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Integrated Agricultural Systems: Methodologies, Modelling and Measuring

Contribution of integrated farm management (IFM) to Defra objectives

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Summary

A farming system comprises a complex of interrelated and interacting factors. Any study of an isolated part of the system will not provide adequate understanding of the behaviour of the entire system and interactions may be equally or more important than individual 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 on the environment. This must be achieved whilst maintaining the economic viability of the farm enterprise. Our 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. Carbon footprinting is used to quantify the impact of some integrated farming practices.

Key words: Integrated farm management, Defra policy objectives

Introduction

Sustainable 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 together with a viable, diverse rural economy; and consistently high standards of environmental performance minimising impacts on natural resources. A farming system comprises a complex of interrelated and interacting factors. Any study of an isolated 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 individual 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 on the environment, whilst maintaining the economic viability of the farm enterprise. The overall aim of the study described in this paper, was to improve the understanding, promotion and adoption of integrated farming practices (IFM) in cropping systems. One of the key objectives was 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.

Materials and Methods

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. Similarly, a list of current Defra economic, environmental and social (EES) policy objectives was identified. The IFM practices applicable to arable and horticultural crop production were scored against the list of current Defra EES objectives in the form of a matrix, a selection of which are shown in Table 1. 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 = 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.

A number of crop/management strategies (scenarios) were chosen to illustrate the effects of specific IFM practices on the carbon footprint (Table 2). 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. Scenarios 7 to 10 are for onion production and include different weed management strategies. Scenarios 11 to 14 are for carrot production with different management practices. The two major contributors to the carbon footprint are crop covers and refrigeration. In Scenario 11 the crop is covered with black plastic and straw to protect mature main crop carrots in the ground over winter; in Scenario 13, the carrot crop is covered with fine mesh netting to exclude carrot fly; and in Scenario 14, clear plastic covers are applied early to advance crop growth. The British Standard PAS 2050 – 'Assessing the life cycle greenhouse gas emissions of goods and services' was used to calculate the carbon footprint and this is expressed in tonnes/ha and tonnes/tonne crop produced (see http://www.bsigroup.com/pas2050).

Results and Discussion

The potential benefits and dis-benefits of adopting particular IFM techniques were summarised for each policy area. For the policy areas of 'Energy', 'Climate change', 'Waste' and 'Resource Protection', adoption of IFM techniques results in 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.

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 study. 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. The IFM techniques associated with soil management also have large positive benefits for the reduction of CO_2 emissions, generally associated with reducing energy consumption. However, although the application of manures to agricultural land has a beneficial impact in terms of many other policy objectives, it has a high negative score for 'Climate Change'. Manures are a valuable source of plant nutrients and can be often 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). Table 2 compares the carbon footprints of a number of production scenarios for wheat. This includes the application of manure (Scenario 6). Although the application of manure reduces applied N, the carbon footprint both in

Table 1. *Matrix to determine the contribution of Integrated Farm Management techniques in achieving policy objectives*

	Energy		Climate change			Waste		Water		Food and Farming						Resource protection						
<u>Scoring system</u>. 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	Reduce methane emissions	Reduce N2O emissions	Reduce CO2 emissions	Reduce waste and CO2 from inputs	Efficient use of resources	Reduce flooding and/or erosion	Improve biological water quality	Has a positive environmental benefit	Ensure food is available	Alternative pesticides and ICM	Inclusion in agri-environment scheme	Practicality	Economically viable	Sustainable management of land	Improve soil management	Maintain/improve physical soil status	Enhance biodiversity Birds	Enhance biodiversity Plants	Enhance biodiversity Insects	Enhance biodiversity Mammals
A diverse winter sown rotation							-2	1		5	4	2		3	3	2	1	3	5	5	5	5
Include a cover crop over winter	-2			-2	-2	-2	-4	2		4			3	-5	-4	-2	2	-1	-2	-2	3	3
Replace an autumn breakcrop with a spring breakcrop	1			1	1	2	-4	-2		4	-2		3	-4	-4		-1	-2	4	4	4	4
Include fertility building crops	3			-3	3	3	4			2	1		3	3	2	2	1				3	
Avoid intensive cultivations	4	4			4	2	4	3	1	2				3	4	2	4	4	4	1	3	
Time cultivations with respect to prevailing weather and soil conditions	4	4		2	4	2	4	5	3	2				3	4	1	4	4				
Match cultivations to crop, weeds, soil type and season	3	4		1	3	1	4	3	1	2				3	5	2	4	4		-2		
Ensure field drainage is maintained	-1	3		1		1	3	1	1	2	3			4	2	3	3	3				
Exclude livestock from watercourses		1	1	2				4	4	4				1	3	3	3	3	3	2	1	
Apply manures and composts to increase OM%	-1		-3	-5	-3		3	3	-1	3				2	4	2	4	5	2	1	2	1
Use cultural control of weeds	-4				-4	1	-4	-2	-2	-4		2		-2	-2	1	-1		-3	-1		
Leave residual levels weeds in crops							-3	2	2	2	-1	2	2	-4	-1	1			4	4	4	2
Establish conservation headlands	-4				1	2	-4	3	3	5	-2	2	5	3	1	3			4	4	4	4
Plan rotation and spatial separation to minimise pest problems	-3				-3	2	4			4	2	3		2		1			1			
Use narrow spectrum PPPs	-3				-3					4	4	2		2	3	3			3		3	
Encourage beneficial enemies	3			1	1	1	1	2	2	5		4	5	4	3	3			5	5	5	5
Use physical barriers e.g. fleece (horticulture)	-4			-4	-4	-3	-4	1		-2	4	4		2	3				-3		-1	
Increase and improve biodiversity areas	-3						2	2	2	5	-3	2	5	3	-2	5			5	5	5	5
Maximise the benefits of set-aside/fallow							4	1	1	5	-3	2	5	3	-2	5	1	1	3	3	3	3

IFM techniques that require an increased use of machinery may have a negative effect on energy consumption and efficiency and increase CO_2 emissions. 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

CO_2e t ha^{-1} and CO_2e t t^{-1} is considerably higher than for approaches using synthetic inputs.
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.

A number of the crop protection approaches advocated through IFM may have negative impacts on the achievement of other Defra policy objectives. For example, cultural methods of weed control and the use of cultivations to control pests such as slugs are likely to have a negative impact on energy consumption and climate change mitigation because of increased use of machinery. This is also true of the inclusion of conservation headlands, which may contribute to pest control, and the spatial separation of crops to minimise pest and disease problems. The carbon footprints of different weed management options in onion are shown in Table 2. Conventional onion production involves a combination of herbicide use and mechanical weeding, because this approach produces the highest yield, onions being particularly sensitive to weed competition. In terms of the carbon footprint/ha, mechanical weeding has the lowest carbon footprint (9.0 CO_2e t ha^{-1}) and the application of herbicides as the sole method of weed control has the highest footprint (9.9 CO_2e t ha^{-1}). However, when the carbon footprints are compared in terms of crop yield, then the conventional approach has the lowest footprint (0.21 CO_2e t t^{-1}) and a hand-weeded crop, the highest (0.26 CO_2e t t^{-1}). 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.

The use of crop covers to exclude pests from horticultural crops, or for other purposes such as crop advancement in spring, may have negative impacts on energy use, climate change mitigation and waste. Table 2 compares various strategies that are used or might be used for the production of carrots in the UK. When compared in terms of carbon footprint/ha, main crop carrots stored in the field over winter have the largest carbon footprint (30.6 CO_2e t ha^{-1}) and netted main crop carrots, the lowest (16.6 CO_2e t ha^{-1}). However, as with the onion example, once yield is taken into account the rankings are changed and although main crop carrots stored in the field over winter still have the highest footprint (0.36 CO_2e t t^{-1}), early carrots grown under plastic now have the lowest footprint (0.29 CO_2e t t^{-1}).

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.

There are a number of constraints associated with uptake of 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 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.

Table 2. *Production scenarios with yield (t ha^{-1}), applied N (kg ha^{-1}), carbon footprint (t/ha), and carbon footprint (t t^{1})*

Crop	Production method	Yield (t ha^{-1})	Applied N (kg ha^{-1})	CO_2e t ha^{-1}	CO_2e t t^{-1}
1st Winter wheat	1. Milling after oil seed rape	7.5	190	4.5	0.59
	2. Milling after beans	7.5	220	4.9	0.65
2nd Winter wheat	3. Feed	8.3	185	4.5	0.55
	4. Feed - Orange Wheat Blossom Midge resistant variety	8.3	185	4.5	0.55
	5. Feed, high black-grass situation	7.4	185	4.5	0.60
	6. Feed, manure applied	8.3	160	6.5	0.79
Onion	7. Conventional	45.0	150	9.4	0.21
	8. Hand weeded	35.6	150	9.1	0.26
	9. Mechanically weeded	36.0	150	9.0	0.25
	10. Herbicide	46.0	150	9.9	0.22
Carrot	11. Maincrop, stored in field	86.0	94	30.6	0.36
	12. Maincrop, autumn harvested	86.0	94	25.6	0.30
	13. Maincrop, netted	50.2	94	16.6	0.33
	14. Early plastic	85.5	94	24.6	0.29

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. Two of the soil management techniques, reducing cultivations on steep slopes and undersowing crops are 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 with economic implications. 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. 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, which may also be a disincentive to uptake. 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 four techniques are currently considered to be impractical in highly profitable winter dominated rotations.

General 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), but there are still adverse effects in terms of waste disposal, in particular, and the environment and landscape in general.

Although the application of manures 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, 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 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.

Using life cycle assessment and carbon footprinting techniques it is possible to attempt to ‘quantify’ the impact of certain farming practices. 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 different ‘results’, highlighted in the present study.

Under a recent 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 final outcome, 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.

Whilst use of life-cycle assessment is relevant to a number of the Defra policy objectives, 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.

One way to assess land management practices holistically is to use an ecosystems approach and indeed, the Government wishes to embed an ecosystems approach (EsA) into its strategic and policy areas (Defra, 2007). It 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 (includes food production), regulating, cultural and supporting. The advantage of using an EsA for delivering policy is the ability to assess different management approaches against any, or all, of the Defra objectives and to compare approaches. It is also a very flexible approach, since it can incorporate any number of ecosystem services and their products, although this means that the approach is less mechanical than a carbon footprint and requires more thought when setting it up 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. Defra and other funders are currently supporting a variety of research projects to explore methodology for taking an EsA and to estimate its utility (e.g. Haines-Young & Potschin, 2007). One such approach has been developed by two of the authors and their colleagues at Warwick HRI (Defra, 2008) and was used in the current study in comparison with life cycle analysis (Defra, 2009). Although the comparisons were relatively superficial and based on 'standard' production systems, they demonstrated that an EsA 'works' for IFM and that this approach should be explored further in this context.

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