

**CENTRE FOR ECOLOGY AND HYDROLOGY**  
NATURAL ENVIRONMENT RESEARCH COUNCIL

**A Review of Research into the  
Environmental and Socio-Economic Impacts  
of Contemporary and Alternative  
Arable Cropping Systems**

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## EXECUTIVE SUMMARY

Arable cropping systems have developed and continue to change in response to economic and social pressures. Concern for the state of wildlife and the quality of soil and water has led to further pressures on the way that crops are farmed. There is therefore an ongoing debate about the future of arable farming. This review summarizes current information about the impacts of arable cropping systems, including contemporary agriculture, which is compared with alternative cropping systems in the UK and elsewhere.

Studies are reviewed to identify differences between contemporary and five alternative arable cropping systems in relation to their environmental and socio-economic impacts. They are also assessed in terms of their profitability and levels of input usage. General insights from the literature on farming systems are presented to ensure that this review builds on existing knowledge.

For three of the alternative arable cropping systems (low-input systems, integrated arable farming systems and organic farming), a significant body of UK and European research is available for review. For these areas, the information available is not comprehensive, but an indicative picture emerges about them. A number of key information gaps are also identified. For two of the alternative systems (reduced tillage systems and precision farming systems), much less UK and European research has been carried out. Research from countries outside Europe is cited to complement the local results, but for both these systems, the potential for confident conclusions for the UK is lower.

Evidence is presented to show the direct and indirect effects of agricultural practices (chemical and physical) on organisms for a range of taxonomic groups. For example: birds, arthropods and earthworms are all detrimentally affected by pesticides; plant and earthworm abundance are affected by nitrogen input; and reduced tillage causes increases in weeds and invertebrates, and reduces earthworm mortality. Therefore, in most cases a reduction of chemical inputs and a reduction in severe soil disturbance will have ecological benefits.

Different arable cropping systems affect the landscape in different ways. This is especially important for birds, mammals and insects that move around in the countryside. Ecological benefits are shown to accrue from mitigation measures such as arable margins, beetle banks, conservation headlands and wild bird cover. These mitigation measures are normally carried out with the assistance of agri-environment scheme payments.

Large scale uptake of planned agri-environment schemes is likely to have widespread positive effects on fauna and flora but these effects might not necessarily be large on a per field scale.

According to one key report, organic farming of crops is relatively profitable. Although it has lower yields than conventional systems, these are compensated by higher prices. We have some concerns about whether the economic analysis has fully captured the costs of switching to different rotations in organic farming (e.g. including

costly years of manure crops to maintain soil fertility) since the study was based on small samples in single years.

Low input systems and integrated arable systems were both variable in their economic performance. Their economic returns compared well with conventional systems in some situations but not in others. There is scope for additional economic modelling to broaden the knowledge base about the performance of these systems in different circumstances.

Reduced tillage currently has limited economic potential in the UK. Farmers have been reluctant to adopt it. Large capital investment is required at the beginning so it is unsuitable for small farms.

Precision farming has been evaluated positively in the one major UK study, but a more sophisticated economic analysis from Australia raises suggests that the UK study may have overstated the likely benefits.

Implications for farm labour were identified, the most important of which are a likely increase in labour demand in low input systems and a requirement for more skilled labour in some systems.

Table 1 summarises the review of each of the five alternative cropping systems compared against conventional cropping. A more extensive summary of the findings of this report is presented in Chapter 5.

Executive Summary

**Table 1.** Summary of the review abridged from Chapter 5 and Table 2. Comments are relative to contemporary practice.

	<b>Low-input systems</b>	<b>Integrated arable systems</b>	<b>Reduced tillage systems</b>	<b>Precision farming</b>	<b>Organic farming</b>
Key projects	Boxworth TALISMAN SCARAB RISC	LIFE LINK:IFS FOFP RPMS	Davies & Finney, 2002	Godwin <i>et al.</i> , 2002 Pannell & Bennett, 1999	Offerman & Nieberg, 2000 Padel & Lampkin, 1994
Extent/quality of evidence	***	****	*	*	***
Economic performance	Variable. More likely to be attractive for cereals and if output prices are low.	Profits vary widely between studies. Similar to conventional on average.	Cost savings recorded, but apparently outweighed by other negative aspects.	UK study says good potential. Detailed overseas study indicates caution needed.	Profitability high for crops. Weaker for livestock.
Social impacts	Minor.	Requires more skilled management. Perhaps higher overall labour demand.	Lower labour use if reduced tillage uses larger machinery.	Unchanged or perhaps slightly lower labour demand. Need for new skills.	Often includes livestock, perhaps leading to increased labour demand.
Environment	Moderate reductions in pesticide use.	Significant reductions in inputs.	Reduced energy inputs. Reduced soil erosion.	Significant reductions in inputs such as pesticides and fertilisers may be possible.	Almost no synthetic chemicals used. Lower greenhouse gas emissions.
Ecological impacts	Some benefits to many taxa.	Some benefits to many taxa.	Benefits especially to soil fauna.	Benefits to many taxa in areas not targeted by inputs.	Benefits to many taxa across all cropped area.
Strengths	Most similar to contemporary practice, so easier to adopt.	Avoid some problems experienced with organic farming.	Lessons from successful adopting countries may be possible.	If successful, reduced inputs without loss of profit.	Currently substantial price premiums and substantial reductions in intensity.
Weaknesses	Only modest environmental benefits.	No price premiums. Need high-level management. Higher risks initially.	Evidence of low adoption suggests poor technical effectiveness and economics in the UK.	Expensive to purchase/run. Doubts about economic benefits if properly evaluated.	Weed management. Maintenance of soil fertility.
Key gaps in information	Applicability of economic results to other farm types and locations. Optimal design of systems to balance profit and pesticide use.	Labour implications. Applicability of economic results to other farm types and locations. Optimal design of integrated systems.	Relatively little R&D into the technique conducted in the UK so far.	Sophisticated analyses of the economic potential for precision technologies. Bio-physical information necessary to conduct such analyses.	Impacts of policy changes. Marketing and processing. Labour implications. Effects of livestock on crop profits. Whole-rotation



# 1 INTRODUCTION

## **Background to the Study**

1.1 Over the last few years the debate about the merits of different agricultural systems has intensified. In one sense the vigour of the debate is encouraging as it shows an interest in the countryside and rural affairs. It is discouraging in the sense that different viewpoints are often only supported by flimsy or contentious evidence. Part of the fragmentation in the debate is due to the different interests of the stakeholders and part is due to divisions between academic disciplines.

1.2 Interest in alternative arable farming systems has gradually increased in the UK since the late 1970s partly in response to concerns over the negative impacts of conventional arable systems. Concerns that high input systems were damaging the environment, uncertainty over the ability of high input systems to remain profitable without subsidies, the negative effects of agrochemicals on human health and the need to reduce European Union food surpluses all served to stimulate research into viable alternative systems that may ameliorate these concerns.

1.3 The current form of the debate and research into cropping systems makes it difficult to compare different aspects of each system, for example, the linkages between economic externalities and social welfare or between return on investment and biodiversity. Defra has commissioned this research to help provide baseline information on what is really known about different arable cropping systems. This report summarises current knowledge, emphasising the differences between systems and identifying where there is consensus, where there is conflict and where there is insufficient evidence to reach a conclusion. The report is a synthesis of information gathered from many sources which have been placed in a database that has been supplied to Defra. A large number of references, but by no means all, from the database are cited in this report and they are included in the reference list at the end of this report. The rest of the references in the database are listed in the bibliography. The database includes fields for: author; report title; type of publication; objective of the study; relevant topics (socio-economics, biodiversity, environmental schemes, mitigation, land use); arable systems compared; indicator organisms; spatial extent; spatial resolution; length of study; temporal resolution; replication; framework for extrapolation; comments and conclusions; and an abstract of the paper. Not all of the fields were filled in for each publication.

1.4 The review focuses on the UK. For some issues, reference is made to research in continental Europe. For some issues where insufficient evidence is available for the UK and Europe, relevant studies from elsewhere are reviewed and the relevance of their conclusions to the UK is assessed. Areas where insufficient UK research has been carried out are also identified.

## **What is included and what is excluded**

1.5 Arable cropping systems are taken to be those that include combinations of crops grown in rotation. The systems may include cereals, oil-seed crops, field vegetables, fruit, livestock, and so on. For the purpose of this report we define an Arable Cropping System as:

‘a cropping system is that includes at least some combinable crops grown in rotation’.

1.6 This report excludes consideration of arable systems growing Genetically Modified Organisms (GMOs) as they form the focus for a separate report. Note that we use the term GMO to describe varieties that have been developed through molecular genetic engineering.

1.7 This report does not consider systems that are wholly or predominantly concerned with livestock, however, organic farms are often ‘mixed’ i.e. have both livestock and arable cropping. In those cases the emphasis has been on the arable component.

1.8 Most of the sources consulted used have come from studies of English and Welsh systems, however, work from other countries has been included, especially where the research is pertinent, conditions are similar or there has been no equivalent research done in this country.

### **Intended readership**

1.9 It is intended that this report be accessible to all stakeholders in the debate over the future of arable agriculture in this country. It is suggested that most readers should start with chapter 5 which lists the key findings of this report. Further information can be gained from the cross-references in chapter 5 to chapters 3 and 4.

### **Nature of this Study**

1.10 This report has been produced by researchers from: the Centre for Ecology and Hydrology (CEH), Centre for Rural Economics Research, Cambridge University (CRER) and the Northmoor Trust (NT). Details of these three organisations and contact details can be found in Appendix 1. Research has taken the form of a desk study reviewing the available literature and data, together with limited consultation with experts and interested parties outside the consortium. Information was stored in a bibliographic database, which included not only summaries of results but comments on their scale and applicability. Appendix 2 lists those published sources that are not referenced in the main report.

1.11 The review includes both formally published peer-reviewed scientific literature, as well as ‘grey’ literature, meaning internal publications of research projects that have not been exposed to the same degree of scrutiny and review. Where possible the research studies considered here are comparative studies, contrasting one or more alternative systems with a contemporary system.

1.12 It is often hard to determine the range of conditions under which published results are likely to apply. Are the conclusions applicable just to one site at one time or are they general across a large area and a long period of time? Consistency between research findings of social scientists and economists on the one hand and biologists, on the other, is made difficult not only by differing system response times but also by major differences in the degree of quantification.

1.13 This study has not classified items in the literature as being either adequate or inadequate, but instead the aim was to ‘rank’ items based on:

- the length of the study,
- the number of replications,
- the geographic extent.

Studies that went on for a long time, over a large area with many replications are given a higher rank (provide greater weight) than short term, one-off, single site studies. Literature that was peer reviewed was generally considered high quality than 'grey' literature. In reality there were so few studies for most subjects that ranking them was irrelevant.

1.14 The economic value of different cropping systems should be viewed as something greater than just the financial implications to the landholder but should include economic externalities to society. There has been a considerable amount of research into ways to value goods and services that are not traded. This includes the development of indirect techniques like: 'travel cost recreation demand', 'hedonic property value (or wage) equation', 'averting behaviour or household production model' and 'choice modelling' as well as direct methods like 'contingent valuation'. None of the methods has met with unanimous acceptance even within the economics community and many have also been criticized on 'philosophical' grounds. Appendix 3 provides an overview of some of the different approaches and their advantages and disadvantages. Although an economic valuation of impacts of different arable cropping systems is theoretically possible, in practice we do not believe it could be defended.

### **General problem of research into arable cropping systems**

1.15 There is a general problem in the way science is conducted in that most studies concentrate on only one part of a system. There are very few systems that have been studied as whole systems. In the arable context, ecological benefits and impacts are especially hard to determine, because of the complexities of phenomena that are expressed at both landscape and field scales.

### **Definitions and terminology**

1.16 Just as farming systems change over time so do the definitions of what constitutes 'contemporary' and 'alternative' practices. What was novel and 'cutting edge' twenty years ago may now be standard practice or even old fashioned. Reports that describe differences between contemporary and alternative systems need to be read with knowledge of when the work was carried out as well as when it was published.

1.17 We interpret contemporary to mean in this context, conventional, that is what the majority of landholders do.

1.18 It is important to recognise that at any point in time there is a continuum in the intensity with which farmers use resources and there are not necessarily any clear 'break points' along that continuum. This is especially obvious among systems described as 'integrated' (integrated farm management, integrated pest management, etc.).

1.19 For the purpose of describing the natural environmental impacts of different systems we have divided arable farming systems into three broad categories:

- Contemporary

- Integrated
- Organic.

1.20 In terms of assessing or describing the socio-economic impacts of the different systems it is possible to further disaggregate the ‘integrated’ category into: low input systems, integrated arable farming systems, reduced tillage and precision farming (although this last category can be combined with any of the others). The six systems examined are as follows.

1. Contemporary practice. Systems that include those practices described in the contemporary ‘*Codes of Good Agricultural Practice*’ (COGAP), or which use resources more intensively than that. It is recognised that what constitutes contemporary practice changes over time.
2. Low-input systems. These are allied to the conventional systems of contemporary crop production, but they involve reduced use of inputs (particularly pesticides) within a more-or-less conventional approach.
3. Integrated Arable Farming Systems (IAFSs). These involve a more concerted attempt to reduce the intensity and adverse impacts of contemporary agriculture, without going to the extent of organic farming. IAFSs may employ mitigation measures that are not yet within the COGAP. Common features of the IAFSs that have been studied include the development of optimal strategies for reducing input rates through management (e.g. more sophisticated decision making) and agronomic factors (rotations, cultivation methods).
4. Reduced tillage systems. These encompass ‘conservation tillage’, ‘minimal tillage’ or ‘low tillage’. For the purposes of this review, we have adopted the definition of Davies & Finney (2002): ‘Sustainable cultivation systems which are less expensive than traditional systems; they may be less energy demanding, and/or quicker and/or have a lower labour demand’. This definition includes direct drilling (zero cultivation), shallow tillage without inversion and deep tillage without inversion.
5. Precision farming systems. There is a range of technologies that allow farmers to target the usage of inputs to parts of crops where they are more needed. They often involve automated decisions about application versus non-application of particular inputs depending on spatially variable characteristics of the crop. They are intended to reduce input usage by avoiding application of inputs to parts of the crop where they are not needed. In principle, precision farming could be combined with any of the five previous systems.
6. Organic Farming. These systems eschew the use of synthetic fertilisers and pesticides. Typically they also attempt to maintain and improve soil fertility by including livestock and attempt to use agronomic practice like crop rotations to reduce off-farm inputs.

### **Structure of the report**

1.21 The following chapters of the report provide: a model of arable agriculture in the UK through the use of a pressure-state-response framework (chapter 2); a review

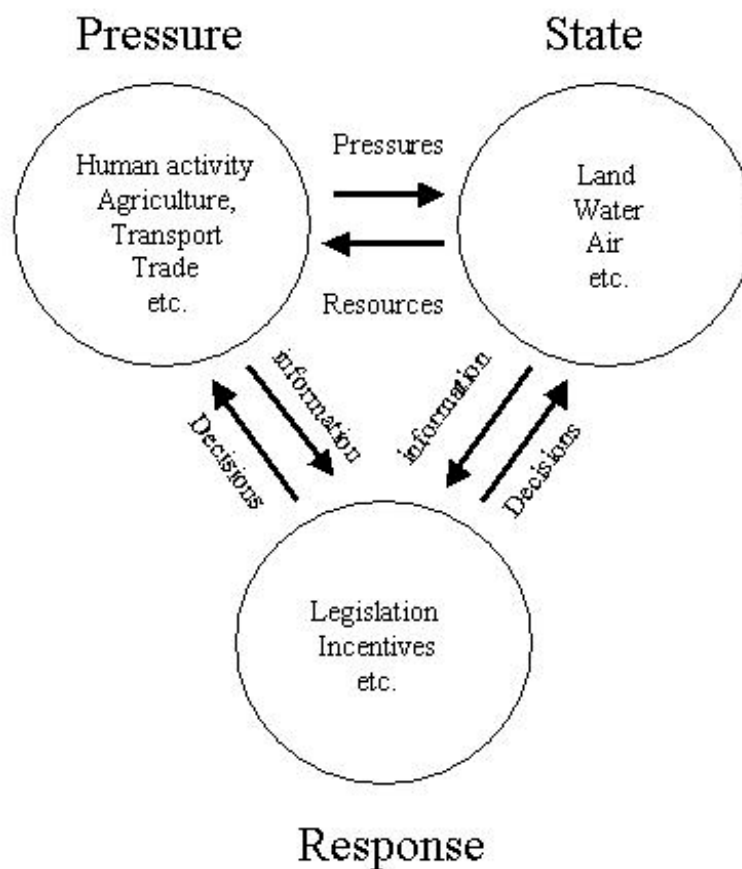
of the ecological impacts of arable agriculture (chapter 3); a review of the environmental and socio-economic impacts of five different arable cropping systems compared to contemporary practice (chapter 4); and the information presented in chapters 2-4 is synthesised into a list of key impacts and conclusions are drawn from the study (chapter 5) .

## Introduction

## 2 CAUSES AND EFFECTS OF CHANGE IN ARABLE AGRICULTURE

### A conceptual model of change in the environment

2.1 One way to consider why the countryside is always changing is to consider the Pressure-State-Response (PSR) framework. A wide range of organisations use the PSR. One of the first was the OECD (United Nations Office of Economic Cooperation and Development) in the 1970's. Since then a range of other 'letters' are occasionally inserted, such as I for impact or D for Driving Force, however, the basic idea is illustrated in a generic form in the diagram below.



2.2 Human activity such as agriculture puts pressures on the environment that in turn supply resources to that activity. Information about the state of the environment and human activity may generate a response to either encourage or discourage a particular activity or to change the state of the environment.

2.3 The advantage of this conceptual framework is that it allows a more dynamic and richer explanation for the environment than steady-state cause and effect models. This is because in the natural environment there is rarely a single cause for any observed state and any pressure may have multiple effects.

2.4 Here is a simple example.

- Changes in technology lead to larger tractors.
- These are attractive as more area can be covered in a shorter period of time (and many farming activities are time critical).
- But, to get the full benefit of increased efficiency farmers require larger fields.
- This means removing some linear features such as hedgerows (walls, dykes).
- This may have a negative impact on biodiversity.
- Society responds by enacting a hedgerow preservation act.
- This response then has the potential to become a different pressure on the environment.

2.5 Larger machines have more than one effect on the environment: they can alter soil structure, reduce the requirement for labour, increase borrowings from banks; similarly the removal of hedgerows can be triggered by other concerns than increased efficiency.

2.6 This report concentrates on the pressures and state of the environment within different arable cropping systems. It is beyond the scope of this work to identify appropriate responses although the report forms part of the flow of information that may eventually elicit a response.

### **Pressures for change in Arable landscapes**

2.7 Many commercial organisations assess the pressures they are under by performing a PEST (Political/Legal, Economic, Social and Technological) analysis. Most of the pressure for change on the arable agriculture sector could also be put within this framework. However, not many changes will fall neatly into one category. For example, is the increase in organic farming economic (premiums on goods produced), social (desire for ‘pure’ products) or technological (better methods of biological pest control)?

2.8 In the long term, climate change may put pressure on arable systems, but in the short-term direct human effects are likely to dominate.

2.9 The primary forces (pressures) driving change in arable landscapes relate mainly to the **intensity** with which resources are used. In arable systems this means the way that nutrients and biocides are applied, tillage is performed, etc.

### **State of environment**

2.10 The state of the environment within arable cropping systems is described by reference to:

- Biodiversity – distribution and abundance of plants and animals;
- Social and economic conditions – employment and profitability (and to a lesser extent with externalities like pollution and energy efficiency);
- Landscape structure – field size, diversity of activities.

### 3 ECOLOGICAL IMPACTS OF ARABLE AGRICULTURE

3.1 This chapter makes an assessment of how arable agriculture has had an impact on ecological processes on the farmed land. The chapter is structured to show how each of six different factors (pesticides, nutrient inputs, tillage, intensity of land use, landscape structure and mitigation measures) have affected different taxa. This information provides the background for the Key findings presented in chapter 5.

3.2 Throughout this chapter review articles are denoted by an asterisk.

#### **General trends**

3.3 During the past fifty years the remarkable increases on food production have come at considerable environmental and human health cost (cf \*Conway and Pretty, 1991; \*Campbell and Cooke, 1997; \*MAFF, 1998; \*Pretty, 1998; \*EPA, 1999). The changing state of arable plants and animals is a cause of widespread concern to land managers and conservationists. National monitoring and long-term studies of birds, butterflies, beneficial invertebrates and annual arable flowers have shown serious declines in some species associated with arable farmland in the late 20th century (\*Aebischer, 1991; \*Donald, 1998; Sotherton, 1998; \*Asher *et al.*, 2001; \*Baillie *et al.*, 2001).

3.4 Declines in biodiversity, therefore, coincided with an increase in the intensity of agricultural production. Several factors played a part in causing these declines (\*O'Connor & Shrubbs, 1986; \*Potts, 1991). Farming became more specialised, with arable increasing in the east of the UK and decreasing in the west. Fertilisers and crop-protection chemicals were improved and applied in increasing amounts. Non-cropped habitat was removed to enlarge field sizes. Crop rotations were simplified with an increase in winter cereal production. Subsidies were created by European and national governments to pay farmers to remove hedges and drain wetlands to increase agricultural production.

3.5 In 1999, the Government published the White Paper Achieving a better quality of life, which contained a draft set of 150 indicators of the sustainability of lifestyles in the UK. Fifteen of the proposed indicators were identified as 'headline' indicators, and one of these was based on population trends of breeding birds. The Government has pledged to reverse the long-term trends in woodland and pertinent to this project, farmland birds. In particular, Defra has published a Public Service Agreement target to reverse the long-term decline in the number of farmland birds by 2020. Although a series of policy initiatives have been launched to help farmland birds, meeting this target will be a significant challenge.

3.6 Currently farmland birds are considered the headline indicators for arable cropping systems although the debate about what is a valuable indicator of biodiversity continues.

#### **Limits to what has been studied**

3.7 Although studies of the biodiversity of field margins are relatively numerous, the effects of cropping system on the field interior have received less attention. European studies (of which very few come from the UK) tend in the main to focus on

organic versus contemporary systems, whilst studies examining the biodiversity effects of type, depth or intensity of cultivation are much commoner in the USA and Canada. In order to infer generalities from American studies one must make the assumption that the arable faunas of both temperate North America and Europe react similarly to changes in cultivation.

3.8 In both European and American studies there is a tendency to focus on the epigeal arthropod fauna, especially carabid beetles (Moreby *et al.*, 1994), with transect surveys of butterflies also popular. Other taxa are relatively under-represented.

3.9 It is generally assumed that increasing the abundance and species richness of soil organisms has a positive effect on soil functioning and crop growth. However, there exists much functional redundancy in soil ecosystems, and soils often function adequately with reduced overall species diversity.

3.10 It is very difficult to perform manipulative field-scale experiments with the soil biota, because of the scale and complexity of interactions and the difficulty of sampling the soil itself. Hence, we do not know the exact role of each group of organisms (e.g. the mites and collembola) in relation to soil functions (i.e. increasing nitrogen availability, increasing soil porosity etc.). A number of groups of soil animals are also multi-functional, such as the earthworms, which affect the biological, chemical and physical attributes of the soil matrix. Very little work has been carried out for arable systems (under any management) in the field to mechanistically describe the role of defined groups on soil function in a quantitative, 'model-friendly' manner.

## **Pesticides**

### *Invertebrates*

3.11 To say that pesticide application has an adverse effect on invertebrates (whether by direct mortality or the death of their food plants) is something of a truism (\*Rudd, 1964), supported by numerous studies. Non-target species are often affected (\*McLaughlin & Mineau, 1995). Nevertheless, some authors also found that a few individual (usually common) species could become more abundant after pesticide application. It is usual for studies to find that organic systems result in greater densities of both arthropods and their favoured food plant groups than contemporary systems (e.g. Mäder *et al.*, 2002 for carabids staphylinids and spiders; Feber *et al.*, 1997 for non-pest butterflies; Hald, 1999 for food plants), although effects are often taxon-specific.

### *Earthworms*

3.12 Not all pesticides are alike, and they vary in toxicity to earthworms; a field application of 10 kg ha<sup>-1</sup> of endrin would have a much greater effect than an equivalent application of paraquat (\*Edwards & Bohlen, 1992). In the context of this review, the most useful measures of the effect of pesticides on earthworms are population survivorship and reproduction parameters.

3.13 The most commonly used survivorship measure is the  $LC_{50}$ <sup>1</sup>. A large literature exists quantifying earthworm mortality in response to differing pesticides and exposures. Mostert, Schoeman & van der Merwe (2000) undertook such a study with three different pesticides and the earthworm *Eisenia fetida*. Vulnerability to adverse effects varied greatly between different pesticide products (e.g. after 21 days an imidacloprid exposed population experienced the same mortality as a control population, whereas chlorpyrifos increased mortality by 24%). Pesticides also affect reproduction, which has a direct effect on population sustainability. Panda & Sahu (1999) exposed earthworms to single or double doses of malathion (producing soil concentrations of 2.2. and 4.4 mg kg<sup>-1</sup>) and found decreased cocoon production relative to controls. However, they also found that 105 days after exposure, the earthworms resumed normal growth and reproduction, thus indicating that the timing of pesticide application under field conditions is crucial when predicting the effect of pesticides within an ecologically relevant context. A large-scale field-based investigation into the effects of reduced pesticide use on soil biota was carried out across three farms in the UK during the SCARAB project. Conventional levels of pesticide application were compared to a treatment with a 50% reduction. The treatments began in 1990 and results up to 1994 showed no ecologically significant differences between conventional and reduced pesticide plots in terms of earthworm numbers or species diversity. Substantial differences between farms were noted, but these were largely explained by differences in climate, soil type, crop type and cultivation technique (Tarrant, 1997).

#### *Birds*

3.14 Pesticides have been shown to have both direct and indirect effects on the abundance of chick-food for game and non-game bird species. Reduction in food for chicks is an important factor in the decline of farmland birds (\*Campbell & Cooke, 1997; Potts, 1986).

3.15 The loss of raptors (and also fish-eating birds and seed eaters) due to poisoning by organochlorine pesticides (withdrawn from sale and banned) is one of the best documented incidences of direct pesticide effects on birds (e.g. Newton, 1986; Ratcliffe, 1970). Other pesticides known to represent a direct hazard to birds include alkyl-mercury compounds (withdrawn from sale and banned), carbamates and organophosphates; other problematic compounds include pyrethroids, polychlorinated biphenyls (banned but will still be released to the environment from a variety of sources, even though production has been stopped) and certain second generation rodenticides (some are restricted to professional use only) (\*Newton, 1998). With respect to the latter, control of rodent pests on farmland can result in secondary poisoning of raptors and other species via the ingestion of poisoned (both live and dead) rats and mice (\*Burn, Carter & Shore, 2002; Newton et al., 1999). Molluscicides may also pose a hazard to some bird species. Evidence of population-scale effects is currently lacking, but secondary poisoning is again a hazard (Dolbeer, Avery & Tobin, 1994; Shore et al., 1997). Indirect effects of pesticides on birds via their food supply is also well established, the best documented example being the widespread decline of the Grey Partridge *Perdix perdix* (Potts, 1986; Potts & Aebischer, 1995). No other species have been studied in such detail, but declines in other farmland birds are also likely to be linked to reductions in invertebrates, weeds

<sup>1</sup>  $LC_{50}$  (Lethal Concentration 50) is the amount of a substance that, over a specified period of time, is expected to cause death in 50% of a defined animal population.

and seeds due to pesticide use. Various studies have indicated links with both reductions in breeding success and problems with winter food supplies (Brickle et al., 2000; \*Burn, 2000; Campbell et al., 1997; Evans et al., 1997; Moorcroft et al., 2002; \*Sotherton & Self, 2000). Pesticide usage may also damage bird breeding success by reducing the availability nesting cover, by direct destruction of nests by machinery during application and by exposing existing nests to predation following the collapse of vegetation cover after spraying.

### **Nutrient inputs**

#### *Weeds, Invertebrates and Birds*

3.16 Fertilisers have an essential role in agricultural ecosystems. Nutrient inputs are obviously designed to favour crop growth and hence certain 'weed' species may be suppressed by dense crops, quite apart from any adverse effects of high nutrient levels *per se*. Similar effects may also occur due to vigorous growth of relatively few weed species which can exploit such conditions, leading to loss of plant species diversity which may in turn affect invertebrate abundance and diversity (Kleijn & van der Voort, 1997; Wilson & Tilman, 1993). Dense growth of crops can also impede access to the crop and ground by foraging birds, and may be particularly problematic for young precocial chicks (e.g. partridges, pheasants, lapwings; Shrubbs & Lack, 1991). Such problems may be exacerbated during cold, wet weather; chicks attempting to forage in, or negotiate, dense, wet crops may risk becoming soaked and chilled, although no evidence for such effects was found in one study of set-aside and permanent pasture (Poulson, Sotherton & Aebischer, 1998). Similarly, nests of altricial young under such conditions may take longer to dry out and rewarm, increasing risk of chilling to eggs and chicks. Agricultural chemicals also contribute to eutrophication of freshwater, estuarine and shallow coastal habitats, but the consequences are not always harmful. Depending on initial conditions and the degree of pollution, productivity may increase to the benefit of certain bird species (\*Newton, 1998).

#### *Earthworms*

3.17 Edwards & Lofty (1982) studied the effect of different combinations of N fertiliser (farmyard manure, inorganic, liquid and solid sewage sludge and sewage cake) on earthworm populations in a wheat crop. They found a strong positive correlation between inorganic N addition and earthworm abundance over an application range of 0 to 300 kg N ha<sup>-1</sup>, with plots that received both inorganic and organic N having highest earthworm populations (95 individuals m<sup>-2</sup>, 110 g m<sup>-2</sup>). However, the relationship between N addition and earthworm population density is not always clear-cut. Ma, Brussaard & Deridder (1990) found positive relationships between N addition rate and earthworm biomass for only 2 out of 6 fertilisers tested (organic-coated urea and ureaformaldehyde) in a grassland ecosystem. In the other treatments, 3 out of the other 4 formulations reduced soil pH with increasing N addition rate (by approximately 2 pH points over 7 years) creating sub-optimal habitat for earthworm populations.

### **Tillage**

#### *Weeds*

3.18 Reduced tillage has been very successful in reducing erosion and nutrient losses on some soils, but results are very variable. In all cases of reduced tillage there is the possibility that weeds will become more prevalent (and hence may require

control by non-mechanical means). Reduced tillage is generally not successful on poorly drained soils, on soils with high organic matter content, or soils that compact easily or where crusts form.

#### *Invertebrates*

3.19 In reviews, Kromp (\*1999; carabids), Paoletti & Hassall (\*1999; woodlice) and Sunderland & Samu (\*2000; spiders) all indicated that reduced tillage led to increases in their respective taxa. Two studies from Europe (Krooss & Schaefer, 1998; Germany; Baguette & Hance, 1997; Belgium), seem to support many American studies such as those by Neave & Fox (1998) and House (1989), which found greater arthropod diversity and/or abundance in reduced tillage regimes. A third, a German study by Wick *et al.* (2001) found no effect of tillage on carabids. Buntin, Hargrove & McCracken (1995) found no effect of tillage amongst foliage-inhabiting arthropods, and both Marasas, Sarandon & Cicchino (2001) in Argentina, and Gallo & Pekar (2001) in Slovakia found that reduced tillage favoured predatory species relative to 'pests'.

#### *Earthworms*

3.20 Plots at the Rothamsted Experimental Station in the UK that have grown the same crops since 1843 showed that the largest earthworm populations occurred under continuous cereals, with much lower populations under root crops and the lowest of all under fallow (Edwards & Bohlen, 1996). The main reason for this is that cereals leave considerable litter residues, which are usually ploughed into the soil, encouraging the build-up of organic matter and hence earthworm populations. In contrast, root crop residues decompose quickly and leave little organic matter in the soil. Food supply is limited and subsequent earthworm numbers are low. This finding was supported by Fraser & Piercy (1998) who compared earthworm numbers under different stubble management regimes over a 4 year period. They found that after 4 years, earthworm densities in plots where stubble was burned or removed had a population density of approximately 150 individuals m<sup>-2</sup>, whereas plots with residue incorporation had 400 individuals m<sup>-2</sup>. They also noted that undersowing barley with clover seed brought about a large increase in earthworm density, with numbers increasing from 150 individuals m<sup>-2</sup> before clover sowing to over 1000 individuals m<sup>-2</sup> afterwards.

3.21 Tillage has an immediate impact on earthworms themselves (through injury or direct mortality) and on their habitat, but the severity of effect is dependent on the mode of tillage practiced by the farmer. There exists conflicting evidence regarding the effect of tillage on earthworm abundance and diversity. For example, Doube, Buckerfield & Kirkegaard (1994) found no significant decline in earthworm abundance after one to two years following conversion of pasture to various types of crop. However, increasing the depth and frequency of tillage decreases the density of earthworms. Gerard & Hay (1979) compared deep ploughing (30-35 cm, furrows 45 cm apart), normal ploughing (15-20 cm, furrows 22.5 cm apart), tined cultivation (12-30 cm deep, tines 22.5 cm apart, two to three passes) and no-tillage in two experimental UK soils. Earthworm population density (numbers m<sup>-2</sup>) decreased with increasing ploughing severity, from 120 in no-tillage, through 70 and 60 in normal tillage and tined cultivation to 55 under deep tillage. Curry, Byrne & Schmidt (2002) studied the effect of severe tillage on earthworm populations and found that earthworm population density dropped from 319 to 40-82 individuals m<sup>-2</sup> in a wheat

to potato conversion after intensive cultivation (grubbing, ridging, bed-tilling, destoning and ridging). Furthermore, after mechanical potato harvesting at the end of the season, populations declined to virtually undetectable levels and showed little sign of recovery over a year later.

3.22 Due to the negative effect of conventional tillage on earthworm populations, conservation tillage is now widely practiced as a means of reducing damage to earthworms themselves and to their habitat. In the United States, Klavivko, Akhouri & Weesies (1997) studied 14 paired no-till/conventional sites and found that 8 no-till had higher earthworm population densities, 4 had roughly equal numbers and 2 had lower populations, when compared to contemporary practice.

### **Intensity of Land Use**

#### *Earthworms*

3.23 The most fundamental form of management alteration in arable systems is conversion from contemporary to organic farming. Blakemore (2000) compared earthworm densities between a contemporary arable field, requiring inorganic fertilisers and pesticides with an organic ley-arable section (8-10 year rotation of corn, root-crop, grass ley) supporting stock and found densities of 100.0 and 178.6 individuals m<sup>-2</sup> respectively. Blakemore also noted that earthworms preferred organic soils when placed in choice chambers (headcounts of 96 to 73 organic/contemporary). Even larger differences were found by Pfiffner & Mader (1997) who studied earthworms in a Swiss experiment running continuously since 1978. They found that earthworm population densities in 1991 under wheat were 130 and 350 individuals per m<sup>2</sup> for contemporary and organic treatments respectively. This difference has been sustained in recent years and now both biomass and abundance are higher in organic treatments, compared to contemporary by a factor of 1.3 to 3.2 (Mäder *et al.*, 2002). Intermediate 'sustainable' treatments can also augment earthworm population densities. Schmidt *et al.* (2001) compared earthworm communities in a contemporary winter wheat monocropping system and a low-input intercropping system in which successive crops of winter wheat were direct-drilled into a permanent white clover sward. The wheat-clover system supported a higher population density than the monocropping system (548 to 194 individuals m<sup>-2</sup>) and also showed higher species diversity (between 1 and 5 more species were found in the wheat-clover system compared to the monocrop). Length of time since conversion from contemporary methods is one of the most important factors determining population size, as shown by the UK LIFE (Less Intensive Farming and Environment) project. The study compared earthworm abundance and diversity between contemporary and integrated treatments from 1990 to 2000. Within the project, Hutcheon, Iles & Kendall (2001) found no significant differences between treatments in terms of earthworm population density or biomass over the first three years of the experiment. Thereafter, differences were found, with higher biomass and density found on the integrated treatment, but for selected species only. Numbers of *Allolobophora chlorotica*, *Lumbricus festivus*, *L. rubellus* and *L. terrestris* averaged over all years were significantly greater in the integrated management treatment, whereas there were no consistent differences for *Aporrectodea caliginosa* or *A. rosea*. Species diversity was also consistently higher under integrated management.

*Other Soil Organisms*

3.24 When considering soil bacteria and fungi, the relationships between soil treatment, total microbial biomass, species diversity and soil function are of fundamental importance. Breland & Eltun (1999) found that microbial (bacterial + fungal) carbon biomass was approximately 50% higher under 'ecological' (i.e. integrated) farm treatments, compared to contemporary treatments. However, whereas N mineralisation was slightly higher under ecological as opposed to contemporary treatments, the rate of carbon mineralisation was equal in the two systems. Carpenter-Boggs, Kennedy & Reganold (2000) found that biodynamic treatments increased soil biomass C and a range of soil functions (dehydrogenase activity, basal soil respiration and soil C mineralised in 10 days) when compared to contemporary treatments amended with mineral fertilisers. A study into the functional role of microbes in arable soils demonstrated that microbial species diversity can be greatly reduced, but soil function can still remain. Griffiths *et al.* (2001) decreased biodiversity (via dilution) in a conventional arable soil in laboratory microcosms by 15, 40 and 60%. This treatment could mimic the effect of stressors such as fungicides. They found no consistent effect of biodiversity on a range of soil processes measured (incorporation of thymidine and leucine, potential nitrification, nitrate accumulation, respiratory growth response, community level physiological profile and decomposition). Neither was there a direct effect of biodiversity on the variability of the processes, nor on the stability of decomposition when the soils were perturbed by heat or copper. The biodiversity of, and inter-relationships within, the microbial communities was such that the experimental reductions had no direct effects on soil function. These papers show soil microbial communities are inherently variable (Smit *et al.*, 2001), but that soil function is usually maintained under stress as there are many species remaining in niche space which are 'waiting in the wings' to take over the role of microbes dominant under previous management regimes.

3.25 Hendrix, Guo & An (1995) found large differences in mycorrhizal community dominance, diversity, equitability and species richness associated with different crop types. Interpreting the functional significance of these differences is extremely difficult as definitive experiments have not been carried out to quantify the relation between microbial diversity and crop productivity in the field. One of the few studies related to this was carried out by van der Heijden *et al.* (1998). In a field plot experiment simulating a North American old-field system they established 70 macrocosms, inoculated with varying numbers of mycorrhizal species and planted with mixed grass/herb species. They found that plant biodiversity; nutrient capture and productivity increase significantly with increasing mycorrhizal diversity.

3.26 Alvarez, Frampton & Goulson (2001) analysed collembola communities in winter wheat fields in the UK and found few systematic differences between contemporary, integrated and organic systems. However, a small number of consistent, though not significant treatment related abundance trends were noted, i.e. 1) *Entomobrya multifasciata* and *Isotomurus* species were more common in contemporary treatments than others, 2) *Isotoma viridis* and *Isotoma notabilis* were higher in organic fields and 3) for *Sminthurinus elegans* and *viridis*, variation was explained by interactions between treatment and area. Also, organic fields had the most equitable community structure, equitability being an attribute which has been linked with ecosystem resilience and sustainability (Naeem *et al.*, 1995). Interestingly,

organic and contemporary systems did not differ from each other, but integrated differed from both.

3.27 Bouwman & Zwart (1994) showed that the protozoan biomass (dominated by amoeba) in a Dutch system (the Lovinkhoeve Experimental Farm) under integrated management was significantly higher than under contemporary, but this is difficult to explain as bacterial biomass remained the same in the two treatments. They suggest that bacterial production rate may be higher under integrated management. Also, soil physical properties (soil organic matter content, soil moisture etc.) differed under the treatments, with higher organic matter content under integrated management. These factors may provide more favourable habitat for protozoa. Differences in nematode activity were not significant. About 30% of N mineralisation in Lovinkhoeve was due to the bacterivores.

### *Birds*

3.28 Agricultural intensification converts farming into an industrial process with little regard for the environmental effects of increasing production (Chamberlain *et al.*, 2000; \*Donald, Green & Heath, 2001; \*Pain & Pienkowski, 1997; \*Schifferli, 2000). Landscape-scale effects (habitat loss and fragmentation, loss of landscape connectivity, loss of diversity and the creation of monoculture, loss of habitat quality, direct poisoning and loss of food supplies) are discussed below. Other effects, notably the change from spring to autumn sowing with the concomitant loss of winter stubbles, have received much attention from ornithologists. Loss of stubbles reduces the availability of winter food supplies for a large number of farmland bird species (Moorcroft *et al.*, 2002; Robinson & Sutherland, 1997; Whittingham & Markland, 2002). Autumn sowing also changes the characteristics of crop structure in relation to the timing of breeding (Donald & Vickery, 2001). Autumn-sown crops, especially cereals, become unsuitable as nesting habitat for certain species, especially Skylark *Alauda arvensis*, earlier in the season, resulting in an early end to breeding and a reduction in the number of broods that can be raised (Donald & Vickery, 2000). Birds attempting to compensate for unsuitable crop height and density by locating nests on the edges of wheel marks may also suffer higher predation rates, but results concerning predation differ between studies and may depend on a range of factors (e.g. characteristics of local predator populations, availability of alternative prey, local and larger-scale landscape structure) which may vary widely between sites (Wilson *et al.*, 1997).

3.29 Different crops offer different foraging opportunities for birds, in relation to crop type itself, weed and invertebrate abundances and physical access. Where nesting habitat is limited, crop rotation, in conjunction with field sizes and monoculture methodology may affect foraging efficiency, especially if a particular crop type is being exploited (Holland *et al.*, 2002; Moorcroft & Wilson, 2000; Moreby & Southway, 2002; Morris, Bradbury & Wilson, 2002). Rotational set-aside may have similar effects, but management of set-aside is likely to be more important (Henderson & Evans, 2000; \*Sotherton, 1998). For example, spraying, mowing and ploughing should be timed to minimize impacts on breeding birds. Predation may also be a problem with set-aside, especially where lack of alternative habitat results in high nest densities (Donald & Vickery, 2000).

## Landscape Structure

### Birds

3.30 In some studies, the structure and biodiversity of the surrounding landscape, or the crop type, were found to have more effect on field-inhabiting invertebrates than the farming system itself. The fact there is in most cases no attempt to quantify this variable may be significant.

3.31 Many species of farmland birds are highly mobile in the landscape and thus have the potential to access resources on a scale of kilometers rather than meters. Therefore, the overall abundance of resources and their patterns of distribution in the landscape will influence bird survival and performance (Eybert, Constant & Lefeuvre, 1995; Frey-Roos, Brodmann & Reyer, 1995; Mason, 1998). Resource abundance will itself be influenced by landscape structure, for example, small patches may be more vulnerable to extreme weather conditions and other edge effects which act to reduce patch resource potential (\*Murcia, 1995). The location of patches will influence the costs of their exploitation in terms of time, energy and risk (Hinsley, 2000). Thus patches with good resources may be under-exploited if the costs of getting there outweigh the benefits. For breeding birds, estimation of costs will include consequences for parental, as well as chick, condition and survival (Hörak, 1995; Rytönen, Koivula & Orell, 1996). Similarly, in terms of risk, exposure of patches may increase losses to predators and good patches may be under-exploited if their use incurs too high a predation risk (Newton, 1967; Suhonen, 1993). Therefore, landscape structure in general (not just that of the resources themselves) will influence bird usage. Factors associated with arable land-use likely to directly affect bird populations via landscape structure include field size, availability and condition of field boundaries, especially hedgerows, and the availability and condition of other semi-natural habitat, including gardens and individual trees.

3.32 Birds will do best under any system that:

- Maximises the availability of semi-natural habitat in farmland (e.g. correlates with smaller field sizes);
- Maximises the quality of the semi-natural habitat that is available (e.g. minimal pesticide/herbicide usage, sensitively managed hedges of a range of structures, use of field margin habitat, conservation headlands etc.);
- Minimises the isolation of patches of semi-natural habitat;
- Supplies diversity in terms of both the semi-natural habitat available, and the crop types; and
- Supplies temporal diversity as well as spatial/physical diversity (e.g. so that food supplies and cover are not suddenly altered/removed at the same time over a large area).

3.33 In general, the concept of greater habitat diversity being associated with greater overall biodiversity and population viability is well established (\*Wilson, 1992). Similarly, the benefits to birds of mixed farming are well known (e.g. Aebischer & Ward, 1997; Burel *et al.*, 1998; Evans *et al.*, 1995; Hurford, 1997; \*Lack, 1992; \*O'Connor & Shrubbs, 1986; Robinson, Wilson & Crick, 2001). The minimum requirements of breeding birds are nest sites and foraging areas and for many species of farmland birds these are not located in the same habitat types. Similarly, requirements in winter differ from those of the breeding season, increasing

the range of resource diversity required for population persistence. Any agricultural monoculture, be it arable or grassland, reduces habitat diversity and has the potential to damage bird populations. The effects of monoculture may operate temporally as well as spatially, for example causing rapid changes in resources availability depending on the stage of crop development or cultivation (\*Holland *et al.*, 2002).

3.34 Habitat quality influences bird performance and survival, but in many cases is difficult to quantify in terms meaningful to the organism in question (Dias, 1996). Overall species diversity (Boecklen, 1986; Mills, Dunning & Bates, 1991), breeding success (Hinsley, Rothery & Bellamy, 1999), territory occupancy (Matthysen, 1990; Newton, 1991) and survival (Hinsley, Bellamy & Newton, 1994; Watkinson & Sutherland, 1995) have all been used to quantify quality; in general, abundance alone is not a good measure of quality (Brawn & Robinson, 1996; Van Horne, 1983; Vickery, Hunter & Wells, 1992) and in extreme cases, the habitat currently occupied by a species may be a consequence of exclusion from preferred sites rather than the result of choice (Caughley, 1994; Newton, Davis & Davis, 1989), i.e. making the best of a bad job. Transient availability of nesting habitat may offer opportunities to some species, but will be of less (if any) value to sedentary species and specialists whose requirements include later/mature stages of vegetation. Transient foraging habitat should be of use to a wider number of species, especially if widely available across the landscape. Factors influencing habitat loss include increasing field sizes and poor management (e.g. repeated ploughing of roots). Factors influencing quality (most of which have the potential to be positive as well as negative if properly managed) include patch size, management of woodland edges, hedgerows, field boundaries, ditches and tracksides, management of set-aside, spray and fertilizer drift, grazing by livestock, leaching of chemicals etc. into waterways and alternative uses of semi-natural habitat such as for recreation, shooting and game rearing.

#### **Mitigation Measures**

3.35 Concerns about these losses in biodiversity led researchers to investigate how farmland habitats can be manipulated and managed to benefit wildlife. For example, conservation headlands were designed as a game management measure to prevent further declines in grey partridge (Sotherton, Rands & Moreby, 1985). Many of these mitigation methods have since been incorporated into agri-environment schemes which were introduced in the late 1980s to encourage farmers to restore and recreate habitats for wildlife on farmland (Haines-Young *et al.*, 2000; Anon., 2001, 2002).

3.36 Results of the most recent Countryside Survey indicate the length of hedges, which declined in England and Wales up to the 1980s, now appears to be increasing (Haines-Young *et al.*, 2000). Furthermore, cereal field margins are considered such an important habitat that they are now a Biodiversity Action Plan (BAP) Priority Habitat. The BAP target is to maintain, improve and restore by management the biodiversity of some 15,000 ha of cereal field margin in the UK by 2010.

3.37 Permanent field margins have received considerable research interest in terms of their role in the conservation of biodiversity associated with farmland. Many taxa have been shown to rely almost exclusively on field margins or hedgerows for at least part of their life cycle, including shrews and voles (Tew, Todd & Macdonald, 1994); farmland birds such as yellowhammer and whitethroat (Bradbury *et al.*, 2000; Stoate & Szczur, 1994) and arthropod predators of cereal pests (Sotherton, 1984, 1985). In a

recent study by Meek *et al.* (2002) butterfly, bumblebee, carabid, spider, millipede and harvestman abundance was significantly higher in sown field margins and margins left to regenerate naturally compared to where the field margin had been conventionally cropped to the field edge. Feber *et al.* (1997) also found that non-pest butterfly abundance was greatest over uncropped field boundaries compared to the crop in both organic and contemporary farming systems. Whilst there is a substantial amount of evidence to show that where these mitigation measures are implemented within either contemporary or sustainable systems there are likely to be significant benefits to biodiversity (\*Marshall & Moonen, 1998; \*Marshall & Moonen, 2002), very little research has investigated whether there are any differences in terms of their effectiveness between different farming systems. Differences between farming systems in terms of intensity of management of cropped areas, pesticide use, crop rotation and quality and quantity of non-cropped habitat could all play a role in the effectiveness of these mitigation measures.

3.38 Organic farming is often cited as a model of sustainable farming, with sympathetic field margin management forming part of the 'whole farm' approach towards sustainability. The majority of research investigating the effectiveness of field margins between systems has focused almost wholly on comparing organic with contemporary farming the latter being perceived to be less sustainable.

3.39 Feber *et al.* (1997) investigated butterfly abundance on eight pairs of organic and contemporary farms in areas bordered by Dorset, Shropshire, Lincolnshire and Essex. Organic field margins were significantly richer in non-pest butterflies than field margins on contemporary farms. Reasons for this were unknown but may have reflected management differences between the two systems such as lack of spray drift or cropping pattern, or a greater abundance and diversity of food plants in organic boundaries. In another study conducted on 22 pairs of organic and contemporary farms across England and Wales, Chamberlain, Wilson & Fuller (1999) suggested the quality of field boundaries for farmland birds was greater on organic farms. Organic farms tended to have taller, wider hedges and field boundaries containing more trees which was thought to explain the higher densities of birds found using field boundaries on organic farms. Recent reviews have also suggested that the quantity and quality of non-cropped habitat on organic farms is greater than that on contemporary farms and field boundaries on organic farms support a higher level of wildlife (\*Azeez, 2000; \*Bartram & Perkins, 2002). However, Bradbury *et al.* (2000) showed that yellowhammer territories are associated with hedgerows and wide uncultivated grassy field margins but found no difference in breeding success between four organic and five intensively managed farms in the midlands and south of England.

3.40 These studies suggest that organic field boundaries are of superior quality and support higher biodiversity than contemporary boundaries. However, this has only been shown for a limited number of taxa and some of the studies were only carried out on a small number of farms. Further large-scale research is needed to test the generality of these results.

3.41 It is common for all farms other than organic to be labelled 'conventional' and to be seen as unsustainable. However, there has been an increase in the popularity of 'integrated' farming whereby farmers strive to reduce pesticide inputs. As with

organic farming, management of field margins and other non-cropped habitats forms part of the 'whole farm' approach. Research is required to investigate whether there are any differences in terms of effectiveness of field margins between 'integrated', organic and 'conventional' systems. Obtaining a definitive answer to these questions is inherently difficult. Quantity and quality of non-cropped habitat and dominant farming type surrounding a particular study area may affect the colonisation of field margins by flora and fauna at that site. Furthermore, the effectiveness of field margins for biodiversity may differ with the length of time under which a farm has been organic or less intensively managed.

#### *Conservation headlands and field margins*

3.42 Concerns about the decline of grey partridge in intensive arable farmland resulting from the direct and indirect effects of pesticides on invertebrate chickfood, first led to the concept of conservation headlands. Studies in the UK, Sweden and Finland showed that cereal headlands left unsprayed with herbicide and insecticide supported higher densities of weeds and arthropods, including those species important in the diet of gamebird chicks (Chiverton & Sotherton, 1991; Sotherton *et al.*, 1985; Chiverton, 1994; Helenius, 1994). Furthermore, partridge and pheasant chick survival was higher on farms where unsprayed margins were implemented (Sotherton *et al.*, 1985; Chiverton, 1994).

3.43 Following this research numerous studies have shown that conservation headlands also benefit non-game species (\*Marshall & Moonen, 1998; \*Marshall & Moonen, 2002). Research conducted in England and the Netherlands has shown that higher numbers of individuals and species of butterfly are found in unsprayed compared to sprayed headlands (de Snoo, van der Poll & Bertels, 1998; Dover, 1997; Sotherton *et al.*, 1985) and foraging activity by butterflies is higher in unsprayed headlands (Dover, 1997) also found that whereas spring emerging butterflies in fields without conservation headlands were associated with the pre-existing hedgerow margin, in fields with conservation headlands they were associated with headlands. However, Kells, Holland & Goulson (2001) in a study in the UK found greater numbers of foraging bumblebees in uncropped margins left to regenerate naturally than in conservation headlands. Where fertiliser was also excluded from conservation headlands in the Netherlands, Kleijn & van der Voort (1997) showed that endangered arable weeds can benefit as a result of increased light penetration. In another study in the Netherlands de Snoo *et al.* (1994) found that unsprayed headlands were visited more frequently than sprayed headlands by *Motacilla flava flava* (blue-headed wagtail) but no effect was found for *Alauda arvensis* (skylark) or *Anthus pratensis* (Meadow pipit). In a three-year study on two farms in Oxfordshire unsprayed headlands were preferred to sprayed headlands by the wood mouse *Apodemus sylvaticus*. Increased food availability in terms of higher weed and insect abundance was thought to influence this behaviour (Tew *et al.*, 1992).

3.44 All of these examples suggest that conservation headlands can benefit a wide range of taxa on intensive arable farmland. However, there has been no documented research to investigate whether there are any added benefits in terms of the effectiveness of conservation headlands where pesticide inputs are carefully controlled across the whole of the farm for example in integrated systems.

### *Beetle banks*

3.45 Many key invertebrate predators important in the control of cereal aphids overwinter almost exclusively in field boundaries, particularly on raised grassy hedge banks (Sotherton, 1984, 1985). Beetle banks aim to increase the proportion of overwintering habitat for these invertebrates, and so enhance predator densities within cereal fields during spring and summer.

3.46 Studies in the UK (Hampshire & Leicestershire) and Sweden showed that beetle banks sown with tussock forming grasses support higher densities of predators than bare ground or banks sown with matt-forming grasses or left to regenerate naturally (Collins, 1999; Thomas, Wratten & Sotherton, 1991, 1992; Chiverton, 1994). These authors also showed that beetle banks sown with tussock forming grasses could support densities of predators similar to or greater than that found in contemporary field margins. Furthermore, in an experiment in Leicestershire, Collins *et al.* (2002) showed that invertebrate predators emigrating from a beetle bank significantly reduced numbers of cereal aphids in an adjacent crop of winter wheat.

3.47 More recently the value of beetle banks for other taxa has been examined. Beetle banks sown with tussock forming grasses on a game estate in Leicestershire were found to provide ideal nesting habitat for harvest mice (Bence, Stander & Griffiths, 1999). A study of 22 beetle banks and contemporary field margins from five farm estates in Hampshire & Wiltshire also found beetle banks to be a valuable source of chick food for farmland & game birds (Thomas, Goulson & Holland, 2000, 2001). Murray, Wilcox & Stoate (2002) showed that beetle banks were used as foraging habitat by skylarks significantly more than un-managed set-aside and broad-leaved crops. Moreover, although newly established beetle banks are generally less botanically diverse compared to contemporary field margins, diversity increases with age and banks over a decade old can be nearly as diverse as contemporary margins (Thomas *et al.*, 2002).

3.48 All these studies were either carried out on single estates or a small number of estates, covering a limited geographical area. There have been no direct comparisons of the effectiveness of beetle banks either in terms of wildlife conservation or for biological control across different farming systems. Nevertheless, it has been hypothesised that intensity of insecticide regime may affect carabid abundance and subsequent colonisation of beetle banks (Collins, 1999; Thomas *et al.*, 1992). Thomas *et al.* (2001) sampled invertebrates from beetle banks on farms managed for game and other environmental benefits; they found little variation in abundance between sites. However, once the experiment was extended to include a wide range of farm types invertebrate abundance differed significantly between farms. The authors suggested that this was due to differences in pesticide management between farms. These results indicate that further research is warranted to investigate the effectiveness of beetle banks under different farming systems particularly in terms of predatory invertebrates and the role of these habitats in biological control.

### *Wild bird cover*

3.49 Wild bird cover mixtures were originally designed to provide habitat for game birds and are based on cereal or kale based mixtures. Cereal mixtures were designed to provide brood-rearing cover whilst kale provides winter cover. The majority of literature on wild bird cover comes from studies conducted on the Loddington estate

in east Leicestershire where the aim is to integrate game and wildlife conservation with viable commercial farming. In a four-year study on this estate Boatman & Bence (2000) showed that set-aside sown with wild bird cover provides nesting and foraging habitat for pheasant and skylark and this habitat was preferred to all or most other available habitat on the farm. Murray *et al.* (2002) also showed that set-aside managed as wild bird cover is an important foraging ground for skylark and yellowhammer. Kale set-aside was used more by skylarks whereas cereal-based set-aside was better for yellowhammers. Butterfly transects carried out on the estate revealed that wild bird cover yielded more observations of butterflies than any other habitat (Boatman & Bence, 2000). Other studies conducted on the estate have shown that wild bird cover constitutes the main feeding habitat on the farm for seed-eating birds during winter and is a preferred habitat of brown hares (Boatman & Bence, 2000; Boatman, Stoate & Watts, 2000; Stoate & Leake, 2002).

3.50 Following this research a three-year experimental project was conducted at Loddington, Leicestershire and two other estates in Norfolk and Hertfordshire to examine the value of a wider variety of crops which could be sown as a food source for birds in winter (Boatman & Stoate, 2002). Annual crops tested were barley, borage, buckwheat, fat hen, forage rape, linseed, millet, mustard, quinoa, sunflower, triticale and wheat. Biennial crops were kale, teasel, chicory and evening primrose. This research indicated kale and quinoa mixtures sown on set-aside would benefit the widest range of birds and addition of teasel would benefit goldfinches. However, larger buntings require cereals and addition of linseed would broaden the range of species attracted to this mixture. These mixtures also provide good foraging and nesting habitat for birds in summer (Boatman & Bence, 2000; Murray *et al.*, 2002). A variety of mixture types are therefore likely to provide the greatest conservation benefits for birds in both summer and winter.

3.51 This research has only been carried out on a small number of farms and covers a fairly limited geographical area. Much of this work has also been conducted on farms where there is a history of environmentally conscious management to encourage game. Further research is needed to test the effectiveness of this mitigation method under different farming systems.

#### *The influence of agri-environment schemes*

3.52 Agri-environment schemes began in the late 1980s with the first of the Environmentally Sensitive Areas (ESAs). Although hedgerow management and the reversion of whole arable fields to grassland were addressed from the beginning it was not until the introduction of the Countryside Stewardship Scheme (CSS) and the later tranches of ESAs that arable margins, and beetle banks were introduced on a large scale.

3.53 A sample of 51 CSS agreements were evaluated by a combination of desk-study, survey and expert opinion against five criteria: agreement negotiation, appropriateness, environmental effectiveness, compliance and side-effects (Carey, 2000). Of relevance to this review were environmental effectiveness and compliance. The vast majority of the 51 agreements were expected to provide environmental benefit ecologically as they would provide habitats for invertebrates and small mammals and would provide protection for hedgerows and ditches. In some cases where management was to allow natural regeneration on light soils or where

wildflower mixtures were sown there was expected to be benefit for flora and the nectar-feeding insects dependant on them. In the very great majority of cases it was expected, and indeed there was evidence that farmers would comply with the conditions of their agreement and carry out the management on the arable margins. The survey has not been repeated to see whether the expected benefits have materialized.

3.54 Currently a new agri-environment scheme is being devised by Defra and its advisors. In addition to the existing agri-environment measures it is expected that there will be a new entry tier for farmers with simple and proven management tasks to be carried out. For arable farmers this is likely to include field margins and buffer strips alongside streams and hedges as well as hedge management and the protection of trees.

3.55 If uptake is even close to the target then this new scheme is likely to have a large effect on the ecological quality of arable fields but more importantly the arable landscape. The effects will be widespread but as yet it is difficult to gauge how large the effects will be either on the countryside as a whole or even on a field per field basis.

3.56 A continuing debate within and outside Defra concerns whether agri-environment schemes provide 'value for money'. In many cases the calculations for the savings to society of agri-environment over contemporary farming have not been carried out. Most economic activities affect the environment, either through the use of natural resources as an input or by using the 'clean' environment as a sink for pollution. The costs of using the environment in this way are called externalities, because they are side effects of the economic activity and their costs are not part of the prices paid by producers or consumers. When such externalities are not included in prices, they distort the market by encouraging activities that are costly to society even if the private benefits are substantial (EEA, 1998; Brouwer, 1999; Pretty et al, 2000). Until the calculations are made on the true costs of farming on the environment are made including externalities (e.g. the cost of a pair of skylarks) it will be difficult to fully assess how one arable cropping system compares with another.

### 3 Ecological Impacts of Arable Agriculture

## **4 SOCIO-ECONOMIC, SOCIAL AND ENVIRONMENTAL IMPACTS OF DIFFERENT CROPPING SYSTEMS**

4.1 This Chapter provides the background socio-economic and environmental (rather than ecological) information gathered from large projects that have looked at five different cropping systems (low input systems, integrated arable farming systems, organic farming, reduced tillage, and precision farming). This chapter provides the key information used for the key findings presented in Chapter 5.

4.2 Throughout this Chapter review articles are marked with an asterisk

### **General insights**

4.3 Studies are considered in respect of the differences between contemporary and alternative systems rather than their absolute levels of performance. Where possible, three criteria are used to compare the systems:

1. Yields and profitability;
2. Input usage and environmental impacts; and
3. Social impacts.

4.4 There is a vast literature studying different aspects of farming systems around the world, and this literature provides some general insights that are relevant to this review.

1. Yields tend to be higher in research trials than in commercial production. This means that comparisons of yields from commercial production using contemporary systems with yields from research trials of alternative systems are unlikely to be valid. In order to compare contemporary and alternative systems in a valid way, they should both be grown within the comparable production regimes.
2. There are many different factors that influence the farm-level profitability of particular systems or system elements. Pannell (1995) grouped them into five categories:
  - (a) Short term profit factors (e.g. crop yields, output prices, input costs)
  - (b) Dynamic factors (short to medium term) (e.g. impacts on subsequent crop yields due to current fertilizer use, weed control, tillage method, crop disease)
  - (c) Sustainability factors (e.g. pesticide resistance, soil degradation)
  - (d) Risk factors (e.g. yield variability, price variability, system flexibility, the farmer's attitude to risk)
  - (e) Whole-farm factors (e.g. machinery capacity, finance availability and cost, labour, the farmer's objectives, knowledge and experience).
3. As a result of variation in the five factors above, the economic performance of particular farming systems or system elements often varies widely among farmers in a region, and even more so between farmers of different regions. This means that caution is needed in drawing general conclusions about the performance of any particular system. Even systems that perform well for many farmers may perform poorly for other farmers in the same region. Similarly, systems that

generally perform well in one region may perform poorly in another region due, for example, to differences in soils, climate, or markets.

4. As a generalisation, given sufficient time and experience, commercial farmers are reasonably successful at identifying which systems are suitable for them under current conditions (\*Lindner, 1987). It is not wise to expect that scientists or others without considerable farming experience and highly detailed site-specific knowledge of a farm can prescribe practices that would be more successful at meeting a farmer's personal objectives than the farmer's or his agronomic advisor's own choices.
5. When considering different possible rates of application of farming inputs to a crop, there is often a reasonably wide range of input levels either side of the economic optimum that give only slightly lower profits (Anderson, 1974). In other words, there is often a wide margin for error, and scope for flexibility in choosing input levels, without substantially reducing profits.
6. As market prices and/or the level of price support under the CAP vary, economically optimal input levels will vary accordingly (\*Dillon, 1977). While price support remains high, there is a tendency for low input systems to be relatively economically disadvantaged, particularly in those systems that do not attract market premiums on account of their environmental or health benefits. However, as noted above, the actual economic performance depends on a multitude of factors and it is possible for low input systems to compete economically if they have other advantages to offset their typically lower yields.
7. Where a relatively profitable farming system generates adverse impacts on the environment or human health, more is required than simply quantification and communication of those impacts in order for farmers to act decisively to reduce those impacts. Specifically, legal or financial tools are needed to create incentives for change (Cary & Wilkinson, 1997; Pannell, 1999).
8. Work is currently being carried to identify the "economic footprint" of farm systems; however, results of that analysis are not yet available.

4.5 Gross margins for individual crop or livestock enterprises can be a misleading indicator of their profitability within the farming system, or their different levels of profitability in different systems. For example, livestock may appear unprofitable if viewed as an individual enterprise, but provide complementary benefits to the cropping enterprise by rotational benefits of including pastures (Pannell, 1987), or by providing a degree of weed control. Legume crops or green manure crops may provide nitrogen to subsequent cereal crops (Gladstones, Atkins & Hamblin, 1998). In such cases, gross margins should be compared for whole rotations, rather than individual crops.

#### **Low-input systems**

4.6 Research into low-input arable systems was initiated in the UK at the end of the 1970s after a decade of increasing pesticide use in cereals. This period had seen a decline in invertebrate populations in cereal crops in Southern England and a link was considered possible.

## 4 Impacts of Different Cropping Systems

### *Relevant projects*

#### 1. The Boxworth Project

4.7 The Boxworth Project (Greig-Smith, Frampton & Hardy, 1992) was the first long-term study of Low-Input Systems to be set up in the UK. A key feature of the study is that it was conducted at the scale of a whole farm rather than a field or sub-field.

4.8 The project had three objectives:

- (a) to investigate the effects of three pesticide regimes on plants, birds, small mammals and arthropods;
- (b) to assess the economic performance and commercial viability of crops under the various pesticide regimes so that comparisons could be made; and
- (c) to assess the management of the pesticide regimes.

4.9 Three treatments were used:

- (a) A 'full insurance' treatment, based on the high and prophylactic use of pesticides that typified intensive cereal production in the late 1970s;
- (b) a 'supervised' treatment, in which pesticides were only used only when pests, weeds and diseases reached levels above economic thresholds; and
- (c) an 'integrated' treatment, in which husbandry practices and economic thresholds were used to reduce input levels further.

4.10 The usefulness of the experiment for current purposes was compromised because the 'full insurance' regime did not reflect the trend towards declining pesticide inputs that occurred within commercial farming during the project's life span and has continued since. A decision was made to keep the pesticide regimes fixed so as not to overcomplicate the study. However, this did mean that by the end of the study, the full insurance regime had levels of pesticide inputs that were higher than the bulk of contemporary practice. The continuous wheat-cropping regime that was followed in the study also became out-dated.

4.11 The Boxworth study was useful in highlighting some common problems experienced in reduced input trials. Problems identified included:

- the difficulty of maintaining long-term pesticide regimes under experimental conditions;
- the difficulty of investigating multiple factors (in this case, economic, environmental and agronomic) due to the conflict between scale and replication;
- the use of cultivar mixtures in an integrated regime failed to reduce the incidence of cereal diseases (Holland *et al.*, 1994).

4.12 These problems were taken into account when subsequent studies were designed. Specifically, the problem of investigating multiple factors within a single project was addressed in the subsequent TALISMAN and SCARAB projects.

#### 2. TALISMAN

4.13 TALISMAN (Towards A Lower Input System Minimising Agrochemicals and Nitrogen) Was a follow-up studies to the Boxworth Project, commissioned by MAFF and undertaken between 1989 and 1996 (Young *et al.*, 2001). They were designed to

address in further detail many of the issues highlighted in the Boxworth Project. TALISMAN investigated the economic and agronomic effects of reduced input arable systems. The project investigated whether the results produced by the Boxworth Project could be achieved over a wider range of locations, and soil types.

4.14 The TALISMAN Project used two pesticide regimes: Current Commercial Practice (CCP) and a Reduced Input Approach (RIA), on two contrasting crop rotation systems. The 'Standard Rotation' was based entirely on autumn sown crops, and an 'Alternative Rotation' included spring-sown cereals and break crops. In the RIA regime, nitrogen was applied at 50 per cent below the CCP levels and pesticides were either omitted or applied at no more than 50 per cent of CCP rates.

### 3. SCARAB

4.15 The SCARAB (Seeking Confirmation About Results At Boxworth) project assessed the impact of pesticides on non-target populations of insects and spiders typically found in arable crops, soil microbial activity and biomass, and earthworms. As with TALISMAN, two pesticide regimes were implemented, CCP and RIA. In the RIA no insecticides, molluscicides or nematicides were used, while fungicides and herbicides were applied at reduced or full rates only when needed to avoid significant reductions in crop yield or value.

4.16 Like TALISMAN economic and agronomic factors were considered, but given lower priority.

### 4. RISC

4.17 Another project, RISC (Reduced Input Systems of Cropping), which had similar objectives, design and treatments to TALISMAN, was initiated in Northern Ireland by DANI (Department of Agriculture for Northern Ireland) in 1991 and completed in 1999. There were certain differences between RISC and TALISMAN; notably RISC reflected the different cropping practices and pesticide use found in Northern Ireland. The RISC Project was unusual in that it included a comparison of an arable rotation with a mixed arable and grass ley system. As grassland is a major component of the farming system in Northern Ireland, it was considered important to evaluate the potential for reducing pesticide inputs by the use of grass leys in the rotation. A six-year arable rotation was compared with a four-year arable rotation with a two-year break crop of grass. Four treatments were used on each rotation; Current Farm Practice (CFP), Low Input Approach (LIA), Integrated Low Input Approach (ILIA) and a minimum input treatment (MIN).

#### *Yields and profitability*

4.18 Results from the Boxworth Project demonstrated that although the full insurance regime produced the highest yields, the supervised regime was equally as profitable and occasionally more profitable due to lower input costs. The more extreme integrated treatment resulted in lower yields and gross margins than either the full insurance or the supervised regime and experienced problems with grass weeds. However, it was recognised that the integrated treatment was a compromise and unrepresentative of typical integrated systems. The main conclusions from the Boxworth project were that high inputs of pesticides are likely to be unnecessary in a well-managed crop, are likely to be detrimental to the environment and unlikely to realise increased economic benefits.

4.19 In the TALISMAN project, crop yields were generally lower in the low-input regime; in winter wheat they were reduced by 6 per cent. However, the average gross margin for all crops under the low-input regime was 2 per cent higher than the contemporary regime. The gross margin of the Standard Rotation was on average 15 per cent higher than the Alternative Rotation. Nevertheless, the low input regimes are not suitable for all sites or crops and it may be necessary to adapt crop rotations to suit local conditions in low-input regimes. The main conclusions were that although crop yields are generally lower under reduced input regimes, lower variable costs were incurred due to reduced input levels, which tended to give rise to slightly higher gross margins than the contemporary regime. There was found to be greater potential for reducing inputs of fungicides than herbicides or insecticides. Consistent with the earlier General Insight 6, Young *et al.* (2001) concluded that low-input regimes may become more attractive under conditions of declining profitability in arable farming. They also noted that local knowledge and management skills are vital to the profitability of a low-input system (consistent with General Insight 3, para. 4.2).

4.20 The non-use of insecticides and nematicides in the reduced input regime of the SCARAB project resulted in lower yields in 75 per cent of the comparisons, with an average 12 per cent reduction in yields. Sugar beet and potato crops suffered the greatest reductions, followed by wheat yields, with relatively small losses in barley, beans and oilseed rape crops. For more than half of the crops, gross margins were lower, with an overall reduction of 5.5 per cent. However, in commercial practice, a more flexible approach to pesticide application would be adopted than was the case in this study.

4.21 In the RISC Project, reduced inputs of pesticide were found to be cost-effective on cereal crops when fertiliser was applied at the full rate, with gross margin improvements ranging from £14/ha to £35/ha. However, reduced rates of pesticides were not cost-effective in oilseed rape and potato crops at full-rate fertiliser applications nor in any of the crops when fertilisers were applied at half rates. Weed populations were better controlled at reduced-rate applications of herbicides in the arable/grass ley rotation than in the arable-only rotation. The ILIA generally performed better financially than the LIA and profitability of crops grown following a grass ley was generally higher. These results suggest that reducing agrochemicals is more likely to be economically feasible when undertaken as part of an integrated whole-farm approach. The RISC study underlined the interacting influences between choice of rotation and the long-term impacts of reducing agrochemical application rates.

4.22 The general conclusion that can be drawn from the UK studies into low-input arable systems is that reducing pesticide rates is likely to be economically viable in certain crops, notably cereals. However, profitability is influenced by numerous factors such as cost of inputs, market value of the crop, rotation system, location, soil type and agronomic factors. Furthermore, a high level of site-specific management and knowledge are of prime importance. Reducing input levels is likely to become increasingly financially viable if the economic squeeze on arable crop prices tightens.

*Input usage and environmental impacts*

4.23 All of the systems in this category involved moderate reductions in pesticide use. Other inputs were maintained at levels comparable to contemporary practice.

4.24 The results of the SCARAB study showed that the use of pesticides had limited impact on the indicator organisms.

4.25 No studies of the implications of Low-Input Systems for energy use and greenhouse gas emissions were identified in the review.

*Social impacts*

4.26 No social impacts of the low input systems were identified in the research reviewed. Considering the nature of the systems, it appears likely that any social impacts from adoption of these systems would be minor.

*Strengths and weaknesses*

4.27 A strength of the Low-Input Systems is that, of the systems examined here, they are the most similar to contemporary practice, and so their adoption may meet with less resistance from farmers (provided benefits from their adoption can be demonstrated to farmers).

4.28 On the other hand, the Low-Input Systems involve only modest changes in farm management, and so may be seen by the community as generating only low external benefits.

*Key gaps in information*

4.29 Optimal design of systems for a balance between profit and reduced pesticide use. The systems examined in the field studies reviewed represent a very small set from the full range of possibilities. It may be that other systems not yet studied would provide greater reductions in pesticide use while maintaining or increasing profits. Further exploration of this possibility would require computer modelling to integrate pest/pesticide responses within a detailed economic framework. If this work successfully identified more profitable systems with lower pesticide use, it could enhance their uptake by farmers, and guide further field research into areas where it is most likely to make a difference.

4.30 Applicability of economic conclusions to a wider variety of farm types and locations. There are many different farm types and farming environments that differ in a variety of ways from the sites used for the reviewed trials. The differences would particularly affect economic conclusions, even if the biological conclusions were reasonably consistent. The type of bio-economic model suggested above in 4.24 could be useful for extending the range of situations for which conclusions can be reached about the economics of Low-Input Systems.

**Integrated Arable Farming Systems**

4.31 Interest in Integrated Arable Farming Systems (IAFS) or Integrated Crop Management (ICM) in arable crops has grown since the late 1980s, both in the UK and in Europe. Growing economic, environmental, political and social pressures have forced a reappraisal of arable production systems. IAFS is considered by many to be a viable option for sustaining agricultural production and farm incomes and

safeguarding the environment. The interest in IAFS also stemmed from the limited success and adoption of Integrated Pest Management approaches despite their environmental benefits and cost saving potential. It was hoped that a more integrated approach that addresses economic, political, agronomic, sociological and environmental aspects of arable crop production would be more likely to attract wide farmer uptake.

*Relevant projects*

4.32 A number of long-term studies to evaluate the feasibility of IAFS as an approach to arable crop production for wide-scale adoption were undertaken in the 1990s. This was as a consequence of the International Organisation for Biological Control of Noxious Animals and Plants (IOBC) forming a working group in 1986, which established guidelines for the design of experiments on IAFS and brought together interested researchers from various European Countries. In 1992, the EU funded the establishment of a European Network of research teams working on IAFS. Two UK based organisations are members of the European Network: the Less Intensive Farming and Environment project (LIFE) and LINK Integrated Farming Systems (LINK:IFS) (see below).

4.33 In the UK, IAFS research has been largely dominated by seven organisations. These organisations co-ordinate research into IAFS, the development of findings and the dissemination of results under the umbrella organisation: the Integrated Arable Crop Production Alliance (IACPA), which was established in 1994. IACPA ensures that research projects undertaken complement one another, ensuring that a diverse range of crops, soils types, geographical areas and climatic areas are covered by the combined research of the member organisations and that duplication is avoided. The member organisations and their interests in integrated arable farming are as follows:

1. **LIFE** (Less Intensive Farming and the Environment). Based at Long Ashton, this 10-year (1989-1999) research project was funded by MAFF. It was set up to develop options to enable input reductions in order to minimise the environmental impact of crop production, without loss of production. Findings are being applied to two pilot farms in southwest England.
2. **LINK:IFS** (Integrated Farming Systems). This five-year project (1992-1997) undertook farm-scale comparisons of economic, environmental and agronomic impacts of contemporary and Integrated Farming Systems. The study took place at six sites to establish the impact of different locations, soils and climates: Midlothian, Herefordshire, Hampshire, Yorkshire and Cambridgeshire (two sites). The project was funded by MAFF, SOAEFD, Home-Grown Cereals Authority, Zeneca Agrochemicals and the British Agrochemical Association.
3. **FOFP** (Focus on Farming Practice) A seven year (1992-1999) comparative evaluation of Conventional and Integrated farming systems undertaken on a 60 ha commercial CWS farm in Leicestershire. The project was funded by CWS Agriculture, Profarma and Hydro Agri.
4. **RPMS** (Rhône Poulenc Management Study) A comparative study of Conventional and Integrated Farming Systems on a 57 ha Rhône Poulenc farm in Essex.
5. **LEAF** (Linking Environment and Farming). Demonstrates Integrated Crop Management and Integrated Farming Systems through a network of LEAF

demonstration farms throughout the UK. Has developed the LEAF Audit as a management and planning tool to assist farmers in developing an Integrated Crop Management approach.

6. **FWAG** (Farming and Wildlife Advisory Group). Promotes and advises farmers on wildlife and landscape conservation throughout the UK.
7. **TIBRE** (Targeted Inputs for a Better Rural Environment). A Scottish Natural Heritage Initiative which promotes the use of technologies that reduce the environmental impact of farming, whilst maintaining or increasing profitability and not significantly increasing the management burden.

4.34 Four of the above projects are research-focused: LIFE, LINK:IFS, FOFP and RPMS. These had different objectives to the Boxworth, SCARAB and TALISMAN projects in that they focused on the development of field scale integrated farming systems rather than looking at the various effects of different levels of agrochemical inputs. Similar research studies have been undertaken in other European countries, with the first major studies initiated in 1979 at Lautenbach in Germany, Nagele in the Netherlands and Ipsach in Switzerland.

4.35 All studies identified have been undertaken over several years, have completed at least one crop rotation and most are comparative studies between IAFS and contemporary systems. Economic issues have been extensively researched and the conclusions drawn from the studies are broadly consistent.

#### *Yield and profitability*

4.36 Yields tend to be lower in integrated systems in comparison with contemporary systems, although comparisons can be complicated by the use of different cultivars in different IAFS treatments (intended to be more appropriate to the system). Various factors contribute to the lower yields, including lower input levels and agronomic decisions, such as delaying the drilling dates of crops in order to avoid using certain pesticides in IAFS treatments.

4.37 In the LINK:IFS project crops grown in the integrated system yielded less than contemporary crops in 66 per cent of comparisons, with winter wheat having a mean yield decrease of 0.71 t/ha. There was a mean reduction in winter bean yield of 1.0 t/ha but differences in the yields of potato, pea and oil seed rape crops were not statistically significant (Ogilvy, 2000).

4.38 The LIFE project compared standard farm practice and lower input options in contemporary and integrated rotations. Over the first five-year cycle, the lower input levels led to yield reductions in both rotations: by an average of 10 per cent in the contemporary rotation and by 15 per cent in the integrated rotation (Jordan *et al.*, 1995). In the contemporary rotation, yields of wheat were reduced by 8 per cent (first wheat) and 10 per cent (second wheat), barley by 11 per cent and oilseed rape by 1 per cent. In the integrated rotation, wheat yields were reduced by 18 per cent, (due to the use of a lower yielding, disease-resistant cultivar), oats by 11 per cent (due to use of naked oats, which have a lower yield potential) and oilseed rape by 18 per cent (because it was spring sown for effective weed control), while bean yields increased by 5 per cent. During phase II of the project (1995-1997) the soil nutritional benefits of including break crops increased the yield of the integrated winter wheat production and improved profitability compared to contemporary wheat production).

4.39 Overall, across the IACPA projects, integrated crop yields were reduced by 8 per cent in winter wheat and barley, but winter oilseed rape yields were increased by 3 per cent (IACPA, 1998). Yield reductions in integrated treatments were also experienced in the Lautenbach project (-7 per cent) (\*Holland *et al.*, 1994) and in the ITCF/ACTA project in France, where average annual yield reductions were in the range of 14.8 per cent to 34.6 per cent over a four year period (\*Viaux & Rieu, 1995).

4.40 Quality of production has not been examined in detail in the projects identified. However, those projects working under the IACPA have found that the quality obtained under integrated systems is comparable with that from conventionally grown crops (\*IACPA, 1998).

4.41 Crop rotation and crop diversity are identified in most studies as having important impacts on the overall performance in integrated systems. Not only do a well-designed rotation and an appropriate choice of crops help to control weeds, pests and diseases and make efficient use of nutrients, but it can also help to spread the workload more evenly.

4.42 Those considerations influence the estimates of the profitability of IAFS treatments relative to contemporary treatment. In addition, of course, profits are affected negatively by the lower yields and positively by lower input costs of IAFS treatments. (The lower input levels are detailed in the following section. For the research projects working under IACPA, all costs were reduced (inputs and operational) except for seed costs as seed rates were increased to compensate for pest damage.) Most projects found that the positive and negative influences on profit are reasonably well balanced, so that gross margins for crops grown in integrated treatments are not greatly different from their contemporary counterparts. Averaged over all sites and all crops there was no statistically significant difference between the gross margins of the integrated and the contemporary system, £831/ha for IAFS and £848/ha for the contemporary system (Ogilvy, 2000).

4.43 However, this average result masks considerable variability in economic results between the different studies undertaken by IACPA member organisations, with both higher and lower profits for IAFS treatments being observed. Similarly wide variation was also observed among other European studies (\*Agra CEAS Consulting, 2002) and is consistent with General Insight 3 (para. 4.2) given earlier. Specific causes for lower profitability have been identified in some cases. Crop rotation appears to have an important bearing; in some studies less profitable spring break crops were included in the rotation. With such variable results in evidence, it is not possible to draw clear conclusions on the relative profitability of IAFS, and nor should such clear conclusions be expected given the insights from past research on farming systems. It is clear that integrated systems can be at least as profitable as contemporary systems in some situations, particularly if careful consideration is given to the crop rotation and management factors, but that in other situations their economics will not compare favourably. As noted in General Insight 6 (para. 4.2), integrated systems are likely to be more attractive to farmers when market prices and/or policy-driven price supports are lower.

4.44 The higher level of risk involved in IAFSs in terms of crop yield loss and financial uncertainty is widely acknowledged in the conclusions of studies into integrated systems, particularly when ‘insurance’ or prophylactic pesticide treatments are reduced. Risks would be expected to decline with experience. There may be some initial costs involved in training to gain the relevant skill and knowledge required, and machinery costs, particularly if a greater diversity of crops are to be grown.

### *Input usage and environmental impacts*

4.45 For the research projects working under IACPA, inputs use in IAFS treatments decreased on average by 52 per cent for fungicides, 48 per cent for herbicides, 40 per cent for insecticides and 17 per cent for fertilisers. There was, of course, variability among the project. For example, in the LINK:IFS project the reduction in costs for the IAFS treatments averaged only 7.8 per cent for inputs and 3.2 per cent for operations.

4.46 Integrated systems also show potential for lower energy use in two respects. Firstly, it may be possible to adopt less intensive cultivation practices, such as reducing ploughing operations (discussed in detail later in this report). Secondly, the incorporation of nitrogen fixing legume crops into the rotation may enable fertiliser application rates to be reduced (Ogilvy, 2000). Legume crops such as lentils and chick peas are traditionally grown successfully in rotational farming systems of the middle east (e.g. Nordblom *et al.*, 1994) and both legume crops and legume pastures play important roles in Australian agriculture (Gladstones *et al.*, 1998; Pannell, 1995; Puckridge & French, 1983).

4.47 No studies of the implications of integrated systems for greenhouse gas emissions were identified in the review.

### *Social impacts*

4.48 No studies specifically on the social factors of IAFS have been identified in this review. However some implications of these systems for labour requirements can be inferred.

4.49 A high level of management and agronomic skills and knowledge are seen as necessary for integrated systems. Relative to contemporary systems, more thorough forward planning and greater attention to detail is required. IAFS approaches often include regular crop monitoring to facilitate improved decision making about input requirements. On the other hand, less time would be spent on application of agrochemicals. It was concluded in the LINK:IFS project that crop-walking and decision making may initially take up 50 per cent more time but that this would decrease as the manager becomes more experienced (Ogilvy, 2000). On balance, it seems likely that a farm adopting an IAFS would have an increased demand for labour, but given the relatively low labour demands of arable cropping relative to other agricultural industries (e.g. horticulture), the increase due to conversion of cropping to IAFS methods may not be very significant in a larger context.

4.50 The need for a high level of site-specific knowledge is highlighted by most studies. Crops, cultivars, input levels and operations need to be tailored to suit local soil conditions, topography and climate to achieve optimal productivity and minimal environmental impact. Machinery operators may also need higher levels of technical skills.

*Strengths and weaknesses*

4.51 A strength of integrated systems is that, because they do not entirely rule out use of mainstream agrochemicals, they may avoid some of the technical problems sometimes experienced with organic farming. These may include difficulty with management of some weeds, or difficulty in maintaining soil fertility.

4.52 On the other hand, the following might be seen as weaknesses.

- There are no niche markets for products from an IAFS. Price premiums are not available as they are for organically produced arable crops.
- There is a need for a high level of site-specific knowledge and greater attention to detail.
- Risks may be increased, especially before the farmer has developed experience with the system.

*Key gaps in information*

4.53 Implications for labour demand have been suggested above, but could be strengthened by a study focussing on this issue.

4.54 As was suggested for Low-Input Systems, bio-economic modelling could be used to investigate the optimal design of integrated systems. The systems examined in the field studies reviewed represent a very small set from the full range of possibilities and it may be possible to select improved systems that combine economic and environmental advantages.

4.55 Also as suggested for Low-Input Systems, models could be used to extend economic conclusions to a wider variety of farm types and locations. Given the inconsistency of conclusions about the economic performance of IAFS, such models could more clearly define the circumstances (e.g. soil types, regions, prices, costs) where IAFS is likely to be economically attractive to farmers.

**Organic Farming**

4.56 Organic farming has recently attracted considerable interest from policy makers both in the UK and within Europe. This has principally been due to the surge of interest in organic produce and the compatibility of the principles of organic farming with EU CAP legislation aimed at redirecting agriculture to respond to market needs and towards more sustainable practices.

4.57 Although this has prompted some comprehensive studies of the socio-economic performance of organic farming, information is lacking in certain areas, including the impacts of future policy changes and issues related to the development of the marketing and processing of organic produce. For the purpose of this study, data for arable crops only is limited. By their very nature, organic farms tend to have a diversity of enterprises and usually have livestock incorporated into the system. This makes direct comparisons of organic arable systems with other arable systems problematic.

*Relevant projects*

4.58 A range of studies is referred to in the review. Particularly noteworthy is that of Offerman & Nieburg (\*2000) who provided a comprehensive and detailed set of

analyses of the economic of organic systems. Their study covered all EU countries and three non-EU countries: Norway, Switzerland and the Czech Republic. It was based on a literature review and on data collected by experts in each country. Indicators of organic farms used in the analysis were compared to comparable contemporary farms in each country and these ratios were compared between countries and studies, thus reducing problems associated with comparing data from countries with different economic circumstances.

##### *Yield and profitability*

4.59 Data taken from various European countries indicates that there is wide variability in organic crop yields, both between farms and between countries (\*Offerman & Nieburg, 2000; \*Padel & Lampkin, 1994). Factors that contribute to yield variability include climate, crop rotation, soil quality and the time the land has been under organic management. Most of those factors influence both organic and contemporary crop yields. In European organic arable systems, yields are generally lower than contemporary systems. Cereal yields are typically 60-70 per cent of yields from conventionally produced crops (\*Offerman & Nieburg, 2000).

4.60 Offerman & Nieburg (\*2000) found that, over a number of European countries, organic potato yields range from 38 to 82 per cent of contemporary yields and yields of pulses average around 20 per cent lower than contemporary production, although in the UK, pulse yields were eight percent higher than contemporary yields. Organic production of oilseeds and beets is comparatively small and little data is available (\*Offerman & Nieburg, 2000). In a seven-year study conducted in the UK by CWS comparing organic farming systems with contemporary systems, organic winter wheat yields were 68 per cent of contemporary yields, winter oats were 81 per cent, winter beans were 72 per cent and peas 61 per cent (Leake, 1999).

4.61 It has been observed that yields from organic crops tend to increase over time as the land has been organically managed for longer (Byström, Jonsson & Martinsson, 2002; Leake, 1999). In addition, the trend of average yields from organic production overall has been increasing (\*Mühlebach & Mühlebach, 1994; \*Padel & Zerger, 1994). However, this has been at a slower rate than the increases occurring under corresponding contemporary systems (\*Mühlebach & Mühlebach, 1994; \*Padel & Zerger, 1994). Specific causes of yield increases are often difficult to determine as they typically result from a combination of factors potentially including: improving soil quality; improving management skills and knowledge; and research and development, leading to improvements such as disease-resistant, higher yielding seed (\*Offerman & Nieburg, 2000; \*Padel & Lampkin, 1994). These factors are potentially relevant to both organic and contemporary yields. The gap between organic and contemporary yields may change overtime as legislation limits the intensity of contemporary arable production, or as developments in technology increase yields of either organic or conventionally grown crops.

4.62 The lower yields achieved by organic crops in comparison with those grown conventionally are due to the non-use of inorganic fertilisers and synthetic pesticides. However, this is compensated financially by lower input costs and price premiums received.

4.63 Data on total costs of organic arable production for 1995/96 set them at 80 per cent of the total costs of contemporary systems, with fixed costs at 86 per cent and variable costs at 66 per cent (\*Offerman & Nieburg, 2000). Low variable costs are due to the significantly lower usage of inputs such as fertilisers and pesticides, although the costs of organic seed are likely to be higher than those of conventionally produced seed. Although fixed costs are generally lower, this can vary according to labour input and how much of the labour input is unpaid family labour.

4.64 Organically grown products generally attract price premiums (except in periods when the organic market for a particular commodity is over-supplied). The level of price premium received depends largely upon the marketing channel. Direct marketing to the consumer tends to bring the highest premiums. However, arable crop commodities tend not to be marketed directly. Data from some EU countries show that less than 10 per cent of organically grown cereals are marketed directly. Organic potatoes are unusual in that direct marketing can account for more than 40 per cent of total sales (\*Offerman & Nieburg, 2000).

4.65 Price premiums vary considerably, both between commodities and between countries, depending on the demand and supply of organic and contemporary produce within each country (\*Padel & Lampkin, 1994). Wheat can be sold for premiums of 50 to 200 per cent in Europe. In the UK, the premium for milling wheat between 1994 and 1997 was 75 to 100 per cent. In 2001 the UK premium was 200% but had dropped in 2002 to approximately 100%. Prices of potatoes can be highly variable due to the high level of yield fluctuation. In the UK, the average price premium for potatoes varied over time between 75 per cent and 775 per cent during the period 1994-1997 (\*Offerman & Nieburg, 2000).

#### 4.66 Crop prices 2002

	Organic	Conventional
Milling wheat	£155	£74
Feed wheat	£135	£61
Feed barley	£120	£61
Malting barley	£160	£70
Triticale	£125	no prices
Oats	£120	£54
Beans	£180	£70
Peas	£190	£83
Lupins	£200	no prices
Soya	£240	no prices

Source: Organic Soil Association Survey, Conventional Farmers Weekly

4.67 Profitability of arable crop production on organic farms is shown in much available data to be considerably higher than contemporary farms, particularly for arable farmers (e.g. Institute of Rural Studies, 2000). (Relative profitability of organic livestock farming is generally found to be lower). In the UK between 1992-1997, organic arable crop farms achieved profits averaging around 30% higher than those from contemporary farms (\*Offerman & Nieburg, 2000).

4.68 This result should be treated with caution for a number of reasons. Firstly, it was calculated from data drawn from surveys involving only small numbers of farms. Secondly, prices for both contemporary and organic arable commodities have changed since the studies underlying that conclusion were conducted and more up-to-date economic comparisons are not available. Thirdly, arable enterprise profitability will be influenced by the mix of crops grown. It will generally not be possible to grow a high nutrient demanding crop such as wheat as frequently in an organic rotation as in a conventional rotation. Other less demanding and less profitable crops may need to be incorporated instead, reducing the overall profitability of the organic system relative to contemporary systems. For example, nutrient building, green manure crops may be incorporated into the rotation, particularly in systems with no livestock (Leake, 1999). These would enhance the profitability of subsequent cereal crops in the rotation, but at the cost of sacrificing income in the year of the green manure crop (\*Padel & Lampkin, 1994). This highlights that it is important to evaluate organic cropping in the context of whole rotations rather than as individual crops (see General Insight 8, para. 4.2). Offerman & Nieburg's (\*2000) result that organic crops give profits 130 per cent of contemporary crops is based on data for whole farms, although the data is taken for individual years and not averaged over whole rotations. If large enough samples of farms were surveyed over enough years, the approach would provide a reasonable comparison, but we have already noted above the small number of farms included in the comparisons.

##### *Input usage and environmental impacts*

4.69 Levels of artificial pesticides in organic systems would, of course, be lower than in contemporary systems. In the case of nutrient inputs, organic systems use different sources (e.g. non-synthetic fertilisers, green manure crops). We examined evidence on whether there are differences between contemporary and organic systems in the overall levels of nutrient inputs. Mäder *et al.* (2002) found that nutrient input into organic systems were 34-51 per cent lower than in contemporary systems. Stolze *et al.* (2000) concluded from a review of European literature that nitrate leaching from organic farming is lower or similar to levels from contemporary farms. However, when calculated for production units, nitrate leaching from organic farms was similar to or higher than that from contemporary farms. Cobb *et al.* (1999) calculated that 25 per cent less leaching of nitrates occurred from organic systems than from contemporary systems. All of these references refer to organic and contemporary systems in general and not to arable farming specifically.

4.70 Potato blight poses the most serious risk in growing potatoes by organic methods. At present it is permissible to use Burgundy mixture to control blight but doubts about the practice of repeated applications of copper to soils may soon mean that the EU imposes a limit or ban its use in the future.

4.71 It is believed that most pests and diseases can be controlled largely by crop rotations (\*Litterick *et al.* 2002) including mixed farming. Several Defra funded research programmes are currently investigating this topic.

4.72 Energy use is divided into direct and indirect energy. Indirect energy use is highest in contemporary arable systems and makes up the largest proportion of energy due to the use of fertilisers and pesticides. In organic production direct energy accounts for the highest proportion of energy use where crops are dried. Transport

costs tend to be higher for organic crops due to fewer certified organic grain facilities. Consequently organic grain has to be transported longer distances on average (\*ADAS Consulting Ltd, 2000).

4.73 Studies of relative energy use of organic and contemporary systems have most commonly found that organic arable systems use less energy than corresponding contemporary systems for single crops or part rotations. In a study commissioned by MAFF, better energy ratios were achieved by individual crops in organic production systems than in contemporary systems (\*ADAS Consulting Ltd, 2000). In a study undertaken in Switzerland, organic systems were found to require 20 to 56 per cent less energy to produce a crop dry matter unit (Mäder *et al.*, 2002). A study commissioned by the German government also showed that energy used, per hectare, in organic crop production in 1991/92 was 65 per cent lower than contemporary crop production systems (\*Köpke & Haas, 1996). However, when whole rotations were compared by ADAS Consulting Ltd (\*2000), the organic system that exclude livestock had poorer energy ratios due to the inclusion of annual fertility building crops and winter cover crops, which had no direct outputs. It is not clear whether the results of the other energy studies cited above would also be less favourable for organic systems if a whole-of-rotation approach were to be applied.

4.74 In a German study that compared energy ratios in organic farming systems with integrated systems for a cereal/root rotation, very little difference was found in energy efficiency (\*Hülsbergen & Kalk, 2001). The integrated system used more fossil fuel per unit area but less energy was recovered from the organic system due to lower yields.

4.75 Comparative studies have been undertaken into the greenhouse gas emissions from organic and contemporary arable systems. In the study by Köpke & Haas (\*1996) it was found that organic systems had more efficient carbon dioxide budgets than contemporary systems due to higher levels of carbon dioxide assimilation in organically managed soils. The high humus content of organic soils reduces carbon losses that otherwise occur through wind and water erosion. However, some nitrous oxide emission levels from organic arable systems have been shown to be higher than contemporary arable systems, particularly during the first year after a ley has been ploughed up (Ball *et al.*, 2002).

#### *Social impacts*

4.76 Evidence suggests that organic farming in general has a positive impact on rural employment (\*Jansen, 2000). In the EU, organic farms use 10-20 per cent more labour than contemporary farms (\*Offerman & Nieburg, 2000). Estimates have been made for the potential for organic farming to increase employment opportunities in the UK. Estimates have been made that 5,521 full time equivalent jobs (Hird, 1997) and 12,000-18,000 (\*Jenkins & McLaren, 1994) additional jobs would be created if 10 per cent of UK agriculture was converted to organic. This would be likely to increase the demand for seasonal labour which is already difficult to meet.

4.77 It is not clear how the figures for organic crop production would vary from these published figures for organic production in general. On one hand, it might be expected that organic arable farming systems would be more labour intensive in certain respects; there may be more time spent in pest prevention, and planning and

observing may be more time consuming. However, there may be less time spent on agrochemical application. Organic farms tend to carry out more processing and direct marketing. However, this is generally only the case with arable crops where field scale vegetables are grown.

4.78 There is some evidence available from a study in Switzerland which calculated the relative labour demands of contemporary and organic crops (Näf, 1995). Wheat was found to require 28 per cent more labour relative to contemporary cropping methods, while the corresponding increases were 36 per cent for barley and 34 per cent for potatoes (Näf, 1995). Lampkin (\*1994) suggests that higher labour costs may be associated with labour-intensive high-value organic crops such as potatoes and carrots. However, Lampkin also suggests that higher labour usage in organic enterprises may be due to low levels of capital available for investment in mechanisation, rather than an intrinsic requirement for greater labour. In view of this, and recognising that arable farming has relatively low labour intensity compared to other farming enterprises such as horticulture, the potential impact on rural employment from conversion of crop production to organic methods is probably of relatively minor significance.

##### *Strengths and weaknesses*

4.79 The outstanding strength of organic production is the availability of substantial price premiums for organic produce, due to consumer preferences in favour of its complete avoidance of synthetic agrochemicals. Whether the price premiums are sustainable in the long term is unknown.

4.80 A weakness is the difficulty of maintaining low weed numbers in the absence of those chemicals. Pernicious weeds may cause significant yield losses and reduce the quality of the crop, or mean the crop requires additional processing (to remove weeds seeds etc.). However, some species of arable weeds are desirable from a biodiversity perspective.

4.81 The need to maintain soil fertility without use of synthetic fertilisers also means that costly practices such as green manure crops may be required, reducing the overall profitability of the system.

##### *Key gaps in information*

4.82 The impacts of future policy changes on the economic attractiveness of organic systems to farmers.

4.83 A range of issues related to the development of the marketing and processing of organic produce.

4.84 Socio-economic data and analysis specific to arable crops (most organic systems include animals).

4.85 The interaction between crop and livestock elements in determining the economic performance of organic systems. Livestock systems viewed separately appear relatively unprofitable, but may enhance the profitability of the crops and thereby the system as a whole (see General Insight 8, para. 4.2).

4.86 Economic comparisons of organic farming and contemporary farming based on whole rotations rather than individual crops. Separate gross margins are likely to overstate the economic performance of organic cereal crops and understate the economic performance of livestock in organic systems.

### **Reduced tillage systems**

4.87 Reduced tillage systems, otherwise known as ‘conservation tillage’, ‘minimal tillage’ or ‘low tillage’ has been defined in a Home-Grown Cereals Authority research review as:

‘Sustainable cultivation systems which are less expensive than traditional systems; they may be less energy demanding, and/or quicker and/or have a lower labour demand’ (Davies & Finney, 2002).

4.88 Reduced tillage has had a relatively low uptake in the UK and Europe, with an estimate of less than 1-2 per cent of European agricultural land cultivated using this system (European Conservation Agriculture Federation, undated). Uptake of the system is however, growing worldwide. The USA has pioneered reduced tillage and the US government has provided a high level of support for its use under various Farm Bills. Much research and development of reduced tillage techniques has taken place in the USA. In 1997, 37 per cent of 120 million hectares were cultivated using reduced tillage or no-tillage techniques in the USA. It is also widely used in Australia, Canada, Brazil and Argentina (European Conservation Agriculture Federation).

4.89 Reduced tillage techniques practised in Europe fall under the following categories:

- direct drilling, whereby no cultivation takes place prior to drilling
- shallow tillage, where the soil is tilled to a depth of less than 100 mm without inversion
- Deep tillage, where the soil is tilled to a depth greater than 100 mm without inversion (Davies & Finney, 2002).

4.90 Reduced tillage is not suitable for all soil and specific problems are associated with the system, which may discourage farmers from adopting it or may influence their choice of reduced tillage techniques. Soil compaction, straw incorporation and grass weeds are all problems commonly experienced (Ball, 1990). In the UK, the most favourable sites for reducing tillage operations are those with stable, well-drained soils in lower rainfall areas (Davies & Finney, 2002).

### *Relevant projects*

4.91 The need to reduce costs has renewed interest in the technique in Europe. There are also significant environmental advantages, specifically in terms of reducing soil erosion. However, research into the economic and social aspects of reduced cultivation systems in the UK and Europe has been limited. Numerous studies have been undertaken in the USA, but differences in soil conditions, climate, farm size, crops grown and rotations make USA produced data of limited relevance in the UK. For this report, the review by Davies & Finney (2002) was particularly valuable.

*Yield and profitability*

4.92 The low uptake of reduced tillage methods in the UK and Europe sends a strong signal that these methods are unlikely to be as beneficial to farmers in these environments as they are in the USA and elsewhere where adoption has been high and rapid (see General Insight 4, para. 4.2).

4.93 Yields achieved by reduced tillage systems are influenced by various site-specific factors such as soil characteristics and cropping patterns. Furthermore, any yield benefits associated with reduced tillage may not be evident for a number of years (at least 10 years on some soils and under certain climatic conditions). Yields may also be dependent upon the type of reduced tillage system adopted (Uri, 1999). The general rule is that the shallower the tillage, the greater the savings in costs, but the greater the risk of reduced yields. It is nonetheless generally accepted that reduced yields are not a necessary consequence of reduced tillage systems and they can be avoided by the adoption of the most suitable system for the site (Davies & Finney, 2002). Long-term field experiments have shown that long-term average yields are usually similar to those achieved by conventionally tilled systems where the soil is ploughed and drilled (Ball, 1990).

4.94 Costs savings are important factors in the decision-making process for most farmers considering reduced tillage systems. Costs can be saved in terms of labour, machinery and energy. As little research has been undertaken into the economics of reduced tillage systems in the UK, there is little data available on cost savings relative to contemporary systems. One exception is a study undertaken at the Scottish Centre of Agricultural Engineering (SCAE) in the 1980s, in which reduced tillage systems were compared with a conventional plough and drill system (Ball, 1990). It was calculated that direct drilling incurred only 28 per cent of the total costs of the contemporary system for establishment of cereal crops, while the result for shallow plough/shallow cultivation and drilling was 85 per cent, and for broadcasting and shallow cultivation, 54 per cent.

4.95 The most important cost saving is in the reduction of energy use. More details are given below under 'Input usage and environmental impacts'.

4.96 Labour savings are also reported to be significant, although this is largely dependent upon farm size and the reduced cultivation system used. More details are given below under 'Social impacts'.

4.97 Although there may be initial high capital costs incurred in the purchase of reduced tillage machinery, in the long term machinery costs may be lower due to lower depreciation and maintenance costs. Wear on parts of reduced tillage equipment, particularly discs, should be low compared with contemporary systems. High initial machinery investment costs suggest that reduced-tillage systems may be more suited to larger farms. It is suggested by Davies & Finney (2002) that farms should be at least 450 ha for maximum benefit and that farms smaller than 250-300 ha would be most efficiently cultivated with a plough based system. It is possible that contractors will be able to carry out the work on smaller farms.

### *Input usage and environmental impacts*

4.98 In the SCAE study, energy use for direct drilling was 29 per cent of contemporary systems, 74 per cent for shallow plough/shallow cultivate and drill and 46 per cent for broadcast and shallow cultivate of the energy demand of the contemporary system (Ball, 1990). In a report by the European Conservation Agriculture Federation, it was estimated that energy consumption could be reduced by 15 - 50 per cent in reduced tillage systems compared to contemporary systems. The same report stated that energy productivity is increased by between 25 and 100 per cent (\*European Conservation Agriculture Federation, 1999). Net energy input for a plough based system is usually in the region of 200-360 MJ/ha for a plough based system, 100-230 MJ/ha for reduced tillage and 80 MJ/ha for direct drilling (Davies & Finney, 2002). Where soils compact or seal over reduced tillage can increase runoff and erosion (\*Guerif *et al.*, 2001; Kingery *et al.*, 2002; Quine & Y. Zhang, 2002; Van Muysen & Govers, 2002).

4.99 In the USA, considerable benefits to society have been made by converting highly erodible land to reduced-tillage systems, in terms of damage prevention to water facilities such as drinking water supplies, water storage, irrigation, and recreation (\*Uri, 1999). Less disturbance of the soil also reduces atmospheric emissions. There do not appear to be any published studies estimating reductions in soil erosion from reduced tillage in the UK. Although there may be some benefits in this category, it seems unlikely that they would be on the scale measured in the USA.

### *Social impacts*

4.100 The use of larger machines, which achieve cultivation at high work rates and low-energy input, will reduce labour requirements. In the SCAE study, time required was 29 per cent for direct drilling, 65 per cent for shallow plough/shallow cultivation and drilling and 20 per cent for broadcasting and shallow cultivation relative to the time demand of the contemporary system.

### *Strengths and weaknesses*

4.101 A possible strength of reduced tillage is that the very high levels of adoption in a number of large agricultural producing countries may provide opportunities for the UK to benefit from lessons already learnt elsewhere. Specific tillage technologies might be adapted for UK application, or different systems for integrating reduced tillage into an overall crop management system might be observed.

4.102 The outstanding weakness of reduced tillage in the UK is the failure so far to identify a system that is sufficiently effective and profitable to attract wide adoption by farmers.

### *Key gaps in information*

4.103 Given the low adoption of reduced tillage in the UK, there has been little incentive for research into the technique, so there are numerous knowledge gaps. There may be a chicken and egg problem here, with widespread adoption depending on increases R&D to develop improved systems. On the other hand, it might be judged that the existing evidence is sufficiently discouraging not to warrant greater investment in R&D for the time being.

### **Precision Farming**

4.104 Precision farming refers to a range of different technologies that allow farmers to manage inputs differently in different parts of a field depending on the crop's need for inputs at each location. Precision farming is intended to generate economic and environmental benefits by reducing inputs on parts of the crop where they are not required. In principle, precision farming could be combined with any of the other systems examined in this review.

4.105 Precision farming systems require:

- A method for detecting the relevant characteristic(s) of a crop at different locations with a field;
- A method for storing that information (in those systems that do not involve real-time detection and immediate application);
- A set of rules for relating the information collected to the crop's need for inputs; and
- A method for altering the application of inputs according to those rules and the spatial information.

#### *Relevant projects*

4.106 Precision farming is a relatively new and evolving system of crop production and consequently few studies have been undertaken into the economics and social implications of this system. It is more widely established in the USA, but research resources tend to have been focused on developing new technologies and less on their economic evaluation. The rapid rate of evolution of technologies has hampered attempts to make evaluations of costs and returns.

4.107 In the UK, a five-year study of precision farming was carried out by Godwin *et al.* (2002) for the Home-Grown Cereals Authority (HGCA). Overseas, an important evaluation of the economics of precision weed management was conducted in Australia by Pannell & Bennett (1999).

#### *Yield and profitability*

4.108 Godwin *et al.* (2002) identified, three main benefits from precision farming:

- Improvements in yield or reductions in inputs,
- less risk of environmental pollution from agrochemicals applied at greater levels than required by the crop,
- improved traceability from precision targeting and recording of field applications.

4.109 Godwin *et al.* (2002) studied precision farming in five fields in Southern and Eastern England. They found that it was economically beneficial to apply nitrogen in a spatially variable manner. Seven out of eight treatments gave positive economic benefits, averaging £22/ ha. Furthermore, applied nitrogen surplus was reduced by one third. It was calculated that benefits from spatially variable applications of nitrogen would be gained by farms growing 75 ha or more of cereals and investing £4,500 in a basic system. More sophisticated systems, costing between £11,500 and £16,000 would be beneficial on farms greater than 200-300 ha. On a 250 ha farm growing cereals where 20 per cent of the land would benefit from spatially variable nitrogen applications, a yield increase of 1.1 t/ha would be required on that 20 per cent to break even on the investment in new equipment. Economic benefits of up to

£20/ha were also estimated from spatially variable applications of both herbicides and pesticides (Godwin *et al.*, 2002).

4.110 On the other hand, economic research in Australia found that analyses of the benefits of precision weed management can give misleadingly positive results unless a range of important complexities are considered in the analysis (Bennett & Pannell, 1998; Pannell & Bennett, 1999). The complexities they highlighted in the context of weeds were:

- (a) The benefits of the technology depend on the spatial distribution of weeds. The more patchy the distribution, the greater the potential for precision weed management.
- (b) The benefits of reducing herbicide usage are partly offset by the costs of increased weed competition in patches where the weed density is greater than zero, but too low to activate the spray nozzle;
- (c) For various reasons, including inherent limitations of the technology, the information provided to the spray nozzle by the weed detector is imperfect. Some areas of the paddock will be sprayed despite a low weed density, while some patches with many weeds will be missed.
- (d) The impact of spraying or not spraying a weed is felt over subsequent years due to the carry over of weed seeds.
- (e) The decision rules built into the technology may not coincide with economically optimal decision rules.

4.111 Commonly the economic benefits of precision technologies are evaluated using models that do not consider all the relevant complexities. Often they consider only the savings in inputs. Pannell & Bennett (1999) found that a precision weed management system that appeared to generate significant benefits (A\$15/ha/year) when evaluated only on the basis of input savings, actually led to substantial losses (-A\$33/ha/year) when evaluated more fully. Those losses were additional to the substantial cost of purchasing the equipment. The findings of Pannell and Bennett highlight that there is a need for great caution in accepting highly positive results from economic evaluations of precision farming systems unless the evaluations are sufficiently comprehensive and sophisticated.

4.112 Costs for precision farming are often high. Factors contributing to these high costs can include the following:

- High up-front purchase costs;
- High annual maintenance costs;
- Rapid obsolescence due to rapidly evolving technology;
- High time costs of gaining the skill to operate new technologies (these have not been considered in existing studies).

4.113 Because of the high fixed costs involved, larger farms probably have greater potential to make profitable use of precision technologies.

#### *Input usage and environmental impacts*

4.114 By tailoring applications of agrochemicals to the crop's specific needs, it seems reasonable to assume that export of nutrients and/or pesticides from the farm would be reduced. Measurements of reductions in application of fertilisers and herbicides reveal that the reductions can be large.

*Social impacts*

4.115 There is no specific data available on the social implications of precision farming. We would anticipate that the methods will mostly be used on farms with high levels of machinery, and therefore with lower intensity of labour demand. However precision farming itself seems unlikely to be sufficiently profitable to prompt conversion of a farm from low to high machinery intensity.

4.116 In relation to labour quality, machinery operators employed to operate precision farming systems are likely to need higher levels of technical skills.

*Strengths and weaknesses*

4.117 If successful, precision farming has the strength of reducing input levels while maintaining or increasing profit.

4.118 The key weakness is doubt about whether the technologies can deliver on this promise, given the high expense of purchasing and running the equipment, and the consideration of a thorough set of issues that determine the actual profitability, beyond just input savings.

*Key gaps in information*

4.119 Analyses of the economic potential for precision technologies in the UK, evaluated using a detailed economic model along the lines of Pannell & Bennett (1999).

4.120 Information necessary to conduct such analyses, such as the spatial distribution of relevant variables (weed density, soil nutrient status) within typical fields, the localised yield response to non-application or reduced application of inputs by the precision technology, and the probabilities of type I and type II errors by precision technologies in their detection of input requirements.

**Further gaps in information**

4.121 A number of information gaps have been identified for each individual farming system. In this section, we identify overall information gaps that cut across the different farming systems.

4.122 Apart from organic farming, we lack analyses of alternative cropping systems outside the context of specific field studies. One concern here relates to General insight 1 (para. 4.2), which highlights the potential for differences between experimental situations and practical farming situations. It is very likely that farmers who adopted the other systems would modify and adapt them, and that as a consequence their performance relative to contemporary systems would be altered. This problem cannot be fully overcome until the systems are widely adopted, as organic systems have been. However it may be reduced if research is conducted with the full participation of farmers, preferably in farmers' fields. This would be a desirable future direction for research for those systems judged to be good prospects and worthy of further development.

4.123 As a step in that direction, it may be worthwhile commissioning economic analyses that attempt to generalise the economic conclusions into other farming

situations and different market/policy conditions. This would help to assess the prospects for successful adoption of the systems in a wider range of circumstances than has been considered in the work attached to specific field sites and in particular years. It would allow a more consistent approach to economic analyses, and facilitate better comparisons between the systems. It would also obviate concerns that some of the economic analyses reviewed here have not properly considered the full range of issues affecting their economic performance.

## 5 KEY FINDINGS AND CONCLUSIONS

### Key Findings - Ecological Impacts

5.1 The different arable cropping systems exert different pressures on the natural environment, but these differences do not form a continuum. The table below summarizes the main differences between the systems.

**Table 2.** Differences in pressures exerted by each arable system

	Organic	Integrated	Contemporary
Use of Pesticides	No synthetic chemicals allowed without derogation	Only applied when needed	Insurance applications may be applied to prevent disease
Use of Nutrients	No synthetic fertilisers allowed; organic fertilisers can be applied liberally	Applied to maximise efficiency of use	Applied to maximise financial return, some precautionary applications.
Tillage	Often intensive especially to control weeds	No-till and reduced till depending on circumstances	Generally annual ploughing
Economic advantage in increased field size?	Variable	Yes	Yes
Economic advantage in simplified landscape?	No - need to maintain some livestock within system	Variable	Yes
Strengths	Reduced inputs	Reduced inputs, reduced tillage	None
Weaknesses	Increased tillage	None	Known to cause reduction in biodiversity
Key gaps in information	No proof yet whether there is benefit to wildlife	No proof on whether there is benefit to wildlife	Little information on how contemporary compares with organic or other cropping systems

### *Pesticides*

5.2 Organic systems usually result in greater densities of both arthropods and their favoured food plant groups compared to contemporary systems (para. 3.7)

5.3 Pesticides do have a detrimental effect on earthworms (para. 3.8, 3.9) but reducing pesticides by 50% had no effect on earthworm numbers or diversity (para. 3.9).

5.4 Adverse effects on non-target species are documented for a number of species (para. 3.9).

5.5 Pesticides impact on bird populations by direct mortality and also indirectly by reducing plant and invertebrate food supplies and destroying habitat (para. 3.11).

*Nutrient inputs*

5.6 The use of fertilizers may change plant species composition in favour of species, which can tolerate, or prefer, such conditions, thus reducing diversity and food supplies for birds (para. 3.12).

5.7 Increased nitrogen inputs increase earthworm density (para. 3.13).

*Tillage*

5.8 Reduced tillage tends to lead to weeds becoming more prevalent (para. 3.14).

5.9 Reduced tillage usually leads to an increase in invertebrates, although there may be no effect on carabids or foliage-inhabiting arthropods (para. 3.15).

5.10 Reduced tillage may favor predatory species relative to 'pests' (para. 3.15).

5.11 Tillage injures or kills earthworms. The severity of the effect depends on the type and depth of tillage (para. 3.17).

*Intensity of land use*

5.12 Soil fauna show few systematic differences between contemporary, integrated and organic systems but organic fields have the most equitable community structure (para. 3.22).

5.13 Protozoan biomass was significantly higher under integrated management possibly due to higher organic matter content (para. 3.23).

5.14 Maximising agricultural output via intensification has damaged farmland bird populations across Europe (and beyond) (para. 3.24, 3.25).

5.15 Variation in soil biota between farms under similar management may be larger than variation between contemporary *versus* integrated *versus* organic treatments due to large-scale process such as climate and soil type. Management sometimes explains only a relatively small amount of variation in soil biota abundance and diversity (para. 3.22).

5.16 In general, the biomass and diversity of earthworms is higher under organic and integrated management than under contemporary, but the trend is highly variable with many notable exceptions (para. 3.19).

*Landscape structure*

5.17 The structure and biodiversity of the surrounding landscape may be more important to field-inhabiting invertebrates than the farming system itself (para. 3.26).

5.18 Bird survival and performance depends on the availability, in both space and time, of a range of resources and thus a greater diversity of land-cover has more potential to supply all requirements than could be expected of monoculture (para. 3.27).

5.19 The effects of habitat loss are obvious in the concomitant reduction in resources, but bird population survival and performance will also be affected by the quality of the habitat that persists, including its temporal availability (para. 3.28).

5.20 Crop rotation, and the location and management of set-aside, may influence bird populations at a local level in relation to the spatial distribution of crop types and nesting habitat, and also at a larger scale, especially in winter, in relation to food availability (para. 3.27-3.29).

*Mitigation measures - Margins, beetle banks, conservation headlands and wild bird cover*

5.21 Field margins (para 3.32), beetle banks (para. 3.41, 3.42), conservation headlands (para. 3.38) and wild bird cover (para. 3.44, 3.45) are of benefit to a wide range of taxa.

5.22 Organic field boundaries generally support a higher abundance of wildlife (para. 3.33-3.35).

5.23 The quality and quantity of non-cropped habitat is often higher on organic farms, however, further research is needed to test the generality of these results (para. 3.34, 3.35).

5.24 No studies were found to compare the relative value of conservation headlands, beetle banks or wild bird cover for wildlife in relation to different whole farm approaches (para. 3.39).

5.25 Further studies are needed to investigate differences between 'integrated', organic and 'contemporary' systems and for a wider range of taxa (para. 3.39).

5.26 Comparing the effectiveness of mitigation methods for wildlife between different farming systems is inherently difficult. Factors such as quality and quantity of non-cropped habitat and dominant farm type in the surrounding landscape of a study site may also influence results (para. 3.46).

5.27 Agri-environment schemes with arable margin options were predicted to be environmentally effective. A new scheme with high uptake should have wide-scale positive effects but those effects cannot yet be quantified (para. 3.48, 3.49)

### **Key-Findings - Socio-Economics**

#### *Low Input*

5.28 In trials yields were consistently lower in low input cropping when compared to contemporary cropping. Profitability in low input cropping was sometimes higher, the same or lower than contemporary cropping (para. 4.16-4.19).

5.29 Reducing pesticide rates is likely to be economically viable in certain crops, notably cereals (para. 4.20).

5.30 Input use fell in all trials but only moderately (para. 4.21).

5.31 There was limited impact on indicator organisms (4.22).

5.32 As there is little change to current practice this may lead to higher uptake (para. 4.25).

5.33 There are likely to be low external benefits (para. 4.26)

#### *Integrated Arable Farming Systems*

5.34 Yields tend to be lower under IAFS than contemporary cropping (para. 4.34)

5.35 There was no statistical difference between gross margins between IAFS and contemporary cropping (para. 4.40).

5.36 Risks are considered higher with IAFS especially until the farmer gains experience and therefore guidance to farmers is required (para. 4.42).

5.37 Inputs in IAFS decreased by an average of 52% for fungicide, 48% for herbicide, 40% for insecticides and 17% for fertilisers (para 4.43). IAFS show potential for lower energy use (para. 4.44).

5.38 A strength of IAFS is that mainstream agrochemicals can still be used (para. 4.46) and a weakness is that there is no niche market (para. 4.50).

#### *Organic*

5.39 Organic cereal yields are typically 60-70% of contemporary yields (para. 4.57). Yields do tend to increase the longer land has been organic (para. 4.59).

5.40 Organic arable crop farms achieved profits averaging around 130% of profits from contemporary farms (para. 4.64) although this value must be treated with caution as it is not based on whole rotations (para. 4.65).

5.41 Evidence suggests that organic farming has a positive effect on rural employment (para. 4.71).

5.42 A strength of organic production is the price premium (para. 4.74), whilst weaknesses are weed control and soil fertility (para. 4.75).

#### *Reduced tillage*

5.43 The low uptake of reduced tillage methods in the UK and Europe sends a strong signal that these methods are unlikely to be as beneficial to farmers here compared to those in the US (para. 4.87).

5.44 Farms should be at least 450 ha for maximum benefits from reduced tillage (para. 4.92).

5.45 Energy consumption is greatly reduced by reduced tillage systems (para. 4.93).

*Precision farming*

5.46 It is economically beneficial to apply nitrogen, herbicides and pesticides in a spatially variable manner (para. 4.104)

5.47 Highly positive results for precision farming should be treated with caution (para. 105, 106)

**Synthesis and Conclusions**

5.48 The ecological impacts of the different cropping systems have not been fully quantified but the generality that fewer chemical inputs and less severe soil disturbance are beneficial to fauna and flora has been substantiated in most cases. The degree to which each of the cropping systems reduces inputs and disturbance must be considered. The impacts of each cropping system will be modified by mitigation measures that are currently employed and whether they are equally employed by farmers undertaking the different cropping systems. Another pertinent question is how is the uptake of mitigation measures are likely to change in the near future

5.49 Overall, it seems that organic farming of crops is relatively profitable in the current climate (up to 2002). Although it has lower yields than contemporary systems, these are compensated by higher prices. We have some concerns about whether the economic analyses of arable cropping have fully captured the costs of switching to different rotations in organic farming (e.g. including costly years of manure crops to maintain soil fertility in crop production years) since the studies are based on small samples in single years. It remains to be seen whether the system would remain profitable without the extra subsidies paid for it.

5.50 Low input systems and integrated arable systems were both variable in their economic performance. Their economic returns compare well with contemporary systems in some situations but not in others. There seems scope for additional economic modelling to broaden the knowledge base about the performance of these systems in different circumstances. There is a difficulty in making predictions as economic conditions can change very quickly.

5.51 Reduced tillage appears to have limited economic potential in the UK. Precision farming has been evaluated positively in the one major UK study, but a more sophisticated economic analysis from Australia raises concerns that the UK study may have overstated the likely benefits.

5.52 Implications for farm labour were identified, the most important of which are the likely increase in labour demand in low input and organic systems and the need for more skilled labour in precision farming systems.

**Recommendations**

5.53 The main recommendation of this report is that there should be a holistic approach to the comparison of contemporary, integrated and organic farming systems. A major programme to compare the systems covered in this report is required. This study should concentrate on farm scale effects.

## 5 Key Findings and Conclusions

5.54 Before such a large study is commissioned a scoping study should be put in place to determine the criteria to be evaluated (e.g. number and abundance of species, inputs and their effects, rural employment etc.) and set rigorous questions that can be answered.

5.55 There is a need for the results of this review and future research to be disseminated quickly to national and local government, the general public and above all the farming community. Outside organisations such as LEAF could be very useful in this role. Agricultural education establishments, in the UK and around Europe, need to be aware of all new developments.

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## **Appendix 1 The Consortium**

### **The Centre for Ecology and Hydrology**

The Centre for Ecology and Hydrology (CEH) is an interdisciplinary research centre for ecology, hydrology, virology and environmental microbiology. Its mission is “to advance the science of ecology, environmental microbiology and hydrology through high quality and interdisciplinary research in support of the NERC mission and international programmes.”

CEH provides independent research to inform government policy on natural resource management and environmental protection, and to raise public awareness of environmental issues. CEH has been responsible for carrying out research underpinning Government policy in areas of current public concern, such as flood risk estimation and flood forecasting, risk assessment of genetically-modified crops, the ecological effects of endocrine disruptors, and the ecological impacts and drivers of land use change.

CEH has an extensive range of specialist laboratories, field facilities and data centres equipped to enable CEH to maintain a world standard research programme in the environmental sciences.

The results of CEH research are available to those responsible for the protection, management and wise use of our natural resources, being published in a wide range of scientific journals and other publications. An Annual Report is published, and a variety of publications are produced for both specialist and non-specialist readers. The CEH web-site, <http://www.ceh.ac.uk> provides access to information on scientific research, publications, data and software.

CEH has an annual income of about £30M; research is financed partly by the UK Government through its science budget and partly by private and public sector customers who commission specific projects or programmes. CEH's expertise is also widely used by European and international organisations, in collaborative projects.

CEH is part of the Natural Environment Research Council (NERC), which is the UK's leading body for research, survey, monitoring and training in the environmental sciences. Established in 1965, NERC is a non-profit making UK government organisation under the direction of a scientific Council consisting of academic scientists and advisors from industry, commerce and government. Its priority research themes focus on five environmental and natural resource issues: Biodiversity, Environmental Risks and Hazards, Global Change, Natural Resource Management, Pollution and Waste. CEH's own science strategy has been designed to support these key NERC issues.

### **Centre for Rural Economics Research at the University of Cambridge.**

The Centre for Rural Economics Research and the Rural Business Unit located within the centre have a history of producing high quality, independent, and objective reports that are delivered on time for both DEFRA and other organisations. It has unparalleled experience in the study of the farm business and the rural economy. A recent example of the work undertaken by the research group is an evaluation of set-aside.<sup>1</sup> Work in the centre has involved all aspects of the rural economy ranging from evaluating the organic farming scheme to the development of indicators of rural disadvantage.

Within the centre, the Rural Business Unit has been monitoring the economic performance of farm businesses since the 1930s (for example see Lang, 2001).<sup>2</sup> During this period it has built up an extensive reference library and also holds an incomparable set of data on the economics of the farm business. The Unit has also conducted a considerable number of one-off studies on the economics of particular farm enterprises (for example see Asby and Renwick, 2000).<sup>3</sup> Staff have also collaborated on comparative studies of farm performance with other European countries (Lang op. cit). The Unit has access to all the resources of the University including the copyright library.

The CRER web-site provides more information on the work undertaken and the personnel involved. <http://www.landecon.cam.ac.uk/economic/index.htm>

<sup>1</sup>) CRER (2001) *An Economic Evaluation of Set Aside*  
<http://www.defra.gov.uk/esg/economics/econeval/setaside/index.htm>

<sup>2</sup>) Lang, B. (2002) *Report on Farming in the Eastern Counties*. Rural Business Unit, University of Cambridge.

<sup>3</sup>) Asby, C. and A. Renwick (2000) *Economics of Cereal Production* Special Study No 34, Rural Business Unit, University of Cambridge

## **The Northmoor Trust**

The Northmoor Trust believes that improving the future for wildlife in lowland Britain requires conservationists to work in partnership with land owners to restore and recreate wildlife habitats on farms and other economically managed areas. The Trust's farmland is centred on Hill Farm, Little Wittenham and here the farming objective is to research and demonstrate ways of making economic agriculture more friendly to wildlife. The work of the farm is guided by a Conservation Plan which includes the planting of hedges, introducing flower-rich field margins and unsprayed headlands as well as creating ponds, resulting in a variety of habitats for both plants and animals. Several key wildlife species are now increasing in number and changes are being monitored so that the wildlife gains and economic performance of the farm can be analysed.

### *Collaboration*

Scientific research and innovation can make important contributions to solving conservation problems. The Northmoor Trust runs several research programmes including collaborative studies and is co-operating with several universities and institutions on ecological farming and forestry work. The Trust's staff have also helped a number of local societies and parish groups to start conservation projects in their own communities and its ecologists and land managers are available to give advice and assist with site surveys and the drafting of management plans.

Further information can be found at <http://www.northmoor.co.uk>



## Appendix 2 Bibliography of sources not cited in the main report

The following works were consulted during the course of the review but are not cited in the main report.

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## **Appendix 3 On valuation of biodiversity and other non-financial assets**

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This document provides some brief commentary on the issues involved in attempting to place monetary values on non-financial assets, such as biodiversity. The methods are referred to here as “non-market valuation” methods, as they are concerned with estimating values of goods that are not bought and sold in markets. There has been increasing interest in this area, perhaps with a view towards encouraging policy makers to give due weight to such environmental outcomes alongside more tangible economic outcomes.

### **Methods for valuing biodiversity**

Several methods for estimating non-market values have been developed and applied by economists. Smith (1996) outlines three indirect methods (“travel cost recreation demand”, “hedonic property value (or wage) equation”, and “averting behaviour or household production model”) and one direct method (“contingent valuation”). More recently, another indirect method called “choice modelling” (Bennett and Blamey, 2001) has increased in prominence. Brief descriptions of the methods are provided here.

Table 1 reproduces Table 1 from the preface of Smith (1996). It provides very brief descriptions of three indirect methods of non-market valuation. Although these indirect methods have been used in applied studies, each is only applicable to a subset of non-market valuation problems (e.g. hedonic property value method is only applicable where the environmental impact of interest is factored into land sale prices). In general, the sorts of non-market values associated with agricultural production (particularly non-use values) are usually not suitable for measurement using any of the methods given in Table 1.

Contingent Valuation (CV) and Choice Modelling (CM) are more relevant. Both are based on social surveys of samples of the broader population. In CV, people are asked to state their willingness to pay for hypothetical improvements in environmental quality or their willingness to accept compensation for hypothetical deteriorations in environmental quality. In CM, people are asked to rank hypothetical options that involve tradeoffs between environmental and other outcomes. Values attributable to the environmental outcomes are inferred from their responses. In both cases, values are aggregated up to the level of the whole population, with the intention that they can then inform decision making about public policies.

MAFF commissioned a number of studies using CV and CM on issues related to agriculture, as reported by Hanley et al. (2001).

### **The debate on the validity and usefulness of the methods**

There has been a spirited academic debate about the validity and usefulness of non-market valuation methods, particularly for CV.

**Table 1:** Indirect methods for non-market valuation

Method	Information observed	Information imputed
Travel cost recreation demand.	The quantity as a visit rate from aggregate data; a count of visits or site selection for a single trip with individual data.	The price as the full cost of using the recreational facility including the vehicle related travel costs; access charges; the on-site time costs; incremental costs of equipment, supplies, etc., directly related to the activity.
Hedonic property value (or wage) equation.	The price measured as the housing price (or rent) for property value models and the estimate hourly wage; with property value ideal measure is sale price.	What people perceive as the quantity of the amenity services conveyed by site location; this quantity is usually measured by technical proxy variables.
Averting behaviour or household production model.	An activity or action that reflects implicit tradeoff of costs to meet an objective such as a risk reduction, improved air quality or water quality.	Quantity and incremental cost assumed to comprise the complete tradeoff considered in deciding about the level of activity or the action; based on hypothesized preference and household production functions as well as prices and what is hypothesized as the relevant budget and time constraints.

Arguments put forward by advocates of CV have included the following:

- (a) CV, when done well, does give plausible and realistic results; and
- (b) Even though it is not perfect, it is very important to do the best job we can in measuring non-market values because they are important values to the community.

On the other hand, many economists reject argument (a), and if their criticisms are accepted, the case for argument (b) is greatly weakened.

A powerful case against the use of CV is made by the contributors to Hausman (1993), which collects the papers presented at a workshop of leading economists. Plott (1993), in summarizing the book says that:

The basic conclusion of all the papers is that CV should be discarded as a public-policy tool for determining economic damages to the environment. In some papers the conclusion is even stronger: that CV should be discarded as a public policy tool – period.

He further observes that:

The conclusion that CV should not be used to measure environmental damages is expressed at each of four different levels of analysis. (1) The numbers are too variable to be reliable. (2) The numbers do not measure what they are supposed to measure. (3) In fact, the object to be measured by the methods might not be measurable at all. (4) Finally, even if the other problems did not

exist, the appropriateness of CV or assessing damages, as opposed to more procedural methods, is challenged.

Much of the debate is rather technical (mostly based on arguments that results from actual CV studies are illogical or inconsistent with economic sense in a variety of ways), but there are also some quite simple arguments against the use of surveys for non-market valuation. The first arises from the results of studies that have attempted to quantify the error rates in surveys asking questions about simple factual matters. Foddy (1993) notes that one study found that 10 percent of respondents in a Philadelphia survey gave different answers to the question, "What is your age in years?" when re-surveyed a week later. In cases where it has been possible to check the answers to simple, factual questions, such as "Do you have a driving license?", between 5 and 17 per cent of answers given are incorrect. Given this, one must seriously doubt the validity of answers to more subtle or complex questions. The main questions asked in CV and CM surveys of environmental values are always subtle and complex.

Another source of concern about CV comes from a detailed study of CV survey respondents, asking them what they made of the questions and what they thought about the way economists would now use the results, which was explained to them for the first time (Clark et al., 2000). Most respondents were unhappy at the way that their responses were to be used, and expressed very low confidence in the validity of their own responses.

A third simple argument against the use of surveys of the public for determining non-market values is that the great majority of people surveyed will have very low levels of knowledge of the complex issues about which they are being surveyed. We are asking them to value items with which they probably have no personal experience and very little knowledge. They may obtain some knowledge in the survey's introductory material, but realistically such knowledge would not be deep. With sufficient investment of time, effort and interest, most people would, no doubt, be better able to express meaningful opinions on the specific environmental issues being examined, but not in a rapidly completed survey that they receive without prior grounding in the issues. In general, it seems quite unrealistic to expect that reasonably well-founded monetary values of environmental assets would come from an approach that does not involve an in-depth assessment of the best available information and a careful weighing up of the issues. Diamond and Hausman (1993, p. 30), in discussing this issue, stated that

It makes no more sense to rely directly on ill-informed members of the public to evaluate the dollar value of such environmental damage than it would be to rely on an ill-informed public to choose between alternative designs for airplanes or nuclear power plants.

Without going into the technical concerns raised by critics of the technique, their seriousness can be gauged by the following quote from Desvousges et al. (1993, p.114) who conducted tests of the validity and reliability of CV.

At the outset, we believed that it was very difficult to estimate nonuse values accurately by using CV. However, we also thought that it could be done with

scrupulous attention to detail, sufficient time and generous funding. After months of listening to conscientious respondents trying to answer difficult questions and of intensively analyzing our data, we cannot maintain our initial confidence in using CV for measuring nonuse values. Given the current state of the art, we do not think that CV provides either valid or reliable estimates of nonuse damages.

CM avoids some, but not all, of the problems associated with CV. On balance, the case against the use of existing non-market valuation methods appears very strong, and some economists believe that this reflects something fundamental about the issue that will never be overcome, rather than a temporary weakness in our research methods.

### **Is there an alternative?**

One of the negative aspects of non-market valuation studies is that they can obscure or divert resources away from studies that ask more basic (and more tangible) questions. For example, a CV study might be done on the value of changing agricultural land management to increase the habitat value (and therefore the biodiversity) of an area of farmland. This sidesteps (i.e. ignores) important questions, such as:

- Which management options are available to increase the biodiversity present on farmland?
- What would be the different effects of different management options on the biodiversity?
- What would be the costs of the different methods?
- In what ways are the biodiversity levels on that land important or significant (e.g. in ecological terms) and why?

In order to properly conduct a non-market valuation study, the answers to basic question like these should ideally be available. In practice, non-market valuation studies are most often conducted in the absence of such information. Often, it would be better to invest funds in research to answer more basic questions like those posed above than in estimating non-market values. It may well be that once they are answered, the appropriate management response is so obvious that no non-market valuation study is needed. In general, non-market valuation studies should not be conducted unless this possibility has been explored.

### **Conclusion**

For a variety of reasons, non-market valuation studies should be approached with great caution. There are numerous reasons to doubt the validity of the available techniques, there are reasons to doubt that valid techniques could ever be developed, and often there are more basic questions about the biology and management of the environmental issues in question that ought to be given higher priority for research.

This is not to say that the framework provided by economics is not useful in considering management and policy questions about environmental values. The general economic approach of identifying alternative courses of action, identifying all the positive and negative consequences of each course of action, and weighing up the options to select a preferred option, is still a very valuable approach even for tackling issues involving relatively intangible values. In my opinion, the best approach is to

consider the management and policy options within that framework and with that style of thinking, without going to the length of placing monetary values on non-market goods. We would estimate the environmental consequences of alternative policies, but would quantify these consequences in terms that are biologically meaningful (such as the number of species affected, or the area of habitat affected, or the increased probability of preventing extinction of a species).

This does not avoid the problem that *somebody* still has to weigh up the information and make a choice between the management or policy options, and that this choice *implicitly* values the environmental assets at some monetary value. Who then should make the choice? In my view, it should be a lay person (or a group of lay people) who have fully come to grips with the best available answers to the basic questions I presented above. One of their options should always be to decide that the best answers currently available are not sufficiently well founded scientifically, and that further research is required before a decision can be made. This important option is, of course, not available to respondents to CV or CM surveys.

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