an arable unit at 87 GJ/ha and reflects the productive capacity of the land and to some extent a system driven by achieving wider sustainability. Baseline yield was 6.8 tonnes per hectare for winter wheat and 74 tonnes per hectare for sugar beet, the latter impacting on the former. However, there has been a significant increase of 18% from the baseline year, reflecting increased yields across all key enterprises over the study period. Enhanced performance is attributable to better agronomic practice including nutrient planning and variable rate fertiliser applications along with varietal improvements, especially for peas. The farm has now stopped growing potatoes and has increased the area of sugar beet instead.

Climate change mitigation and adaptation

The farm manager has noticed the onset of seasonal changes in the weather and in response has started to make suitable adaptations and will continue to do so in future. Changes include: planting trees; agro-forestry; improving drainage systems, creating buffer strips, wetlands, ponds and water meadows, increasing water storage, improving irrigation efficiency and improving manure storage.

Whilst there is a good awareness and understanding of climate change impacts on this farm, the key driver for change is profitable sustainability rather than climate change per se. Changes that are being implemented either help to make the system more resilient to uncertain farming conditions or they make sound financial sense.

Overall this approach is proving successful; the total carbon footprint for the farm has been reduced by 8% since the baseline year (see Table 20). Other factors which have contributed to this positive result include: the installation of 11.8kw of solar panels, a reduction in fuel use (mainly due to a change to minimum tillage) and a reduction in fertiliser use (owing to the implementation of variable rate spreading). Future plans to move more towards a precision farming system and increase the amount of renewable energy generation should help to further reduce the carbon footprint.

Table 20: Farm A4 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO_2e kg/ha)	275	252	-23	-8%
Methane loss CO_2e (kg/ha)	0.00	0.00	0	
Nitrous Oxide loss CO_2e (kg/ha)	2,111	1,938	-172	-8%
Carbon footprint per unit land CO_2e (kg/ha)	**2385**	**2190**	**-195**	**-8%**
Carbon footprint per unit food CO_2e (kg/GJ)	**27.5**	**21.4**	**-6.1**	**-22%**

Water and air quality

There has been a reduction in all pollutant losses with the exception of phosphorus which has remained in a steady state (see Table 21). Reasons for the reductions are similar to those mentioned in the previous section and include changes to agronomic and cultivation practices, the introduction of integrated pest management, minimum tillage and precision farming. Managing the land under an agri-environment scheme is also likely to have contributed to pollution reduction by means of buffer strips and the creation of wet meadows.

Table 21: Farm A4 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	42.9	32.9	-10.0	-23%
Phosphorus loss (kg/ha)	0.1	0.1	0.0	1%
Sediment loss (kg/ha)	19.0	18.6	-0.5	-2%
Pesticide loss (kg/ha)	0.1	0.1	0.0	-21%
Ammonia loss (kg/ha)	12.9	11.6	-1.2	-10%

Water quality is of particular significance as part of the farm is in a Catchment Sensitive Farming (CSF) priority catchment and the farm also has its own private water supply.

Improvements have been made to the filling and washout procedures for the sprayer. The farm manager has also looked into biobeds, but has found them to be cost prohibitive.

<u>Biodiversity</u>

Biodiversity stock: 5 Change: 2

This farm scores particularly highly for biodiversity, with a wide range of high-level AES elements supporting several priority habitats including grazing marsh, hedgerows, lowland meadows and ponds. Several of these habitats have been enhanced, in terms of condition (e.g. raised water levels and reduced grazing intensity on lowland marsh) and extent (e.g. new hedgerows). The farm has won a conservation award, and has been very positive and pro-active: "*Approach centred round agri-environment agreement, also has a general interest in conservation and biodiversity*" as well as supporting a game shoot. There are no plans to make major changes, although "*Big decisions will hinge on policy changes when agreement is up for renewal in 2016.*" The farm hasn't noticed effects on food production.

<u>Landscape</u>

Landscape stock: 4 Change: 1

The landscape stock is high because of the elements also noted for biodiversity, likewise the changes. There is no particular approach to landscape management under the current agri-environment scheme, though that had been the case in the past. The current strategy is to "*Continue to use land-spare approach and manage for game conservation*".

Conclusions

The farm has successfully achieved a simultaneous improvement in food production and environmental indicators and can be said to be delivering sustainable intensification. While this reflects to some extent the base year cropping and yields, it demonstrates a degree of genuine sustainable intensification, despite challenging weather conditions in this region over the last two years which have affected some crop yields, particularly wheat.

The delivery of sustainable intensification on this farm encompasses a range of approaches including land sparing; prudent use of new and efficient technologies; improved agronomic practices and enhancement of biodiversity and game bird habitats through higher level agri-environment scheme measures. The latter has exerted significant influence over the way the land is managed.

Arable Farm A5

Summary

Food production on this 607ha arable farm has fallen between the baseline and latest year due largely to dry conditions in the latter. Additionally conversion of more land from arable to fruit production has increased the potential nitrate loss, although run-off from growbags is carefully monitored. The farm has a rich biodiversity stock which it has built on through membership of a high-level agri-environment scheme. Overall, the mixed picture in terms of indictors means that this farm has not demonstrated sustainable intensification over the period.

The farm reported in this case study extends to 607 hectares of tenanted land and comprises of an intensive soft fruit enterprise, an extensive arable enterprise and parkland. The business is very well managed and employs a large staff, including seasonal labour for fruit harvesting. It is very conscious of its environmental obligations and impact and has put systems in place to ensure compliance.

The approach on the farm is based on the aim "to pass on more than they acquired"; this means that the business needs to be sustainable in the long term. The farm is in a high-level AES as well as having LEAF accreditation and being an RSPB monitor farm. The overall outlook in terms of environmental measures is that they are "underpinned by a profitable business that can afford to divert money/time/resources into environmental enhancement".

Food production, in terms of gross energy per unit area has decreased by 12% between the baseline and latest year, due mainly to drought in 2011. We lack complete data on carbon footprint, though nitrous oxide losses fell. Modelled nitrate loss to water has increased by 15% but in practice pollutants are carefully monitored and managed. Ammonia loss to air reduced slightly and the biodiversity score improved substantially (see Table 22).

Table 22: Farm A5 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	72	63	Medium	-12%
Carbon footprint	kg CO2equiv/ha	Incomplete data			
Nitrate loss to water	kg/ha	34	39	Medium	15%
Ammonia loss to air	Kg/ha	12	11	Medium	-9%
Biodiversity	Index	4		High	2
Landscape	Index	4		High	0

* Specific to sector

Overview of the farm and farming system

The soils on this case study farm comprise of gravel loam over mixed gravel and clay with 50% of the land being poorly drained. The farm is located within a low rainfall area within a National Park and there are 101 hectares of parkland and permanent pasture. There are two key enterprises, a very intensive soft fruit enterprise and an extensive arable enterprise.

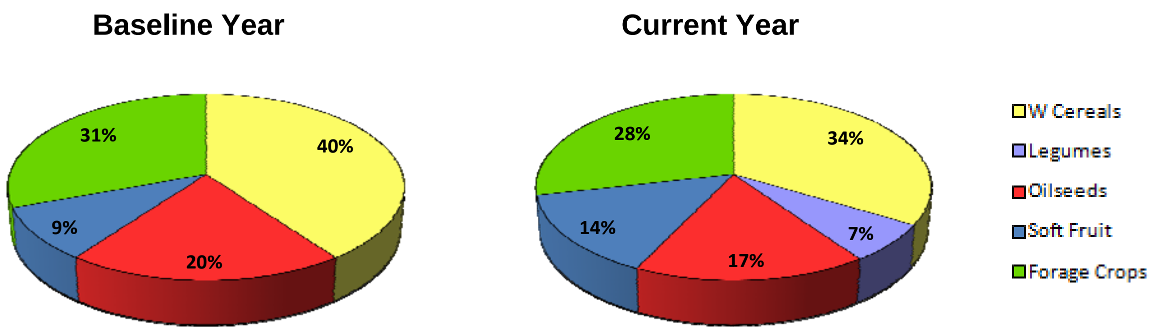

Figure 13: Farm A5 - Changes in cropping from 2005-06 to 2010-11

The soft fruit enterprise extends to over 80 hectares and employs 50 full time staff, including 4-5 administration staff and 6 managers. During the peak summer months, staff numbers increase to 400 for harvesting the fruit (strawberries, blueberries and raspberries). Summer staff are generally European labour of mixed nationalities and this diversity extends to managerial staff to improve communication and achieve an effective workforce.

The arable enterprise comprises winter wheat, winter oilseed rape, spring peas and spring linseed and extends over 425 hectares of grade 3 land and employs one full time and one part time member of staff. The enterprise has invested in larger machinery in order to function more efficiently, with contractors used when required. Due to the limitations of the soil, inputs are tailored to meet the level of expected outputs in order to most efficiently utilise the available resource.

The farm invests in innovation and technology such as poly tunnels, grow bags, tabletop systems, precision fertiliser and computerised irrigation systems. All of the machinery purchased and used on the farm has to be fuel efficient. The diesel tanks are monitored to record the usages by each individual machine and over the past five years diesel powered generators on remote sites have been replaced with electric ones.

The environmental credentials of the farm are important in respect to land in the higher level agri-environment scheme and being audited by the major retailer that purchases the fruit. The farm participates in Open Farm Sunday and has been a LEAF demo farm. The chairman believes that each farm should adopt a local school in order to help educate and engage children in where their food comes from as well as the importance of the environment.

Approach to sustainable intensification

The farm approach is to "maximise the profitability and the return on assets at their disposal"; from this everything else is expected to flow.

The fruit enterprise is a modern system that is highly geared to supply the UK multiples. This means that money is invested in ensuring that modern techniques are used throughout every level of production. For example, the latest varieties are selected to be grown and grow bags are placed on a tabletop system in a polytunnel which uses computerised irrigation.

The arable enterprise is a more stable system and is managed extensively. 'Min till' is implemented along with precision fertiliser applications to ensure that it is run as efficiently as possible.

The management of both enterprises mirrors the enterprise itself in terms of effort. Thus the arable enterprise undergoes quarterly reviews alongside a 5 year plan and annual budgets. The fruit enterprise also has a 5 year plan and annual budget, but it is also subjected to monthly monitoring and weekly KPI (Key Performance Indicator) analysis.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) at 72GJ per hectare in the baseline year is average for an arable system. This has reduced 14% in 2010-11 due to lower yields for winter wheat and winter OSR, reflecting a difficult season[32]. This suggests that the decrease in production between years does not necessarily reflect system changes and may be solely a result of the two years chosen. The pastureland is grazed by a neighbours stock.

Overall, actions to manage the environment have not had any negative impacts upon food production.

Climate change mitigation and adaptation

The nitrous oxide loss on the farm has decreased by 6% (see Table 23) between the years. However, as the energy use data is not available for the case study, it is not possible to estimate the levels of carbon emissions or the overall GHG emissions.

Table 23: Farm A5 - Greenhouse gas emissions per unit area

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	no data	no data		
Methane loss CO2e (kg/ha)	0.00	0.00	0	0
Nitrous Oxide loss CO2e (kg/ha)	2,179	2,055	-124	-6%
Carbon footprint per unit land CO2e (kg/ha)*	**NA**	**NA**		
Carbon footprint per unit food CO2e (kg/GJ)*	**NA**	**NA**		

** CO2 data are not available so total carbon footprints cannot be calculated.*

The business aims to continue to farm effectively and economically and that requires remaining responsive to the requirements of the customer in terms of implementing measures to mitigate climate change. Key management approaches deliver on this agenda. For example, fruit is grown on the farm within a polytunnel, enabling non-native fruit to be grown which "*reduces the requirement to import food which decreases the amount of food miles*". Polytunnels also result in a reduction in inputs as well as preventing the fruit getting wet which reduces the prevalence of disease. On the arable side, no-till and placement of fertilisers are used to reduce inputs. These approaches are largely economically driven but deliver wider benefits.

Water and air quality

The overall nitrate pollutant pressure has increased over the period (see Table 24) in response to moving land from arable cropping to fruit production. The chairman feels he is more aware of water quality as an issue than he was 10 years ago. This has resulted in sewage treatment plants being put in place in all of the work camps as all of the harvest staff

[32] Defra (2012) reports that the drought in spring and early summer of 2011 reduced cereal yields below the 5 year average, especially in the South and having greater effect on the drier and lighter soils.

live on the farm. The run off from the grow bags is monitored which means that they do not consciously allow noxious products to escape into water courses.

Overall the chairman does not believe that the measures he is taking to conserve water are having a negative impact upon food production.

Table 24: Farm A5 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	33.9	39.0	5.1	15%
Phosphorus loss (kg/ha)	0.1	0.1	0.0	10%
Sediment loss (kg/ha)	71.8	82.4	10.6	15%
Pesticide loss (kg/ha)	0.1	0.1	0.0	9%
Ammonia loss (kg/ha)	12.3	11.2	-1.1	-9%

The figures calculated for the farm indicate an increase in both sediment loss and nitrate loss of 15% between the two years. However the tool used to calculate nitrate loss does not differentiate between fruit grown outdoors and fruit grown in a grow bag within a polytunnel; the latter does not entail the same risk of soil or nutrient loss but this is not captured in the metrics.

Biodiversity

Biodiversity stock: 4 Change: 2

The high biodiversity stock arises from the presence of wide range of priority habitats, including rush pasture, wood pasture, ponds and hedgerows, and the high change value comes from both enhancements to some of these, but also farm management changes, notably the area and diversity of non-cropped habitats. The farm is also a member of several food initiatives, including LEAF Marque. The approach to biodiversity is "*Aim to pass on more than acquired. Having a business and a farm that is sustainable in the long term, all underpinned by profitable business that can afford to divert money / time / resources to environmental enhancement*". Management for biodiversity is unlikely to change, "*but will be positive / proactive to initiatives*". No impact on food production has been observed; "*Demands of the higher level agri-environment scheme do not restrict commercial farming practices*".

Landscape

Landscape stock: 4 Change: 0

The high stock for landscape comes from the wide range of habitats and landscape features noted above. There is no sign of an approach to landscape as such, rather to biodiversity, and very clearly to take advantage of initiatives and schemes; thus the present approach to landscape is "*More resource into beetle banks and wild flower pasture in response to agri-environment scheme requirements*", and changes to landscape management "*will continue to be positive and responsive to initiatives*".

Other ecosystem services

The business is keen to incorporate renewable energies where possible and has investigated wind turbines (planning permission an issue within a National Park) and solar PV (the pay back period is too great) and will go on to investigate ground source heat pumps. "*The motivation for investing in renewable energies would principally be financial*".

There is a recognition that the weather is highly unpredictable and the recent dry spring has focused attention on water resources. As a result, plans are being made for a new reservoir as well as investigations into technology for harvesting rainwater from the poly tunnels.

Conclusions

This is a very significant farm business with multiple enterprises and a high degree of management. In particular the soft fruit enterprise requires high levels of organisation and control but is the economic engine of the business. The philosophy of the business is to be business-like, delivering commercial goals through meeting customer and associated environmental assurance. This is delivered through strict systems and controls but also through the use of technology and best practice. Additionally, the farm is in a National Park and has a high biodiversity stock and it has used AES funding to manage and improve this.

Despite this, the change in indicators between the baseline and latest year do not demonstrate sustainable intensification. This is in part an anomaly of the years chosen – crop yields were affected by drought in 2011 – but also of the inability of our assessment tools to capture pollutant management rather than risk.

Arable Farm A6

Summary

This 390ha arable farm has increased outputs of food by 15% between the baseline and latest year. While ammonia emissions have also declined, losses of nitrate have increased, along with the carbon footprint per unit area. The biodiversity score has declined because of the loss of set-aside. This farm has not achieved sustainable intensification.

This arable unit farms around 390 ha of good quality land in a moderate rainfall area (800 mm per annum). Key crops are cereals, oilseed rape and potatoes. The farm approach is to grow the business through improved technical performance and efficiency to deliver high profitability.

This is an intensively farmed unit with a clear focus on yield and quality and the farmer has used technology to help deliver efficiency in terms of inputs and resource use. There is good awareness of environmental responsibilities but limited interest and effort to improve biodiversity or landscape.

Table 25 shows the headline indicators for sustainable intensification. The intensity of food production, expressed as gross energy per unit area, has increased by 15% but nitrate loss to water has increased by 28%, ammonia loss to air decreased by 12% and the overall carbon footprint increased by 11% as food production has increased. The farm had very little resource for biodiversity, and has not joined any environmental schemes: the biodiversity performance of the farm has decreased due to the loss of set-aside.

Table 25: Farm A6 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	112	129	Medium	15%
Carbon footprint	kg CO2equiv/ha	3061	3391	Medium	11%
Nitrate loss to water	kg/ha	57	72	High	28%
Ammonia loss to air	Kg/ha	15	13	Medium	-12%
Biodiversity	Index	1		Low	-1
Landscape	Index	1		Low	0

* Specific to sector

Overview of the farm and farming system

The farm comprises 364 ha of owned land with additional land rented annually for potatoes. The farm has good quality land to grow high value root crops such as potatoes and vegetables. As a result the farm system has changed over the last 20 year from a mixed farm with livestock and grass to an all-arable farm with no livestock. The farm is typical of the region and amongst the top 25% of arable businesses in commercial terms.

Potatoes are the main enterprise and dominate the business with the rest of the land down to combinable cereals. The farm grows 110ha of potatoes, approx half on owned land with the other half on rented seasonal land. The competition for seasonal potato land is fierce and this limits opportunities to grow further. All the potatoes on owned land and most of the let land can be irrigated. The farm has potato storage on 3 sites for 5,500 tonnes, of which 4,000 tonnes is refrigerated. Farm profitability is extremely volatile, dependent on potato prices.

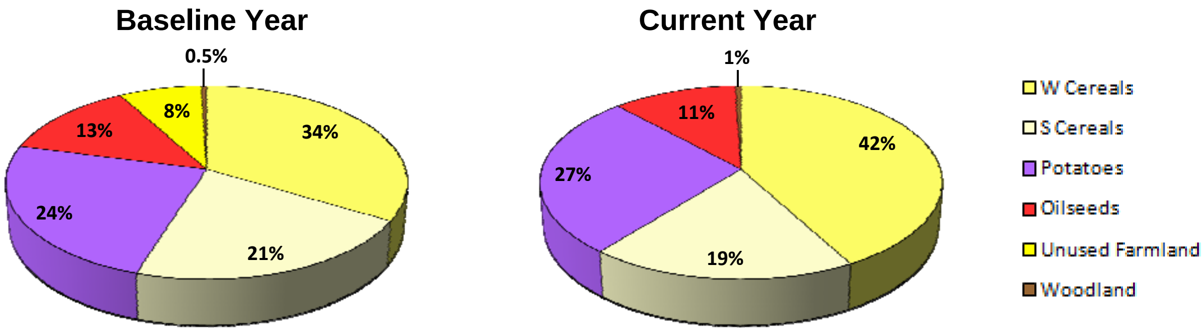

Figure 14: Farm A6 - Changes in cropping from 2005-06 to 2010-11

The farm is run by a father and son partnership and now employs 3 full-time tractor men and seasonal staff for potato grading. The business has invested heavily in mechanisation to access the latest technology, improve work rates and timeliness. There is also an element of risk management and aiming to get things done on time and in good conditions. The farm has adopted precision farming to improve efficiency of input use and improve work rates.

The farm is not in any environmental schemes as they found the schemes inflexible and not cost-effective. However, considerable effort is put into good farming practice to ensure the soil is in good heart and protected. Cereal straw has been chopped and incorporated for some 20 years to ensure that organic matter and soil structure is maintained. In addition, the farm takes in 1,200 tonnes of hen litter annually as a cost effective fertiliser with benefits for soil structure. The farm is in a NVZ and aims to adhere to all the regulations and best practice.

Approach to sustainable intensification

The farm's approach is driven by the ambition to grow the business and be profitable. These efficiency-led actions should also deliver some environmental benefits in terms of resource efficiency as well as supporting high levels of food production.

The main methods which are being used are:

- Adoption of precision farming: soil and yield mapping, auto steer and vari-rate fertiliser spreader.
- Switching from 24m to 36m tramlines in 2010 resulted in huge benefits, particularly for the potato enterprise, with less damage and disease and higher saleable yield.
- Considerable effort was put into improving the marketable yield of the potatoes by improving skin finish and reducing damage / disease include: growing potatoes in wider beds, fertiliser placement, soil testing fields for soil borne diseases, warming potatoes prior to grading, improved grading equipment (less damage) and box fillers.
- Moving from ploughing to sub-soiling / min-till to establish all the oil seed rape to reduce establishment costs and improve yields.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) is high at 112GJ per hectare in the baseline year. This has increased by 15% based on latest year data due largely to an increase in the area of wheat and potatoes (at the expense of barley and oilseed rape) and higher yields for spring barley and winter oil seed rape in 2011.

Climate change mitigation and adaptation

Greenhouse gas emissions from the system have all increased from the baseline figures in absolute terms, but the intensity of emissions (Co2e per GJ of food produced) has declined. Changes are driven by increases in the wheat and potato area but also application of bought-in hen manure (1,200t in 2011 with none used in the baseline year).

Table 26: Farm A6 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	600	763	163	27%
Methane loss CO2e (kg/ha)	0.00	0.00	0	
Nitrous Oxide loss CO2e (kg/ha)	2,461	2,629	168	7%
Carbon footprint per unit land CO2e (kg/ha)	**3061**	**3391**	**330**	**11%**
Carbon footprint per unit food CO2e (kg/GJ)	**27.4**	**26.4**	**-1.0**	**-4%**

The farm has undertaken carbon footprinting and is has submitted a planning application to erect an 800Kw wind turbine. A domestic biomass boiler is used for the farmhouse and a cottage.

Water and air quality

The farm aims to protect water quality through:

- leaving unsprayed /fertiliser margins next to water courses; and
- the full use of precision farming and matching nutrients /agrochemicals to crop requirements with less risk of pollution losses and run-off.

However, the analysis shows an overall rise in pollutant pressure, the exception of ammonia loss which has decreased slightly (Table 27). Again this is due to a combination of more high-N crops and the use of poultry manure application in the latest year.

Table 27: Farm A6 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	56.7	72.4	15.7	28%
Phosphorus loss (kg/ha)	0.2	0.4	0.2	144%
Sediment loss (kg/ha)	91.5	96.6	5.1	6%
Pesticide loss (kg/ha)	0.2	0.2	0.0	15%
Ammonia loss (kg/ha)	14.5	12.8	-1.7	-12%

Biodiversity

Biodiversity stock: 1 Change: -1

The farmer manager has limited interest in biodiversity and provided little information on the presence of habitats. There is no agri-environment scheme membership and the approach to biodiversity is reflected in the comment “have dabbled in conservation schemes but found them inflexible and too much hassle for the return”. The negative change to biodiversity has arisen from the loss of set-aside.

Landscape

Landscape stock: 1 Change: 0

No indication of landscape features or any approach to landscape management was given.

Conclusions

This intensive arable farm has achieved intensification in food production but as a direct consequence has increased the pollutant risk. If this is well managed there may be no material impact on sustainability in practice but the risk will have increased. This intensification has also led to an increase in the farm’s absolute carbon footprint but a reduction the intensity when expressed per unit of food production. The drivers are very much commercial but the business has employed technology to drive efficiency gains and improve yield and product quality; this should deliver associated benefits in terms of sustainability.

The performance of biodiversity on the farm has decreased due to the loss of set-aside. Limited interest in conservation and the absence of an AES suggests that conditions for wildlife have probably reduced.

Arable Farm A7

Summary

This 440ha arable farm has reduced food production and increased the intensity of its carbon footprint, with limited change in other variables. This reflects a commercially driven business which has become more specialised to grow high value crops, including strawberries and broccoli; these crops yield less food energy but make a good economic return. On this basis, the farm has not demonstrated sustainable intensification over the period.

This is an intensively managed, high output arable farm unit of 440 ha, of which 200ha are owned and the rest are rented. The farm approach is to grow output but to strive to improve the resource efficiency, to reduce costs and improve profitability.

Table 28 shows that food production per hectare reduced 14% while the associated carbon footprint remained largely static between the baseline and latest year. Nitrate losses reduced but ammonia emissions increased, neither significantly. The biodiversity and landscape scores are unchanged from a medium/low base.

Table 28: Farm A7 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	104	89	Medium	-14%
Carbon footprint	kg CO2equiv/ha	3991	4075	Medium	2%
Nitrate loss to water	kg/ha	66	70	High	5%
Ammonia loss to air	Kg/ha	11	10	Medium	-7%
Biodiversity	Index	2		Medium	0
Landscape	Index	1		Low	0

* Specific to sector

These changes reflect changes in the farming system, with more land given over to fruit and vegetable production, rather than cereals. Although fruit and vegetables are high value crops, they have relatively low energy contents compared to cereals and require higher intensity of inputs. Profit levels have remained similar.

The focus on high value crops places demands on management in terms of both input management and product quality. The business has used new technology to deliver resource efficiency and cost control. This will deliver environmental benefits for climate regulation and may impact positively on resource protection and the wider environment.

Overview of the farm and farming system

The farm comprises 200 ha of owned land and 240ha rented land. It is an intensively managed, high output farm. The farm is all good arable land with only a small area (2 ha) of permanent grass which is managed under an agri-environment scheme.

Over the last 20 years the farm has reduced the number of enterprises and is now more specialised and professional. High value crops, broccoli and potatoes are the main enterprises. Strawberry production was introduced in 2006. The rotation on the farm is: broccoli, wheat, spring barley, potatoes, oats, and wheat. There is a block of heavy land (50 ha) which has grown continuous wheat for 15 years. The farm is well mechanised with a range of specialised buildings.

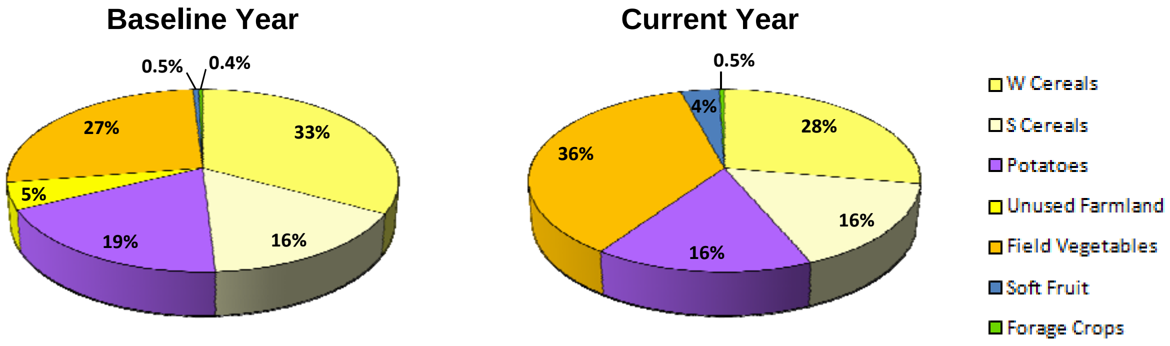

Figure 15: Farm A7 - Changes in cropping from 2005-06 to 2010-11

The number of full-time tractormen has remained constant at four. A broccoli manager has been appointed in the last 3 years. The number of seasonal staff has increased over the 5-year period. The farm now employs 150 seasonal staff: 30 on broccoli harvesting and 120 on strawberries. Two part-time admin staff are employed in office.

The farm makes efforts to achieve good farming practice to ensure the soil is in good heart and protected. For example, cereal straw has been chopped and incorporated for many years to maintain organic matter and soil structure. The farm also takes in 600t hen litter annually. The farm is in an NVZ area and aims to adhere to all the regulations and best practice.

Approach to sustainable intensification

Due to the difficulty of accessing additional land the only way to grow the business was to increase the output through expanding the vegetables and introducing the new strawberry enterprise. Land is expensive and rarely comes on the market and it is increasingly difficult to rent seasonal clean land for potatoes.

The farm's approach is to grow output but to strive to improve the resource efficiency, to reduce costs and improve profitability. Innovation is seen as source of competitive advantage, either to add value or reduce costs. Examples of the changes adopted over the last 5 years include:

<u>Broccoli</u>

- 10% of the crop is grown under plastic to extend the season
- Yields have increased due to new varieties, agronomy, growing techniques (use 3-row beds, etc)
- More particular over field selection, carry out soil testing, only grow where there is access to irrigation
- Now apply fertilisers in bands reducing overall application rate
- The farm is planning to build a reservoir for irrigation; currently river abstraction and bore holes are used.

<u>Strawberries</u>

- New enterprise introduced in 2006 as a route to expand the business
- Grown in polytunnels
- Now grown in coir bags, replacing peat

- 15% now double cropped
- Extended picking season – from mid-May to October
- Seal tunnels, fleece and heat to protect against frost

Potatoes

- Now growing varieties which are more drought resistant
- Soil test for powdery scab
- Have reduced fertiliser rates
- Introduced auto steer to get more efficient use of inputs

Cereals

- Started GPS field mapping for lime and P & K fertiliser application
- Use auto steer which saves 3% on spray /fertiliser applications
- Moving to precision farming to reduce input use and improve efficiency

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) at 104GJ per hectare in the baseline year was high for the sector. This was 14% lower in 2010-11 largely due to the changes in farming system, where more land was switched to fruit and vegetable production from cereals but also reflects decreases in the yield of cereals and potatoes in that year. Although fruit and vegetables are relatively high value (in economic terms) and their yields have increased, they have lower energy contents and require more intensive inputs to grow compared to cereals. The financial output on the farm has doubled over last 5 years but profit levels remained similar. This highlights the need for the farm to focus on improving input efficiency and driving costs down to improve margins.

Climate change mitigation and adaptation

Greenhouse gas emissions from the system have increased on the baseline figures (see Table 29) although these changes are not significant; the intensity of emissions has also increased due to lower production. This is again a reflection of changes in inputs associated with farm cropping, notably an increase in the area of broccoli from 117 to 160ha. Some 600t of hen litter was imported and applied to 70ha of broccoli or potatoes in the latest year with inorganic fertiliser rates adjusted accordingly.

Table 29: Farm A7 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	1,511	1,579	68	4%
Methane loss CO2e (kg/ha)	0.00	0.00	0	N/A
Nitrous Oxide loss CO2e (kg/ha)	2,480	2,496	16	1%
Carbon footprint per unit land CO2e (kg/ha)	**3991**	**4075**	**84**	**2%**
Carbon footprint per unit food CO2e (kg/GJ)	**38.4**	**45.8**	**7.3**	**19%**

The farm aims to improve the efficiency of inputs and reduce waste to reduce GHG emissions through use of technology, farming practices and so on. They are also actively looking at the use of renewable energy. They have been at the planning stage for a 100kw wind turbine for the last two years and have just submitted a planning application.

Water and air quality

The farm has shown an overall rise in pollutant pressure; with the exception of ammonia losses which have decreased slightly (see Table 30). This is largely due to the change in cropping with more land devoted to vegetable production instead of cereals and potatoes.

Table 30: Farm A7 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	66.2	69.8	3.6	5%
Phosphorus loss (kg/ha)	0.2	0.4	0.2	140%
Sediment loss (kg/ha)	100.6	103.6	2.9	3%
Pesticide loss (kg/ha)	0.2	0.2	0.0	2%
Ammonia loss (kg/ha)	10.5	9.7	-0.7	-7%

The farm has taken positive action to protect all waterways through unsprayed and unfertilised margins. It has also planted a reed bed to handle any dirty water run-off from the septic tank from accommodation facilities used by the seasonal staff. The farm plans to maintain current practices and monitor water quality to ensure no pollution. They are likely to be doing more in this area.

Biodiversity

Biodiversity stock: 2 Change: 0

The main biodiversity feature is a small area of permanent grassland, supported by a high level agri-environment scheme. The farm has also been planting hedgerows and establishing beetle banks and unsprayed margins; such benefits have been counter-balanced by the loss of set-aside. The approach to biodiversity is that "*Biodiversity is important; however, it must complement the existing farm system*" ". Want to maintain biodiversity but primary focus is production." *The only impact of biodiversity management on food production is that it is perhaps good PR value*".

Landscape

Landscape stock: 1 Change: 0

The sole landscape element of note is the presence of hedgerows, that have been added to and their condition improved. The farm doesn't have a formal (landscape) policy but is keen to "*protect and enhance it where possible*", and is unsure how landscape management will change in the future.

Other ecosystem services

The farm has plans to improve irrigation management (to build a 1m gallon reservoir to support irrigation) and use of varieties /technology to reduce water requirement.

Conclusions

This intensive arable farm has pursued commercial goals and diversified the business into high value vegetable and fruit crops but this intensification is not reflected in the food production indicator, with a fall in the gross energy. This has also increased the intensity of the carbon footprint (per unit of food production) despite only a marginal increase in absolute GHG emissions at farm level. Other categories of ecosystem services: emissions to air and water and biodiversity have been fairly static.

While the indicators for food and carbon mean that we cannot say this business is delivering sustainable intensification, this relies heavily on the gross energy method as a metric. It is also difficult for an intensive farm like this to deliver large improvements to water quality or biodiversity and it is unlikely to demonstrate sustainable intensification. However, it seems counterintuitive that it has not considered to have intensified food production and suggests that the methodology should be refined to account for additional attributes such as dietary value.

Mixed Farm M1

Summary

Food production on this 1821ha mixed farm has increased between the baseline and latest year, at the boundary of significance; there have been limited changes in environmental performance. While there is an indication of sustainable intensification, the extent of change in indicators between 2006 and 2011 does not demonstrate that this has been achieved.

This mixed farm comprises of 1,373 ha of farmed land and 448 ha of woodland and other non-farmed use. The farm is in a low rainfall area, on medium type, free draining soils. The main farm enterprises are two 200 cow dairy units, around 30 beef cattle and 550 hectares of combinable arable crops.

The approach is based on food production and the environment being able to coexist (land sharing), with each being focused on as an enterprise within its own right. The farm is located within an estate with an established shoot and so maintaining the environment and biodiversity is integral to the success of that element of the business. The farm side is run intensively with an emphasis on it sustaining itself economically.

The indicators in Table 31 show that the intensity of food production, expressed as gross energy per unit area, has increased by 10% while the overall carbon footprint has been static over the period. There is a small reduction in nitrate losses.

Table 31: Farm M1 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	35	38	Medium	10%
Carbon footprint	kg CO2equiv/ha	3398	3358	High	-1%
Nitrate loss to water	kg/ha	28	28	Low	-3%
Ammonia loss to air	Kg/ha	13	13	Medium	0%
Biodiversity	Index	4		High	0
Landscape	Index	4		High	1

* Specific to sector

Overview of the farm and farming system

The farmed land extends to 1460ha, of which 30% is owned and the remainder rented on long and short term tenancy basis. The farm is located within an NVZ.

Labour on the farm comprises a combination of employees and self-employed contractors. The farm manager and secretary work across both the livestock and arable enterprises. The livestock element of the farm employs two full time herdsmen, a stock man and a relief milker. The arable side of the farm employs two full time members of staff plus a full time student from an agricultural university along with a student employed for harvest. Contractors are used for straw baling, foraging, dung carting and muck spreading. The farm also pays a consultant for advice on budgets, business plans and expenditure.

This mixed farm comprises of arable crops (winter barley, winter beans, winter OSR, winter oats, winter wheat, spring wheat and spring OSR), two 200 head dairy herds and a beef enterprise. There has been relatively little change in cropping and stocking over the period.

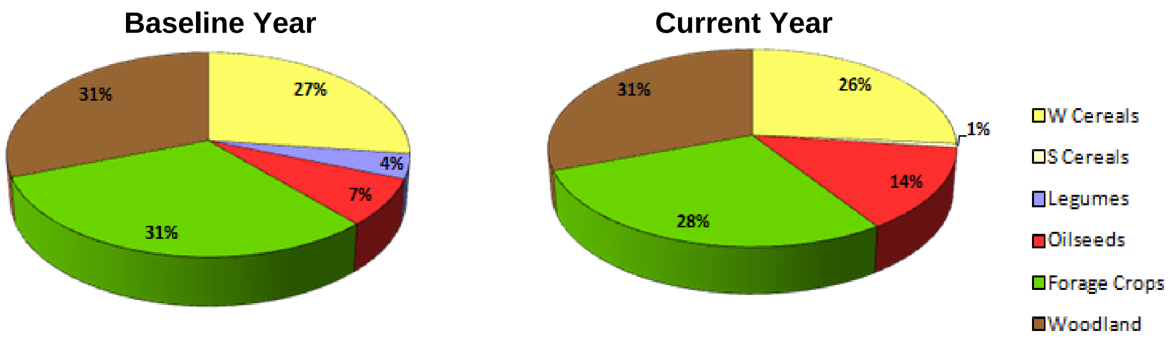

Figure 16: Farm M1 - Changes in cropping from 2005-06 to 2010-11

The farm aims to employ the optimum number of staff for each enterprise. There are two dairies each with roughly 200 cows to one herdsman (yielding 1.75 million litres and 1.6 million litres per year respectively). This is thought to be the maximum number of cows for one person to manage and means that both dairies are both efficient and accountable.

Table 32: Farm M1 - Changes in livestock numbers

	Baseline Year	Current Year
Dairy cows	398	393
Dairy youngstock	218	272
Other cattle	323	350

Approach to sustainable intensification

The farm's approach can be described as one in which "*food production and the environment can coexist*". The farm has intensified and is efficient, investing in innovation and technology where possible. GPS systems with autosteer are used widely in machinery throughout the farm. While this technology results in cost savings, as well as ensuring that resources such as fertiliser are used more economically, the farm manager feels that the main benefit of the system is "*the reduction in wear and tear on the employees*". It leaves the farm staff able to "*think about more important things than driving in a straight line*" as well as meaning that they are more alert to what is going on around them.

Financially the farm manager sees the farm as being sustainable, although he feels that the Single Farm Payment (SFP) backs up the commercial enterprise and allows it to invest in new plant, machinery or the environment. A well thought out plan for the future and vision of the farm is seen as important. The plan encompasses all aspects of the farm such as machinery replacements, cropping and expenditure and is devised with the help of an independent farm consultant. Advice is provided from an agronomist.

The outlook of the farm manager is a key to the success of the farm, in that he is enthusiastic about the farms future and has a realistic perception of the farm in terms of its place within his work life balance.

Farm performance

Food production

The overall aim of the farm is to increase yields in association with actions to manage the environment. Thus 130 ha of land have been taken out of production (prior to the baseline year). As this was less productive land, recorded average yield per ha across the farmed area has increased.

Absolute food production (expressed in gross energy per unit of land area) is at a medium level for this sector at 43GJ per hectare in the baseline year. Gross energy per hectare was 10% lower in the latest year due largely to the impact of dry conditions on the 2011 arable harvest.

Over the five year period from 2006-2011, the dairy enterprise has increased sales from 3.1 million litres to 3.2 million litres. In contrast, crop yields have been largely static. Actions to achieve higher yields include drilling earlier with a reduced seed rate but climate change means that they sometimes feel that they are lucky to achieve any yield at all. The lower yield of cereal crops in the latest year reflects a dip in national yields for the 2011 harvest. However, all crops on this farm were impacted with winter oilseed rape yield down from 3.1 t/ha in the baseline year to 2.6.t/ha in 2011.

Climate change mitigation and adaptation

The farm does not have a prescribed approach towards limiting impacts on climate change; instead, actions are mainly taken to keep in line with industry standards and legislation. Management is conscious of climate change and endeavours to act to mitigate impacts. Key examples include recycling as much waste as possible, planting large numbers of trees and changing the fuel firing the compressors on the farm.

This overall performance is highlighted in Table 33. Carbon dioxide emissions are negative within the farming system as a result of the large area of woodland and land under AES (sequestered carbon outweighs emissions of CO2 form cultivation and energy use). Total GHG emissions have been largely static since the base year; increased methane emissions are balanced by a reduction in nitrous oxide loss. As food production has reduced, the carbon intensity of production has increased per unit food (by 16%).

Table 33: Farm M1 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	-11	-11	0	-3%
Methane loss CO2e (kg/ha)	1608	1686	78	5%
Nitrous Oxide loss CO2e (kg/ha)	1,800	1,700	-100	-6%
Carbon footprint per unit land CO2e (kg/ha)	**3396**	**3375**	**-21**	**-1%**
Carbon footprint per unit food CO2e (kg/GJ)	**79.2**	**92.3**	**13.1**	**16%**

The view of climate change is that the weather patterns have altered and in light of that the farm has had to adapt, although it is a slow process. The main adaptation is seen in changes to drilling dates.

The following actions will also contribute to limiting the impact:

- Many trees have been planted on the estate
- The gas has been changed in the compressors.
- The estate installed a wood burner to heat the main house along with 4 other properties given the availability of woodland.
- The farm will continue to recycle where possible

In the future the farm will try to incorporate renewable energies where possible. This includes investigating the use of alternative fuel sources for a new grain dryer.

Water and air quality

Water and air quality on the farm are well managed and pollutant pressures have reduced slightly from the baseline year. The farm follows best practice guidelines and is in a NVZ which also requires a focus on improving water quality. There is a borehole (with plans to install a second) and the water is rated as being of high quality. The main driver for the latter is the price of mains water.

Table 34: Farm M1 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	28.5	27.6	-0.9	-3%
Phosphorus loss (kg/ha)	0.4	0.3	0.0	-6%
Sediment loss (kg/ha)	110.8	103.4	-7.4	-7%
Pesticide loss (kg/ha)	0.1	0.1	0.0	5%
Ammonia loss (kg/ha)	12.9	12.9	0.0	0%

Biodiversity

Biodiversity stock: 4 Change: 0

The high biodiversity stock score arises from the range of agri-environment scheme activities, on boundary features, arable options and margins, ponds, trees and woodland. The farm is also engaged in biodiversity recording, farm assurance and farmed environment schemes. The diversity of non-cropped habitats has increased, counterbalanced by an increase in livestock stocking density. The incentive for this work is that the landowners wanted to create a wild bird shoot, with partridges breeding on the land, supported by agri-environment schemes.

No change is likely in the near future, because the farm is tied into entry-level and high-level agri-environment schemes. The farm manager notes some impacts of this approach on food production, including:

- the farm no longer block crops, increasing time and fuel spent travelling between fields;
- the decision not to work after dark where the partridges roost also impacts on productivity.

Landscape

Landscape stock 4 Change 1

The landscape stock score arises from the range of agri-environment scheme effort on hedgerows, ponds, wood pasture. The positive change score arises from improvements in hedgerow length and condition, and pond condition. The farm manager notes that “320 acres of land have been taken out of production as a result of environmental schemes; this equates to 600 tonnes less grain being produced. The average yield has increased a little as the land that was taken out of production was the least productive. “

Other ecosystem services

The quality of water in the borehole is very good and efforts will concentrate on the impacts of the quantity of water in the future as opposed to the quality.

Conclusions

The farm manager has taken a land sparing approach, aiming to improve the productivity of the farm, through improving management and putting less productive land put into AES. Together with actively managing the estate and a private shoot, the farm has increased the level of biodiversity and the landscape score. There have also been positive impacts on air and water quality in the surrounding environment.

However, in terms of food production, susceptibility to drought has impacted on yields, with gross energy reduced by 10% across the total farm area in 2011. The farm has altered some of its practices to adapt to this risk and wider climate change, through altering drilling dates, reducing reliance on mains water for the dairy herds and pursuing resource efficiency measures across the farm.

Mixed Farm M2

Summary

This 102ha organic mixed farm has made no substantial changes to the system but more land was down to grass in 2011 and this has led to reduced food production in gross energy terms. Changes in other indicators are not significant, and so overall the farm has not demonstrated sustainable intensification.

This mixed farm comprises 63 hectares of combinable crops and 39 hectares of grassland on a shallow soil with an annual rainfall of 650mm. The farm system is based around growing quality potatoes for packing and uses cereal crops to provide a rotation and finishing livestock to provide fertility in the system. Annually the farm finishes around 100 beef cattle and 150-300 lambs with over 1200 grower pigs finished on contract. The farm philosophy is one of maintaining a profitable business whilst providing quality organic food for consumers. The farm has been organic for over 50 years so reducing negative impacts on the environment has become fully integrated into the farming ethos.

The farm equilibrium has changed little from the baseline year to 2011 except for the erection of a wind turbine in 2010 with a second being investigated at present.

Table 35 shows that food production, expressed as gross energy per unit area, has decreased by 11% while the carbon footprint has also reduced (-5%). Changes in other indicators are not significant; nitrate loss to water has also decreased by 5% and ammonia loss to air increased by 8% while there is no change in biodiversity or landscape scores).

Table 35: Farm M2 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	31	28	Medium	-11%
Carbon footprint	kg CO2equiv/ha	4283	4074	High	-5%
Nitrate loss to water	kg/ha	41	39	Medium	-5%
Ammonia loss to air	Kg/ha	15	16	Medium	8%
Biodiversity	Index	3		Medium	0
Landscape	Index	2		Medium	0

* Specific to sector

Overview of the farm and farming system

The farm unit is run by the farmer and one full time employee with limited use of casual labour (600hrs per annum); contractors are used for lifting potatoes, silaging and spreading manure.

The arable rotation is based on winter wheat, spring barley and potatoes. The rotation has changed little in the period from the baseline year to 2011 as the farmer feels they have now optimised their system. Straw is baled and utilised in the beef enterprise to create farm yard manure and returned to the land to improve soil structure and fertility. Farm yard manure from the pig enterprise is also used for this purpose and is spread at a rate of 18-20t/ha on the potato fields and 12t/ha on the spring barley. All of the manure is field heaped until needed. The farm has a manure management plan and all applications are spread using a calibrated spreader.

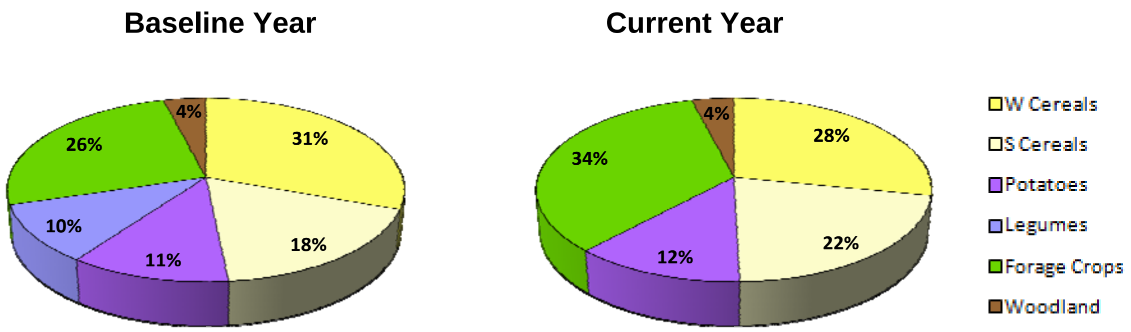

Figure 17: Farm M2 - Changes in cropping from 2005-06 to 2010-11

The farm runs a beef cattle enterprise with 100 cattle bought in at 350-450kg and sold at around 630kg liveweight. Two thirds of the cattle are fully housed, whilst the remainder spend some time grazing outdoors. The store lambs are finished on grass and sold via a premium contract at approximately 40kg liveweight; this enterprise is forage dependant and numbers fluctuate from year to year with forage availability.

The outdoor pig enterprise contributes economically but importantly converts straw to muck as fertiliser for the organic system. The farm acts as a contract rearing unit for a pig producer taking pigs from 40kg to 105kg. The pigs are reared outdoors and are housed for less than a week prior to sale. The pig enterprise is based on batches of 400 stores on an all–in, all–out system[33], finishing 3 batches per year (1200 pigs).

In 2010 the farm erected a wind turbine and planning permission for one further turbine has been started. At present 20,000kWhr are being sold back to the national grid and the remaining units are being utilised to reduce the input for the potato enterprise.

It was difficult to quantify changes in the time period of this study as the farm converted to organic over 60 years ago. Minimising the impact on the environment is very important to the farm but the ability to produce top quality organic food for the consumer whilst maintaining a profitable business is also paramount. The farm has made good use of entry-level agri-environment schemes and has found the actions easy to implement as many were already underway such as replanting hedgerow and trees and use of cover crops.

Approach to sustainable intensification

The farm's approach is based on maintaining the environment whilst creating a premium product and ensuring a profitable business. It is important to the farmer that the farm and environment work in synergy for many years to come. To achieve this, the main focus is:

- Organic farming methods – no fertilisers or agrochemicals
- Use of small tractors for arable land
- Efficient and precise use of manures
- Using more drought resistant crops
- Participation in environmental schemes

[33] All-in, all-out refers to a batch system where all pigs come onto the farm at the same time and all are moved off the farm before the next batch arrives.

- Producing renewable energy on farm through a wind turbine with planning started for another
- Managing risk by having a self-contained system - livestock numbers reflect forage availability and crop outputs (straw and grains) provide inputs for livestock

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) is average for this sector at 31GJ per hectare for the baseline year, but is quite high for an organic system. Food production fell by 11% over the study period due to a combination of lower cropped area, fewer lambs finished and increased feed purchases; the latter effectively increases the area associated with the output. This mainly reflects seasonal fluctuation in a well-established system rather than a decline in productivity. It is also the case the livestock production is less energy efficient generally and year-to-year changes in the balance of cropping and stocking will cause the indicator to fluctuate.

Climate change mitigation and adaptation

Greenhouse gas emissions from the system have decreased from the baseline position (see Table 36); total emission levels have dropped by 5% but intensity has increased by 7% due to the lower food output. Carbon dioxide emissions have reduced by 27% due to the use of renewable energy generated from the wind turbine.

Table 36: Farm M2 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	621	453	-167	-27%
Methane loss CO2e (kg/ha)	1534	1479	-54	-4%
Nitrous Oxide loss CO2e (kg/ha)	2,129	2,142	13	1%
Carbon footprint per unit land CO2e (kg/ha)	**4283**	**4074**	**-209**	**-5%**
Carbon footprint per unit food CO2e (kg/GJ)	**137.3**	**146.3**	**9.0**	**7%**

The farm aims to improve efficiency of all inputs and minimise waste, thus reducing GHG emissions and limiting impacts on climate change. Specific measures undertaken to combat climate change include:

- Re-planting hedges and trees as necessary
- Adopting precision farming
- Making extensive and precise use of organic manures
- Reducing reliance on mains water by recycling roof water and exploring the possibility of a borehole
- Adopting drought resistant crops
- Practicing rotational farming

Water and air quality

The farm results showed little change from the baseline year with regard to pollutant pressure (see Table 37), which reflects a stable system. Small changes in, for example ammonia loss can be attributed to the slight increase in manure spread in 2011.

Table 37: Farm M2 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	40.9	39.0	-1.8	-5%
Phosphorus loss (kg/ha)	0.2	0.2	0.0	2%
Sediment loss (kg/ha)	18.0	17.2	-0.7	-4%
Pesticide loss (kg/ha)	0.1	0.1	0.0	-8%
Ammonia loss (kg/ha)	14.7	15.9	1.1	8%

The farm has undertaken the following measures to protect water quality:

- No spraying or inorganic fertiliser used
- Precise calibrated spreading of manure (NVZ)
- Avoid prophylactic use of medicines for livestock

<u>Biodiversity</u>
Biodiversity stock 3 Change 0

The biodiversity stock score arises from work on field boundaries, trees and woodland, arable options and options to protect soils. There has been little change: the farm has been organic so long they haven't seen any changes in the last 5 years. They won't change in the future unless asked by environmental schemes. "*It works for us, so why change it?*" The farmer reports no impacts of biodiversity management on food production.

<u>Landscape</u>
Landscape stock 2 Change 0

The landscape stock is indicated by agri-environment support for hedgerows, trees and woodland. There is little change: the aim is to "*keep landscape as it is; plant trees if they* fall." No change is expected in the future.

Conclusions

This farm has been organic for over half a century and has tailored the farming system to optimise farm output whilst managing the business risks and the environment. This is a true land sharing approach. While yields could be increased further on this productive land there is a view that equilibrium has to be reached and each part of the farm works synergistically with another. Biodiversity and the landscape have been managed sympathetically by this farm over many years and wildlife is seen as an integrated part of the farming system.

The farm has a focus on securing high prices for organic produce with all crops sold into premium contracts. The organic status or quality of the output is not recognised in the gross energy metric used to quantify food production levels in this study. Although this farm is relatively intensive through utilising animal manures, the pig enterprise involves significant imports of feed and when the land associated with this is allocated to the output, the intensity of production is much reduced.

Mixed Farm M3

Summary

Food production on this 369ha mixed farm has increased substantially, while all environmental aspects have shown improvement. This farm has demonstrated sustainable intensification.

This mixed farm comprises 275ha of combinable crops and 94ha of grassland on medium and clayey soils with low to medium rainfall. The unit has 65 spring calving suckler cows, a pig finishing enterprise and rears over 100,000 free range point of laying pullets. The farm approach is based on running a profitable farm enterprise whilst maintaining a work / life balance, but with ambition to grow if opportunities arise. The aim is to "farm well" and ensure the land is maintained in good heart while minimising the environmental impact of food production.

The ability to adapt and change led to changes in the business in recent years and as a result the farm is more profitable. The farm erected two 800KW wind turbines as a business diversification funded through a bank loan in 2008 and this has become the most profitable enterprise on the farm.

Food production has increased significantly in gross energy terms while the carbon footprint, pollutant losses to air and water have reduced and the biodiversity score has improved (see Table 38). This performance reflects a number of changes from the baseline position, including enterprise change which has impacted on the indicators.

Table 38: Farm M3 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	32	49	Medium	52%
Carbon footprint	kg CO2equiv/ha	5596	4102	High	-27%
Nitrate loss to water	kg/ha	62	54	High	-13%
Ammonia loss to air	Kg/ha	25	18	High	-27%
Biodiversity	Index	4		High	1
Landscape	Index	3		Medium	0

* Specific to sector

Overview of the farm and farming system

The farm is run by a father and son partnership, using both family labour and casual labour (1,200 hrs per annum) to help with pullets and harvest time and makes limited use of contractors (silaging and straw baling). It is well mechanised with large capacity machines. The business has simplified the farming system in recent years, leading to improved profitability. The latter has been driven by a doubling of total economic output compared to the base year 2006, principally due to introduction of the wind turbines and a good year for the poultry enterprise.

The arable rotation is based on winter wheat, winter barley, winter oil seed rape, and spring barley; second wheats[34] are never grown. All wheat and oilseed rape straw has been

[34] A second crop of wheat grown after a wheat crop; these crops require can higher input levels and face higher disease risks.

chopped and incorporated since 2006, with any surplus barley straw also chopped (sold occasionally). Grass is established with direct reseeds and the farm makes extensive use of muck and compost to maintain soil fertility and structure.

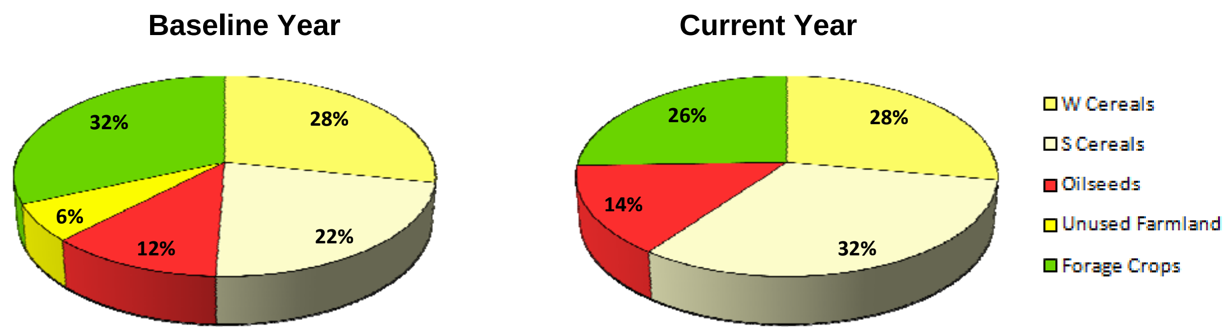

Figure 18: Farm M3 - Changes in cropping from 2005-06 to 2010-11

The business has reduced suckler cow numbers from 120 to 65, releasing 40 hectares of grass into combinable crops. It has also converted a Dutch barn into additional grain storage to give a total storage capacity of 4,000 tonnes. The spring calving suckler cows are put to an Aberdeen Angus bull for easy calving and premium prices. Males are left entire as bulls and intensively finished indoors; females are sold either as stores or finished fat depending on market prices.

The farm has always finished weaner pigs to increase farm output and convert straw into muck. Previously weaners were purchased at 30kg to finish but now due to market volatility, weaners are taken in on a bed & breakfast basis, paying for labour and straw to reduce business risk. The system is based on batches of 600 weaners on an all-in all-out basis with 3 batches reared per year (1,800 head per annum).

In 2006, the farm also contract finished broiler chickens - 6 batches, with 34,000 head per batch in a 9-week cycle (204,000 head per year) at 2.4kg. This has been replaced with an enterprise based on rearing free range point of laying pullets, with 38,000 head per batch for 16 weeks and 3 batches per year (114,000 head per year). This change has allowed the farm to use home-grown cereals (170 tonnes) and produces a higher margin; birds are sold locally.

Changes in livestock enterprises are summarised in Table 39.

Table 39: Farm M3 - Changes in livestock numbers

	Baseline `Year	Current Year
Breeding Cattle	106	64
Finishing pigs	2,910	1,750
Broilers	194,000	-
Point of lay pullets	-	108,000

Approach to sustainable intensification

The farm's approach is based on running a profitable farm enterprise "*while keeping a good balance between work and life and aiming to grow when opportunities arise*". The main mechanisms which are being used to achieve this are:

- Using precision farming (GPS, yield mapping) and N sensors for vari-rate fertiliser applications to improve input efficiency
- Investing (2012) in a new vari-rate grain drill to sow seed rates to the soil type for optimum plant establishment and yield.
- Using liquid fertiliser, matching soil analysis in the form of straight phosphate and potash fertilisers
- Preparing nutrient balances and waste management plans
- Making use of specialist agronomist advice
- Using Estimated Breeding Values (EBV)35 to select bulls for the suckler enterprise and using latest advice to adjust livestock diets
- Producing renewable energy on farm through two 800kw wind turbines (planning for two more wind turbines to be erected in 2013)
- Participation in agri-environment schemes on less productive land
- Maximising margins and managing risk by using own crop outputs (grain and straw) for livestock inputs, and limiting exposure on pig and poultry contracts.

Minimising the impact of farm production on the environment is important. However, conservation activities are focused on the lower grade land leaving the more productive areas for conventional farming, while always adhering to good farming practice. The business has actively used support available under an agri-environment scheme including building five ponds, planting hedges and managing wet grassland, water margins, hedge rows and grass margins. This has been influenced by the opportunity to attract support payments.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) is average for this farm type at 32 GJ per hectare in the baseline year. This increased by 52% over the study period, due largely to an increase in the arable area (no set aside and less grassland/livestock) but also on the basis of higher crop yields (winter wheat yield increased by 10 % and winter oil seed rape by 15%). More winter barley and spring barley were sold off farm in the latest year compared to baseline due to a reduction in cattle numbers. Suckler cow numbers decreased from 120 to 65 (-46%), pig numbers from 3000 to 1800 (-40%) while poultry has reduced from 194,000 broilers to 108,000 laying pullets.

Under constant cropping and stocking, the gains in food production would be much less significant.

[35] EBV is an estimate of an individual's true breeding value for a trait based on the performance of the individual and close relatives for the trait. It offers a systematic way of combining available performance information on the individual brothers and sisters and the progeny of the individual.

Climate change mitigation and adaptation

Greenhouse gas emissions from the system have all decreased from the baseline position; total emission levels have dropped by 27%. This is a result of the decreased livestock numbers on farm and the use of renewable energy (generated from the two wind turbines on site), which has driven down farm carbon dioxide emissions (by 20%). Together with the higher food production level, this has led to a reduction in the carbon intensity of output by 46%.

Table 40: Farm M3 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	724	579	-145	-20%
Methane loss CO2e (kg/ha)	1532	860	-672	-44%
Nitrous Oxide loss CO2e (kg/ha)	3,340	2,662	-677	-20%
Carbon footprint per unit land CO2e (kg/ha)	**5596**	**4102**	**-1494**	**-27%**
Carbon footprint per unit food CO2e (kg/GJ)	**98.3**	**53.5**	**-44.9**	**-46%**

The farm aims to improve efficiency of all inputs and minimise waste, thus reducing GHG emissions and limiting impacts on climate change. Specific measures include:

- Planting hedges and some trees, although not large areas of woodland
- Maintaining existing drainage systems
- Creating ponds & wetlands
- Adopting precision farming
- Making extensive use of FYM /compost to reduce inorganic fertiliser requirements
- Investing in machinery to increase work rates to help timeliness and reduce harvest risk
- Practicing rotational farming

The farm has also installed two 800kw wind turbines to produce electricity for the national grid. The wind turbines operate at approx 34% efficiency and have produced 17.28M KW over the last three years. There is planning permission to erect two further 800KW turbines, which will be completed in 2013.

The business will continue to improve efficiency of inputs and is keen to reduce fuel consumption in tractors further, having already started monitoring fuel consumption. It will continue to be early adopter of technology to improve efficiency.

Water and air quality

The farm has shown an overall reduction in pollutant pressure due to the decrease in livestock numbers and associated input levels. The exception is sediment loss which has increased in line with the switch of land use from set aside and grassland to cultivated arable crops; pesticide loss is static.

The case study farm has undertaken the following measures to protect water quality:

- Unsprayed / unfertilised field margins
- Fencing off cattle from streams with all fields having water troughs

Table 41: Farm M3 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	62.0	53.9	-8.1	-13%
Phosphorus loss (kg/ha)	1.7	1.5	-0.2	-13%
Sediment loss (kg/ha)	351.0	409.6	58.6	17%
Pesticide loss (kg/ha)	0.1	0.1	0.0	14%
Ammonia loss (kg/ha)	24.8	18.2	-6.6	-27%

Biodiversity

Biodiversity stock 4 Change 1

The high biodiversity stock score arises from high level agri-environment scheme activities on hedges, trees, ponds, water margins and unharvested crops. The major changes have been to increase the diversity of non-cropped areas, and reduce areas of drained land, although these have been partially offset by the loss of set-aside. The overall approach is to "*Aim to protect existing biodiversity, with a focus on the less productive land*", with no plans to change. The farmer comments about the impact of biodiversity management on food production: "*Perhaps production has been less but it's marginal*".

Landscape

Landscape stock 3, change 0

The landscape stock score arises from features supported by agri-environment schemes, notably hedgerows, ponds and trees. The farmer has "Tried to maintain the landscape" but has also erected 2 wind turbines, which may be seen as a negative impact. No further changes are foreseen.

Conclusions

This mixed farm has performed well economically and improved in all the headline indicators. Of the more detailed indicators, soil loss has increased as more land has been taken into cultivation. The business has responded to commercial opportunities, including adjusting the enterprise mix and producing renewable energy but also in terms of payment for ecosystem services under agri-environment schemes. The approach is very much land sparing rather than land sharing, but use of technology and attention to environmental risks has allowed the farming enterprises to demonstrate sustainable intensification.

This case study does highlight a limitation of using gross energy as an indicator of food production, namely that substituting livestock enterprises with cropping will register as increased food production, regardless of the level of productivity of the enterprises.

Mixed Farm M4

Summary

This 385ha mixed farm has increased food production. Biodiversity and landscape scores have improved while emissions of ammonia and losses of nitrate have not increased by significant levels. The total carbon footprint per hectare of land has increased, but not significantly. On this basis the farm has demonstrated sustainable intensification.

This farm comprises of an intensive system of cereal and livestock production. The approach is to maximise cereal yields and to finish cattle utilising the grassland. This reflects a commercially responsive approach with technology used to deliver resource efficiency as well as output increases.

The farm has also undertaken environmental work, notably creation of new public access and facilities. This has been funded through agri-environment schemes under a land sparing approach. There has also been investment in energy efficiency and energy generation technologies, which contribute to climate regulation. Whilst, these are to some degree separate from the intensive agricultural operations, they contribute in aggregate to overall sustainability.

Farm performance has improved against three key indicators (see Table 42), notably food production, biodiversity and landscape. Food production, expressed as gross energy per unit area, has increased 20% due to yield increases in both crop and cattle production. Carbon intensity per unit area along with emissions to air and water have increased but not at significant levels.

Table 42: Farm M4 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	69	83	Medium	20%
Carbon footprint	kg CO2equiv/ha	3964	4130	High	4%
Nitrate loss to water	kg/ha	57	60	High	4%
Ammonia loss to air	Kg/ha	14	15	Medium	9%
Biodiversity	Index	3		Medium	1
Landscape	Index	3		Medium	2

* Specific to sector

Overview of the farm and farming system

The farm comprises 345 ha of owned land and 40ha rented land, with 280ha of winter and spring cereals and 100 suckler cows, finishing all offspring. The farm has all owned machinery and contractors are only used for bailing straw and silage.

The farm is run by a family partnership between a semi-retired father and full time son. One full time member of staff is employed in addition to the family labour.

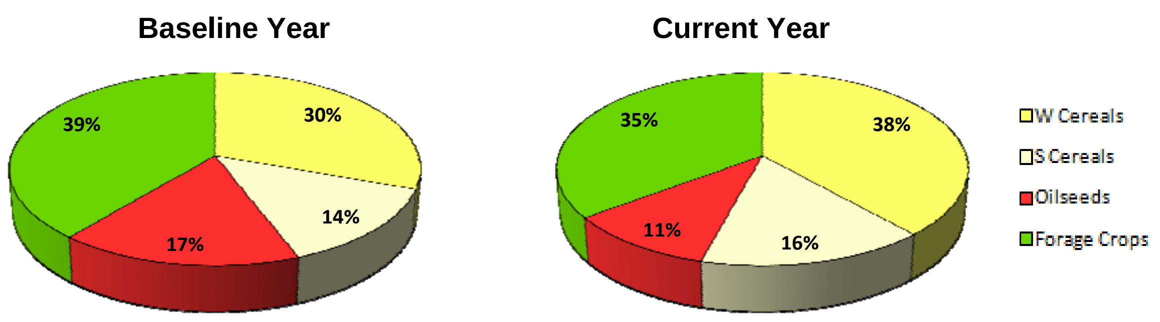

Figure 19: Farm M4 - Changes in cropping from 2005-06 to 2010-11

Approach to sustainable intensification

The farm's approach to sustainable intensification is based on maximising cereal yields and finishing cattle utilising the grassland. The main mechanisms to increase yield and efficiency of input are:

- Soil mapping since 1998;
- Yield mapping on the combine;
- Lime being spread using GPS, with tractors equipped with GPS steering
- Keeping more replacements for cattle in order to increase production and utilise facilities.

In terms of management, the farm is achieving efficiency through:

- Using business planning and tools; and
- Use of consultants for financial and environmental work.

Farm performance

<u>Food production</u>

Absolute food production (expressed in gross energy per unit of land area) in the baseline year is high for this farm type at 69GJ per hectare. This increased by 20% in 2010-11 largely due to increases in crop yields for winter barley (8.7 to 9.4 t/ha), spring barley (7.0 to 7.5 t/ha) and oilseed rape (3.8 to 4.1 t/ha), although the yield for winter wheat dropped slightly (8.7 to 8.2 t/ha) due to poor establishment.

The yield increase in winter barley is due to variety change (now using hybrids) and the increase in yield of spring barley was due to weather conditions. This suggests that the extent of the increase in food production may vary between years.

<u>Climate change mitigation and adaptation</u>

Greenhouse gas emissions from the system have all increased on the baseline figures (see Table 43), an aggregate increase of 4% in CO_2e. This is largely a result of the increase in suckler cows on farm (from 94 to 100) and additional land cropped. The intensity of emissions has reduced by 13%.

Table 43: Farm M4 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	582	620	37	6%
Methane loss CO2e (kg/ha)	625	697	72	12%
Nitrous Oxide loss CO2e (kg/ha)	2,756	2,813	56	2%
Carbon footprint per unit land CO2e (kg/ha)	**3964**	**4130**	**166**	**4%**
Carbon footprint per unit food CO2e (kg/GJ)	**57.5**	**49.9**	**-7.5**	**-13%**

The farm has adopted the following measures to limit impacts on climate change:

- Felling and replanting commercial woodland;
- Creating buffer strips and shelter belts;
- Improving drainage systems;
- Creating wetlands, ponds and water meadows;
- Increasing water storage;
- Improving manure storage;
- Improving irrigation efficiency and use of precision farming;

The farm has also installed a wood burning biomass boiler on the grain drier to reduce the use of oil. This has reduced the cost of production due to lower grain drying cost whilst at the same time minimising the negative impact on climate change by using more renewable energy. The business also plans to expand the use of the biomass boiler to supply heat for the three houses.

Water and air quality

The farm has shown an overall rise in pollutant pressure, with nitrogen-based pollutants and sediment increasing (see Table 3). This is largely due to the increase in livestock numbers and increased crop area. Pesticide losses are effectively unchanged. In aggregate, these increases in pollutants are not significant (all less than 10%).

Additional measures to protect water quality include bunds on fuel tanks and catchments for washing areas, spray residues applied to fields, avoidance of spreading of fertiliser or application of manures to headlands near water. Additionally, water margins are used to protect water quality, collecting and storing water run-off and keeping livestock away from watercourses

Table 44: Farm M4 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	57.4	59.6	2.2	4%
Phosphorus loss (kg/ha)	0.4	0.5	0.0	6%
Sediment loss (kg/ha)	69.2	75.4	6.2	9%
Pesticide loss (kg/ha)	0.1	0.1	0.0	-2%
Ammonia loss (kg/ha)	14.1	15.4	1.3	9%

<u>Biodiversity</u>

Biodiversity stock 3 Change 1

This farm engages with a range of habitat management programmes, funded by agri-environment schemes. These include hedgerow creation and maintenance, pond clearing and arable options. While the area and diversity of non-cropped habitats has increased, more land has been drained and livestock densities have increased.

<u>Landscape</u>

Landscape stock 3, change 2

The landscape stock of hedgerows, meadows, ponds and parkland has been enhanced in terms of both area and condition, while the farm has created a 150-acre public access and fishing lake, with 5 miles of new public access paths. The farm intends to continue to add cultural value to the farm; “We have a view to build more paths … and we are going to restore listed buildings”. The paths will take up some land, impacting on food production.

Conclusions

This intensive mixed farm has achieved improvements in three key categories of ecosystem services: food production, landscape and biodiversity. While there are associated increases in carbon footprint and pollutant pressures these are not significant. As such, the balance between productivity gains and environmental impact is notable. It is not clear how much scope there is to continue this further but the farm demonstrates an innovative approach and further progress is likely to be possible through technology uptake.

The landscape and biodiversity gains reflect a very positive attitude to stewardship of the land with significant investment in infrastructure and protecting important habitats. This has been to a large extent discrete and separate from the farming system as part of a land sparing approach but makes a valuable contribution to overall sustainability. The availability of public funding for these actions is key.

Dairy Farm D1

Summary

This 147ha dairy farm has increased food production through technology uptake and efficiency gains, but GHG emissions and nitrate losses have increased and the biodiversity score has fallen. The intensity of GHG emissions fell but overall, this farm has not demonstrated sustainable intensification.

This specialist grassland farm comprises 147 ha of grassland and forage maize. Of the total area 74 ha is owned, 32 ha is rented on a 5 year FBT, and the remainder is rented on an annual basis. All but 13 ha is improved land and is highly productive based on short term leys and maize silage production. Annual rainfall is high (1500mm per annum) and the farm is situated in a major milk / grass producing area.

Table 45 shows that the farm has increased food production (+14%) but ammonia losses to air have also increased (+36%) as cow numbers have expanded and animals have been housed for longer periods. The business policy is to improve efficiency to drive economic performance without a negative effect on the environment and the farm is currently in an entry level agri-environment scheme. Good levels of profitability are essential to meet the high reinvestment levels required on a modern dairy farm. While overall carbon emissions have increased, the intensity of emissions has reduced per unit of output.

Table 45: Farm D1 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	38	43	Medium	14%
Carbon footprint	kg CO2equiv/ha	14,220	15,796	High	11%
Nitrate loss to water	kg/ha	72	73	High	1%
Ammonia loss to air	Kg/ha	66	91	Medium	36%
Biodiversity	Index	3		High	-1
Landscape	Index	2		Medium	0

* Specific to sector

Overview of the farm and farming system

This specialist dairy farm comprises of 135 ha of grass and 12 ha of maize for silage. The herd consists of approx 260 high yielding Holstein dairy cows and followers. The holding itself is on free draining soils, largely medium textured (90%), situated in a high rainfall area. It is an excellent grass growing location. Milk yields now average just under 10,000 litres per cow (per annum) and considerable attention is given to using best management practice to improve breeding interval, extend cow longevity and lower replacement rates.

The farm is family owned with one of the partners working part time as a dairy consultant which allows access to latest best practice in the industry. The farm employs two herd managers, plus 2 full time and 1 part time members of staff. Cows are milked three times per day. Contractors are employed for all harvesting and slurry applications.

Milk is sold on a non-retailer contract with a standard Farm Assurance based scheme of accreditation.

Approach to sustainable intensification

The approach on this farm is to make sufficient profit to invest in farm infrastructure but many investments will also benefit the environment and cow welfare. These include improved storage of slurry for timely application, better storage of silage to reduce waste and investment in modern and efficient milking equipment, milk storage equipment and water heating facilities. In addition, energy saving measures are being adopted wherever possible, including installation of solar panels.

The farm's philosophy on sustainable intensification is described as follows: *"We are trying to produce a sustainable agricultural model based on margin over fixed costs and finance charges, which gives us the ability to re-invest in infrastructure whilst not having a negative effect on the environment."*

Key mechanisms employed to achieve these aims include:

- Energy efficiency and generation - the farm office has solar panels on the roof and there is energy saving equipment in the milking parlour and dairy;
- Monitoring of performance - including computerised farm records, nutrient management planning, forward business planning and group benchmarking;
- Investment in infrastructure - to allow better use of inputs such as additional slurry store, facilities for recycling water.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) in the baseline year is high for this farm type at 38 GJ per hectare. This has increased by 14% in 2011. There has been an absolute increase in the quantity of milk produced (from 1.5 to 2.5 million litres per annum) and number of cows (160 to 267) over this period due to a policy of expansion.

Cows are also now housed all year and so efficiencies have been made in milk production by improved feeding of both lactating and dry cows. In addition heifer management has been enhanced so that heifers are easier to get back in calf once they enter the dairy herd for the first lactation.

Grassland management has improved via a major reseeding programme over the last 5 years. Leys are now high based on modern swards with high sugar grasses producing substantial yields of high quality silage. A system of zero grazing is possible as the farm location lends itself to this. To accommodate the increase in herd cows and youngstock numbers, the amount of land farmed has increased by approximately 40ha. Stocking rate has therefore increased per unit of land.

Climate change mitigation and adaptation

The business regularly undertakes a carbon foot-print as part of its business practise. The dairy unit achieves a good carbon footprint per litre of milk as recognised by Kite/ EC02 carbon foot-printing tool but performance in terms of kilograms carbon per hectare is less good.

The analysis in this project shows that total GHG emissions increased (Table 46) but emissions of carbon dioxide declined (-13%) due to investment in energy saving equipment such as variable speed vacuum pump, solar panels and energy saving milk cooling equipment. Methane levels per hectare have increased in absolute terms (+22%) due to the increase in cow numbers and there has also been a small increase in nitrous oxide loss

(+4%). Emissions per unit of food production (CO2e per GJ gross energy) fell by 3% between the baseline and latest year.

Table 46: Farm D1 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	1,533	1,327	-205	-13%
Methane loss CO2e (kg/ha)	7,265	8,840	1,575	22%
Nitrous Oxide loss CO2e (kg/ha)	5,422	5,629	207	4%
Carbon footprint per unit land CO2e (kg/ha)	**14,220**	**15,796**	**1,576**	**11%**
Carbon footprint per unit food CO2e (kg/GJ)	**374**	**364**	**-10**	**-3%**

Water and air quality

Overall, nitrate loss has remained static despite the increase in food production. Other pollutants, including phosphorous, sediment and pesticide reduced significantly due to the absence of cattle grazing and improved fertiliser efficiency. However ammonia levels have increased significantly (+36%) due to the increased stocking, the proportion of time cattle spend housed and associated manure spreading. A 'slurry exchange' with a neighbouring farm is reducing the travel time to move slurry and allowing for better timing of applications.

Spraying of the maize crop is kept to a minimal and a crop walker is employed for advice on spraying. Pesticide use on grassland is minimal.

Table 47: Farm D1 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	72.2	73.1	0.9	1%
Phosphorus loss (kg/ha)	1.3	1.0	-0.3	-25%
Sediment loss (kg/ha)	169.0	137.4	-31.6	-19%
Pesticide loss (kg/ha)	0.0	0.0	0.0	-48%
Ammonia loss (kg/ha)	66.4	90.6	24.2	36%

Biodiversity

Biodiversity stock 2 Change -1

The biodiversity stock score arises from the presence of hedgerows, buffer strips and unimproved grassland in an entry-level scheme, while the negative change score comes from increasing livestock density. The farmer states that "*Making the farm more efficient is the priority … however this strategy has a positive impact on our carbon footprint. No other approach to biodiversity however*". This is unlikely to change: in the future the farm will "*leave 50 % of our hedgerows untrimmed each year*" for agri-environment payments.

Landscape

Landscape stock 2 Change 0

The landscape stock score arises from the hedgerows. Nothing has changed since the baseline date. The farmer wants to farm to look good and appear well-farmed and considers the environment *"if it has a financial benefit or is cost neutral*".

Other ecosystem services

As an intensive dairy farm, large amounts of water are used. This is currently sourced free of charge from a local spring so there is little pressure to reduce usage. If this was to be charged for then the efficient use and re-use of water would be considered, for example, roof water capture.

Conclusions

The farm has increased food production over the last 5 years through a programme of expansion of dairy cow numbers, investment in infrastructure and in efficient technology. The farmer/owner is well informed and has access to the latest knowledge on production technology and best practice. This is ultimately driven by commercial returns but many measures also have benefits for cow welfare and for the environment. This is evident in this case as the increase in food production has reduced the intensity of carbon emissions per unit of food produced.

Investment in energy saving equipment and facilities that provide a direct payback will continue. There is a general respect for the environment and the regulations that apply, but limited interest in pursuing environmental objectives *per se*. In many ways this is typical of many progressive dairy units that have specialised and expanded.

Dairy Farm D2

Summary

This 325 ha dairy farm has increased food production significantly over the last 5 years but pollutant pressures from GHG emissions and nitrate losses have *increased*. ***The biodiversity indicator score is unchanged but that for landscape has increased. Overall, this farm has not demonstrated sustainable intensification.***

The dairy farm comprises of 270 hectares of owned and 55 hectares of tenanted land on free draining, medium soils. The farm milks 230 dairy cows, alongside an arable enterprise growing combinable cereals. Forage maize is used for the dairy herd, but all cereals are sold at a premium for malting or milling respectively. Of the total land area, one hectare is allocated to non-farmed habitats and another hectare to permanent set-aside.

The farm has intensified with the aim of maximising the output of milk and cereals within the constraints of available acreage and infrastructure. In light of this the attitude towards biodiversity and the landscape is one where it should not detract from food production but should be managed with the same effort as farm enterprises.

The farm has delivered intensification in food production (+26%) through expansion in milk production and improved crop yields; the landscape score has improved but pollutant impacts have increased (see Table 48. Nitrate loss to water has increased by 9% and ammonia loss to air increased by 29%. The overall carbon footprint has increased by 19% but the intensity of emissions per unit of output has decreased by 9%, illustrating increased efficiency.

Table 48: Farm D2 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	72	91	High	26%
Carbon footprint	kg CO2equiv/ha	6029	7197	High	19%
Nitrate loss to water	Kg/ha	48	52	Medium	9%
Ammonia loss to air	Kg/ha	32	41	Medium	29%
Biodiversity	Index	2		Medium	0
Landscape	Index	3		Medium	1

* Specific to sector

Overview of the farm and farming system

The farm milks 230 cows, each yielding on average 9500 litres per year (with 2.2 million litres sold per year). In the baseline year the herd size was 185 cows and the average yield 8900 litres. The dairy unit is contracted to a major processor for yoghurt; the contract has specific requirements in terms of milk fat, protein and hygiene levels with a bonus for level production (no seasonality). For this reason, the farm calves all year round. In addition to grassland, the farm grows maize and winter oats which are ensiled as forage for the cattle. Winter wheat, winter barley and winter OSR are mainly sold off farm.

The farm is managed by the director and his father who are both full time; there are four full time staff and one part time worker. The quality of staff is important and includes a student from an agricultural university and a part time student from the local agricultural college. Contractors are employed for silage making.

The business invests in innovation and technology and describes the approach as "early adopters but not innovators". They currently have GPS installed in one of their tractors and find that it has had a positive effect with regards to application speed and efficiency. The intention is to have autosteer put into the next new tractor that is purchased. Minimum tillage is being investigated as an alternative to ploughing and may be implemented in future. For the dairy herd, 'Heat Time' is used for the dairy cows in order to detect oestrus; this has made a big step forward and has resulted in a reduction in the calving interval from 440 days to 400 days.

Approach to sustainable intensification

The current aim of the farm is to *"maximise output of milk and cereals with the available acreage and infrastructure"*. This indicates the attitude of the directors of the farm and their emphasis on food production. The longer term aim is to *"improve the infrastructure and grow the business, increase the herd and acquire extra land"*.

The director thinks that they have a sustainable business model, which is based on achieving good technical performance in both the arable and livestock enterprises as well as having reasonable control over costs. This is achieved through annual meetings with the bank manager and the accountant to review the performance of the business. The farm does not have a formal written business plan.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) at 72GJ per hectare for the baseline year is very high for the sector and is boosted by the arable crops. This provides an important context for the 26% increase which was achieved by 2011 and relied on increased cow numbers (+24% to 230), increased milk yields (+7% to 9500 litres per cow) but also by increases in most crop yields (wheat up 10% to 8.9 tonnes per hectare).

Climate change mitigation and adaptation

The farm constantly strives to improve the efficiency of the dairy herd as a means to increase profitability. It is perceived that this will also dilute the GHG emissions per unit of production. Resource efficiency measures such as the installation of a heat recovery system (to utilise the heat generated from the refrigeration unit to heat the water at the dairy) has reduced electricity use on the farm. Further savings have been achieved by installing variable speed motors on the vacuum pumps and a 50kw solar panel system. A borehole has also been installed on the farm to reduce water costs.

The impact of a change in the weather has been apparent through earlier harvests; for example last year the harvest finished 10 days earlier than normal. Other contributing factors include better crop varieties being sown and modern machinery being used, meaning that drilling can occur earlier. Further to this, the farm has been able to grow forage maize for the last 10 years which it wouldn't have been able to do 20 years ago.

Analysis of the farm's carbon footprint shows that total GHG emissions increased by 19% due to intensification in milk production (see Table 49) but emissions per unit of food reduced by 6%. It is thought that the buyer for the farm's milk will impose a requirement to carry out carbon foot printing within the next 5 years. The farm will continue to be an early adopter of new technology to reduce energy usage and GHG emissions whilst also increasing efficiency. Overall it is not thought that the approach taken to limit climate change has negatively impacted upon food production. *"If anything, it has improved food production as efficiency has increased"*.

Table 49: Farm D2 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	528	627	98	19%
Methane loss CO2e (kg/ha)	2,587	3,446	859	33%
Nitrous Oxide loss CO2e (kg/ha)	2,914	3,125	210	7%
Carbon footprint per unit land CO2e (kg/ha)	**6,029**	**7,197**	**1,168**	**19%**
Carbon footprint per unit food CO2e (kg/GJ)	**84**	**79**	**-5**	**-6%**

Water and air quality

The analysis suggests that pollutant pressure has increased (Table 50) over the period due to intensification of milk production. Increased nitrate and ammonia losses (+9% and +29% respectively) relate directly to the increase in cow numbers and associated manures. There is also a small increase in sediment loss associated with additional cultivated land and a marginal increase in phosphorus loss and pesticide losses.

Table 50: Farm D2 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	47.8	52.2	4.5	9%
Phosphorus loss (kg/ha)	0.5	0.5	0.0	2%
Sediment loss (kg/ha)	78.0	79.4	1.3	2%
Pesticide loss (kg/ha)	0.1	0.1	0.0	4%
Ammonia loss (kg/ha)	31.5	40.5	9.0	29%

The farm is in an NVZ and the director has attended CSF meetings and is making efforts to reduce risks that relate to the inputs required on an intensive dairy and arable farm.

In order to limit the impact on water and air quality the following measures have been taken:

- plant and soil nutrient levels are taken into account so that levels of phosphate and potassium can be altered to ensure the amounts applied are the optimum for the crop and field;
- the integrity of slurry stores is maintained and muck is spread on the fields at more appropriate times of the year, partly as a result of legislation as well as the desire to get greater returns from nutrient applications;
- fertiliser and pesticides are spread at more appropriate times of year, in good weather conditions and buffer strips are observed near watercourses;
- sprayer washings are contained as the sprayer is washed out in the field that has already been sprayed
- using precision farming where possible to secure efficiencies in input use and reduce losses to water

<u>Biodiversity</u>

Biodiversity stock: 2 Change: 0

The farm is in an entry-level AES, supporting hedges and buffer strips and also includes some ponds. Both the area of non-cropped habitats and length of hedgerows have increased, but the benefits were offset by the loss of arable options from the agri-environment scheme, new land drainage and increased livestock density. The approach to biodiversity is "*Not really interested. Overall feeling is that land should be farmed properly or not at all*". Future management for biodiversity "*depends on financial incentives*". The farmer does not consider that food production has been affected by biodiversity management: the areas of unproductive land have been "*too small to make a difference*".

<u>Landscape</u>

Landscape stock: 3 Change: 1

The landscape stock consists of ponds, unimproved grassland and hedgerows. Improvements have arisen both from the enhancements to hedgerows and the recent use of agri-environment scheme payments for vernacular buildings. The approach is to "*Maintain as is; no change in last 5 years; last 50 years, maybe*".

<u>Other ecosystem services</u>

The farm does not use irrigation for the arable crops and uses borehole water for the dairy herd. In this way mains water use is kept to a minimum.

Conclusions

The farm has intensified as part of a deliberate aim to be as productive as possible. This has been achieved from a high baseline through increasing dairy cow numbers and milk yield and increasing crop yield. The farm has also used technology and good practice management systems to improve resource efficiency. The philosophy is that nothing should be undertaken on the farm that would compromise the farming system. Thus, while a small area of less productive land is set aside for environmental purposes and there are field edge initiatives under an entry level AES, this is also in large part, a commercial decision.

Dairy Farm D3

Summary

This 650ha specialist dairy farm has increased food production by over 50% between the baseline and latest year in absolute terms, almost entirely through expansion of the land area and herd size. Food production, carbon footprint, ammonia emissions and nitrate losses have all increased but on a per hectare basis, there has been no significant change. Biodiversity and landscape scores are unchanged. Overall, the farm has not demonstrated sustainable intensification.

This dairy unit covers over 650ha across two holdings. The main farm holding is located in an area of medium rainfall, with soils ranging from free draining light sands to deep impermeable clays. The second farm, which was acquired between 2006 and 2011, is at a higher altitude with higher rainfall and heavier soils. All land is down to permanent grassland for both grazing and making silage.

The farm approach is based on growing the business and making enough profit to be able to invest it back into the business. The strong focus on economically sustainable food production has led to the intensification of the grass-based milk production system with a focus on getting as much production from grass as possible, with minimal inputs. In terms of environmental impact, the emphasis is on responsibility for managing losses to water/air and the landscape in a sustainable way without relying on payments from agri-environment schemes.

Table 51 highlights the fact that farm food production per hectare has increased only marginally. This reflects the fact that while cow numbers have increased by 52% from 920 to 1400, land area has increased pro rata while milk yield from the Jersey x herd has remained static at 4500 litres per cow per year. Emissions to air and water have also reduced, but by less than 10%. Scores for landscape and biodiversity are unchanged.

Table 51: Farm D3 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	22	23	Low	5%
Carbon footprint	kg CO2equiv/ha	14003	14159	High	1%
Nitrate loss to water	kg/ha	77	80	High	4%
Ammonia loss to air	Kg/ha	36	36	Medium	1%
Biodiversity	Index	2		Medium	0
Landscape	Index	1		Low	0

* Specific to sector

Overview of the farm and farming system

This farm runs a spring calving, New Zealand intensive system milking 1400 Jersey x Friesian cows. Cows are block-calved in early spring and produce milk from low inputs by fully utilising the grass available. They are housed when the grass and soil is wet, which is highly dependant on the weather. Roughly 15% of the year they are housed in outdoor yards on a bedding-free cubicle system and get 300kg per cow of purchased feed in the parlour. All herd replacements are reared on the farm, and put out to grass; bull calves are reared on grass and sold on as store cattle. Initially Jersey x Friesians were bought in and Jersey x bulls kept to maintain the herd but this has proved difficult and the farm is moving to beef bulls (Aberdeen Angus).

In addition to the director/ farm manager, the farm employs 7 full time staff and 5 additional seasonal staff working part time; all of the groundwork is carried out by contractors throughout the year.

Approach to sustainable intensification

The farm's approach is described as follows: *'we are trying to grow the business thorough a share farming approach, by making as much money as possible off a simple, grass based system with minimum inputs to achieve maximum outputs."*

The main mechanisms which are being used to achieve these aims are:

- A focus on grassland management, ensuring that it is productive and well utilised through careful monitoring.
- Using farm management and business planning tools to ensure that the farm keeps developing. The use of benchmarking and discussion groups helps the business to stay aware of the latest developments in the area and the industry.

There is also an ambition to make use of renewable energy generation; although nothing is in place yet, there are plans for solar and wind turbine sites.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) is low for a UK dairy system but relatively high for a low-input, grass based system, at 22GJ per hectare and reflects a high stocking rate and a higher energy value for Channel Island milk[36]. The increase in absolute output is very much due to an increase in milking cow numbers (and replacements reared) rather than an increase in milk yield per cow.

The increase in cow numbers has meant an increase in the grass requirements and accommodation. For the latter, development of outside winter cubicles with mattresses has been key. There is a gradient off the concrete cubical floor that means the slurry flows straight into the slurry pit. Cows calve in an outside corral and the herd feeds from a 'self service' silage pit.

The amount of manure produced on farm has also increased and this has required investment in new and improved storage facilities for spring/summer application. Inorganic fertiliser use has increased slightly.

Climate change mitigation and adaptation

Total greenhouse gas emissions have changed from the baseline figures on a per hectare basis but only marginally (see Table 52) while emissions per GJ have declined by 4%. There is no change in carbon dioxide emissions, a small reduction in methane emissions (-1%) but a 4% increase in nitrous oxide emissions.

[36] The Dairy Council. The Nutritional Composition of Dairy Products (http://www.milk.co. uk/page.aspx?intPageID=197)

Table 52: Farm D3 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	266	266	0	0%
Methane loss CO2e (kg/ha)	7,441	7,356	-85	-1%
Nitrous Oxide loss CO2e (kg/ha)	6,296	6,537	241	4%
Carbon footprint per unit land CO2e (kg/ha)	**14,003**	**14,159**	**156**	**1%**
Carbon footprint per unit food CO2e (kg/GJ)	**647**	**624**	**-23**	**-4%**

Water and air quality

The farm has shown an overall increase in pollutant pressure but not at significant levels (see Table 53). These changes relate to a more intensive system per unit of land and a higher reliance on inorganic fertilisers.

Table 53: Farm D3 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	77.5	80.4	2.9	4%
Phosphorus loss (kg/ha)	2.7	2.8	0.1	4%
Sediment loss (kg/ha)	108.4	116.1	7.7	7%
Pesticide loss (kg/ha)	0	0	0.0	N/A
Ammonia loss (kg/ha)	35.8	36.3	0.5	1%

The data above does not capture the management protocols that the farm has put in place to protect water quality, namely:

- care in the application of manure and fertilisers near water courses;
- fencing off all water courses to animals
- effective management of water run off
- use of a permanent cow track.

Biodiversity

Biodiversity stock: 2 Change: 0

The biodiversity stock is low, arising purely from the presence of hedgerows and participation in farm assurance. The farm does not participate in agri-environment schemes, though has been "*fencing all water courses and undertaking hedge-laying and management*". This approach to biodiversity is unlikely to change.

Landscape

Landscape stock 1: change 0

The landscape scores come purely from the presence of hedges and their continued management. The farmer states that "*farmers have responsibility to manage the landscape, even without payment*". This is unlikely to change.

Other ecosystem services

For dairy farms water is an important commodity; dairy cows have a high water demand in order to produce milk. The farm is aiming to increase reliance on the borehole and increase rainwater storage through roof harvesting in order to be self sufficient in water.

Conclusions

This farm is intensive but based on a low input system. The main change since the baseline year has been in expanding the business overall. While this is on a significant scale, it is not clear that the intensity of food production, in terms of gross energy per hectare, has increased. Our estimates of change suggest a 5% increase and this is mirrored by small changes in environmental indicators, reflecting proportionate changes in inputs.

What is not evident from the analysis are the increased efforts to manage resource use (manure management, fencing streams and winter housing) and cow welfare (cow tracks and outdoor cubicles). This has been achieved using the same attention to management as is given to milk production and business growth.

Dairy Farm D4

Summary

This 300 ha dairy farm has increased food production by 11% between the baseline and the latest year. However, losses of nitrate and ammonia have increased substantially. Biodiversity and landscape remain unchanged. This farm has not demonstrated sustainable intensification.

This large dairy farm unit of 300ha carries 350 milking cows on an intensive system. The farm approach is based on running a profitable farm enterprise while maintaining a high standard of welfare for the dairy cows. The strategy is based on getting as much from the grass as possible, focusing on a simple system that maximises outputs.

The farm has delivered an increase in food production while maintaining biodiversity and landscape but other environmental impacts have increased (see Table 54). The intensity of food production, expressed as gross energy per unit area, has increased by 11%, but emissions to air and water have also increased: nitrate loss to water has increased by 21% and ammonia loss to air increased by 30%. The overall carbon footprint has also increased due to an increase in dairy cow numbers but at a lesser rate (8%) illustrating increased efficiency improvement for inputs in the food production and lower emissions per unit of output.

Table 54: Farm D4 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	29	33	Medium	11%
Carbon footprint	kg CO2equiv/GJ food	10651	11488	High	8%
Nitrate loss to water	kg/ha	60	72	High	21%
Ammonia loss to air	Kg/ha	47	60	Medium	30%
Biodiversity	index	3		Medium	0
Landscape	index	2		Medium	0

* Specific to sector

Overview of the farm and farming system

The farm comprises 250 ha of owned land and 50ha rented land on short term lets. The farming system is based around an intensive dairy enterprise, with 350 milking cows producing an average annual output of 3.2 million litres. Land use is based around grassland (154ha) and cereals (125ha) with all cereals produced on the farm used to provide feed and bedding for the cows and followers. This creates a degree of self-reliance and limits the farms exposure to volatile markets.

In addition to the milking herd, there are 200 dairy followers and 200 beef heifers and bullocks (with some black and white bulls). The heifer replacements are reared on the farm and other calves not used for replacements are sold mostly as stores, some to a next door neighbour and some through the local market. The cows in the dairy are split into four groups and are fed according to time of lactation and yield. The feeding system is based on grass silage and concentrates. Another change has been the greater intensification of the dairy and an increase in overall cow numbers. A greater proportion of the feed is in the form of concentrates with stock housed for longer periods to allow greater control of their diet.

Changes in livestock numbers between the baseline and latest year are shown in Table 55. The business also operates a commercial timber enterprise on 21 ha of woodland.

Table 55: Farm D4 - Changes in livestock numbers

	Baseline Year	Current Year
Dairy cows	292	350
Dairy followers	183	184
Beef cattle	173	210
Lambs	800	800

In addition to the farm owner, the farm employs four individuals; two in the dairy and another two as general farm workers. Operations including spraying, silage harvesting, slurry spreading, sowing and combining are outsourced to contractors, whist milking and care of livestock, ploughing, fertiliser spreading, some carting in and some mowing are carried out using farm staff and equipment.

Approach to sustainable intensification

The farm's approach is to run a profitable farm enterprise while maintaining a high standard of welfare for the dairy cows. The main mechanisms being used to achieve this are:

- Maintaining existing drainage systems
- Making extensive use of slurry and FYM to reduce inorganic fertiliser requirements
- Working with contractors to increase efficiency and improve timeliness, reduce harvest risk etc
- Practicing rotational farming
- Maximising the health of the livestock, through a number of means:
  - improved genetics
  - use of health plans and regular vet visits
  - good hygiene, in particular the use of automated cluster cleaning systems to reduce the incidence of mastitis

The farm entered an entry level agri-environment scheme in 2006 and has planted some 200m of hedges and fenced off water margins and wetland areas.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) is medium at 29 GJ per hectare in the baseline year. This had increased by 11% in 2010-2011, due largely to a 6% increase in milk yield - from 9,000 to 9,500 litres per cow. This has been achieved through a steady improvement in genetics and nutrition. More concentrate is fed in the diet and more attention is given to developing a proper nutritional balance.

The area of cereals has increased in order to reduce the dependence of the farm on bought in feeds. This has been achieved by acquiring land on a short term basis. Forage maize used to be grown but the crop was not sufficiently reliable. All cereals and straw are used on the farm.

Climate change mitigation and adaptation

Total greenhouse gas emissions from the system have increased by 8% on the baseline figures (see Table 56). This is a result of the increased dairy cow numbers (methane up 9%) and the increase in area of cultivated land (carbon dioxide emissions are up 19%). Total GHG emissions per unit of output (GJ gross energy) are actually down by 3% reflecting improvements in input efficiency.

Table 56: Farm D4 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-011)	Change	% change
Carbon dioxide (CO2e kg/ha)	971	1,158	187	19%
Methane loss CO2e (kg/ha)	5,988	6,527	539	9%
Nitrous Oxide loss CO2e (kg/ha)	3,692	3,803	111	3%
Carbon footprint per unit land CO2e (kg/ha)	**10,651**	**11,488**	**836**	**8%**
Carbon footprint per unit food CO2e (kg/GJ)	**362**	**353**	**-10**	**-3%**

The farm aims to improve efficiency of all inputs and minimise waste, thus reducing GHG emissions and limiting impacts on climate change. For example, the farm has made greater use of contractors who have more modern and efficient equipment. The business has also installed a variable speed milk pump to maximise the efficiently of milk cooling.

The farm owner is considering installing a 45kw biomass boiler to produce hot water for the dairy and heat for the farmhouse and cottages in the near future. A report has been commissioned to investigate the feasibility of the biomass boiler and quantify the electricity and fuel savings that can be achieved.

<u>Water and air quality</u>
The farm has shown an overall rise in pollutant pressure, with nitrogen-based pollutants and sediment increasing (see Table 57).

Table 57: Farm D4 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	59.9	72.3	12.4	21%
Phosphorus loss (kg/ha)	1.0	0.8	-0.2	-16%
Sediment loss (kg/ha)	230.5	258.9	28.4	12%
Pesticide loss (kg/ha)	0.1	0.1	0.0	61%
Ammonia loss (kg/ha)	46.5	60.4	13.8	30%

This is largely due to the increase in livestock numbers and associated input levels but also an increase in cultivated area. Phosphorus losses have decreased slightly but sediment losses are higher than for the other dairy farms. These data represent potential increases in losses and take no account of management practices put in place to manage pollutants.

Relevant actions include:

- fencing off water margins
- slurry injection on all the silage land, to increase utilisation rates and reduce runoff
- Soil sampling and subsequent liming is used to optimise soil pH to improve productivity. Phosphate and potash sampling is used to plan subsequent applications.

Biodiversity

Biodiversity stock: 3 change 0

The farm contains hedges, meadows, buffer strips and ponds, supported and enhanced where appropriate by an entry-level scheme. The farm management has changed, with more non-cropped habitats (with greater habitat diversity) more autumn sowing and reduced crop diversity. The objective is to "*protect existing biodiversity, however, the focus is on the less productive land*", which is unlikely to change. The farmer notes "*very little difference*" to food production: "*any reduction in output on the land under the AES has more than been made up from an increase in production in other areas of the business.*"

Landscape

Landscape stock 2: change 0

The landscape score derives from the hedgerows and ponds, and their continued management. The farmer has "*tried to maintain the landscape*" and "*does not foresee any change*".

Conclusions

This intensive dairy farm has achieved a significant increase food production through expanding and intensifying the dairy and cereals enterprise but in doing so has increased the potential losses of pollutants to water and air. Management practices have been put in place, underpinned by regulation and agri-environment funding to avoid water pollution. While total GHGs have increased, the carbon footprint has reduced in intensity per unit of food production, highlighting efficiency gains. This is typical of many progressive dairy farms that seek efficiency largely for commercial reasons but in doing so reduce their carbon footprint per unit of output.

The limited investment in landscape and biodiversity has been to a large extent discrete and separate from the farming system, and reflects a land sparing approach on a modest scale.

LFA farm L1

Summary

This 160 ha LFA cattle and sheep farm has increased food production between the baseline and latest year, whilst enhancing biodiversity and landscape. In addition it has reduced its carbon footprint and losses of nitrate and ammonia, scoring positively on all environmental indicators. While the increase in food production is at the border of significance, this farm is considered to have demonstrated sustainable intensification.

This farm is a part owned LFA unit of 160ha (77ha is owned and 83ha rented) with access to a further 266ha of common land grazed by the cattle. The 160ha of in-bye land overlies free draining old red sandstone and is subject to a high rainfall (1500 mm per annum). The unit has just over 700 breeding ewes and around 50 suckler cows.

The farm approach is based on running a profitable farm enterprise and being as self sufficient as possible whilst investing in the environment. The business has reduced ewe numbers considerably, changing breed to increase both the physical and financial performance of the flock.

Table 58 shows that the farm has increased food production by raising output per ewe while reducing flock size. This has been achieved while reducing nitrate and ammonia losses and increasing landscape and biodiversity scores. The intensity of food production has increased by 10% while nitrate loss to water decreased by 18%, ammonia loss to air decreased by 20% and the carbon footprint reduced by 14%.

Table 58: Farm L1 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	1.1	1.2	Medium	10%
Carbon footprint	kg CO2equiv/ha	5676	4898	High	-14%
Nitrate loss to water	kg/ha	25	21	Low	-18%
Ammonia loss to air	Kg/ha	16	13	Low	-20%
Biodiversity	Index	5		High	2
Landscape	Index	4		High	2

* Specific to sector

Overview of the farm and farming system

The farm is run by a father and son partnership and other family labour. Contractors are used occasionally for hedge cutting and sometimes to bale wholecrop silage.

The farm reduced total ewe numbers from 1048 to 734 over five years, moving from hill ewes and some crossbreds to a greater emphasis on the crossbreds that are heavier and more prolific, retaining 200 hill ewes. Rearing percentage has increased from 130% to 167% over 5 years. The farm is also able to sell lambs sooner and at heavier weights (up to 19 kg from 18.5 kg previously). The numbers of flock replacements has also reduced from 250 replacements five year ago to 200 replacements in the last year; this has avoided the need to send stock away over winter. Ewes are housed for a short period around lambing time. The farm has reduced the amount of concentrates used for the flock by nearly half by making better use of grass and managing grassland well.

The farm suckler herd has fluctuated considerably, mainly due to TB. There were 52 suckler cows on the farm until TB struck in 2006 and cattle numbers went as low as 37 in 2008 before being built back up to 48 in 2011. Calves are now mostly sold a few months older and are at least 100kg heavier at 500-600 kg. The cattle are housed for a shorter period of time over winter compared to the baseline year.

Changes in livestock numbers between the baseline and latest year are shown in Table 59.

Table 59: Farm L1 - Changes in livestock numbers

	Baseline Year	Current Year
Suckler cows	52	48
Other cattle	108	97
Breeding sheep	1048	734
Replacement sheep	250	200
Lambs	1358	1231

Approach to sustainable intensification

The farm approach is based on running a profitable farm enterprise that is as self sufficient as possible whilst building up capital for the environment through investing in the environment as well as farm infrastructure. The aim is to farm well and ensure the land and environment is enhanced.

In 2011 the farm invested in solar panels as a business diversification project and to produce green energy.

Maintaining the environment at the same time as producing food is important. However, the conservation areas are focused on the less productive areas of the farm leaving the more productive areas for conventional farming. The farm is outstanding for its grassland management and always adheres to good farming practice. A wide range of actions have been undertaken under a high level agri-environment scheme including planting trees, hedgerows and hay meadow reversion.

The main mechanisms which are being used to achieve these aims are:

- Planting trees on unproductive land
- Hay meadow reversion
- Producing renewable energy with solar panels.
- Nutrient applications tailored to where they are needed.
- Livestock diets adjusted according to latest advice
- Utilising on-farm bracken as bedding instead of importing bedding from elsewhere. The used bedding has a useful fertiliser value, given its high potash content.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) was at 1.1GJ/ha in the baseline year. The low absolute level reflects a dependence on livestock outputs (lower gross energy than crops) and less productive land. Gross energy per hectare had increased by 10% by 2011, largely due to an increase in the total weight of lambs and calves sold, despite a reduced sheep flock.

Climate change mitigation and adaptation

Greenhouse gas emissions from the system have decreased from the baseline position in absolute terms (see Table 60). Total emission levels have dropped by 14%, largely due to decreased livestock numbers as outlined above but also due to reduced fertiliser use.

Table 60: Farm L1 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-011)	Change	% change
Carbon dioxide (CO2e kg/ha)	-30	-2	28	-92%
Methane loss CO2e (kg/ha)	2,640	2,127	-513	-19%
Nitrous Oxide loss CO2e (kg/ha)	3,065	2,773	-292	-10%
Carbon footprint per unit land CO2e (kg/ha)	**5,676**	**4,898**	**-778**	**-14%**
Carbon footprint per unit food CO2e (kg/GJ)	**5,002**	**3,933**	**-1,068**	**-21%**

** Carbon dioxide emissions are negative as a result of the area of woodland on the farm.*

There is a recognition that weather patterns have altered and the farm must adapt to these changes. The farmer is aware of disease risk and the spread of disease. All boundaries with neighbours are now double fenced and the flock is closed (apart from purchasing rams that are quarantined) to minimise risk of new disease.

The farm will continue to improve efficiency of inputs and in particular production and is also keen to reduce fuel consumption. They aim to make better use of EID to record more information on animals to compare performance, fields, health treatments etc. to achieve a more productive and efficient flock.

The farm aims to improve efficiency of all inputs and minimise waste, thus reducing GHG emissions and limiting impacts on climate change. Specific measures undertaken to combat climate change include:

- Planting trees
- Making extensive use of FYM
- Does not plough to avoid releasing carbon
- Reduced ewe numbers and improved production per ewe to reduce emission intensity per unit of food produced.

The farmer is currently developing a water turbine to generate and sell renewable electricity.

Water and air quality

The water and air quality on the farm were good in the baseline year and the farm has shown an overall reduction in pollutant pressure, with losses of nitrate, phosphorus, sediment and ammonia all declining (see The case study farm has undertaken the following measures to protect water quality:

- Unfertilised margins
- Fencing off streams from livestock
- Doesn’t feed near rivers and streams
- Collects rubbish, slurry and silage effluent to stop it getting in water course
- Careful assessment of land carrying capacity to avoid overstocking

Table 61). Success can partly be attributed to more efficient grassland management, requiring less nutrients and the use of best practice guidelines. Fertiliser use has fallen as result of using red and white clover in new leys.

The case study farm has undertaken the following measures to protect water quality:

- Unfertilised margins
- Fencing off streams from livestock
- Doesn't feed near rivers and streams
- Collects rubbish, slurry and silage effluent to stop it getting in water course
- Careful assessment of land carrying capacity to avoid overstocking

Table 61: Farm L1 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	25.2	20.8	-4.4	-18%
Phosphorus loss (kg/ha)	0.6	0.6	-0.1	-10%
Sediment loss (kg/ha)	132.9	111.8	-21.1	-16%
Pesticide loss (kg/ha)	0.0	0.0	0.0	N/A
Ammonia loss (kg/ha)	15.6	12.5	-3.1	-20%

Biodiversity

Biodiversity stock: 5 Change 2

This farm has achieved maximum biodiversity scores for both stock and change, and has won conservation awards. The stock includes hedgerows, ponds, rush pasture, orchards, upland meadow and wood pasture as well as three native breeds of sheep and cattle. The whole farm is in a higher level AES, supporting woodland planting and streamside corridors. The whole farming system has changed recently: "*it was more intensive when on headage payments but is more extensive now*". This change has involved more spring sowing, more use of hay, increased crop diversity and reduced livestock density, all of which favour biodiversity.

The farm approach to biodiversity is that it "*depends on initiatives and new technologies*". The farmer comments that management for biodiversity "*has been good to keep in with the general public to show that farmers don't just produce food, they also look after the environment. It justifies public money.* "

Landscape

Landscape stock 4: change 2

Again, both stock and change score very highly, through improvements to a wide range of habitats and features. The approach to landscape is that it is "*Important to keep farm tidy to create a good image to the public.*" No change is foreseen.

Other ecosystem services

The farm is using roof rainwater run off to provide drinking water for livestock.

Conclusions

This hill cattle and sheep farm has responded to a change in farm support policy (decoupling of headage payments) by reducing hill sheep numbers and using a larger, more productive crossbred ewe for the main flock. This has been an economically led response which has increased the weight of lamb produced and contributed to an increase in food production.

There have also been environmental benefits including a reduction in fertiliser and concentrates used. The overall success of the farm in reducing inputs whilst continuing to increase outputs is also reflected in the reduction of the farm's carbon footprint. The change has been managed effectively and supported by very good grassland management and increased use of clovers. The farmer has also actively sought to enhance both biodiversity and landscape character of the farm. Agri-environment schemes have funded tree planting, increased the length and condition of hedgerows, improved the condition of ponds, increased the area and condition of traditional orchards as well as improving the condition of both hay meadows and woodlands by reducing grazing intensity. This strategy incorporates both land sharing and land sparing approaches.

Livestock Farm L2

Summary

This 300ha LFA cattle and sheep farm has increased its food production between the baseline and latest year but not at a significant level. However, modelled losses of nitrate, ammonia and GHG emissions have increased. While there have been improvements to biodiversity and landscape, this farm has not demonstrated sustainable intensification.

This owner occupied hill livestock unit of 300ha is situated in a medium to high rainfall area, on medium, free draining soils. The majority of the land is permanent grassland with an area of combinable crops (approx. 20ha) grown for own use. The aim is to "produce meat as efficiently as possible whilst minimising environmental impacts".

There has been an increase in both the area of crops and livestock numbers on the farm. This has delivered a small increase in food production over the five years (see Table 62). However, pollutant pressures have increased; nitrate loss to water has increased by 49% and ammonia loss by 33%. The overall carbon footprint per unit area has also increased (+17%). However, landscape and biodiversity scores have improved.

Table 62: Farm L2 - Overall sustainability performance

Indicator	Unit	2007	2011	Baseline level*	Change
Food production	GJ /ha	0.4	0.4	Low	5%
Carbon footprint	kg CO2equiv/ha	4520	5294	High	17%
Nitrate loss to water	kg/ha	39	58	High	49%
Ammonia loss to air	Kg/ha	9	11	Medium	33%
Biodiversity	index	2		Medium	1
Landscape	index	2		Medium	1

* Specific to sector

Overview of the farm and farming system

The land is farmed in partnership with the family, largely comprising grazing land for cattle and sheep with a small area of combinable crops. Approximately 60ha of land is rented on a Farm Business Tenancy. The farm employs two full time staff. The holding itself is situated in a medium to high rainfall area on medium, free draining soils.

The suckler herd is spring calving, and housed overwinter for five and a half months on straw bedding. The farm rears its own replacements for both the suckler herd and the sheep flock. Sheep are housed for 8-10 weeks prior to lambing, before being turned out for grazing. Flock numbers have been increasing for the last ten years.

Changes in livestock numbers between the baseline and latest year are shown in Table 63.

Table 63: Farm L2 - Changes in livestock numbers

	Baseline Year	Current Year
Suckler cows	60	84
Other cattle	55	80
Breeding sheep	950	1,575
Replacement sheep	200	200
Lambs	1,200	1,750

Approach to sustainable intensification

The farm's approach is described as follows: "*We are trying to produce meat as efficiently as possible with as little environmental impact as practically possible, whilst financially consolidating the business*".

The main mechanisms which are being used to achieve these aims are:

- Being involved with industry meetings, focus groups and on local farming discussion boards so the farm is able to stay ahead of industry developments
- Recommendations of an independent agronomist are tailored specifically on a field by field basis.

Although there is currently nothing in place as yet, there are plans for wind turbines on farm to generate energy.

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) is relatively low for this farm type at 0.4 GJ/ha in the baseline year, reflecting the area of hill land in the system. Food production increased by 5% in the latest year due to the increase in cattle and sheep numbers; sale weights for both cattle and lambs have largely remained unchanged.

Climate change mitigation and adaptation

The carbon footprint results demonstrate a significant increase of 17% in absolute greenhouse gas emissions and a 12% increase in the intensity of emissions (see Table 64). The higher levels of methane loss reflect the increase in livestock numbers while the increase in N_2O emissions reflects to some degree the additional manure produced by increased livestock numbers. However, the importing of some 1,000 tonnes per annum of poultry manure in 2011 also has a significant impact. While this has helped reduce the reliance on bagged fertilisers, total nitrogen in the system has increased.

The farm is looking to establish 3 large wind turbines and is currently in the process of seeking planning permission. The farm is also looking at solar panels as a means to generate more of its own electricity.

Table 64: Farm L2 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-011)	Change	% change

Carbon dioxide (CO2e kg/ha)	16	22	5	33%
Methane loss CO2e (kg/ha)	1,650	2,027	378	23%
Nitrous Oxide loss CO2e (kg/ha)	2,854	3,245	391	14%
Carbon footprint per unit area CO2e(kg/ha)	**4,520**	**5,294**	**774**	**17%**
Carbon footprint per unit food CO2e (kg/GJ)	**10,606**	**11,886**	**1,280**	**12%**

Water and air quality

The farm has shown an overall increase in pollutant pressure, with all indicators increased from the baseline year (see Table 65).

Table 65: Farm L2 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	39.1	58.2	19.1	49%
Phosphorus loss (kg/ha)	1.0	1.4	0.4	39%
Sediment loss (kg/ha)	81.1	98.6	17.5	22%
Pesticide loss (kg/ha)	0.0	0.0	0.0	N/A
Ammonia loss (kg/ha)	8.5	11.3	2.8	33%

This increase can partly be attributed to the increase in livestock numbers, coupled with the use of poultry manure instead of bagged fertilisers.

In terms of mitigation, there is now increased awareness of the importance of looking after water quality. In particular, this has resulted in increased working distances from water courses and the erection of additional fencing. The farm uses an agronomist for pest management and fertiliser usage; this helps to reduce the amount of pesticides and manage the use of fertilisers and manures.

Biodiversity

Biodiversity stock: 2 Change 1

The stock levels arise from the range of priory habitats: ponds, hedgerows and meadows. The farmer also keeps records of farmland birds. The improvements have arisen from an increase in the area and improved condition of non-cropped habitats. The approach to biodiversity is "*based on policy*", with marginal effects on food production.

Landscape

Landscape stock 2: Change 1

Both stock and change for landscape are derived from the same features and actions as for biodiversity. The farmer did not identify a specific approach to landscape; when asked how the landscape will change in the future, the farmer responded that he wishes to install 3 wind turbines, subject to planning permission.

Other ecosystem services

Animal health is an important consideration for this farm, and it has been using a faecal egg count (FEC) pack for the past 2 years in order to reduce the amount of medicine used on the animals and to ensure that medicines are used only when needed.

Conclusions

This hill livestock farm has a focus on increasing food production with efforts to manage inputs sustainably. However, while there has been a significant increase in stock numbers from the baseline year, animal performance is unchanged and the increased stocking (together with the use of imported poultry manure) has led to greater pressures on water and air quality. Actions have been taken to mitigate impacts but the metrics used in this study may not capture these sufficiently.

The farm has an increased awareness of biodiversity and landscape and has made efforts to improve the existing stock through agri-environment scheme membership.

Livestock Farm L3

Summary

This 329 ha LFA cattle and sheep farm has increased food production between the baseline and latest year. However, there was an increase in the farm's carbon footprint per unit area, and increases in losses of nitrates and ammonia. Landscape quality has improved but overall this farm has not demonstrated sustainable intensification.

This owner occupied hill livestock unit of 283ha comprises improved LFA grassland for cattle and sheep grazing. Another 45ha of land is rented to over-winter stock. The holding is situated in a medium to high rainfall area overlying a mixture of medium to heavy, deep clay and peat soils.

The aim of the business is to make enough profit to be able to invest in the environment as well as into farming infrastructure. The strategy includes land sparing, investment in technology for production, processing and storage, detailed financial monitoring and planning as well as the generation of renewable energy in future.

The farm has delivered significant intensification in food production (+35%) (see Table 66) but other categories of ecosystem services, notably N losses to water and air, have increased by 15% and 39% respectively. The overall carbon footprint has increased by 13% but the intensity of carbon per unit of production has reduced by 16%. Landscape has improved whilst the biodiversity score has remained static.

Table 66: Farm L3 - Overall sustainability performance

Indicator	Unit	2007	2011	Baseline level*	Change
Food production	GJ /ha	0.3	0.5	Low	35%
Carbon footprint	kg CO2equiv/ha	3936	4460	High	13%
Nitrate loss to water	kg/ha	14	16	High	15%
Ammonia loss to air	Kg/ha	9	12	Medium	39%
Biodiversity	index	2	2	Medium	0
Landscape	index	1	0	Low	1

* Specific to sector

Overview of the farm and farming system

The farm is an intensive LFA livestock unit where all the output is finished on farm and sold directly to processors. The farm comprises two distinct areas: the first is on the farmstead with a combination of gently sloped fields and steeper hills around the farmstead; the second is hill grazing land that has been agriculturally improved.

In addition to the family partners there is one full time apprentice and two part time workers on the farm. A small amount of the fieldwork is done by contractors who have specialist equipment for the job.

Texel lambs are finished off grass and taken directly to slaughter before being sold via a livestock marketing group to a premium retailer. The farm sells 1.7 lambs per ewe, which receive premiums for weight and conformation. Beef animals (Charolais, Simmental and Saler) are sold as store bulls or as finished cattle on a retailer contract; the farm is also a member of the retailer's national suckler strategy group.

Changes in livestock numbers between the baseline and latest year are shown in Table 67.

Table 67: Farm L3 - Changes in livestock numbers

	Baseline Year	Current Year
Suckler cows	85	105
Other cattle	180	200
Breeding sheep	1,100	1,300
Replacement sheep	200	250
Lambs	1,800	2,200

Approach to sustainable intensification

The farm's approach is described as follows: 'We are trying to produce the best quality meat from a grass-based system'.

- The main mechanisms used to achieve these aims are:
- Making use of genetics to ensure access to the most efficient breeds for the farming system. For example, the farm has changed from Beltex sheep to Texel in order to improve lamb weights and conformation.
- Management tools, including external advice for farm and enterprise management and environmental issues. IT and other technology are used as part of this, including EID for the sheep flock.
- Membership of an agri-environment scheme which helps to support the cost of staying within environmental constraints
- There are plans to invest in a small wind-farm to provide electricity for the farm.

Farm performance

Food production

While this farm practices a fairly intensive system, absolute food production (expressed in gross energy per unit of land area) at 0.3GJ/ha in the baseline year is low for the farm type; this reflects the area of hill land in the system. This had increased by 35% in 2011, mainly due to an increase in breeding livestock numbers and associated youngstock.

Climate change mitigation and adaptation

The increase in GHG emissions can be attributed to the increase in livestock numbers and associated volume of manure and straw over the period. Inorganic fertiliser use has fallen, however, due to the use of slurry injection. The housing period for stock has not changed.

Table 68 shows that overall GHG emissions per ha have increased by 13% but fell 16% per unit of food produced.

Table 68: Farm L3 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-011)	Change	% change
Carbon dioxide (CO_2e kg/ha)	no data	no data		
Methane loss CO_2e (kg/ha)	1,465	1,803	339	23%
Nitrous Oxide loss CO_2e (kg/ha)	2,471	2,657	186	8%
Carbon footprint per unit area CO_2e(kg/ha)	**3,936**	**4,460**	**524**	**13%**
Carbon footprint per unit food CO_2e (kg/GJ)	**11,467**	**9,598**	**-1,869**	**-16%**

The farmer is looking at the use of renewable energy on the farm and is going through the planning stage for a small wind turbine for house/ farm use.

Water and air quality

The farm has exhibited an overall increase in pollutant pressure, with nitrate, ammonia and phosphorus losses all increasing; these increases can be attributed to the overall increase in the livestock numbers kept on the farm. Sediment and pesticide losses remain unchanged.

Table 69: Farm L3 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	13.9	16.0	2.1	15%
Phosphorus loss (kg/ha)	0.4	0.4	0.0	9%
Sediment loss (kg/ha)	108.4	108.4	0.0	0%
Pesticide loss (kg/ha)	0.0	0.0	0.0	N/A
Ammonia loss (kg/ha)	8.9	12.4	3.5	39%

The farmer is very aware of the need to limit the impacts of farming on water quality including the need to observe regulations on avoidance of spreading fertilisers, slurry and FYM within a 10m radius of any watercourses. The farm uses a farm computer package through farm advice that helps with a range of business areas from soil sampling to business plans.

Biodiversity

Biodiversity stock 2: Change 0

The landscape stock score arose because of participation in agri-environment schemes, though the impact on landscape and habitat features is restricted to the hedgerow network and its improvement. There has been a further change, in that up to 2007, the emphasis was on "*reseeding / improving hill ground. Now the emphasis is on maintaining improved land, to complement with environmental schemes that suit best*". When asked about impacts of biodiversity management, the response was that "*no land was taken out of production*".

Landscape

Landscape stock 1: change 1

The landscape stock and change arises from improvements to the hedgerows; the farmer also maintains stone walls. These actions have minimal impact on food production.

Other ecosystem services

One of the main aims of the farmer is to reduce the use of medicines by adopting a preventative approach where ever possible.

Conclusions

This hill farm has intensified as far as it can in terms of breeding livestock numbers with all progeny finished on farm and sold under premium contracts. Food production has increased significantly and while the intensity of the farm's carbon footprint has increased on a per hectare basis, it has reduced per unit of food production. More efficient use of inputs has resulted in a reduction in the use of inorganic fertilisers but the increase in livestock numbers has outweighed these savings and the overall pressures on both water and air have increased. This is a direct consequence of the intensification strategy adopted. Improvements to landscape and biodiversity have been made through participation in agri-environment schemes.

Livestock Farm L4

Summary

This 508ha LFA cattle and sheep farm has seen little change over the study period, with a non-significant reduction in food production and in associated pollutant pressures. Biodiversity and landscape change has also been minimal, albeit from a high base. Overall, this farm has not demonstrated sustainable intensification.

This LFA farm unit comprises 508ha of land of which 50 ha is not farmed (woodland, wetland etc.). The business approach is based on making optimum use of all land on the farm, whether for livestock/crop production or environmental management schemes. The farm has many natural habitats and it is often more economic to receive payments for managing these than to keep them in food production.

There have been only slight changes in performance since the baseline position. Food production has declined by 3%, due to the combined effects of reducing the numbers of cattle and increasing the level of sheep production. Whilst all environmental indicators have improved marginally (see Table 70) none of these changes is greater than 5 %. There have been very slight enhancements to biodiversity and landscape but again not significant.

Table 70: Farm L4 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	2.6	2.5	High	-3%
Carbon footprint	kg CO2equiv/ha	2519	2500	Low	-1%
Nitrate loss to water	kg/ha	26	25	High	-2%
Ammonia loss to air	Kg/ha	11	11	Medium	-4%
Biodiversity	Index	3		Medium	0
Landscape	Index	3		Medium	0

* Specific to sector

Overview of the farm and farming system

This LFA farm comprises 508 ha of owned land, of which 50ha of is in non-farmed habitats. Over the winter/spring months livestock use inbye land to enable close monitoring during lambing/calving and finishing stock are housed. During the summer months, the farm switches to a high reliance on grazing. It aims to finish all stock in the top end brackets of classification through buying in good quality replacements for both cows and sheep and buying the best bulls and rams that it can afford.

Changes in livestock numbers between the baseline and latest year are shown in Table 71.

Table 71: Farm L4 - Changes in livestock numbers

	Baseline Year	Current Year
Suckler cows	223	203
Other cattle	208	201
Breeding sheep	778	820
Replacement sheep	250	300
Lambs	1,300	1,800

There are around 30ha of spring barley with the majority of crop output used on the farm as animal feed and some sold as high N malting barley (roughly 60t each year).

In addition to the farm manager and family labour, the farm employs one full time employee. All the grassland operations are carried out in-house using a comprehensive range of machinery and equipment. For arable operations, all the winter/spring ploughing is carried out in-house and contractors are utilised from this point onward to grow and care for the crops through to harvest.

Approach to sustainable intensification

The farm's approach is based around selling quality products (calves/lambs) at top end of the market based on high health status, while maintaining and preserving the environment to a high standard. The main mechanisms which are being used to achieve this are:

- Actively planting hedges and trees
- Managing wet areas and other habitats for birds
- Working with contractors to increase efficiency and improve timeliness, reduce harvest risk etc
- Maximising the health of the livestock

Farm performance

Food production

Absolute food production (expressed in gross energy per unit of land area) is high for this farm type at 3.7GJ per hectare in the baseline year, boosted by the sales of a small volume of cereals. This reduced 4% by 2011, largely driven by reduction in the scale of the suckler herd, and was a response to a bad spring in 2010 which resulted in less silage, high straw prices and fewer cows being replaced. The decrease in cattle was offset to some degree by an increase in sheep numbers.

Climate change mitigation and adaptation

Greenhouse gas emissions per ha have decreased marginally (-1%) from the baseline position while the intensity of emissions has increased (+2%) (see Table 72). This would appear to have resulted from the aggregate effect of a decrease in cattle numbers and an increase in sheep numbers, and as such reflects a year on year variation rather than real changes in trend.

Table 72: Farm L4 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO_2e kg/ha)	-1,046	-1,046	0	0%
Methane loss CO_2e (kg/ha)	1,468	1,470	2	0%
Nitrous Oxide loss CO_2e (kg/ha)	2,098	2,076	-22	-1%
Carbon footprint per unit area CO_2e(kg/ha)	**2,519**	**2,500**	**-20**	**-1%**
Carbon footprint per unit food CO_2e (kg/GJ)	**968**	**991**	**23**	**2%**

The farm has had 2 turbines newly installed (not yet commissioned) as part of a strategy to reduce electricity consumption.

Water and air quality

The farm has shown an overall reduction in pollutant pressure, with the exception of the rate of sediment loss which has increased slightly (see Table 73). These changes are not significant and would appear to be due to changes in cropping and stocking.

Table 73: Farm L4 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	25.6	25.0	-0.6	-2%
Phosphorus loss (kg/ha)	0.4	0.4	0.0	-2%
Sediment loss (kg/ha)	82.5	83.7	1.2	1%
Pesticide loss (kg/ha)	0.0	0.0	0.0	N/A
Ammonia loss (kg/ha)	11.0	10.6	-0.4	-4%

The case study farm has dedicated stock watering points which aim to address diffuse pollution issues and bank erosion.

Biodiversity

Biodiversity stock: 3 Change: 0

The biodiversity stock comprises hedges, woodland, grass buffer strips, hay meadows and arable options, supported by a higher level agri-environment scheme. Few changes have taken place over the study period because much the management was already in place at the baseline date. The farmer is "*not just doing this because of the financial incentive, 8ha of woodland planting in 2006*" and is "*happy with the results with noted increases in some indicator species; the management of these habitats complement the farm management system*". Looking ahead, "*Woodland planting and other landscape features like hedgerows are at their maximum but would like to continue to manage wet areas and other habitats for birds*." Management for biodiversity is seen as a win/win; food production has "*improved as a result of the shelter aspect created by woodland and hedgerows*".

Landscape

Landscape stock 3 Change 0

The landscape stock arises from the diversity of features noted for biodiversity. The farmer *"enjoys the diversity hedges and woodland bring";* no major changes are anticipated, other than trimming and laying the new hedges as they become established. "*Loss of area to woodland has made no impact (on food production) as (the farm is) so extensive*."

Conclusions

This LFA farm has an established stock of environmental features which are largely discrete from food production but environmental change indicators are largely static over the period of this study. While cattle numbers may have been impacted in 2011 to some degree by seasonal issues, it is not thought that the farm has intensified significantly. Indeed the farmer's philosophy is about a balance between food and environmental outputs using a land sparing approach and the focus is on adding value rather than increasing the quantity of the agricultural outputs.

LFA Farm L5

Summary

Due to organic conversion which commenced in 2009 and the acquisition of extra grazing land in 2010, this 650ha farm has exhibited a reduction in food production on a per hectare basis between the baseline and latest year. Entry into further land stewardship schemes has held back productivity by effectively "capping" livestock numbers below that which the farmer feels could be easily maintained on the land. However, all environmental measures have improved, with substantial reductions in the loss of nitrate, ammonia and GHGs, and substantial improvements in landscape and biodiversity. The farm has not demonstrated sustainable intensification and is actively extensifying under the new policy.

This LFA cattle and sheep farm comprises 60ha of moorland and in-bye with a small area (14 ha in 2011) of spring cereals and 60ha of red clover. The land is free draining on light sandy soils. The unit has 150 spring calving suckler cows, with a beef finishing enterprise and 1500 breeding hill ewes.

The initial farm approach was to maximise all yields whilst minimising the input within an organic system. To enable the efficiencies to be implemented a second grassland farm was purchased in 2010. All winter feed is grown on farm and the aim was to expand both sheep and cattle enterprises in line with the forage availability as the change to organics bedded in. However, a recent review has highlighted that it is more economic to utilise environmental schemes than increase stock numbers. Adding more land into agri-environment schemes has effectively capped the number of cattle and sheep which can be grazed, which will place limits on food production. Whilst the farmer still believes it is possible to increase stock numbers further, reducing livestock numbers is optimising farm profit.

The intensity of food production expressed in gross energy per unit of land area has decreased by 18% while the performance in terms of the other ecosystem services has improved (see Table 74). There has been a reduction in N losses by 23%, and ammonia losses have declined by 43%, largely reflecting the extensification of stocking rate. Biodiversity and landscape scores have increased.

Table 74: Farm L5 - Overall sustainability performance

Indicator	Unit	2006	2011	Baseline level*	Change
Food production	GJ /ha	1.3	1.1	Medium	-18%
Carbon footprint	kg CO2equiv/ha	4037	3439	Medium	-15%
Nitrate loss to water	kg/ha	22	17	Medium	-23%
Ammonia loss to air	Kg/ha	10	5	Medium	-43%
Biodiversity	Index	3		High	2
Landscape	Index	3		High	1

* Specific to sector

Overview of the farm and farming system

The farm is run by the farmer, his father and one shepherd, using casual labour (1344 hrs per annum) to help with lambing. Contractors are used for spreading manure, drilling and combining oats, ploughing, drying corn, cutting the grass crop and rowing it up.

In 2009 the farm became fully organic and has a low stocking density, due to the acquisition of a further 210 ha of grassland. The cattle are mainly native breeds such as Aberdeen

Angus and Hereford that are able to utilise and finish on grass and forage more easily. The 1,500 sheep are all native breeds with the majority being Swaledale, Suffolk, Hampshire Down, Romney and Blackface. Tups are Blue Faced Leicester to produce the Mule progeny, Suffolk for fat lambs and Swaledale for purebred replacements. It was planned to increase the sheep numbers to 2000 productive ewes but a recent change in the farm's policy has meant greater use of higher level agri-environment schemes, which has effectively capped sheep number at 1500. The farm is also looking into purchasing Lleyn sheep for their prolificacy and smaller size; this may allow the farm to increase flock numbers within the constraints of the AES agreement.

Cattle are housed from October until March and calves are finished on farm, fed on conserved forage crops or grass and sold into premium contracts at 21 months of age at approximately 550kg liveweight. The ewes lamb outdoors and lambs are finished on farm and are sold on a premium contract at around 5 months of age and 20kg liveweight. Some 300 replacement females are kept on farm each year to increase the size and productivity of the flock.

Changes in livestock numbers between the baseline and latest year are shown in Table 75.

Table 75: Farm L5 - Changes in livestock numbers

	Baseline Year	Current Year
Suckler cows	108	135
Other cattle	210	271
Breeding sheep	1184	1400
Replacement sheep	300	400
Lambs	1600	2200

The arable rotation has changed from the baseline year in which a total of 42 ha were sown with winter barley, spring barley and beans for straw and animal feed. The arable area fell to only 28 ha in 2011, based on spring oats and wholecrop oats followed by clover or lucerne for the following 3 years. The latter is seen as an alternative protein source for the cattle to allow all animals to be finished.

Soil fertility and structure is maintained by using farmyard manure at 25t/ha using a discharge spreader. A proportion of the manure is covered in situ until needed in July for spreading on the silage aftermath. A further 600t is heaped until needed on either pasture or arable land. In 2011 a more targeted fertiliser plan was constructed in order to increase grass yields. This resulted in extra turkey manure being purchased to cover the shortfall of fertiliser needed.

So far the new system appears to be successful and the farmer is happy with the profitability of the farm since making the decision to convert to organic.

The aim of increasing productivity whilst enhancing and adding something back the environment is important to the farmer. The whole farm is organic and as such is farmed sensitively under strict guidelines where no inorganic nitrogen is used on the land and no chemicals and sprays are used. Agri-environment options are used on specific areas of the farm. The farm has not taken up any habitat creation actions; instead the focus is on managing existing areas such as restricted grazing, heather regeneration and managing trees and woodlands to a high standard.

Approach to sustainable intensification

The farm's approach is based on increasing economic output through enhancing the quality of production and reducing inputs whilst ensuring the environment is well maintained so they can continue to farm into the future. To achieve this, the main strategies are:

- Uptake of organic farming methods
- Growing alternative proteins sources for livestock
- Using livestock with increased genetic potential (EBVs)
- Using smaller native breeds that can utilise moorland grazing
- Efficient and precise use of manures and better storage facilities
- Making use of specialist advice in relation to livestock, nutrition and agronomy
- Managing water resources via an irrigation pond and looking to install a rainwater harvesting system in near future
- Producing renewable energy on farm through a wind turbine and planning for another more wind turbine to be erected in 2012
- Participation in agri-environmental scheme options on specific areas of land
- Managing price and disease risks by using own crop outputs as livestock feeds

Farm performance

<u>Food production</u>

Absolute food production at 1.3 GJ/ha was moderate in the baseline year for this farm type; this reduced 18% by 2011 due to an increase in the farm area which is not compensated for by increased livestock numbers.

<u>Climate change mitigation and adaptation</u>

Greenhouse gas emissions from the system have all decreased from the baseline position; total emission levels have dropped by 15% (see Table 76). The reduction is largely a result of the decreased livestock numbers per hectare; emissions per unit of food production increased by 4%. Carbon dioxide emissions increased by 30% over the period.

Table 76: Farm L5 - Greenhouse gas emissions per unit area and per unit food production

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Carbon dioxide (CO2e kg/ha)	46	60	14	30%
Methane loss CO2e (kg/ha)	1,371	1,191	-180	-13%
Nitrous Oxide loss CO2e (kg/ha)	2,620	2,189	-432	-16%
Carbon footprint per unit area CO2e(kg/ha)	**4,037**	**3,439**	**-598**	**-15%**
Carbon footprint per unit food CO2e (kg/GJ)	**3,042**	**3,165**	**123**	**4%**

The farm has recently changed two old tractors for one new tractor which has had a dramatic effect on fuel bills; reducing them by approximately one third.

Specific measures undertaken to combat climate change include:

- Finish livestock on farm more quickly
- Increased food conversion ratios of livestock

- Maximise output from breeding animals
- No compound feed bought in
- Making extensive and precise use of FYM
- Minimal tilling where appropriate
- No inorganic fertiliser and chemicals
- Maintaining streams and wetlands
- Carbon sequestration where possible
- New fuel efficient tractor

The farm has just erected a wind turbine that will yield approximately 52,000kW/yr which will all be exported to the national grid due to the turbines location. A second will be erected later in 2012 It is hoped the turbine will increase the farm's profitability further.

Water and air quality

The farm has shown an overall reduction in pollutant pressure, again due to the decrease in livestock numbers per hectare and associated input levels. The exception is the rate of phosphorous loss which has increased due to the use of turkey manure on the land.

The farm has undertaken the following measures to protect water quality:

- No spraying or use of inorganic fertiliser on farm land
- 6 meter margins (adjacent to watercourses)
- Spreading manure at optimal times of the year to maximise uptake and minimise losses
- Ploughing across slope to reduce extent of water run off

Table 77: Farm L5 - Losses to water and air (excluding GHGs)

	Baseline Year (2005-2006)	Latest Year (2010-2011)	Change	% change
Nitrate loss (kg/ha)	22.2	17.1	-5.2	-23%
Phosphorus loss (kg/ha)	0.5	0.5	0.1	18%
Sediment loss (kg/ha)	143.7	119.2	-24.4	-17%
Pesticide loss (kg/ha)	0.0	0.0	0.0	N/A
Ammonia loss (kg/ha)	9.5	5.4	-4.1	-43%

Biodiversity

Biodiversity stock: 3[37] Change 2

The farm has put in place a wide range of management actions likely to benefit biodiversity. The farm already included rush pasture, wood pasture, hedgerows and upland hay meadows. Some of these are beneficial to wildlife, including increased area and diversity of

[37] Probably an underestimate, we lack data on agri-environment schemes – isn't this true of all case studies? And anyway, don't you usually have more info on stock where farms are in AES?

non-cropped habitats, spring-sown crops and reduced livestock density. Although this is an organic farm, the approach is still land sparing; "*We keep productive fields out of schemes as we have to be productive – on others we use as many schemes as possible – we look at the value of the scheme and decide which would be best suited for the land*." More changes are expected, with wild flower margins and bird cover crops planned." The farm has good biodiversity records, and there is a game shoot on the land.

Landscape

Landscape stock: 3 Change 1

The landscape stock arises from the range of features noted under biodiversity. The approach to landscape is to "*put hedgerows and hedgerow trees back in to the landscape*". These changes should improve food production: "*Shelter for lambing: the field should grow more grass due to sheltering effect from winds*."

Other ecosystem services

The farm will continue to improve efficiency of inputs and is keen to adopt new technologies such as rainwater harvesting techniques to reduce dependence on mains water supplies, reduce costs and actively manage risks on farm.

Conclusions

The analysis for this LFA case study farm is dominated by the combined effect of an expansion of the land area and organic conversion between the baseline and latest year. The short term impact has been a reduction in food production and environmental pressures per unit of land. The initial ambition to push hard for higher yields and productivity may have seen a recovery food output but an economically-led decision to commit further to agri-environment schemes means that livestock numbers are now capped. The farm is keen to reduce its environmental impact further whilst increasing profitability and is undertaking a range of actions to deliver this.

Biodiversity increases have been delivered through sympathetic stewardship and an understanding of the need to maintain flora, habitats and non-productive areas through using the support available under agri-environment schemes. The farmer is motivated by optimising yield but not at the cost to the environment and believes that the farm will be more profitable and therefore sustainable if the land and environment are managed together. The approach is both land sparing and land sharing.

Appendix 5: Focus Group write ups

Arable sector

A total of eleven farmers were consulted with across two events – a focus group event in Yorkshire and a research open day in the West Midlands. The consultees covered a broad spectrum of arable farmers, with some having large, very intensive/ high-tech units on grade 1 land, and others with smaller farms with mixed cropping and/or agri-environment schemes.

Eight of the eleven farmers demonstrated good background knowledge of the concept of SI and were able to communicate definitions covering its key aspects. The remaining three farmers were unaware of the term and its meaning. Common elements of the definitions included: *"Increased production; reduction of inputs whilst maintaining outputs; management of or reduction of harm to the environment."* Other factors included: "*maintaining these changes over the long term; increasing quality as well as total yield; and increasing yield without additional economic costs."*

SI Strategies

Seven of the eleven respondents asserted that they already practiced SI. The strategies employed are summarised in Table 78.

Table 78: SI Strategies adopted by arable focus group farms

Strategy	Yes	No	In Future	Comments
Land Sparing - set aside land for environmental purposes	8	1		YES responses: ELS, buffer strips; wild bird covers; unprofitable areas taken out of production. NO response: land too expensive to take out of production (Two respondents left this answer blank)
Use of latest / most efficient technologies - equipment - plant genetics	10			YES responses: GPS (8); other precision farming – yield mapping (1); low drift nozzles (1); would use GM if available (2) (One respondent left this answer blank)
On farm renewable energy generation	3	2	6	Yes responses: solar (1); biomass (1); part of larger scheme (1)
Business management tools / benchmarking / strategic planning	4	7		YES responses: Specific mention of budgeting strategies NO responses: 'would like to but others are reluctant; keep an eye on it but don't really benchmark; benchmarking is too general
Reduction of inputs whilst maintaining outputs	11			Gate Keeper / fertiliser planning (3); Variable rate (3) GPS (1) NVZs (1); try to do this year on year, but doesn't always work (3)
Reduced cultivations / zero tillage	9	2		YES responses: Min till (8); No-till (1); NO responses: 'Have to plough as soil slumps (1)
Implementation of agri-environment schemes	8	2	1	YES responses: all 8 are in ELS ; CSF (1); HLS (1); addition of hedgerows/ shelter belts (2) NO responses: not economically viable or practically achievable; have implemented some good voluntary measures

Business Drivers

Profit was considered by all respondents as the primary driver. Additional drivers are set out in Table 79.

Table 79: Business drivers cited by arable focus group farms

Economic	▪ Input costs (dictated by the price of crude oil) ▪ Business expansion (both in terms of size and economic growth ▪ Re-investing into the business (infrastructure and technology)
Environmental	▪ Coping with weather extremes / climate change ▪ Aesthetics ▪ Sustainability ▪ Carbon footprinting
Social/ political	▪ Legislation ▪ Aesthetics ▪ Succession- leaving a profitable and workable business for future generations ▪ Lifestyle - personal health / wellbeing / enjoyment of work

EU and UK Policy and Legislation

The most discussed topics were the Single Payment Scheme (SPS), the Rural Development Programme (RDP) and agri-environment schemes. With reference to SPS, it was felt that, in general terms, it is helpful and *(as the whole of the agricultural industry is currently reliant on it) it would be very difficult to farm without it (if suddenly removed).* However, when considered in relation to SI, it was felt that it does very little to encourage this approach: *subsidies create a false economy; any business model that relies on government subsidies is not sustainable. Single Farm Payment rewards scale and risk-averse attitudes; it props up the less efficient farmers.*

Agri-environment schemes were generally viewed more favourably, but the most intensive arable farmers, farming on grade 1 land, felt that they were largely excluded from such schemes and asserted that: *policies should focus on supporting the right crop in the right place and having the right environmental stewardship scheme in the right place. There needs to be a tiered / varied approach depending on farm sector / intensity / area etc. Policymakers tend to think that one size fits all. But actually depending on the grade of your land, subsidies have different value and appeal to farmers. We need a 'high end' stewardship model for high intensity, high land value areas.*

There was strong consensus on the need for increased dialogue between farmers and policy makers and increased research and development (for SI): *Regulations need to be justified more to the recipient. They need to be more evidence based / the evidence needs to be better communicated to farmers. Policymakers need to be more grounded and have a working knowledge of farming*. This point was illustrated with a specific example, whereby a consultee had hosted a visit from policymakers: *they had no knowledge of arable systems, epitomised by asking 'why don't you just grow two crops of wheat a year?'*

Dairy Summary

Seven dairy farmers attended the dairy focus group meeting in North Wales, ranging in age from their mid twenties to over sixty. The size and scale of dairy farms varied from a unit of forty cows, to a more intensive unit of 225 Holsteins. There was abroad representation of alternative approaches including the use of non-Holstein breeds and New Zealand style, forage based production.

At the start of the workshop, approximately half of the group stated that they had little or no previous experience of the term SI; the other half proposed the following definitions:

- Expanding the herd on the same farm
- To maximise output from the land, in a profitable manner, that has long term stability
- To increase cow / stock numbers and sustain the same amount of land; can also mean being more efficient.

However, further discussion around the concept led to a total of five participants subsequently thinking that they were in fact practicing SI on their farms.

SI Strategies

Table 80 shows that the most popular SI strategies were those which related directly to cost efficiency and/or increased profitability, largely through the use of new technologies.

Table 80: SI Strategies adopted by dairy focus group farms

Strategy	Yes	No	In Future	Comments
Land Sparing - set aside land for environmental purposes	2	4	1	YES responses: Implementation through Glastir and Tir Cynnal
Use of latest / most efficient technologies: - equipment; - genetics	6	1		YES responses: breed genetics; cow tracks; better seeds; cattle breeding (smaller, hardier cow); cow tracks; high sugar grasses, use of sexed semen; grassland management (including grass measurement); computerised ID for feeding cows; variable rate fertiliser spreading
On-farm renewable energy generation		5	2	NO responses: cost of wind / solar is prohibitive; not enough land for Miscanthus
Use of business management tools and benchmarking / strategic planning	7			YES responses: use of benchmarking, target setting, discussion groups and consultants
Reduction of inputs whilst maintaining outputs	7			YES responses: Soil testing every two years; fertiliser planning
Reduced cultivations / zero tillage		5	1	YES responses: Plans to direct drill grassland in future (One consultee left this answer blank)
Implementation of agri-environment schemes	4		2	YES responses: Glastir and Tir Cynnal

Business Drivers

As with the other groups, profitability was the primary business driver amongst the dairy farmers. Lifestyle and family related drivers were also mentioned by the majority of the group. Whilst some drivers have been categorised as environmental, they primarily relate to increased cost efficiency rather than an environmental focus *per se*.

Additional drivers are set out in Table 81.

Table 81: Business drivers cited by dairy focus group farms

Economic	▪ Increase total output and efficiency ▪ Increase profitability ▪ Improve livestock health and quality
Environmental	▪ Maximise food production whilst maintaining landscape quality ▪ Reduce external inputs ▪ To move to a home grown forage based system
Social/ political	▪ To provide income for my family ▪ To maintain and develop the business for future generations

EU and UK Policy and Legislation

Initially, broad support was voiced for the Single Payment Scheme as an essential element of income: *we wouldn't be farming at all without it*. However the debate quickly opened out to include more critical views, particularly in relation to SI: *it doesn't encourage you to intensify; it promotes inefficiency; it pushes rent prices up; it encourages supermarkets to keep squeezing prices as they know that farmers' incomes are supported.*

With reference to agri-environment schemes it was felt that: *they are putting pressure on people to rent more land, as you have to reduce stocking densities, but no-one wants to get rid of their stock; they (environmental schemes) bring in an income - paying most for the worst land; environmental payments should be ring-fenced for environmental improvements.* Some participants stated that they *disliked seeing land go out of production,* adding that *no farmer wants to damage the environment.*

With specific reference to UK policy, the constraints on management from NVZs were seen to be undesirable, although farmers in this locality were not in the scheme. Grants were viewed favourably; four participants had received Farming Connect grants for soil testing, which was seen to be directly helpful for implementing SI. There was demand for increased access to grants specifically for animal welfare and resource efficiency. It was also felt that there is good access to advice in Wales but not enough research and development - *Ireland is the only place in GB investing in dairy research.*

Recommendations for further improvements included: redirecting generic Single Farm Scheme funding to provide direct support for business improvements such as better slurry systems, or herd health planning.

LFA Livestock Summary

Eleven farmers participated in the focus group in Northumbria, ranging in age from mid-thirties to over sixty five. Although the farms are located within a thirty mile radius of each other, they encompass a range of different systems, owing in part to variations in topography and soil type. Whilst all of the farms include cattle and/or sheep, some are extensive and/or organic, particularly those which are predominately in the LFA, whilst others with some lowland have integrated their livestock with arable systems.

Initial perceptions of SI were quite varied, and included the following key statements and shared views:

- Reducing waste; efficiency; water usage; not polluting above specified levels; efficient production- inputs vs. outputs.
- It involves economic considerations such as productivity efficiencies, and of course should strive to be 'low carbon'.

- There is a need to think on a global scale.
- The term SI seems to be a contradiction in terms; the aims of sustainability are opposing to those of intensification.
- SI is what you (the farmer) are forced to do.
- From and organic view point, SI involves working within the natural carrying capacity of the land.
- Sustainability in this context seems to refer to environmental sustainability.
- Soil is really important for sustainability.

Seven of the consultees considered themselves to already be practicing sustainable intensification on their farms. The remainder stated that they were farming sustainably, but not simultaneously intensifying.

SI Strategies

The table below outlines a range of SI strategies, collated from the case studies for this sector. It can be seen that there was also a high uptake of such strategies amongst the focus group participants.

Strategy	Yes	No	In Future	Comments
Land Sparing - set aside land for environmental purposes	5	1	5	4 out of 5 yes responses listed HLS as their means for doing this
Use of latest / most efficient technologies	10		1	7 out of 10 yes responses used EBVs
Renewable energy generation-on farm	6	4	1	4 out of the 6 yes responses had installed solar PV.
Business management tools/ benchmarking/ strategic planning	10		1	Group costings and benchmarking were most popular.
Reduction of inputs whilst maintaining outputs	10		1	Yes responses included feed rationing, reduced use of concentrates and reduced use of fertiliser
Reduced cultivations / zero tillage	5	4	1	Less applicable to this sector/scale of arable operations, some use of min. tillage/ under-sowing
Implementation of agri-environment schemes	10		1	High prevalence of HLS. Those currently not in HLS hoped to be in future.
Animal Health Plans / Best practice	11			Everyone used herd health plans. Also evidenced good communication with vets.
Self reliant for feed and forage	10		1	Most respondents now used forage based systems. Use of red clover

The most popular strategy for this sector was the implementation of best practice for animal health, including herd health plans and regular communication with vets. Whilst this practice has a direct link to profitability, it is also supported through legislation and industry regulation such as farm assurance. Similarly, for the other most popular strategies profitability and/or legislation featured highly as an underlying driver.

Business Drivers

The group largely agreed with and reiterated the drivers from the case study presentation, nominally: *leaving a profitable business for future generations, reduction of inputs, increased outputs and environmental sustainability.*

Other drivers included: *expanding the business and increasing the level of job satisfaction and family time and, reducing inputs.*

Economic	▪ reduction of inputs ▪ increased outputs ▪ expanding the business
Environmental	▪ environmental sustainability
Social/ political	▪ leaving a profitable business for future generations ▪ increasing the level of job satisfaction ▪ Ensuring time for family

EU and UK Policy

There was a general feeling that the current legislative systems do little to encourage SI, at least within this sector. The views of the group have been précised below.

- *The current subsidy system is more focussed on the environment than productivity. However proposals to further green the Common Agricultural Policy have the potential to initially create some negative environmental impacts, such as people ploughing out permanent pastures before the new regulations are imposed.*
- *The Single Payment Scheme enables inefficient and unsustainable farmers to keep farming, whereas exposure to real market forces would prevent this from happening. The system favours landlords and makes it difficult for youth to come into farming. Although the current system is strongly disliked it would be impossible to farm without it, unless it was phased out altogether; individuals cannot function outside of the system. The New Zealand system does much more to support and promote sustainable intensification. Agriculture over there functions very well without subsidies, although there is also less 'red tape' than in the UK.*
- *Without any form of Cross Compliance type regulations farmers would become increasingly focussed on intensification and sustainability would be much reduced.*
- *Increased government funding for research and development and knowledge transfer would help increase the prevalence of sustainable intensification in the UK. There is also a need for more joined up thinking between different policies to help cut waste. It is also important to open up the debate on GM crops.*