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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: IF0127
2. Project title: Contribution of integrated crop management practices to Defra objectives
3. Contractor organisation(s): ADAS UK Ltd; University of Warwick-Warwick HRI
4. Total Defra project costs (agreed fixed price): £ 132,176
5. Project: start date .... 01 March 2007
   end date .... 31 March 2009

6. It is Defra's intention to publish this form.
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(a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

NB some of the schemes referred to have been updated since this report was completed

Sustainable development of agriculture faces economic, environmental and social challenges. Key considerations include the production of safe, healthy products in response to market demand; farming systems that support sustainable land management and a viable, diverse rural economy; and consistently high standards of environmental performance avoiding impacts on natural resources (particularly soil, water and biodiversity). A farming system comprises a complex of interrelated and interacting factors. An isolated study of a part of the system will not provide adequate understanding of the behaviour of the entire system and the interactions may be equally or more important than the components. There is therefore a requirement for the development of integrated approaches and practices to help farming systems adapt to eliminate or reduce the negative impacts of production, without unduly affecting economic viability of the farm enterprise. The overall objective of this project was to **improve the understanding, promotion and adoption of integrated farming practices (IFM) in cropping systems**. Specific objectives were to consolidate the evidence on IFM and to include the latest information from recent arable and horticultural projects and to determine the contribution of specific IFM practices in achieving economic, environmental and social (EES) objectives. This included identification of instances where specific IFM practices do, or do not, achieve these objectives, and the spatial and temporal constraints on achieving these objectives through IFM. The final objective was to compare the available options for benchmarking IFM and to identify ways in which these could be used for adoption and improvement of IFM. The project was extended to explore the links between IFM and ecosystem services, including the effect of IFM practices on the carbon footprint of agriculture and the delivery of ecosystem services.
The project covers all annually rotated arable crops and field vegetables in England and Wales and the information has been related to Defra "One Planet Living" objectives and policy requirements. The project considered the contribution of Integrated Farming Practices and related them to Defra EES objectives of Energy, Climate Change, Waste, Water, Food and Farming and Resource Protection. The outcome was a matrix which indicated that most of the IFM techniques considered deliver successfully to objectives within policy areas of Food and Farming and Resource Protection. However, they are currently less effective at delivering benefits for the newer policy areas of Energy, Climate Change and Waste. This process identified several conflicts, indicated the nature of the conflict and examined the potential to overcome the barriers. One major area of 'conflict' highlighted is the mechanical or physical techniques that are aimed at reducing pesticide use. A number of these involve an increased or inefficient use of energy and other

resources and, in the case of physical barriers, may create other problems through the creation of additional waste and other adverse effects on biodiversity and the overall landscape. Similarly, whilst the application of manures and composts to agricultural land has a beneficial impact in terms of many policy objectives, it has a high negative score for 'Climate Change'. Considerable research funding is already being directed towards maximising the benefits of manures and composts, whilst minimising their negative effects. Finally, a number of the techniques within 'Rotation' score negatively for 'Waste' as they involve 'inefficient use' of some resources. Their benefits are related particularly to biodiversity and some of these approaches are also unlikely to be practical or economically viable.

An assessment of the level of adoption of certain IFM techniques highlighted some of the constraints to achieving EES objectives through IFM. Spatial constraints include the geographical location and size of the holding and the spatial distribution of the fields within it. The ease with which some of the IFM techniques can be adopted depends on soil type and field type (e.g. sloping or flat). Temporal constraints are associated mainly with the weather, market requirements and the risk associated with uncertainty about future weather conditions. Other factors such as impracticality and/or economic constraints are common reasons for lower levels of adoption, as is the limited availability of certain 'tools' such as varieties resistant to key pests and diseases.

Benchmarking may offer an opportunity for farms to improve their IFM performance and, certainly, at the very least, knowledge exchange in terms of the execution of certain practices is extremely valuable. A benchmark needs to be quantifiable and easy to measure. It also needs to be something that is currently not achieved widely, so that increases over a baseline can be measured. Whilst an increase in the uptake of certain IFM practices is desirable, it would be even more challenging to benchmark IFM in terms of outcome, so that the direct contribution to Defra's targets could be assessed and improved upon. Outcomes that are already measured and could be used in benchmarking include fuel and other energy consumption, water consumption, yield return for fertiliser input and pesticide usage. Others that might be measured include water quality, soil compaction, soil structure, earthworm populations, soil organic matter, moisture holding capacity. Within a locality, it might also be possible to benchmark certain plant or animal species e.g. birds. Benchmarks need to be regional, related to soil type and the effects of annual variation in weather conditions should also be taken into account. Benchmarks could be set annually by an expert panel who take into account the previous season; these would then be subject to revision.

Eighteen crop/management strategies (scenarios) were chosen to illustrate the linkage between carbon accounting and an ecosystems approach (EsA) when comparing integrated farming practices. The scenarios included winter wheat, beans, oil seed rape, carrot and onion and incorporated management strategies which illustrated how IFM techniques could be assessed using the two accounting techniques. The greatest effect was from the crop. Beans provided the highest (most environmentally benign) EsA score (per ha) and onion the lowest. Within crop variation in response to different management practices was quite small. There was no clear relationship between the carbon footprint and the EsA score or applied nitrogen and the EsA score. This indicates that although both the carbon footprint and applied nitrogen are important inputs into the EsA, they do not completely determine the score. Both the carbon footprint and the EsA score are 'only as good as the data available'. This is particularly true for the EsA score since the involvement of stakeholders is critical in the process of identifying themes, products and establishing values. The results of the comparisons made in this project must be considered in this context. The advantage of using an EsA for delivering IFM is the ability to score different management approaches against any, or all, of the Defra objectives and to use the matrix to compare approaches. In addition, the EsA supports more 'rounded' decision-making since it is possible to consider 'all' impacts and it reduces the risk of making a decision based on measurement of one or two parameters that might be 'wrong' in a wider context. Although the comparisons presented here are relatively superficial and based on 'standard' production systems, they demonstrate that the EsA works for IFM. This is a step beyond the assurance schemes in use already which tend to be prescriptive about inputs and pay little regard to outcome. If standard systems (benchmarks) could be agreed for individual crop production systems, these could be used as a baseline in a crop specific EsA matrix which could enable all other farming systems, not just IFM, to be judged against a common standard.

Recommendations

- Further work is required to develop the EsA to include all the objectives in the IFM matrix.
- Further work is required to identify and 'value' the EES contributions of different IFM practices. Until the nature and scale of the 'services and products' that IFM delivers are identified and valued, it is difficult to prioritise and target specific practices.
- It is important to recognise that an increase in yield achieved using the same inputs will lower the carbon footprint per product unit, but that certain ecosystem services and products are delivered irrespective of yield. More work is required to determine how the two contrasting methods of assessment (carbon footprint and EsA) can be brought together.
- Future research should be assessed in terms of impact in relation to both carbon footprint and EsA scores. Any IFM practices which cause significant yield reductions, especially without reductions in input, will not assist in the delivery of Defra objectives.
- The analysis in this report could be developed further if Defra policy objectives were prioritised or weighted. This would allow fine-tuning of desired management practices.

- There is a need for significantly more funding for research into, and development of, tools and techniques that provide alternatives to artificial inputs, but which do not increase the carbon footprint (e.g. biological control, cultural control, host-plant resistance). This includes support for knowledge transfer to ensure that techniques are viable commercially and will be used by farmers and growers.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

1. Introduction

Sustainable development of agriculture faces economic, environmental and social challenges. Key considerations include the production of safe, healthy products in response to market demand; farming systems that support sustainable land management and a viable, diverse rural economy; and consistently high standards of environmental performance avoiding impacts on natural resources (particularly soil, water and biodiversity). A farming system comprises a complex of interrelated and interacting factors. An isolated study of a part of the system will not provide adequate understanding of the behaviour of the entire system and the interactions may be equally or more important than the components. There is therefore a requirement for the development of integrated approaches and practices to help farming systems adapt to eliminate or reduce the negative impacts of production, without unduly affecting economic viability of the farm enterprise. The overall objective of this project was to **improve the understanding, promotion and adoption of integrated farming practices (IFM) in cropping systems**. It follows on from two previous projects; ‘A review of research papers, reports and other publications on Integrated Farm Management (Garstang *et al*., 2003) and an ‘Integrated approach to farming and land management – a role in delivering Defra’s policies’ (Clarke and Cook, 2006). Specific objectives were to consolidate the evidence on IFM and to include the latest information from recent arable and horticultural projects and to determine the contribution of specific IFM practices in achieving economic, environmental and social (EES) objectives. This included identification of instances where specific IFM practices do, or do not, achieve the EES objectives, and the spatial and temporal constraints on achieving the EES objectives through IFM. The final objective was to compare the available options for benchmarking IFM and to identify ways in which these could be used for adoption and improvement of IFM. The project was extended to explore the links between IFM and ecosystem services, including the effect of IFM practices on the carbon footprint of agriculture and the delivery of ecosystem services.

2. Objectives

The overall objective is to improve the understanding, promotion and adoption of integrated farming practices (IFM) in cropping systems

The specific objectives were:

1. To consolidate the evidence on IFM, to include the latest information from recent arable and horticultural projects.
2. To determine the contribution of specific IFM practices in achieving economic, environmental and social (EES) objectives.
   a) To determine where specific IFM practices do or do not achieve the EES objectives.
   b) To identify the spatial and temporal constraints on achieving the EES objectives through IFM.
3. To compare the available options for benchmarking IFM and to identify ways in which these could be used to develop site specific targets and processes for local improvement and adoption.
4. To explore the links between IFM and ecosystem services and demonstrate how IFM can affect the delivery of ecosystem services.
   a) To examine the effects of IFM (and ecosystems services) on the carbon account of agriculture, specifically to quantify whether IFM practices change the carbon footprint of arable and horticultural production systems.
   b) To examine how IFM principles might be used to increase the potential to reduce carbon footprints. To involve some case studies which examine how

existing, or novel, management might be enhanced to deliver both improved carbon footprints and still retaining delivery of ecosystem services

3. Results

3.1 Objective 1. To consolidate the evidence on IFM, to include the latest information from recent arable and horticultural projects.

The project considered Integrated Farming Practices and relates them to Defra policy objectives in relation to energy, climate change, waste, water, food and farming and resource protection.

A list of IFM practices applicable to arable and field vegetable crop production was drawn up based on 'Arable Cropping and the Environment – a guide' (HGCA, 2002). Additional practices were included where gaps were identified, particularly in relation to water and which were more specific to horticulture. The list is shown in Table 1.

Table 1 List of IFM practices considered during the project

1. Rotation
1a).Arable - A diverse winter sown rotation with at least 3 different crop types
1b) Include spring crops where profitable and practical
1c) Include a cover crop over winter
1d) Replace an autumn breakcrop with a spring breakcrop
1e) Include legumes/fertility building crops in the rotation
1f) Provide a crop mosaic
1g) Avoid erosion prone crops e.g. potatoes on erosion prone soils e.g. sands
2. Soils
2a) Produce a soil management plan
2b) Avoid intensive cultivations, use minimum tillage techniques (not horticulture)
2c) Time cultivations carefully with respect to prevailing weather and soil conditions
2d) Match cultivations to crop, weeds, soil type and season
2e) Reduce cultivations on steep slopes, especially on headlands and near watercourses
2f) Cultivate and plant across slopes
2g) Consider undersowing crops
2h) Minimise harvesting passes in horticultural crops
3. Water
3a) Produce a water management plan
3b) Ensure field drainage is maintained
3c) Manage ponds for biodiversity
3d) Exclude livestock from ditches, ponds and watercourses
3e) Undertake an irrigation water use assessment
3f) Avoid irrigating before it rains
3g) Apply sufficient irrigation at critical timings
4. Establishment
Variety
4a) Grow resistant varieties wherever possible
4b) Exploit the characteristics of competitive and vigorous varieties
Sowing date
4c) Optimise sowing date
4d) Sow spring crops when seedbeds are suitable
Seed rate
4e) Consider reducing seed rates
4f) Consider increasing seed rate in some circumstances
5. Nutrition
5a) Have a nutrient management plan
5b) Buy good quality fertiliser
5c) Calibrate fertiliser spreader
5d) Predict crop needs (ie decision support systems or canopy management or sensing)
5e) Adjust the timing and amounts of split applications as accurately as possible

5f) Avoid fertiliser application to field boundaries
5g) Consider using starter fertiliser (horticulture)
5h) Apply manures and composts to increase organic matter
6. Crop protection - General
6a) Have a crop protection management plan
6b) Ensure all operators trained to appropriate level
6c) Calibrate sprayers
7. Weeds
7a) Plan rotational strategy to take weed control into account
7b) Use cultural control for weeds where appropriate
7c) Leave residual levels of non-aggressive weeds in crops where possible
7d) Establish conservation headlands
7e) Alter drilling date
8. Pests
8a) Plan rotation and spatial separation to minimise pest problems
8b) Use cultivations to control pests (e.g. slugs)
8c) Use pest resistant varieties
8d) Identify crops at risk by forecasting, sampling, monitoring or trapping and using thresholds
8e) Use narrow spectrum PPPs
8f) Encourage beneficial enemies e.g. field margins, conservation headlands and set-aside
8g) Use physical barriers e.g. fleece (horticulture)
8h) Alter drilling or harvesting date
8i) Trap cropping
9. Diseases
9a) Plan rotation and spatial separation to minimise disease problems
9b) Use disease resistant varieties
9c) Identify crops at risk by forecasting, sampling, monitoring or trapping and using thresholds
9d) Use appropriate dose techniques
9e) Avoid early sown or out of season crops
9f) Maintain good intercrop hygiene e.g. residues
10. Environment
10a) Increase and improve biodiversity areas (field margins, conservation headlands)
10b) Maximise the benefits of set-aside/fallow

Similarly, a list of current Defra economic, environmental and social (EES) policy objectives was drawn up from Defra's strategic objectives and indicators (provided in consultation with Defra). These are shown in Table 2.

Table 2 Economic, environmental and social (EES) objectives.

Policy area	Objectives
Energy	Reduce energy consumption Increase energy efficiency Increase use of renewable energy
Climate change	Maintain/improve air quality (particulates) Reduce methane emissions Reduce NOx emissions Reduce N_2O emissions Reduce CO_2 emissions
Waste	Reduce waste and CO_2 emissions from inputs Reduce waste and CO_2 emissions from outputs Efficient use of resources Increase recycling/composting, reduce landfill Use of recycled materials
Water	Reduce flooding and/or erosion Maintain/improve water supply improve water quality - chemical

Policy area	Objectives
	improve water quality - biological
Food and farming	Has a positive environmental benefit Provides rural employment in thriving communities Ensure food is available to meet consumer demand Provision of safe good quality food Pesticides, availability of PPPs Pesticides: more alternatives and greater use of ICM Inclusion in agri-environment scheme Practicality Economically viable
Resource protection	Sustainable management of land Improve soil management Maintain/improve physical soil status Maintain/improve chemical soil status Value, safeguard and enhance biodiversity - Birds Value, safeguard and enhance biodiversity - Plants Value, safeguard and enhance biodiversity - Insects Value, safeguard and enhance biodiversity - Mammals Improve leisure access to natural environment Improve cleanliness of local environment Maintain and improve living landscape

The information gathered by Garstang *et al*. (2003) on the major Integrated Farm Management (IFM) projects was updated (Appendix 1). These projects related to arable crops only. There have been no similar major studies on horticultural production. Each publication was reviewed using headings which mirror the Defra policy objectives; Table 3 is a summary of the information contained in Appendix 1.

Table 3 Summary of policy areas covered by the major integrated farming projects

	The Boxworth project 1981-1991	Talisman and Scarab 1990-1998	LINK Integrated Farming Systems 1992-1997	Focus on Farming Practice 1993-2002	LIFE 1995-2001	3D Farming 2000-2004	SAFFIE 2001-2006
Energy	-	-	√	√	√	-	-
Climate change	-	√	√	-	√	-	-
Waste	√	√	-	-		-	-
Water	-	-	-	√	√	-	-
Food and farming							
Economics	√	√	√	√	√	-	√
Food	-	-	-	-	-	-	-
Pesticide use	√	√	√	√	√	√	-
Schemes	-	-	-	-	-	-	-
Resource protection							
Land	-	-	-	-	-	-	-
Soil	-	-	-	√	√	-	-
Biodiversity	√	√	√	√	√	√	√
Landscape	-	-	-	-	-	-	-

√ = main area covered, - = area not covered

These major projects covered a period of significant change in farming practices. When the Boxworth project began in 1982, pesticide usage was high (Figure 1) and the introduction of IFM practices to lower pesticide inputs, and the use of thresholds, was ground-breaking. When the TALISMAN experiment introduced a 50% reduction in inputs in the early 1990's, this was seen as a challenging target. Today all farm inputs, including pesticides, are targeted through a better understanding of their use.

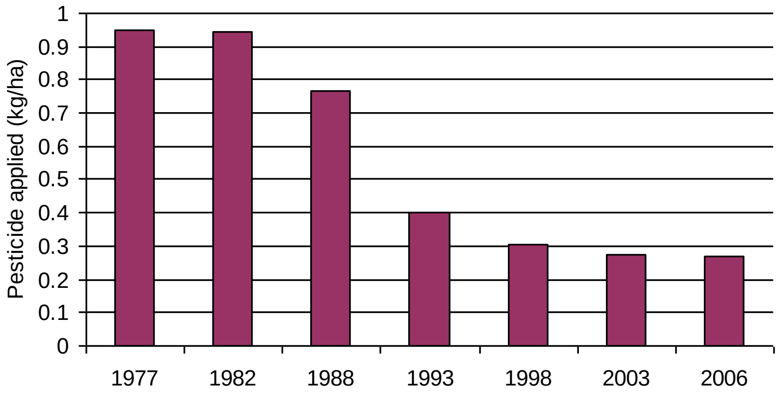

Figure 1 Pesticide usage on cereals from 1977 to 2006 (kg/ha) (PUSSTATS, 2009)

All the projects monitored the effects of treatments on biodiversity and their results have contributed to the mass of data that has been used to support the environmental schemes which are an integral part of modern farming. Recent changes of emphasis in government policies i.e. energy, climate change, waste and water were not covered by these studies, as at that time biodiversity was the main interest. For the majority of projects, the data collected can be re-assessed in the light of current policies (Table 3).

Most research that pertains to IFM looks at individual techniques over shorter periods of time, further information was collated concerning the sixty-one specific IFM practices listed in Table 1. The review is available in Appendix 2 and follows the structure shown in Table 1. Each practice was reviewed separately, providing information (with references) on both arable and field vegetable crops. Field vegetable crops are generally grown as part of an arable rotation, so many of the IFM techniques used for arable crops are also appropriate for horticulture. Instances where the arable and horticulture systems differ have been highlighted.

Much of the information acquired and evaluated in Objective 1 provided the background for Objective 2.

3.2 Objective 2. To determine the contribution of specific IFM practices in achieving economic, environmental and social (EES) objectives.

This objective comprised two parts.

3.2.1 To determine where specific IFM practices do or do not achieve the EES objectives.

The list of IFM practices applicable to arable and horticultural crop production (Table 1) were scored against the list of current Defra economic, environmental and social (EES) objectives (Table 2) in the form of a matrix (Table 4; Appendix 3). The effect of implementing each IFM practice compared with accepted standard practice was assessed by the project team and given a rating to reflect its potential effect on the outcome of each policy objective. Thus a score of +5 = large beneficial effect, +1 = beneficial effect, 0 = very small or no change from conventional, -1 = negative effect, -5 = large negative effect. Positive scores ≥ 3 and negative scores ≤-3 have been highlighted in the matrix using green and red respectively.

The matrix was then analysed to identify IFM practices whose effect is likely to be entirely beneficial and practices that are likely to be beneficial for one or more policy outcomes but detrimental to others. The analysis concentrates on IFM practices which can lead to benefits over and above those that might be achieved from Cross-Compliance or through Good Agricultural Practice or additional regulatory burden.

Table 4 Matrix to determine the contribution of Integrated Farm Management techniques in achieving policy objectives.

Policy Objective	Energy			Climate change					Waste					Water				Food & Farming									Resource protection										
Scoring system. The effect of implementing the IFM practice over the accepted standard practice is given a rating to reflect the effect on the policy objective. +5 for a large beneficial effect, 0 very small or no change from conventional, -5 large negative effect	Reduce energy consumption	Increase energy efficiency	Increase use of renewable energy	Maintain/improve air quality (particulates)	Reduce methane emissions	Reduce NOx emissions	Reduce N_2O emissions	Reduce CO_2 emissions	Reduce waste and CO_2 emissions from inputs	Reduce waste and CO_2 emissions from outputs	Efficient use of resources	Increase recycling/composting, reduce landfill	Use of recycled materials	Reduce flooding and/or erosion	Maintain/improve water supply	improve water quality - chemical	improve water quality - biological	Has a positive environmental benefit	Provides rural employment in thriving communities	Ensure food is available to meet consumer demand	Provision of safe good quality food	Pesticides, availability of PPPs	Pesticides: more alternatives and greater use of ICM	Inclusion in agri-environment scheme	Practicality	Economically viable	Sustainable management of land	Improve soil management	Maintain/improve physical soil status	Maintain/improve chemical soil status	Value, safeguard and enhance biodiversity - Birds	Value, safeguard and enhance biodiversity - Plants	Value, safeguard and enhance biodiversity - Insects	Value, safeguard and enhance biodiversity - Mammals	Improve leisure access to natural environment	Improve cleanliness of local environment	Maintain and improve living landscape
IFM technique																																				
1. Rotation																																				
1a) Arable A diverse winter sown rotation with at least 3 different crop types										-2			1				5	1	4	1		2		3	3	2	1	3		5	5	5	5	1		5
1a) Horticulture - A diverse rotation with at least 3 different crop types										-2			1	-1			5	2	3	1		2		-3	-3	3	3	3		5	5	5	5	1		5
1b) Include spring crops where profitable and practical	1						1	1	2		-4			-3				4			1		2	3	-4	-3		-1	-2		4	4	4	4			
1c) Include a cover crop over winter	-2						-2	-2	-2		-4			2				4						3	-5	-4	-2	2	-1		-2	-2	3	3			
1d) Replace an autumn breakcrop with a spring breakcrop	1						1	1	2		-4			-2				4		-2	1			3	-4	-4		-1	-2		4	4	4	4			
1e) Include legumes/fertility building crops in the rotation	3						-3	3	3		4							2		1	1			3	3	2	2	1					3				
1f) Provide a crop mosaic	-3										-3			1				4							-2	-2	4				5	5	5	5	1		5
1g) Avoid erosion prone crops e.g. potatoes on erosion prone soils e.g. sands	1			2			2				3			5	3	3	3	4							-2	-2	2	4	4			1					2
2. Soils																																				
2a) Produce a soil management plan																																				
2b) Avoid intensive cultivations, use minimum tillage techniques (not horticulture)	4	4		1		1		4	2		4			3	1	1	1	2							3	4	2	4	4		4	1	3		1		
2c) Time cultivations carefully with respect to prevailing weather and soil conditions	4	4		1		1	2	4	2		4			5	1	1	3	2							3	4	1	4	4								
2d) Match cultivations to crop, weeds, soil type and season	3	4				1	1	3	1		4			3		1	1	2							3	5	2	4	4			-2					
2e) Reduce cultivations on steep slopes, especially on headlands and near watercourses	3							3	2		4			5		1	1	2						3	4	-3	4	5	4								
2f) Cultivate and plant across slopes	-1							-1						5		1	1	1							2	-1	4	4	1								
2g) Consider undersowing crops	3							3	-2		1			3		2	2	3							-2	-3	1	1			-1	-1	2				
2h) Minimise harvesting passes in horticultural crops	4							4	2		4			2			4								-1	-1		1	1		2						
3. Water																																				
3a) Produce a water management plan																																				
3b) Ensure field drainage is maintained	-1	3				1	1		1		3			1	2	1	1	2		3					4	2	3	3	3								
3c) Manage ponds for biodiversity														2	1	1	5	5						3	3	-1	1				5	4	2	1			5
3d) Exclude livestock from ditches, ponds and watercourses		1			1	1	2							4			4	4							1	3	3	3	3		3	2	1				2
3e) Undertake an irrigation water use assessment	1	1						2	1		4			3	2				2	4	4				4	2		1									
3f) Avoid irrigating before it rains	2					1	1	2	1		4			4	4	1	1	1							1	4		1									
3g) Apply sufficient irrigation at critical timings	2							2			4			4											3	4											

Policy Objective	Energy			Climate change					Waste					Water				Food & Farming									Resource protection										
Scoring system. The effect of implementing the IFM practice over the accepted standard practice is given a rating to reflect the effect on the policy objective. +5 for a large beneficial effect, 0 very small or no change from conventional, -5 large negative effect	Reduce energy consumption	Increase energy efficiency	Increase use of renewable energy	Maintain/improve air quality (particulates)	Reduce methane emissions	Reduce NOx emissions	Reduce N_2O emissions	Reduce CO_2 emissions	Reduce waste and CO_2 emissions from inputs	Reduce waste and CO_2 emissions from outputs	Efficient use of resources	Increase recycling/composting, reduce landfill	Use of recycled materials	Reduce flooding and/or erosion	Maintain/improve water supply	improve water quality - chemical	improve water quality - biological	Has a positive environmental benefit	Provides rural employment in thriving communities	Ensure food is available to meet consumer demand	Provision of safe good quality food	Pesticides, availability of PPPs	Pesticides: more alternatives and greater use of ICM	Inclusion in agri-environment scheme	Practicality	Economically viable	Sustainable management of land	Improve soil management	Maintain/improve physical soil status	Maintain/improve chemical soil status	Value, safeguard and enhance biodiversity - Birds	Value, safeguard and enhance biodiversity - Plants	Value, safeguard and enhance biodiversity - Insects	Value, safeguard and enhance biodiversity - Mammals	Improve leisure access to natural environment	Improve cleanliness of local environment	Maintain and improve living landscape
4. Establishment																																					
Variety																																					
4a) Grow resistant varieties wherever possible	1							2	2		2									3	3		3		3	2											
4b) Exploit the characteristics of competitive and vigorous varieties	1							2	2		2			1	1	1	1	1		3			3		2	2					-1	-3	-1	-1			
Sowing date																																					
4c) Optimise sowing date									1		2			2				-1		3			1		3	1	3	1									
4d) Sow spring crops when seedbeds are suitable	1							1	2		2			3			2	2		2					1	3	1	4	2		1	1	1				
Seed rate																																					
4e) Consider reducing seed rates									3		2			-2			-1			1	1		1		3	3					1	1	1				
4f) Consider increasing seed rate in some circumstances									2		1			2			2			1	1		1		3	2					-2	-1	-1				
5. Nutrition																																					
5a) Have a nutrient management plan																																					
5b) Buy good quality fertiliser	1	1				1	1	1	2		2														-1	-2											
5c) Calibrate fertiliser spreader	1	1				1	1	1	3		3							2							3	3		1									
5d) Predict crop needs (ie decision support systems or canopy management or sensing)									4		3								1						-2	2	1										
5e) Adjust the timing and amounts of split applications as accurately as possible	3	3				1	2	3	1		3														2	2	1										
5f) Avoid fertiliser application to field boundaries	1						1	1	3		5							4							-1	4	2				4	3	1				
5g) Consider using starter fertiliser (horticulture)							-1				3									1					-1	3											
5h) Apply manures and composts to increase organic matter	-1				-3		-5	-3			3	5	5	3		-1	-1	3							2	4	2	4	5	-1	2	1	2	1			
6. Crop protection - General																																					
6a) Have a crop protection management plan																																					
6b) Ensure all operators trained to appropriate level	1	2					2	2	2		1					2	2	3	2		2				4	2	2				2						
6c) Calibrate sprayers	1	2					2	2	4		5					2	2	3	1		2				4	2	2										
7. Weeds																																					
7a) Plan rotational strategy to take weed control into account	3							3	3		4							1		2	1		3		2	2	3					-1					
7b) Use cultural control for weeds where appropriate	-4							-4	1		-4			-2	-2	-2	-2	-4			1		2		-2	-2	1	-1			-3	-1					
7c) Leave residual levels of non-aggressive weeds in crops where possible											-3			2	2	2	2	2		-1	1		2	2	-4	-1	1				4	4	4	2			
7d) Establish conservation headlands	-4							1	2		-4			3	3	3	3	5		-2			2	5	3	1	3				4	4	4	4			
7e) Alter drilling date														1							1		2		2	2											

Policy Objective	Energy			Climate change					Waste					Water				Food & Farming									Resource protection										
Scoring system. The effect of implementing the IFM practice over the accepted standard practice is given a rating to reflect the effect on the policy objective. +5 for a large beneficial effect, 0 very small or no change from conventional, -5 large negative effect	Reduce energy consumption	Increase energy efficiency	Increase use of renewable energy	Maintain/improve air quality (particulates)	Reduce methane emissions	Reduce NOx emissions	Reduce N_2O emissions	Reduce CO_2 emissions	Reduce waste and CO_2 emissions from inputs	Reduce waste and CO_2 emissions from outputs	Efficient use of resources	Increase recycling/composting, reduce landfill	Use of recycled materials	Reduce flooding and/or erosion	Maintain/improve water supply	improve water quality - chemical	improve water quality - biological	Has a positive environmental benefit	Provides rural employment in thriving communities	Ensure food is available to meet consumer demand	Provision of safe good quality food	Pesticides, availability of PPPs	Pesticides: more alternatives and greater use of ICM	Inclusion in agri-environment scheme	Practicality	Economically viable	Sustainable management of land	Improve soil management	Maintain/improve physical soil status	Maintain/improve chemical soil status	Value, safeguard and enhance biodiversity - Birds	Value, safeguard and enhance biodiversity - Plants	Value, safeguard and enhance biodiversity - Insects	Value, safeguard and enhance biodiversity - Mammals	Improve leisure access to natural environment	Improve cleanliness of local environment	Maintain and improve living landscape
8. Pests																																				
8a) Plan rotation and spatial separation to minimise pest problems	-3							-3	2		4							4		2	3		3		2		1				1						
8b) Use cultivations to control pests (e.g. slugs)	-3							-3	-3		-3							-4		2	2		2		2	2	1	-1						2			
8c) Use pest resistant varieties	1							1		1	2					1	1	2		2	2		4		2	2							-1				
8d) Identify crops at risk by forecasting, sampling, monitoring or trapping and using thresholds	-2							-2	2		3							4	1	4	4		4		3	3	3				3		3				
8e) Use narrow spectrum PPPs	-3							-3										4		4	4		2		2	3	3				3		3				
8f) Encourage beneficial enemies e.g. field margins, conservation headlands and set-aside	3					1	1	1	1	1	1			2		2	2	5			4		4	5	4	3	3				5	5	5	5	2		4
8g) Use physical barriers e.g. fleece (horticulture)	-4						-4	-4	-3		-4	-4	1	1		1		-2	3	4	4		4		2	3					-3		-1			-2	-3
8h) Alter drilling or harvesting date									1		3			1		1					2		3		-2	2											
8i) Trap cropping	-2							-2	1		-2			1		1	1	4			3		4		-3	-1					-1						
9. Diseases																																				
9a) Plan rotation and spatial separation to minimise disease problems	-3							-3	2		4							4		2	3		3		2		1				1						
9b) Use disease resistant varieties	1							1	1		2					1	1	2		2	3		3		2	2	1										
9c) Identify crops at risk by forecasting, sampling, monitoring or trapping and using thresholds	-2							-2	2		3							4	1	4	4		4		3	3	3				3		3				
9d) Use appropriate dose techniques	2	2					1	2	2		4					1	1	2		2	3		1		1	3	2										
9e) Avoid early sown or out of season crops	1							1	1		3			2			1	2		-1			3		-2	-1	1				1						
9f) Maintain good intercrop hygiene e.g residues									2		3							-2		1	1		2		1	1	1				-3	-3	-1	-1			
10. Environment																																				
10a) Increase and improve biodiversity areas (field margins, conservation headlands)	-3										2			2		2	2	5		-3			2	5	3	-2	5				5	5	5	5	2		5
10b) Maximise the benefits of set-aside/fallow											4			1		1	1	5		-3			2	5	3	-2	5	1	1		3	3	3	3			

Table 4 contains an overall summary for each policy area of the potential benefits and dis-benefits of adopting particular IFM techniques. Each policy area contains a variable number of objectives (those detailed in Table 2). For the policy areas of ‘Energy’, ‘Climate change’, ‘Waste’ and ‘Resource Protection’, adoption of IFM techniques accounts for large beneficial effects in approximately 20-30% of incidences. In the areas of ‘Water’ and ‘Food and Farming’ this figure is substantially higher at 41-43%. The number of large negative effects is small (<10%) for all policy areas.

Table 5 Summary by policy area of the number of times adopting an integrated farming technique will have a beneficial or adverse effect on policy objectives.

	Policy area					
	Energy	Climate change	Waste	Water	Food and Farming	Resource Protection
Number of times using IFM technique results in a large **beneficial** effect for policy area	40	58	84	94	223	168
% Beneficial	**23**	**20**	**29**	**41**	**43**	**26**
Number of times using IFM techniques results in a large **negative** effect for policy area	16	18	17	11	28	34
% Negative	**9**	**6**	**6**	**5**	**5**	**5**

Each policy area was considered separately and the matrix was condensed to highlight large positive or negative effects. Where there were large scores (≥3 or ≤-3) due to a particular IFM technique in one policy area, the effects on other policy areas are discussed below. The condensed matrices are provided in Appendix 4.

Energy (Appendix 4; Table 1)

Many of the IFM techniques that have a large negative effect on energy consumption and efficiency require an increased use of machinery. A key aim of an integrated farming system is to achieve a crop mosaic, where there is a pattern of different crop types in adjacent fields, within which there should be un-cropped areas and conservation headlands. This approach should have a large beneficial effect on the environment and biodiversity. However, producing crops in this manner increases fuel consumption, due to the greater distances that have to be travelled compared with a ‘block-cropping’ approach, and because of the extra input required to establish and maintain additional areas for biodiversity. In addition, a number of the techniques intended to reduce pesticide use are energy-intensive, such as the use of additional cultivations to control pests or weeds, and the use of physical barriers to exclude pests.

In contrast, most of the IFM techniques associated with soil management have large positive benefits for energy consumption and efficiency and, generally these techniques score positively towards meeting all policy objectives considered in this project. Approaches to minimise artificial inputs e.g. by using fertility building crops, managing weeds through rotation or encouraging natural enemies of pests are also likely to reduce energy consumption, as is the careful management of field drainage and of fertiliser applications.

Climate change (Appendix 4; Table 2)

The IFM techniques associated with soil management have large positive benefits for the reduction of CO_2 emissions, generally associated with reducing energy consumption. These techniques also score positively towards meeting objectives in other policy areas, although two techniques are not considered to be economically viable (reducing cultivations on steep slopes and undersowing crops). Whilst farmers should aim to reduce cultivations on steep slopes, this may be difficult to achieve in practice. Farmers can mitigate against erosion in these areas by cultivating across the slope, which prevents the downward spread of soil.

Although the application of manures and composts to agricultural land has a beneficial impact in terms of many other policy objectives, it has a high negative score for ‘Climate Change’. Manures and composts are a valuable source of plant nutrients and can often be a direct replacement for inorganic fertilisers. But they are also a source of environmental pollution because of nitrogen and phosphate losses to water courses, as well as gaseous emissions of N_2O and ammonia (NH_3). N_2O

accounts for 66% of the total greenhouse gas emissions from agriculture. These emissions are derived, in part, from leaching of animal manures to water (27% of total N_2O produced by agricultural soils) and manure used as fertiliser (9%) (AEA, 2007).

Several IFM techniques for controlling weeds, pests and diseases increase CO_2 emissions as they rely on a higher level of mechanical inputs, already referred to in 'Energy' above.

Waste (Appendix 4; Table 3)

Many of the IFM techniques described in the matrix score positively in terms of the 'Efficient use of resources'. This is because integrated farming techniques generally consider actions and outcomes carefully; for example, by matching cultivations to the crop, weeds, soil and season; predicting crop needs through canopy management and undertaking irrigation water use assessment. These considerations have been incorporated into management plans for water, nutrients and crop protection and form part of ELS and HLS schemes.

A number of the techniques within 'Rotation' score negatively for 'Waste' as they involve 'inefficient use' of some resources. Their benefits are related particularly to biodiversity (birds, plants, insects, mammals) and this is why they are promoted. Some of these approaches are also unlikely to be practical or economically viable.

Some of the techniques to reduce or replace pesticide use through cultural or physical control methods may also constitute an inefficient use of resources and the physical barriers to control pests may increase waste disposal problems.

Water (Appendix 4; Table 4)

The majority of techniques either have little effect or a positive beneficial effect on policies associated with 'Water'. Techniques which reduce the risk of erosion are particularly beneficial.

The inclusion of spring crops in a rotation increases the risk of erosion, as the newly turned soil is exposed to rainfall. The cultivation of spring crops is neither economically viable nor practical on heavier soil types, but has major benefits for biodiversity. The cultivation of spring crops is already encouraged in current schemes.

Food and farming (Appendix 4; Table 5)

Most of the IFM techniques associated with 'Rotation' should have positive effects on the environment and biodiversity, but a number of them are unlikely to use resources efficiently and/or are neither practical nor economically viable. These include a diverse horticultural rotation, spring crops, cover crops over winter and replacing an autumn breakcrop with a spring breakcrop.

Two of the soil management techniques, reducing cultivations on steep slopes and undersowing crops are also unlikely to be economically viable on a large scale. Generally only part of a field is a steep slope and it is not easy to alter the direction of cultivation to incorporate this, removing this area may make farming the rest of the field impractical. In addition harvesting machinery is unable to cope with working across slopes. Undersown crops involves sowing a grass/clover crop into a standing wheat crop, this limits the yield potential for the wheat crop due to competition with the understory.

Whilst the application of manures and composts may have a positive environmental benefit, it is likely to have a negative impact on the mitigation of climate change (methane, NO_2 and CO_2 emissions).

In terms of crop protection approaches, the use of cultural methods of weed control and the use of cultivations to control pests such as slugs are unlikely to have a positive benefit on some environmental aspects. Several of the crop protection practices which will have a positive environmental benefit and/or ensure the provision of safe, good quality food, will have a negative impact on energy consumption, climate change mitigation and waste. This includes conservation headlands, spatial separation to minimise pest and disease problems, the use of narrow spectrum Plant Pprotection Product (PPPs) and the use of physical barriers to exclude pests.

Environmental approaches which take land out of production and have a positive environmental benefit e.g. field margins, conservation headlands, set-aside or fallow will reduce the amount of land available for food production.

Resource protection (Appendix 4; Table 6)

Several of the techniques associated with crop rotation including a diverse horticultural rotation, spring crops, cover crops over winter and replacing an autumn break crop with a spring break crop have a highly positive effect on biodiversity. These 4 techniques are currently considered to be impractical in highly profitable winter dominated rotations.

Whilst reducing cultivations on steep slopes will have a beneficial effect on soil management and soil status, it may not be economically viable.

In terms of crop protection strategies, cultural weed control and the use of physical barriers for pest control may not be beneficial for birds. Good intercrop hygiene may also be detrimental to birds and to plant biodiversity. In addition, plant biodiversity may be affected adversely by growing vigorous and competitive crop varieties.

Physical barriers to exclude pests may have a detrimental effect on the living landscape.

Discussion

This analysis has confirmed that IFM techniques generally have far more beneficial than adverse effects on current Defra policy objectives. However, there are some notable ‘conflicts’ where a technique that has a large beneficial effect in one policy area has a large negative effect in another.

One major area highlighted is the mechanical or physical techniques that are aimed at reducing pesticide use. A number of these involve an increased or inefficient use of energy and other resources and, in the case of physical barriers, may create other problems through the creation of additional waste and other adverse effects on biodiversity and the overall landscape. Whilst, to date, most of these techniques have been used principally in organic production systems, their use in conventional farming is increasing. This is not necessarily because of an increased desire to embrace integrated farming, but more often due to necessity because appropriate ‘Approved’ pesticides are not available for certain crops. This applies almost exclusively to horticultural crops, which are all ‘minor’ crops when compared with arable production.

A specific example is the widespread use of crop covers to exclude the cabbage root fly from culinary swede crops. This was triggered by the withdrawal of chlorfenvinphos, the sole effective insecticide approved for this use. Swede growers have been successful in making this technique viable economically. Part of this involves the re-use of covers over a number of years (equipment has been developed to deal with this e.g. http://www.wondermesh.co.uk/). However, there are still adverse effects in terms of waste disposal, in particular, and the environment and landscape in general.

Using life cycle analysis and carbon footprinting techniques it is possible to attempt to ‘quantify’ the impact of certain farming practices. For example, a study at Nottingham University indicated that the more intensive use of cultivations and mechanical weed control, rather than herbicides, increased the overall carbon footprint of organic systems (http://www.fwi.co.uk/Articles/2007/11/05/108084/organic-weed-control-has-poor-carbon-credentials.html). However, there is a caveat, highlighted in a report by the University of Hertfordshire (2007), since assessing environmental performance in terms of area or yield can produce large differences. In the University of Nottingham study, the calculation was based on the amount of CO_2 produced per tonne of grain and so the lower yield produced by organic crops increased the ‘difference’ between the two methods of weed control. If the yields from the two approaches were similar then the difference between the carbon footprints would have been smaller. The University of Nottingham study also only focused on weed control, not the whole system, so, for example, did not include fertiliser use.

Under a proposal for a regulation of the European Parliament and of the council concerning the placing of plant protection products on the market, it is planned that cut-off criteria for pesticide approvals will be based on hazard rather than risk. Depending on the outcome of discussions, there could be substantial losses to active substances available for use in UK agriculture and horticulture, with subsequent impact on pest, disease, and weed management for key crops. In a recent report (ADAS, 2008), developing methodology (Defra project FO0404) was used to estimate the percentage increase in the carbon footprint of wheat and potato production under a range of proposed scenarios for pesticide withdrawals. This assumed mitigation of crop loss using available technologies (e.g. mechanical weeding or resistant varieties) but did not take account of developing or implementing new technology or innovations that might be required. The estimated increase in the carbon footprint was determined largely by yield effects and ranged from 35-95% for wheat and 25-102% for potato.

Although the application of manures and composts to agricultural land has a beneficial impact in terms of many other policy objectives, it has a high negative score for 'Climate Change'. Considerable research funding is already being directed towards maximising the benefits of manures and composts, whilst minimising their negative effects. Direct injection of manures into the soil, manipulation of ruminant diets and strict guidelines on application dates for manures (e.g. Defra projects AM0120, AC0207, NT1406) are all areas in which research is progressing and providing uptake by farmers is high, climate change objectives could be met.

A number of the techniques within 'Rotation' score negatively for 'Waste' as they involve 'inefficient use' of some resources. Their benefits are related particularly to biodiversity (birds, plants, insects, mammals) and this is why they are promoted. Some of these approaches are also unlikely to be practical or economically viable. Thus again, it may be necessary to compare their value for biodiversity with their negative impact on resource use. One of these techniques is the inclusion of spring crops in a rotation, which also increases the risk of erosion, as the newly cultivated soil is exposed to rainfall. The growing of spring crops is neither economically viable nor practical on heavier soil types, but has major benefits for biodiversity. The cultivation of spring crops is encouraged in current schemes and can benefit growers on lighter soil types. Fallow or set-aside is more suitable for growers on the heavier soil types.

3.2.2 To identify the spatial and temporal constraints on achieving EES objectives through IFM

Table 6 broadly summarises the authors' view of the level of adoption of each technique assessed in the matrix and identifies the likely reasons for the level of uptake that has been achieved. An assessment of the level of adoption of certain IFM techniques highlighted some of the constraints to achieving EES objectives through IFM.

There are a number of spatial and temporal constraints associated with uptake, although these are not the only constraints. Spatial constraints include the geographical location and size of the holding and the spatial distribution of the fields within it. The ease with which some of the techniques can be adopted depends on soil type, field type (e.g. sloping or flat) and the interaction between these physical attributes and the local climate (especially rainfall). For example, spring cropping is generally practiced only on lighter soils where higher income crops such as sugar beet and potato can be grown. Similarly, the recommendation to avoid erosion-prone crops (e.g. potatoes) on erosion-prone soils is difficult to implement as the best soils for such crops are those that are most prone to erosion. The spatial distribution of fields in terms of their soil type and proximity to one another can also reduce flexibility. For example, a recommendation to spatially separate old and new crops to reduce colonisation by pests such as carrot fly may not be possible because of holding size or because the fields with soil suitable for carrot production are situated close to one another. Growers have to optimise their use of the land available to them and sometimes this restricts their options in terms of the IFM practices they can adopt.

Temporal constraints to adoption of certain IFM practices are associated mainly with the weather, market requirements and the risk associated with uncertainty about future weather conditions. With their relative importance depending on the crop, market requirements include quality (physiological, biochemical, cosmetic appearance) and continuity of supply (particularly with field vegetables). In addition, business economics dictate that growers should maximise yield and minimise waste (also a Defra objective). Extreme weather conditions at certain times of year may themselves constrain the implementation of certain IFM practices, whilst in other cases the risk associated with the possible occurrence of extreme weather conditions in the future precludes their adoption.

Apart from spatial and temporal constraints, impracticality and/or economic constraints are common reasons for lower levels of adoption, as is the limited availability of certain 'tools' such as varieties resistant to key pests and diseases. Further information on each technique can be found in Appendix 2.

Whilst the level of uptake of certain IFM techniques may be limiting achievement of EES objectives, Section 3.2.1 has shown that some techniques may also be constraining the achievement of certain key objectives because their outcome has a negative impact (e.g. the impact of mechanical weed control on 'Energy' and 'Climate change'). Objective 4 will examine some of these issues in more detail by attempting to compare the impacts of particular techniques semi-quantitatively using carbon footprinting and an ecosystems approach (Defra, 2009).

Table 6 Integrated farm management techniques and their levels of adoption.

IFM technique	Level of adoption	Comment
1. Rotation		
1a) Arable - A diverse winter sown rotation with at least 3 different crop types	High	High break crop prices and weed problems will encourage crop rotations to be used.
1a) Horticulture - A diverse rotation with at least 3 different crop types	High	The diversity of the rotation will depend on pest, disease and weed problems, but also on other constraints such as the quality of land and proximity to pack house etc.
1b) Include spring crops where profitable and practical	Low	Currently only 28% of the total crop area in England is spring cropped compared to 84% in 1960. Economic sustainability limits to lighter soils where higher income crops can be grown e.g. sugar beet and potatoes.
1c) Include a cover crop over winter	Low	Has too many problems associated with their inclusion in a rotation.
1d) Replace an autumn break crop with a spring break crop	Low	Depends on commodity prices, spring crop yields are often too low, weed and pest problems too great.
1e) Include legumes/fertility building crops in the rotation	High	Legume area has increased by 66% since 1984. Can help with weed control and fertility building.
1f) Provide a crop mosaic	Low	Holding size is increasing and economies of scale are encouraging block cropping.
1g) Avoid erosion prone crops e.g. potatoes on erosion prone soils e.g. sands	Low	Included in Environmental stewardship (ES) schemes, difficult to avoid as the best soils for these crops are the most erosion prone.
2. Soils		
2a) Produce a soil management plan	High	Included in ES schemes.
2b) Avoid intensive cultivations, use minimum tillage techniques (not horticulture)	High	Economy of production and larger farm size has encouraged adoption.
2c) Time cultivations carefully with respect to prevailing weather and soil conditions	High	Problems caused have too many knock on effects.
2d) Match cultivations to crop, weeds, soil type and season	Moderate	Made difficult by large holding sizes.
2e) Reduce cultivations on steep slopes, especially on headlands and near watercourses	High	Included in ES schemes.
2f) Cultivate and plant across slopes	Moderate	Adopted where practicable.
2g) Consider undersowing crops	Low	Limited to specialist areas e.g. mixed farms and organic production.
2h) Minimise harvesting passes in horticultural crops	Moderate	Adopted where practicable.

IFM technique	Level of adoption	Comment
3. Water		
3a) Produce a water management plan	High	Included in ES schemes.
3b) Ensure field drainage is maintained	Moderate	Maintains productivity but possibly neglected on large holdings due to recent economic situation.
3c) Manage ponds for biodiversity	Low	Million ponds project launched Feb 2009
3d) Exclude livestock from ditches, ponds and watercourses	Moderate	May be limited by poor returns on livestock farms.
3e) Undertake an irrigation water use assessment	High	Driven by profitability as irrigation is costly and use has to be optimised on crops.
3f) Avoid irrigating before it rains	Moderate	Limited by size of holding and mobility of equipment.
3g) Apply sufficient irrigation at critical timings	Moderate	Limited by size of holding.
4. Establishment		
Variety		
4a) Grow resistant varieties wherever possible	Moderate	Limited by availability, disease threat and variety spread on farm.
4b) Exploit the characteristics of competitive and vigorous varieties	Low	Limited information available.
Sowing date		
4c) Optimise sowing date	Moderate	Limited by size of holding and weather.
4d) Sow spring crops when seedbeds are suitable	High	Ensures success especially in horticulture.
Seed rate		
4e) Consider reducing seed rates	High	Good research background for arable, cost saving.
4f) Consider increasing seed rate in some circumstances	Moderate	Limited opportunity.
5. Nutrition		
5a) Have a nutrient management plan	High	Part of ES.
5b) Buy good quality fertiliser	Moderate	Limited by cost and availability.
5c) Calibrate fertiliser spreader	High	Good practice.
5d) Predict crop needs (i.e. decision support systems or canopy management or sensing)	High at the basic level e.g. RB209 Low at the highly technical scale	Limited by economies of scale, training in techniques.
5e) Adjust the timing and amounts of split applications as accurately as possible	Moderate	Limited by size of holding.
5f) Avoid fertiliser application to field boundaries	Moderate	Depends on 5a and 5b.
5g) Consider using starter fertiliser (horticulture)	Moderate	Limited to specialist horticultural crops and potatoes.
5h) Apply manures and composts to increase organic matter	High	But limited to area where available, usually for nutrients.
6. Crop protection - General		
6a) Have a crop protection management plan	High	Part of ES.
6b) Ensure all operators trained to appropriate level	High	Part of ES.
6c) Calibrate sprayers	High	Part of ES.
7. Weeds		
7a) Plan rotational strategy to take weed control into account	Moderate	Depends on weeds present. High in grass weed areas.
7b) Use cultural control for weeds where appropriate	Moderate	Used in field vegetables in organic systems and where herbicide availability restricted.
7c) Leave residual levels of non-aggressive weeds in crops where possible	Low	Growers dislike dirty fields.

IFM technique	Level of adoption	Comment
7d) Establish conservation headlands	Low	Low take up in ES schemes.
7e) Alter drilling date	Low	Limited by size of holding and risk.
8. Pests		
8a) Plan rotation and spatial separation to minimise pest problems	Low arable, moderate horticulture	Access to suitable land is a constraint?
8b) Use cultivations to control pests (e.g. slugs)	Low	
8c) Use pest resistant varieties	Low arable, moderate horticulture	Arable and horticulture - few varieties available.
8d) Identify crops at risk by forecasting, sampling, monitoring or trapping and using thresholds	Moderate	Increasing number of methods available due to research.
8e) Use narrow spectrum PPPs	Low	Limited number available, usually insecticides.
8f) Encourage beneficial enemies e.g. field margins, conservation headlands and set-aside	Moderate	Due to inclusion in ES.
8g) Use physical barriers e.g. fleece (horticulture)	High	In certain high value crops in horticulture, expensive.
8h) Alter drilling or harvesting date	Low	Due to other pressures – yield, production dates.
8i) Trap cropping	Low	Limited positive research.

9. Diseases		
9a) Plan rotation and spatial separation to minimise disease problems	Moderate	In arable situations.
9b) Use disease resistant varieties	Moderate	Yield and market is more important.
9c) Identify crops at risk by forecasting, sampling, monitoring or trapping and using thresholds	Low	Increasing number of methods available due to research.
9d) Use appropriate dose techniques	High	Backed by extensive research and saves growers money.
9e) Avoid early sown or out of season crops	Moderate	Market driven.
9f) Maintain good intercrop hygiene e.g. residues	Moderate	
10. Environment		
10a) Increase and improve biodiversity areas (field margins, conservation headlands)	Moderate	Part of ES.
10b) Maximise the benefits of set-aside/fallow	Moderate	Was high but now low as zero set-aside.

3.3 Objective 3. To compare the available options for benchmarking IFM and to identify ways in which these could be used to develop site specific targets and processes for local improvement and adoption.

Techniques currently most beneficial in meeting policy objectives

Combining information on the uptake of IFM techniques with the information from the matrix (Table 4) should indicate which of the techniques are currently most beneficial in meeting policy objectives (Table 7). The majority of these techniques have moderate or high uptake, not necessarily because they meet policy objectives but because they result in financial benefit for the farmer or are part of the environmental schemes. Non-fertilised conservation headlands currently have a low level of uptake in ES schemes, <1% (Defra, 2006), as they can be problematical for the grower. A greater level of financial support could increase their uptake and provide a benchmarking tool.

Table 7 IFM techniques with the most positive beneficial effects on policy objectives

IFM technique	Positive scores (%)	Negative scores (%)	Level of adoption
8f) Encourage beneficial enemies e.g. field margins, conservation headlands and set-aside	62	0	Moderate
2b) Avoid intensive cultivations, use minimum tillage techniques (not horticulture)	57	0	High
2c) Time cultivations carefully with respect to prevailing weather and soil conditions	49	0	High
1a) Arable A diverse winter sown rotation with at least 3 different crop types	46	3	High
3d) Exclude livestock from ditches, ponds and watercourses	43	0	Moderate
4d) Sow spring crops when seedbeds are suitable	43	0	High
2d) Match cultivations to crop, weeds, soil type and season	43	3	Moderate
3b) Ensure field drainage is maintained	43	3	Moderate
7d) Establish conservation headlands	43	8	Low
6b) Ensure all operators trained to appropriate level	41	0	High
9d) Use appropriate dose techniques	41	0	High
10b) Maximise the benefits of set-aside/fallow	41	5	Moderate
10a) Increase and improve biodiversity areas (field margins, conservation headlands)	41	8	Moderate
1a) Horticulture - A diverse rotation with at least 3 different crop types	41	11	High

Most IFM techniques are not modern developments; they have been used by UK growers since farming began. For example, crop rotation was introduced as early as the 19th century with the Norfolk four-course rotation. Other techniques have been developed to take advantage of the introduction of modern technology e.g. minimum cultivations following the invention of the tractor. Most IFM techniques have evolved rather than been developed and uptake within the industry is already high.

The IFM techniques that have the greatest negative effects on policy objectives are summarised in Table 8. Cover crops are used to protect the soil during periods of fallow and have been shown to reduce the amount of nitrogen lost by leaching (Harrison *et al.*, 1996). In practice, integrating a cover crop into a rotation results in additional field work and a range of problems for farmers, with few perceived benefits.

The use of physical barriers has been a major breakthrough in allowing the control of pests whilst minimising pesticide usage. This method of pest control has positive effects on the supply of safe, good quality food but there are many disadvantages because their manufacture requires additional energy consumption and because of problems with their disposal. Further research in this area could minimise the negative effects, as use of these products is high.

Cultural control for weeds is used successfully on lighter soil types and mainly in row crops, but compared with herbicide application, energy usage and the time taken are considerably higher. Damage to ground nesting birds can be considerable during the spring and summer months.

Table 8 IFM techniques that are most negative to policy objectives

IFM technique	Positive scores (%)	Negative scores (%)	Level of adoption
1c) Include a cover crop over winter	16	30	Low
8g) Use physical barriers e.g. fleece (horticulture)	24	30	High
7b) Use cultural control for weeds where appropriate	11	35	Moderate

Benchmarking

Defra has challenging targets in terms of climate change, pollution, biodiversity and other environmental factors and it is important that IFM practices achieve a positive outcome in terms of these targets. There are a number of schemes associated with IFM that are already assessing ‘performance’. These include crop assurance schemes such as the Assured Produce Scheme, Eurepgap, and LEAF. The University of Hertfordshire (2007) has completed a review of integrated farming standards and eco-labelling world-wide. Their conclusion was that, in general, compliance with such schemes is based on undertaking various production practices to a set standard (‘Best Practice’) rather than on the outcome of such tasks. This is to a great extent because ‘outcome’ is difficult to measure. The tacit assumption is made that the relationship between various practices and the desired outcome is robust across a variety of situations. However, this may not be the case.

What is benchmarking?

The definition of a benchmark is ‘a standard by which something can be measured or judged’. There are a number of different types of benchmarking (Business Performance Improvement Resource, www.bpir.com):

- **Informal benchmarking**: Learning from the experience and expertise of others through comparing practices and processes e.g. through best practice tours, conferences, best practice websites, networking
- **Performance benchmarking**: Comparing performance levels of a process/activity with other organisations
- **Best practice benchmarking**: Following a structured process for comparing performance levels and learning why better performers have higher levels of performance and adapting/implementing those better practices

Benchmarking can be used as a way for farms to cut costs and otherwise improve their performance, by exchanging information with other farms (Food Chain Centre, 2003). Farmers join a group and each member contributes data. The data are then analysed and group members are given a summary e.g. figures for the average, highest and lowest in each group. Each farmer can then compare his or her performance with the rest of the group. This highlights opportunities for improvement. From this information it is possible to see the approaches that the most effective farmers are taking and so if, for example, the most profitable farmers are being successful because of the lower costs of inputs per hectare, then it should prompt others to ask whether they could save money by applying their own inputs more carefully. Benchmarking may offer an opportunity for farms to improve their IFM performance and, certainly, at the very least, knowledge exchange in terms of the execution of certain practices is extremely valuable. Organisations such as LEAF and FWAG, and Defra advice contracts already promote such knowledge exchange.

What can be benchmarked?

A benchmark needs to be quantifiable and easy to measure. It also needs to be something that is currently not achieved widely, so that increases over a baseline can be measured. Whilst an increase in the uptake of certain IFM practices is desirable, it would be even more challenging to benchmark IFM in terms of outcome, so that the direct contribution to Defra’s targets could be assessed and improved upon.

A group at Leiden University (de Snoo *et al.,* 2006) have developed a benchmarking tool for arable farmers in the Netherlands. The tool is applicable to all farm types and is accessible via the internet. The pilot version of the benchmarking tool is based on pesticide usage. There is great variation between individual farmers in the amounts of pesticide they use, indicating that there must be considerable scope for improvement. Many farmers do not know how their pesticide usage compares with others and the benchmarking tool allows them to ask questions about their approach and perhaps become more motivated to modify their practice, improving both their environmental and economic performance.

Pesticides are obviously not the only area suitable for benchmarking, and too much focus on them could be detrimental to wider issues. Environmental benchmarking of arable farming was developed using the MEASURES (Multiple Environmental Outcomes from Agricultural systems) framework (Defra, 2004), benchmarks were produced for environmental burdens and crop outputs for five main different arable and mixed farming types over regions of England. Likewise farm nutrient auditing and benchmarking have been developed as support for the PLANET software (Defra, 2005). There are several existing audit tools or systems under development which refer only to energy use and/or emissions of greenhouse gases or identify where savings and improvements could be made ranging from the simple e.g. CALU 2007, SAVFuel and Refuel. These use electricity and fuel bills to indicate energy demands of the business. Others e.g. CALM are more complicated and have been developed to determine to inputs to individual farm operations including machine type, tractor power and work rate. These have been reviewed as part of a Defra funded project OF0347 (Little, 2007).

The project team assessed the policy objectives used in the matrix (Table 4) to identify those that may be suitable for benchmarking. These are summarised in Table 9. Outcomes that are already measured and could be used in benchmarking include fuel and other energy consumption (per hectare), water consumption (crop dependent), yield return for fertiliser input and pesticide usage. Others that might be measured include water quality, soil compaction, soil structure, earthworm populations, soil organic matter, moisture holding capacity, within a locality, it might also be possible to benchmark certain plant or animal species e.g. birds (common bird census).

Some current schemes such as the agri-environment schemes are less suitable for benchmarking, initial uptake can be benchmarked, but as the schemes run for several years there is little change over time.

Practicalities of setting up a benchmarking system

Farms can benchmark against their own performance or that of a group, or they might benchmark against the results of a survey of farmer practice such as the pesticide usage survey (PUSSTATS, 2009). However, survey information might need to be presented in more detail to be of greatest use.

Because of the constraints that geographical location imposes on the ability to undertake certain IFM practices (Section 0), benchmarks need to be regional and related to soil type. In addition, most surveys tend to be at farm level and not at crop level.

There may also be seasonal variation so, for example, comparing pesticide usage with a benchmark can be limiting, as each farming year brings a different range of problems that the farmer has to overcome. This can include different diseases and pests and varying levels of such e.g. potato blight in the wet years of 2007 and 2008. Often growers are allocated sowing dates for crops such as vining peas. There are also different approaches to production.

Benchmarks could be set annually by an expert panel who take into account the previous season; these would then be subject to revision. Some of the benchmarks would not be applicable to each farm every year. An assessment, such as the LEAF audit, might indicate the most important areas for each farm to focus on.

The pilot group of farmers tested in the Dutch project (de Snoo, 2006) responded positively to the benchmarking tool. However, there are difficulties associated with setting up a benchmarking system, such as the need to engage a sufficiently large group of farmers and the availability of appropriate data. If such an approach were taken, it would be important to ensure that the burden of data collection and administration was not too great. Farmers would also require easy access to information and advice, both in terms of data collection and entry and also in terms of improving their performance (Tzilivakis & Lewis, 2004).

Farm benchmarking was a core activity for the Food Chain Centre between 2004 and 2007 (Food Chain Centre, 2007) and they ran a programme funded by Defra’s ADS Scheme with the aim of increasing the uptake and impact of farm benchmarking, at this stage mainly related to business performance. Their ‘preferred’ model was to organise farm benchmarking through business clubs led by a facilitator and they envisaged that comparisons should take place between clubs locally, regionally, nationally and even internationally. The aim would be to generate and implement improvement plans based on benchmarking results and then to repeat the process at regular intervals. The Food Chain Centre made some progress in increasing farmer participation, with help from the Levy Boards in particular, but this has not reached a critical mass of farmers. Barriers to uptake that they identified included farmer resistance to sharing information, difficulties with data capture and reporting results revolving around IT, and suspicions amongst farmers that the data might be used against them. These barriers would obviously need to be overcome if methods were developed to benchmark IFM.

Table 9 Policy objectives - suitability for benchmarking at the farm level.

Policy objective	Suitability for benchmarking	Comment
Energy		
Reduce energy consumption	√	

Policy objective	Suitability for benchmarking	Comment
Increase energy efficiency	√	
Increase use of renewable energy	√	
Climate change		
Maintain/improve air quality (particulates)	x	Could use PAS 2050 approach, gives a framework from which this could be developed
Reduce methane emissions	x	
Reduce NOx emissions	x	
Reduce N_2O emissions	x	
Reduce CO_2 emissions	x	
Waste		
Reduce waste and CO_2 emissions from inputs	x	Also involved in PAS 2050
Reduce waste and CO_2 emissions from outputs	x	
Efficient use of resources	x	
Increase recycling/composting, reduce landfill	x	
Use of recycled materials	x	
Reduce flooding and/or erosion	x	Few have this information on a farm basis
Maintain/improve water supply	x	
Improve water quality - chemical	x	
Improve water quality - biological	x	
Food & farming		
Has a positive environmental benefit	x	Not specific enough
Provides rural employment in thriving communities	x	Not farm specific
Ensure food is available to meet consumer demand	x	Not farm specific
Provision of safe good quality food	x	Meets existing regulations
Pesticides, availability of PPPs	x	Not farm specific
Pesticides: more alternatives and greater use of ICM	√	
Inclusion in agri-environment scheme	√	
Practicality	x	Dictates success but not measurable
Economically viable	x	Already in use
Resource protection		
Sustainable management of land	x	
Improve soil management		
Maintain/improve physical soil status	√	
Maintain/improve chemical soil status	√	
Value, safeguard and enhance biodiversity – Birds	√	
Value, safeguard and enhance biodiversity – Plants	√	Very expensive to measure and driven by multiple factors
Value, safeguard and enhance biodiversity – Insects	√	
Value, safeguard and enhance biodiversity – Mammals	√	
Improve leisure access to natural environment	x	Not farm specific
Improve cleanliness of local environment	x	Not farm specific
Maintain and improve living landscape	x	Not farm specific

3.4 To explore the links between IFM and ecosystem services and demonstrate how IFM can affect the delivery of ecosystem services.

The natural environment provides a wide range of goods and services – 'ecosystem services' – that underpin human health, well-being and prosperity. The Government (Defra) wishes to embed an ecosystems approach (EsA) into its strategic and policy areas (Defra, 2007) and has chosen to follow the approach established by the Millennium Ecosystem Assessment (MA, 2005) which provided a framework for an EsA by allocating services to four categories: provisioning, regulating, cultural and supporting. Although land management influences all four services, this study focuses on the provisioning and regulating services provided by agriculture.

There is current interest in determining the carbon footprint of agriculture and this is relevant to a number of the Defra policy objectives outlined in Table 2 and presented in the IFM matrix (Table 4: Appendix 3). These are specifically the objectives associated with energy, climate change and waste. However, the carbon footprint does not take account of impacts on water, food and farming and resource protection, which are also targets for IFM, and this project has already identified some conflicts, where IFM practices targeted to achieve one policy objective have a negative impact on the delivery of another. Similarly, the impacts of IFM practices on production are not always assessed. So while it is easy to show environmental gains from altered management practices, these are often at the expense of production.

The EsA matrix developed in Defra project AC0308 (Ecosystem Services for Climate Change Adaptation in Agricultural Land Management) contains a number of ‘service themes’ (stable climate, clean water, soil status, biodiversity) which are identical or similar to the policy objectives used in the IFM matrix developed in the current project. In addition, because production is a provisioning ecosystem service, the EsA matrix can be used to assess not only the effects of a certain management practice on the environment but also on production. This section of the report explores and compares the use of carbon accounting and an EsA to assess the impact of integrated farming on the environment and human well-being and to develop strategies that reduce conflicts between policy objectives.

Crop management scenarios

Eighteen crop/management strategies (scenarios) were chosen to illustrate the linkage between carbon accounting and an EsA when comparing integrated farming practices. The scenarios were selected to include several crops (winter wheat, beans, oil seed rape (OSR), carrot, onion) but also incorporated a number of management strategies which would illustrate how IFM techniques would be assessed using the two accounting techniques.

Scenario 0 represents set-aside and is the baseline against which all other scenarios are judged.

Scenarios 1 to 6 are for winter wheat and include both milling and second wheats, as well as different varieties and applications of nutrients and herbicides. Manures were included in Scenario 6. Scenario 7 is for winter oil seed rape as a contrast to winter wheat.

Scenarios 8 and 9 are for field beans (spring, winter) and represent a low input system since they receive no additional nitrogen fertiliser.

Scenarios 10 to 13 are for carrot production with different management practices. The two major contributors to the carbon footprint are crop covers and refrigeration. In Scenario 10 the crop is covered with black plastic and straw to protect mature main crop carrots in the ground over winter and in Scenario 13, clear plastic covers are applied early to advance crop growth.

Scenarios 14 to 17 are for onion production and include different weed management strategies.

3.4.1 Carbon footprinting

To quantify many of the impacts on Under Climate change, the British standard PAS 2050 - Assessing the life cycle greenhouse gas emissions of goods and services could be used. PAS 2050 is the Publicly Available Specification (PAS) for a method for measuring the embodied greenhouse gas (GHG) emissions from goods and services. A working version of PAS 2050 has been published (see http://www.bsigroup.com/pas2050).

Details of the inputs for the carbon footprint inventories prepared for different crops/management systems are in Appendix 5.

3.4.2 Ecosystems approach

The EsA developed in project AC0308 provides a provisional framework for decision making in a highly heterogeneous terrestrial environment through utilising best available knowledge and resources. The ‘ecosystem service cascade’ was used as a basis for the EsA, which shows that ecosystem services can be viewed as ‘service themes’ (Haines-Young & Potschin, 2007) that capture a variety of ‘products’ with direct value to well-being. The themes can be refined and expanded to meet the circumstances of any particular study. The service themes used in the present project are shown in Table 10.

Due to its recognition internationally, the MA Typology was used within the EsA to create ‘service themes’ with clearer links to well-being that encompass a series of associated ‘products’. ‘Products’ are defined as features and qualities of the natural environment that matter directly to people. ‘Product’ implies something physical, and this physical quality is crucial to measuring the product and placing a value on it. ‘Products’ are manufactured through ‘land units’ by utilising natural and managed inputs, and the ecological functions and natural capital pertaining to the land unit. As with the ‘service themes’, ‘products’ can be chosen to meet the circumstances of any particular study. The ‘products’ used in the present study are shown in Table 10.

Table 10 Service themes and products used in present study.

SERVICE THEMES	PRODUCTS
Cultivated Food (for human consumption)	Wheat Oil seed rape Field beans Carrot Onion
Cultivated Non-food crops (utilised by humans)	Timber Oil seed rape for biodiesel Biomass for fuel
Clean air (impact on human health)	Ammonia Tropospheric ozone Dust Pollen
Stable climate: global (regulation of greenhouse gases)	Carbon dioxide Nitrous oxide Methane
Stable climate: local (regulation of natural hazards)	Off-farm flood prevention Storm regulation Fire regulation Landslide regulation
Clean water (within ecosystem)	Herbicide residues Fungicide residues Insecticide residues PGR residues Molluscicide residues
Clean water (for human consumption)	Water availability Phosphate Nitrate Faecal Indicator Organisms Veterinary medicines
Regulation of pests and diseases (of humans)	Coliform bacteria *E. coli*
Regulation of soil status	Soil status - physical Soil status - chemical Preventing soil erosion
Biodiversity (for protection of key species/habitats)	Skylarks Crop Pollinator 1 Wildflower Pollinator 1 Freshwater invertebrate 1 Habitat provision Spare
Recreation	Countryside visit expenditure

The EsA matrix enables the user to consider the ‘value’ of a range of ‘products’ in terms of human ‘well-being’. This ‘value’ captures current product supply and demand, in addition to future demand. The matrix then provides a framework in which the relative values of ‘well-being’ can be assessed. The EsA matrix allows the user to assess the impact of a range of management options on future ‘product’ supply - the ‘marginal change’. It calculates the ‘total marginal change in value’ for each management option automatically and therefore can assist in an assessment and decision-making process.

The EsA matrix can be used to assess any number of different scenarios and to score them on their delivery of ecosystem products against a baseline (set-aside in this study). The scoring system is relative rather than absolute. The baseline is zero; scores greater than zero indicate that the scenario delivers more ‘benefits’ than set-aside, while scores below zero indicate that fewer benefits are delivered. The EsA matrix is an area-based scoring system, so outputs should be considered on a ‘per hectare’ basis. The ‘user manual’ for the EsA matrix (developed in project AC0308) is provided in Appendix 6.

The approach followed here allows all 18 scenarios to be compared with one another. The data for the scenarios are taken from 17 carbon footprint inventories prepared for the different crops/management systems (ignoring the set-aside option). Where available, ‘real’ data (nitrogen fertiliser, pesticides, carbon dioxide, nitrous oxide) were used in the EsA matrix. However, expert opinion was used to populate other areas of the matrix (ammonia, water quality and quantity, biodiversity).

The EsA matrix contains two parameters that can be altered to change the overall delivery of ecosystem ‘products’: ‘product value’ and ‘change in supply’; the range of both parameters is set between +10 and -10 and actual data values are scaled to fit. ‘Product values’ are set at the outset of any investigation and any changes affect every scenario. ‘Change in supply’ values are set for the individual scenarios and reflect differences in: yield; fertiliser use, pesticide use, water use, leachate, soil quality and biodiversity etc. Some inputs impact on more than one ecosystem service, for example, nitrogen fertiliser impacts on a ‘stable climate’ through emissions of both carbon dioxide (carbon footprint) and nitrous oxide: on ‘clean water’ through nitrate leaching and it also reduces ‘biodiversity’. The values of all the different products are summed to give an EsA matrix score. A full description of this EsA can be found in the final report for Defra project AC0308.

3.4.2.1 Results

The production scenarios with their yield (t/ha), applied N (kg/ha), carbon footprint (t/ha), carbon footprint (t/t) and EsA score (/ha) are shown in Table 11

The EsA scores for the 18 crops/management strategies (scenarios) ranged from -4.5 (winter beans) to -114.9 (carrots under early plastic). Averaging the scenarios by crop shows that beans provided the highest EsA score (-5.3) > oil seed rape (-68.0) > winter wheat (-88.1) > carrot (-98.8) > onion (-109.8); within crop variation was quite small. There was no clear relationship between the carbon footprint (Figure 2) and the EsA score or applied nitrogen and the EsA score (Figure 3). This indicates that although both the carbon footprint and applied nitrogen are important inputs into the EsA, they do not completely determine the score.

Table 11 Production scenarios with yield (t/ha), carbon footprint (t/ha), carbon footprint (t/t) and ecosystem services assessment (ha)

Scenario number	Crop	Production method	Yield (t/ha)	Applied N (kg/ha)	CO_2e t/ha	CO_2e t/t	EsA/ha
0	Set aside		0	0			0
1	1st Winter wheat	Milling after oil seed rape	7.5	190	4.5	0.59	-86.5
2		Milling after beans	7.5	220	4.9	0.65	-96.6
3	2nd Winter wheat	Feed	8.3	185	4.5	0.55	-81.5
4		Feed, OWBM resistant variety	8.3	185	4.5	0.55	-87.5
5		Feed, high black-grass situation	7.4	185	4.5	0.60	-80.3
6		Feed, manure applied	8.3	160	6.5	0.79	-96.1
7	Oil seed rape	Winter	3.2	190	4.1	1.29	-68.0
8	Beans	Spring	3.7	0	0.4	0.12	-6.0
9		Winter	4.5	0	0.5	0.12	-4.5
10	Carrot	Maincrop, stored in field	86.0	94	30.6	0.36	-90.6
11		Maincrop, autumn harvested	86.0	94	25.6	0.30	-86.2
12		Maincrop, netted	50.2	94	16.6	0.33	-88.5
13		Early plastic	85.5	94	24.6	0.29	-114.9
14	Onion	Conventional	45.0	150	9.4	0.21	-105.3
15		Hand weeded	35.6	150	9.1	0.26	-112.7
16		Mechanically weeded	36.0	150	9.0	0.25	-113.7
17		Herbicide	46.0	150	9.9	0.22	-107.9

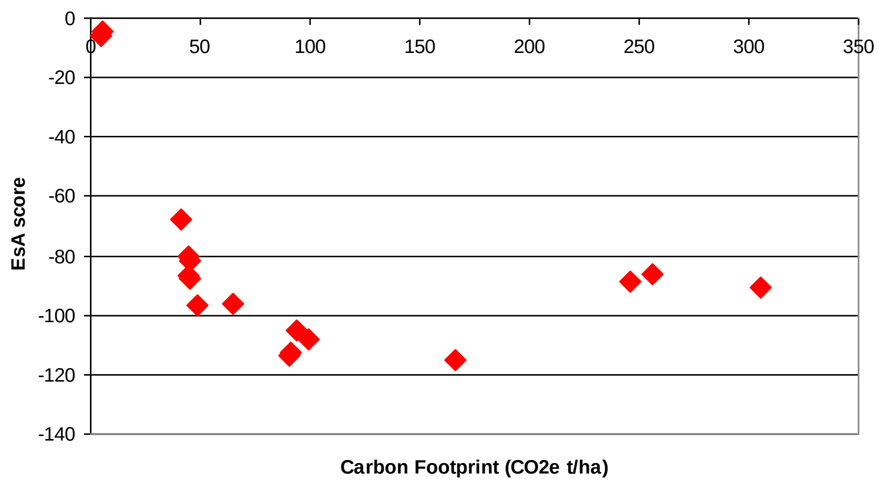

Figure 2 Relationship between the EsA score and the carbon footprint

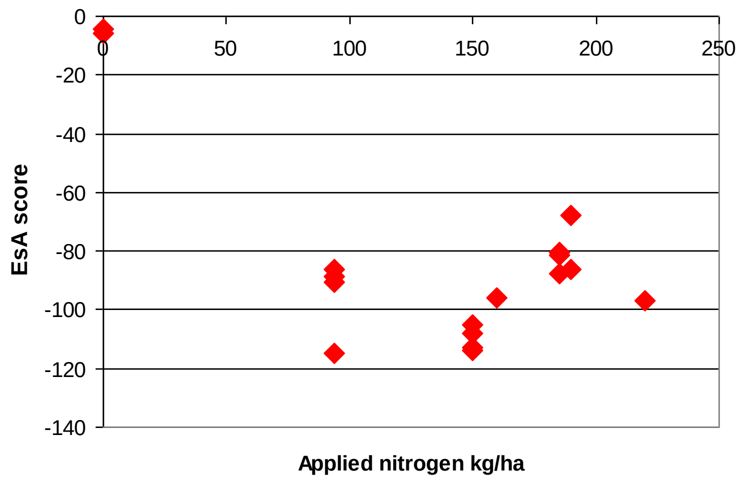

Figure 3 Relationship between the EsA score and applied nitrogen

Winter wheat and oil seed rape

Six scenarios were considered; the main differences were in the type and rate of nutrients and rate of herbicide application. EsA scores ranged from -80.3 (Scenario 5) to -96.6 (Scenario 2) (Figure 4). Manures were included in Scenario 6; they provide valuable nutrients to the crop, the organic matter improves soil structure and increases water holding capacity. However, the use of manures increases the carbon footprint of wheat production significantly due to the gaseous emissions of ammonia and nitrous oxide. Nitrous oxide emissions remain the biggest influence in the EsA score even where manure is applied, since ammonia has less impact than nitrous oxide. Oil seed rape receives a similar amount of nitrogen to wheat, but fewer pesticides, resulting in a lower carbon footprint (per ha, but not per tonne) and EsA score.

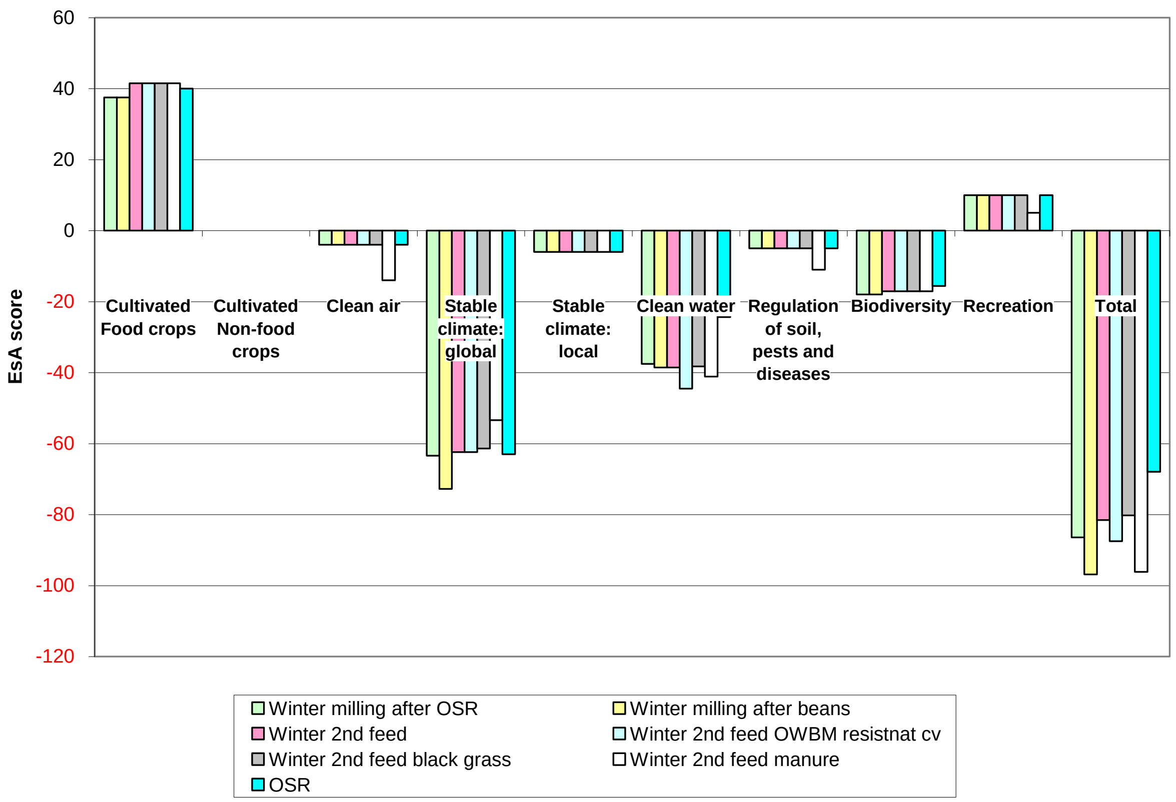

Figure 4 EsA scores for wheat and oil seed rape (OSR) production scenarios – contributions from each service theme and total.

Field beans

The scenarios for beans illustrate the value of growing a low-input legume crop to the delivery of ecosystem services. Beans require no additional nitrogen and few applications of pesticides and consequently result in a relatively low carbon footprint and high EsA score, whilst producing a valuable product.

Carrot

Four scenarios were considered; the main differences are due to the use of covers in Scenarios 10 and 13 and additional foliar nutrients in Scenario 13. Refrigerant inputs resulted in the carbon footprint being up to three times higher than that of onion, and up to six times higher than winter wheat (Figure 5). Although these data were obtained from a reliable source, they should be treated with caution. The carbon footprint is only one input into the EsA matrix, so although carrot had the highest carbon footprint scores, the impact of the high carbon footprint was 'reduced' using the EsA.

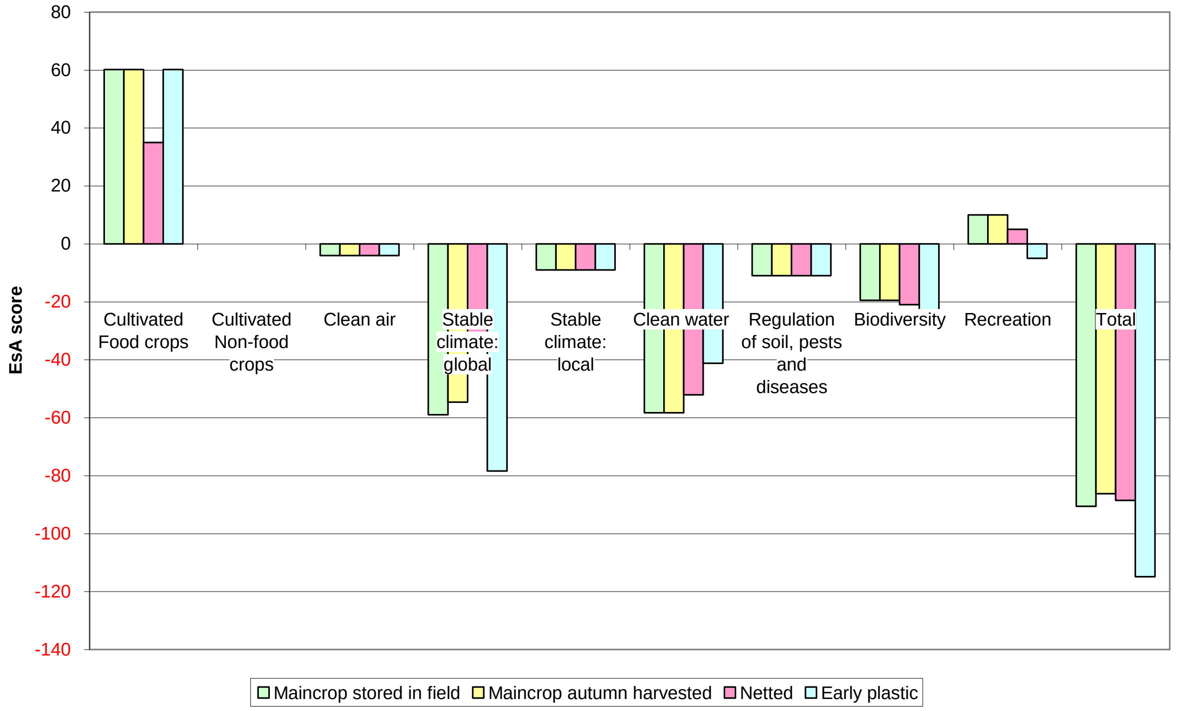

Figure 5 EsA scores for carrot production scenarios – contributions from each service theme and total

Onion

Four scenarios were evaluated. The carbon footprint was greatest for the onions treated with herbicide, whilst the EsA score was least for the onions that were weeded mechanically. In onion production, the greatest driver affecting the carbon footprint is yield. Yield is lost where either hand weeding or mechanical weeding is used alone, because it is difficult to achieve a high level of weed control. As a result, yield is reduced through competition and a greater percentage of the crop is damaged. A reduction in the footprint could be achieved by utilising crop residues.

3.4.2.2 Conclusions

Both the carbon footprint and the EsA score are 'only as good as the data available'. This is particularly true for the EsA score. It has been acknowledged that ecosystem service valuation is ultimately a socio-political process, and that science may inform and assist in this process, but that it is not a scientific process (Wallace, 2007). The involvement of stakeholders is critical in the process of identifying 'themes', 'products' and establishing values. The results of the comparisons presented here must be considered in this context.

The advantage of using an EsA for delivering IFM is the ability to score different management approaches against any, or all, of the Defra objectives and to use the matrix to compare approaches. It is also a very flexible approach, since it can incorporate any number of service themes and products, although this means that the approach is less mechanical than a carbon footprint and requires more thought when setting up the matrix initially. In addition, the EsA supports more 'rounded' decision-making since it is possible to consider 'all' impacts and it reduces the risk of making a decision based on measurement of one or two parameters that might be 'wrong' in a wider context.

At this early stage in its development, this particular EsA is very basic and the results should be used for guidance only, rather than being taken as 'exact science'. There was a general, although statistically poor, relationship between the carbon footprint and the EsA score; high footprints tended to result in a lower EsA score. The EsA tended to 'highlight' high use of nitrogen fertiliser but 'reduced' the impact of a high carbon footprint. The approach can highlight some interesting comparisons. A good example of this is the comparison between Scenario 2 (milling wheat following beans) and Scenario 6 (feed wheat with manure). Both scenarios produced the same EsA score but achieved it in different ways. Scenario 2 was heavily influenced by the high application rate of nitrogen fertiliser, resulting in high nitrous oxide emissions and nitrate leachate, but it still yielded less wheat/ha than Scenario 6. Scenario 6 produced a good yield, using less nitrogen fertiliser, but was 'handicapped' by ammonia emissions and potential bacterial problems from manure use. The wheat scenario with the lowest carbon footprint and the highest EsA score was Scenario 5, which despite the highest level of herbicide use, achieved a good yield with a lower amount of nitrogen fertiliser.

Although the comparisons presented here are relatively superficial and based on 'standard' production systems, they demonstrate that the EsA works for IFM. This is a step beyond the assurance schemes in use already, which tend to be prescriptive about inputs and pay little regard to outcome. The EsA allows the provision of ecosystem services to be judged against crop production.

Although it may be difficult to use the EsA to interpret specialised systems, for example, early carrots under plastic, it could potentially be used with main season crops to resolve some of the long standing questions about maintaining environmental stewardship without jeopardising yields. If standard systems (benchmarks) could be agreed for individual crop production systems, these could be used as a baseline in a crop specific EsA matrix which could enable all other farming systems, not just IFM, to be judged against a common value.

The EsA matrix described here is simple; it contains only a limited number of IFM objectives and was conceived to test the hypothesis that a matrix methodology could deliver useful results. We suggest that it does, and that further work is required to develop the matrix to include all the objectives in the IFM matrix. If successful, truly integrated farming may be a step closer.

The EsA provides a holistic assessment of land management strategies, rather than focusing on cropping alone. No single input (crop, yield, fertiliser, pesticides, pollution, GHG) is dominant, but all contribute to the overall score. Individual IFM strategies contribute little to the overall EsA score, but use of the matrix permits a broader, more balanced, view of the overall approach to land management. However, the EsA matrix can be used only on an 'area' basis, which may cause conflicts when comparing EsA scores with carbon footprints, which can be presented both in terms of area, and yield. This mis-match is an issue that should be recognised during policy development and implementation.

4. Recommendations

- Further work is required to develop the EsA to include all the objectives in the IFM matrix.
- Further work is required to identify and 'value' the EES contributions of different IFM practices. Until the nature and scale of the 'services and products' that IFM delivers are identified and valued, it is difficult to prioritise and target specific practices.
- It is important to recognise that an increase in yield achieved using the same inputs will lower the carbon footprint per product unit, but that certain ecosystem services and products are delivered irrespective of yield. More work is required to determine how the two contrasting methods of assessment (carbon footprint and EsA) can be brought together.
- Future research should be assessed in terms of impact in relation to both carbon footprint and EsA scores. Any IFM practices which cause significant yield reductions, especially without reductions in input, will not assist in the delivery of Defra objectives.
- The analysis in this report could be developed further if Defra policy objectives were prioritised or weighted. This would allow fine-tuning of desired management practices.
- There is a need for significantly more funding for research into, and development of, tools and techniques that provide alternatives to artificial inputs, but which do not increase the carbon footprint (e.g. biological control, some methods of cultural control, host-plant resistance). This includes support

for knowledge transfer to ensure that techniques are viable commercially and will be used by farmers and growers.

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References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

S K COOK, R COLLIER, J H CLARKE and R LILLYWHITE (2009) Contribution of integrated crop management practices to Defra objectives. *Aspects of Applied Biology 93. Integrated Agricultural systems: Methodologies, modelling and measuring.*