FINAL REPORT

REVIEW OF THE COMPARATIVE EFFECTS OF ORGANIC FARMING ON BIODIVERSITY

MAFF Contract OF0149

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July 1998

EXECUTIVE SUMMARY

1. The report reviews the impact of different farming regimes and makes a comparative study of their influence on the biodiversity of arable farmland.

2. Within this review, the evaluation of impacts on biodiversity focuses on species and habitats, and includes both the number, abundance and activity of species (section 1.3).

3. Five farming regimes are defined and discussed, namely Conventional Arable, Conventional Mixed Lowland, Organic and two integrated production regimes - LEAF (Linking Environment and Farming) and IFS-Experimental regimes The main differences between the regimes in relation to the use of external inputs and other agricultural practices are discussed. The review draws on both UK and European information (section 1.4).

4. The effect of each farming regime on biodiversity is assessed according to the agricultural practices adopted and to the occurrence and management of uncropped land present. Agricultural practices are reviewed within the following categories: cultivation, crop production, crop protection and post-cropping practice (section 2.1).

5. Among the agricultural practices examined, those associated with crop protection and the artificial inputs associated with crop production were seen as the most adverse for biodiversity. Several practices were seen to benefit the biodiversity of arable land. These included set-aside, crop rotations with grass leys, spring sowing, permanent pasture, green manuring and intercropping (section 2.7).

6. Uncropped areas, such as sown grass strips (beetle banks), grass margins and conservation headlands, were seen as critical for the maintenance of biodiversity on arable farmland. Changes in the balance of cropped to uncropped land within some farming regimes, linked to increase in field size, have had a major impact on the diversity of flora and fauna associated with those regimes (section 3.4).

7. Based on the evaluation of agricultural practices used, the occurrence of uncropped land and the extent of the farming regime within England and Wales, it was concluded that Conventional Arable regimes act effectively to maintain the impoverished status of biodiversity on arable land. Extreme examples can be found of intensively managed farms that further deplete biodiversity and sympathetically managed farms that try to enhance it. Increased adoption of agricultural practices such as direct drilling, use of farmyard manure, set-aside, use of crop rotations with leys, or an increase in the incidence and sympathetic management of uncropped areas may well assist biodiversity on farms within this regime (sections 4.3 & 4.4)

8. Organic regimes were shown to have an overall benefit for biodiversity at the farm level, both in terms of the agricultural practices adopted and in the occurrence and management of uncropped areas (sections 4.3 & 4.4).

9. Conventional Mixed Lowland and LEAF regimes were both seen to have the potential for enhancing biodiversity on arable land. Here, adverse impacts associated with crop protection and crop production may be mitigated by beneficial effects associated with post-cropping practices, the occurrence of permanent pasture and uncropped land. At present, the extent to which enhancement may be achieved, may well depend on the extent, condition and management of uncropped land present within these regimes (sections 4.3 & 4.4).

10. IFS-experimental regimes were seen to have a beneficial effect on biodiversity, due to the stringent procedures used for targeting herbicides and pesticides and for establishing and managing uncropped areas. At present these regimes occupy a tiny area of the national resource of arable land and thus their impact on national biodiversity is likely to be insignificant at the present time (sections 4.3 & 4.4).

11. A number of areas are highlighted for further consideration. These include:
    - monitoring of biodiversity on farms pre- and post- conversion to organic farming,
    - comparative studies that focus on the effectiveness of different regimes or agricultural practices in enhancing biodiversity on species-impoverished intensively managed arable land,
    - manipulative experiments to determine the optimal balance of cropped to uncropped areas for enhancing biodiversity,
    - manipulative experiments to examine the separate impacts of rotational regimes and agricultural inputs on biodiversity,
    - an economic assessment of the costs and benefits in both production and biodiversity terms, of conversion to organic, integrated production or uptake of available agri-environment schemes.

CONTENTS

1. INTRODUCTION AND DEFINITIONS

1.1 Background

The impact of post-war intensive agriculture on biodiversity and the environment has been a subject of intense debate over the last 30-35 years. Concern over this impact, was one of the driving forces behind the development and implementation of the organic farming movement (H. Browning, 1998: pers. comm.), and the establishment of standards for organic farming (e.g. UKROFS, 1997). These standards focus on protecting the long-term fertility of soils, encouraging nitrogen self-sufficiency, controlling pest and diseases through cultivational rather then chemical practices, minimising the impact of the farming regime on the environment and the conservation of habitats for wildlife (Lampkin & Measures, 1995).

Since the late 1970s, there has been increasing interest in the design of farming regimes that reduce the quantity of agrochemical inputs and enhance the management practices for maintaining uncropped and/or boundary habitats present on farmland. Specific examples include research and demonstration initiatives in Integrated Farming Systems (IFS), and the establishment of agri-environment schemes such as Countryside Stewardship, Habitat Scheme, Nitrate Sensitive Areas (NSAs), Environmentally Sensitive Areas (ESAs) and most recently, the Arable Stewardship Pilot Scheme (ASPS). It is an objective of each of these schemes and initiatives to enhance and maintain the farmland environment for wildlife, but the importance of the biodiversity element in relation to other objectives varies between schemes.

Numerous studies have focused on the significance of specific elements (*e.g.* conservation headlands) within different farming regimes in promoting biodiversity and/or creating suitable habitat for wildlife. Direct comparisons between farming regimes are, however, difficult due to the confounding effects of landscape structure, management history and biogeographical position in the UK. It is evident though, that the benefits for wildlife diversity differ between regimes, and that they vary in scale, extent and impact on different species groups. The aims of this review are firstly, to identify those factors which bring about change in biodiversity in agricultural areas and secondly, to consider the effectiveness of different farming regimes, (broadly conventional, integrated and organic) in maintaining or enhancing biodiversity.

1.2 Objectives

The review focuses on a comparative assessment of the effects of five main farming regimes on biodiversity. These are i) conventional arable, ii) conventional mixed lowland farming, iii) organic, iv)LEAF (Linking Environment and Agriculture Farms) and v) IFS-experimental farms. Each of these is defined in section 1.4 below. An additional aim is to identify the species and/or species groups that are likely to show change when management systems change, and areas where further information is required. The specific objectives are listed below.

1. To review existing UK and European published information on the effects of organic agriculture on micro and macro flora and fauna.

2. To review the effects of organic agriculture on field margins, including grass strips, hedges, ditches, streams and wetlands.

3. To consult with the UK organic movement on the principles of organic farming and perceived benefits for biodiversity.

4. To identify the potential benefits of other agri-environment schemes and agricultural management practices for biodiversity.

5. To evaluate the different agricultural management systems in terms of their potential benefit to biodiversity and to identify the groups of organisms that are particularly sensitive to management systems change.

6. To identify areas where monitoring information on these 'sensitive' groups is lacking, and to provide recommendations on appropriate studies to address these information gaps.

1.3 Definitions and scope

Within this study, biodiversity is taken to include both the number of species present (species richness), species abundance and/or activity. Biodiversity can include variation at the genetic, species and habitat levels. This study concentrates on the last two levels.

Conservation and restoration of biodiversity can be considered in their own right and in relation to their significance for ecosystem function. Both issues are considered in this review. The factors impacting on biodiversity, such as habitat fragmentation and landscape structure, and their possible causes are also included in the review. Potential positive impacts of management actions are also considered.

A number of terms used in this report may be interpreted in different ways according to circumstance or points of view. To avoid confusion, the definitions of terms as they have been used in this report are included here.

- *Uncropped areas:* are defined as all the areas and features on a farm that are **not** subject to the agricultural practices identified in Table 2.1. Such areas include field margins, conservation headlands, beetle banks, hedges, woodland, ditches, unimproved pasture and semi-natural rough grazing. It is recognised that management operations are required to maintain and enhance the 'condition' of these areas as a resource or environment for wildlife.

- *Cropped areas:* are defined as all the areas managed for arable or livestock production. As indicated above, unimproved pasture and semi-natural rough grazing are defined as uncropped areas (see above) in this review. Two categories are defined: *arable* areas which include land cropped for cereals, oilseeds, root crops *e.g.* potatoes, sugar beet, and field vegetables, and *grass and pasture* which include sown grass leys, naturally regenerating grass, improved permanent pasture and rotational fallow.

1.4 Principles of different farming regimes

Conventional farming regimes are normally distinguished from organic regimes by the use of synthetic chemicals in crop and livestock production (ADAS, 1995), whilst integrated production regimes are identified by approach to cultivation and targeted inputs (Brown, 1997a).

1.4.1 Organic farming

Organic farming is defined in EU Regulation 2092/91, and each member state has a national regulation that conforms with this EU regulation. In the UK, the regulatory body is the United Kingdom Register of Organic Food Standards, which certificates and audits seven certified bodies with whom farmers must register (one only) in order to legally sell produce as organic. Key characteristics of organic farming (Lampkin & Measures, 1995), include:

- protection of the long-term fertility of soils through the maintenance of organic matter content, encouraging soil biological activity and careful mechanical intervention,

- indirect provision of crop nutrients using relatively insoluble nutrient sources,

- weed, disease and pest control based on crop rotations, natural enemies, organic manuring, resistant varieties and limited (preferably minimal) thermal, biological and chemical intervention,

- careful management of livestock to take account of behavioural needs, evolutionary adaptation and animal welfare,

- conservation of wildlife and natural habitats and minimisation of the impact of the farming regime on the wider environment.

There is considerable variation between different European countries in their description of organic farming. For example, in Denmark, the Danish Association of Organic Farmers (LO) was established in 1981 to provide animals with good living conditions, to develop sustainability and to further the nature and wildlife value of farms (Halberg, 1997). German guidelines quote preservation of diversity as an aim of organic farming in relation to both plants and animals (Frieben & Kopke, 1996). In Central Italy, Dalla Ragione *et al.* (1996) identified organic farming practices as including no chemical control of pathogens or weeds, little or no use of chemical fertilisers and frequent use of intercropping. Within the UK, there is variation between different sector bodies, for example UKROFS (1997) standards contain few requirements in relation to margin management whereas Soil Association guidelines are specific in this respect (Soil Association, 1997). Such variation has been highlighted by Halberg (1997), who suggested that there is a need for multi-dimensional descriptions of European organic (livestock) farming systems.

1.4.2 Integrated production regimes

These are difficult to place in a single system classification. Within Europe, integrated production regimes have been defined by the International Organisation for Biological Control (IOBC, 1993) as “farming systems that produce high quality food and other products by using natural resources and regulating mechanisms to replace polluting inputs and to secure sustainable farming". Broad principles for integrated production are also set out in IOBC (1993). These have been developed as a theoretical prototype for use in the design of integrated production projects, nine of which have been established across Europe (Vereijken, 1995). The methods on which the theoretical prototype is based are outlined below (Vereijken, 1992, 1995).

- Multifunctional crop rotation (MCR) to maintain soil fertility and crop vitality whilst minimising inputs that are polluting and based on fossil energy.

- Integrated nutrient management (INM) or ecological nutrient management (ENM using all nutrients from recycling of organic waste) to maintain agronomically desirable and ecologically acceptable nutrient reserves in the soil.

- Minimum soil cultivation (MSC) through the incorporation of crop residues, weed control and restoration of physical soil fertility.

- Ecological infrastructure management (EIM) to maintain 'natural' areas that provide food and over-wintering sites for beneficial organisms to enable their recovery and dispersal in spring, and that confer nature/landscape benefits.

- Integrated crop protection (ICP) and environment exposure-based pesticide selection (EEPS) designed to selectively control harmful species with minimal exposure of the environment to pesticides.

- Farm structure optimisation (FSO) designed to determine the minimum amounts of land, labour and capital goods needed to achieve a net profit and energy efficiency.

In England, there are four main, field-scale research projects focusing on integrated production, as defined above. These are grouped together as the Integrated Arable Crop Alliance (IACPA) - an alliance of commercial and farming interests investigating the large scale application of integrated farming techniques, and in this review, these farms are referred to as IFS-experimental farms (results from the monitoring of two of these are reported in Appendix 1). These regimes adopt all of the points highlighted above.

A second integrated production regime considered in the review is the LEAF (Linking Environment and Farming) regime. This regime includes a series of demonstration farms selected throughout the UK to illustrate working examples of environmentally responsible farming (LEAF, 1991). The LEAF regime does not set specific prescriptions but combines principles and procedures which take account of the specific circumstances of the farm and its surroundings. The LEAF Environmental Audit is central to the implementation of the LEAF approach (Drummond, 1995). This demonstration project focuses on a whole farm policy, based on systems combining crop rotations with targeted use of crop protection chemicals and fertilisers, cultivation choice, variety selection and improved energy efficiency, together with a positive management plan for landscape and wildlife features (LEAF, 1991).

There is now a Research Network for European Union and Associated Countries on Integrated and Ecological Arable Farm Systems (Vereijken, 1995). Integrated production is very much knowledge-based and science-led. Learning processes, indicators and appropriate techniques require time, effort and structured training (Brown, 1997c). This more detailed research-led approach is demonstrated on the IFS-experimental farms, and involves more complex husbandry practices than those generally incorporated into widespread LEAF practices at the moment.

1.4.3 Conventional farming

Within the UK, conventional farming is divided into eight robust types (MAFF, 1997a**)**. These are: cereals, general cropping, horticulture, pigs and poultry, dairy, cattle and sheep (lowland), cattle and sheep (Less Favoured Areas) and mixed. For the purposes of this review, we have identified two farming regimes, conventional arable and conventional mixed. These two regimes include three of the robust farm types named above. For *conventional arable*, these types are cereals and general cropping, and for *conventional mixed lowland*, this is the mixed farm type. The two regimes are thus defined as follows (MAFF, 1997a).

- *Conventional arable*: includes farms on which cereals and other crops generally found in cereal rotations (*e.g.* oilseeds, peas and beans harvested dry and land set-aside) account for more than two thirds of their total Standard Gross Margins (SGM). It also includes farms on which arable crops (including field scale vegetables) account for more than two thirds of their total SGM and farms on which arable crops account for more than one third of their total SGM and no other group accounts for more than one third. This regime does <u>not</u> include horticulture farms.

- *Conventional mixed lowland:* includes farms on which crops account for one third, but less than two thirds of their total SGM, and livestock accounts for one third but less than two thirds of total SGM.

Modernisation of conventional arable and mixed lowland farms during the 1970s, largely in response to EU Common Agricultural Policy (CAP) demands (Potter, 1996), led to increased mechanisation, field size and use of synthetic pesticides and fertilisers (Brown, 1997b; UNEP, 1995; WCMC, 1992). Such increases have had a significant impact on the agricultural landscape (occurrence of hedges, woodlands, field margins *etc.*), wildlife and soil systems (Samways, 1994; UNEP, 1995; WCMC, 1992**)**. With the introduction of UK government supported agri-environment schemes (*e.g.* ESAs, NSAs, Countryside Stewardship), considerable efforts are being made to restore and conserve the agricultural landscape fabric and to reduce inputs of synthetic pesticides and fertilisers, whilst still maintaining profitable, high-yielding crop production.

1.4.4 Summary of the different regimes

In summary the different regimes can be distinguished as follows.

- Organic farming focuses on avoiding the use of synthetic chemicals and managing soil fertility, crop nutrition and protection through careful crop management practices that incorporate features such as rotations with leys, use of natural enemies and organic manuring as common features of farming practice.

- Integrated production (LEAF and IFS-experimental) also focuses on crop rotation to maintain soil fertility and targets chemical inputs to reduce their impact on wildlife and the environment. Where possible such inputs are replaced by mechanical processes and management to enhance indigenous natural enemies.

- Conventional farming (conventional arable and mixed lowland) is still dependent on high levels of inputs - pesticides, fertilisers and energy, although economic and environmental concerns are requiring farmers to target these more carefully.

All regimes have agricultural landscape conservation and enhancement as part of their practice now. This is a requirement within organic regimes, is central but not a requirement in integrated production, and is largely voluntary, except for farms signed up to an agri-environment scheme, in conventional regimes.

1.5 Approach and report structure

In a study of Agriculture and Natural Areas for English Nature, Tilzey (1996) concluded that the ‘survival’ of biodiversity (taken as meaning maintenance and enhancement) will be dependent on the continuation of traditional, low intensity or mixed farming practices. Within Tilzey’s (1996) study, 10 generic agricultural causes of biodiversity loss and decline were identified. These are quoted below.

- Loss and fragmentation of semi-natural 'infield' habitats through improvement or arabalisation.

- Abandonment or under-management of extant semi-natural 'infield' habitats (mainly in the lowlands).

- Overgrazing of semi-natural habitats (mainly uplands).

- Loss or mismanagement of interstitial (fabric) habitats.

- Drainage or drying out of wetland habitats due to over-abstraction of water.

- Pollution or eutrophication of surface and groundwater leading to loss or degradation of aquatic ecosystems.

- Loss of crop rotations and arable-pasture mosaics leading to severe reduction in characteristic farmland species.

- Shift from spring-sown to autumn-sown cereals leading to loss of winter stubbles and to loss of suitable nesting sites for characteristic bird species.

- Universal application of pesticides leading to loss of arable weed species, invertebrates and thereby food sources for other wildlife groups.

- Universal application of artificial fertiliser leading *inter alia* to the loss or degradation of characteristic hedgerow and field margin vegetation.

These issues are considered and compared for the five farming regimes within the contexts of the agricultural practices used (Section 2) and management of the structural elements (e.g. field margins, hedges) present within the farmland landscape (Section 3).

To undertake an evaluation of the impact of different regimes on biodiversity, comparisons should, as far as possible, be made between areas with similar topography, enterprise type, farm size and non-cropped area. However, such information is scarce within the literature and indeed is difficult to collect from existing, established farms. This means that exact comparisons between farming regimes have not been possible for this review. Our approach has, therefore been to identify the different components present in each regime and to examine the impact of each component, as reported in the literature, on biodiversity. The nature of our approach is outlined below.

- To identify the occurrence of different agricultural practices within the different farming regimes and to assess their impact on biodiversity (Section 2).

- To examine the management and significance of different cropped and uncropped farmland areas for biodiversity (Section 3).

- To assess the role of different agri-environment schemes in influencing biodiversity (Section 3).

- To evaluate the impacts of each farming regime on biodiversity, taking into account the approximate scale and geographical extent of each regime (Section 4).

- To evaluate the sensitivity of different species groups to agricultural management change (Section 4).

- To draw up conclusions on the impact of each regime on biodiversity, to identify areas where reliable quantitative information is lacking and to provide recommendations on appropriate studies to address these information gaps (Section 5).

This review is based on the published literature and on unpublished reports from MAFF and other government or non-government organisations and case studies (Appendix 1). Information arising from consultation with the organic movement and other interested parties, has been incorporated into the evaluation (Section 4) and conclusions (Section 5) and is included as a separate workshop report in Appendix 3.

2. IMPACT OF DIFFERENT AGRICULTURAL PRACTICES ON BIODIVERSITY

2.1 Agricultural practice in different farming regimes

The principal agricultural practices and inputs used for crop production vary between farming regimes and are shown in Table 2.1. Agricultural practices are categorised under the following broad headings.

- *Cultivation*: includes practices involved in preparing the ground for sowing. Inversion ploughing, deep tillage, minimal tillage and direct drilling are included in this category.

- *Crop production*: includes the inputs and practices used to enhance crop growth, specifically fertiliser use, green manuring, intercropping and irrigation.

- *Crop protection:* includes the inputs and practices used to reduce the incidence of weeds, pathogens and pests.

- *Post-cropping:* includes the options that can be adopted for managing cropped land after harvest. Crop residue incorporation, stubble retention, set-aside, autumn or spring sowing, crop rotations with leys and permanent pasture are all included in this category.

Within Table 2.1, each practice or input is assigned a ranking to indicate its approximate frequency of occurrence within each regime for the UK. The rankings are approximate rather than quantitative measures of the actual occurrence of each practice within each regime.

The following sections summarise the results of studies where the effects of individual practices and inputs on different groups of species have been examined specifically. Comparative studies of specific practices across the different agricultural regimes are generally rare and difficult to interpret, due to confounding effects of the surrounding farm environment, variation in the extent and occurrence of uncropped areas and biogeographical effects.

Table 2.1 *Occurrence of different agricultural practices within each farming regime.*

CP = Common Practice, occurs on almost every farm within the category; not to be used is the exception (85%+). WU = Widespread Use, occurs commonly and is used by a large number of farms within a particular category (45-84%). LU = Local Use, used by some farms within a category, frequently with a particular geographical or process bias (10-44%). IU = Infrequent Use, rarely used within the category (< 10%). O = Not Used, not associated with farms in the category, occurrence is the exception.

AGRICULTURAL PRACTICE	CONVENTIONAL ARABLE	MIXED	IFS-LEAF	IFS EXPERIMENTAL	ORGANIC
Cultivation					
Inversion ploughing	CP	CP	CP	LU	CP
Minimal tillage	LU	LU	LU	LU	LU
Direct drilling	IU	IU	LU	LU	O
Crop production					
Fertiliser use					
• synthetic/slurry/other	CP	WU	WU	WU	O
• FYM/organic slurry	IU	WU	WU	LU	CP
Green manure/intercropping	O	LU	LU	LU	CP
Irrigation	LU	LU	LU	LU	LU
Crop Protection					
Weed control					
• Mechanical	LU	LU	LU	LU	CP
• Chemical	CP	WU	WU	WU	O
Pest control					
• chemical (synthetic)	CP	WU	WU	WU	O
• biological	LU	LU	LU	LU	LU
• natural products	IU	IU	IU	IU	LU
Post-cropping					
Incorporation	CP	CP	CP	CP	WU
Set-aside/stubbles	WU	CP	WU	WU	CP
Autumn sowing	CP	WU	WU	LU	LU
Spring sowing	LU	LU	LU	LU	LU
Rotation with grass ley	IU	CP	WU	CP	CP
Permanent pasture	IU	CP	WU	CP	CP

2.2 Cultivation

Approximately 5 million ha (of the 18 million ha of agricultural land) is cultivated annually in the UK (ADAS/SRI, 1996). Primary cultivation can involve inversion ploughing, deep or minimal tillage followed by drilling, or crops may be drilled directly. The use of these operations varies between farming regimes (see Table 2.1). Minimal tillage and direct drilling are more commonly associated with integrated production, particularly IFS-experimental regimes, but minimal tillage is becoming more widespread in other regimes in response to a need to reduce costs. A recent survey of farmland cultivation practice by ADAS/SRI (1996) indicated that 98% of the 868 respondents used inversion ploughing, 26% used deep or minimal tillage (non-plough cultivation) and 3% used direct drilling (no cultivation). Although the survey did not take account of farming regime, these figures indicate the general frequency of occurrence of each practice within UK agriculture. The choice of primary cultivation is strongly influenced by soil type and rainfall (ADAS/SRI, 1996).

In addition, 92% of respondents undertook secondary cultivation with rolling or pressing being the most popular operations. Forty-five percent of respondents sowed crops in combination with soil cultivation passes, and only 6% directly seeded, disc drill and broadcast being the most common methods used in direct seeding. Eighty-six percent of respondents cultivated after sowing, mainly by rolling - 83% of respondents, and harrowing - 16% (ADAS/SRI, 1996).

The impacts of the different primary cultivation methods on biodiversity are discussed below. The impacts of mechanical weeding are discussed in section 2.4.1. Little specific information is available on the impacts of other secondary cultivation practices on biodiversity.

Table 2.2 *Impacts of Agricultural Practices on Different Organism Groups.*

+ positive impact, **O** no significant impact, **-** negative impact, **?+/?-** possible positive/negative impact, **?** unknown.

AGRICULTURAL PRACTICE	SOIL ORGANISMS	PLANTS	INVERTEBRATES	BIRDS	MAMMALS	OVERALL IMPACT
A. Cultivation[A]						
Inversion ploughing	-	?	-	?	?+	-1.5
Minimal tillage	?-	?	?+	?-	?-	-1
Direct drilling	+	?	+	?	?-	+1.5
B. Crop production[B]						
Fertiliser use						
• synthetic/slurry/other	-	-	?	?	?	-2
• FYM/organic slurry	+	0	?	?	?	+1
Green manure/intercropping	+	?	+	+	?	+3
Irrigation	?	?	?	?	?	?
C. Crop protection[C]						
Weed control						
• Mechanical	+	-	?	?-	?	-0.5
• Chemical	0	-	?-	?-	?-	-2.5
Pest control						
• Chemical (synthetic)	?-	0	-	-	-	-3.5
• Biological	0	0	-	0	0	-1
• natural products	?	?	-	?	?	-1
D. Post-cropping[D]						
Incorporation	+	+	?+	0	0	+2.5
Set-aside/stubbles	+	+	+	+	0	+4
Autumn sowing	-	?	?	-	0	-2
Spring sowing	?+	?	?+	+	?+	+2.5
Rotation with grass ley	?	?+	+	?+	?	+2
Permanent pasture	+	?	+	?+	?+	+3

Key studies and review papers

A den Boer, 1997; Brown, 1997b; Christensen, 1988; Frieben & Kopke, 1996; Glen, 1997; Holland *et al.,* 1996; Reddersen, 1994; Stopes, 1997.

B Alteri & Letourneau, 1982; Armstrong & McKinlay, 1990; Brown, 1995b, 1996; Frieben & Kopke, 1996; Frylestam, 1986; Fuller, 1997; Madar *et al.,* 1996; Reddersen, 1995a; Tew, 1987; Theunissen, 1997; Yeates *et al.,* 1997; Young & Armstrong, 1996.

C. Campbell *et al.,* 1997; Frampton *et al.,* 1992; Frampton & Cigli, 1992; Frieben & Kopke, 1996; Fuller, 1997; Grieg-Smith *et al.,* 1992; Holland *et al.,* 1994; Halberg, 1997; Moreby *et al.,* 1994; Tew *et al.,* 1992.

D. Biederbeck *et al.,* 1980; Christensen *et al.,* 1996; Frampton *et al.,* 1992; Fuller, 1997; Glen, 1997; Holland *et al.,* 1996; Holland *et al.,* 1994; Hopkins, 1997; Reddersen, 1994; Ward & Aebischer, 1994.

2.2.1 Inversion ploughing and deep tillage

Inversion ploughing involves physically turning the soil over, normally to a depth of 16-25 cm (ADAS/SRI, 1996), and is common practice in conventional and organic regimes. Deep tillage involves the use of discs, tines or powered rotors to disturb the soil up to a depth of 10-15 cm. Inversion ploughing reduces the abundance of invertebrates (Fuller, 1997; Madar *et al.*, 1996), particularly deep burrowing earthworms (Edwards & Lofty, 1982). The creation of cracks, after ploughing, does, however, appear to encourage small mammal activity especially in bare field situations (see Appendix 1 and Brown, 1997b). The impact of deep tillage on biodiversity does not appear to have been well-researched. With respect to soil organisms, the level and depth of soil disturbance would suggest an impact similar to that for inversion ploughing. Impacts on small mammals may, however, be similar to those recorded for minimal tillage (see 2.2.2 below). The accumulated impact of very heavy machinery, used for both primary and secondary cultivation, on the densities of soil invertebrates should also not be overlooked (Horn reported by MacKenzie, 1998).

2.2.2 Minimal tillage

This involves disturbing the soil surface, often using discs or tines, without physically turning the soil over. Another version drags a horizontal blade below the surface of the soil, thus lifting without turning over. Minimal tillage and direct drilling are recommended practices within IFS-experimental regimes. Minimal tillage can create unfavourable conditions in a bare-field situation for foraging small mammals, due to the lack of cracks for shelter, and can cause short-term depletion in populations of some of the shallow-living, non-burrowing earthworms and superficial-living earthworms (*e.g. Allobophora chloritica*, see Appendix 1). Reduced or no tillage leads to increased survival of polyphagous predators (carabids, staphylinids and linyphiids) but the reported value is circumstantial in terms of predator control actually on crops (Reddersen, 1994; Glen, 1997). It can also lead to increased slug numbers initially, but these may be reduced by the build-up of natural predators over a period of several years (Glen, 1997).

2.2.3 Direct drilling

This involves planting seeds directly into shallow slots created by specialised discs so that the soil surface is not disturbed and weed seeds are not encouraged to germinate. Evidence from IFS-experimental case studies (see Appendix 1) indicates that earthworm density and biomass, particularly *Lumbricus*, builds rapidly after 2-3 years of direct drilling and may exceed that achieved under long-term unfertilised pastures or grass leys (Appendix 1 and Brown, 1996) Similar results are indicated by Stopes (1997)). However, repeated practice of direct drilling and minimal tillage can lead to a build-up of plant species such as black grass (*Alopecurus myosuroides*) and sterile brome (*Anisantha sterilis*). These species can reduce crop yield and the overall diversity of the weed community by out-competing other plant species (Clarke & Davies, 1995; Critchley, 1994).

2.2.4 Cultivation and biodiversity impacts in different farming systems

Inversion ploughing is widespread in geographical and agricultural practice terms and is normal practice on conventional arable and mixed lowland farms which together occupy around 90% of the arable land in England (MAFF, 1997b). It is common practice on LEAF and organic farms. Its impact on floral and faunal diversity (both micro, meso and macro) is substantial *e.g.* earthworms, collembola and some oribatid mites (Wallwork, 1970). Deep and minimal tillage are also becoming more common on conventional arable farms (ADAS/SRI, 1996) and minimal tillage is the preferred practice for IFS-experimental regimes. Clearly the impact of inversion ploughing is geographically greater than the other cultivation practices, but mitigation of this impact can be achieved on farms where population reservoirs for wildlife are provided by uncropped habitats that enable the recolonisation of cropped areas to occur rapidly (Glen, 1997).

2.3 Crop production

2.3.1 Fertiliser use

Fertiliser use across the five farming regimes varies in nature and extent. The use of synthetic fertiliser and slurry is common practice within conventional arable regimes and both are widely used within conventional mixed lowland, LEAF and IFS-experimental regimes. By contrast, farmyard manure is the most common fertiliser used in organic regimes.

Fertiliser impacts on biodiversity by altering the level of nutrients available to biological organisms. Plant and soil organisms are most directly affected but indirect effects impinge on invertebrate and vertebrate communities as a result, for example, of changes in plant community composition (e.g. loss of arable weed seed for birds - Fuller, 1997). Indirect effects of fertiliser use also arise from leaching of nutrients into ground and surface waters, which has implications for biodiversity at the local and regional scale. These widescale effects are examined in the ADAS (1995a) report on the Environmental Effects of Organic Farming. This section focuses on the extent to which different inputs are used within each farming regime (Table 2.1), and their effects on plant, animal and soil organism communities at the farm level.

The efficiency of nutrient cycling in soil within organic regimes was considered as part of a general review reporting on the Organic Farming Study Forum (IACR, 1997). A study of whole farm nutrient budgets undertaken at the Duchy Home Farm, UK, (Goulding *et al.,* 1997) established that soil nutrient levels in field margins varied greatly according to management treatment. Considerable seasonal variation and spatial heterogeneity was observed in the dynamics of nitrogen cycling, both within and between fields at different points in the rotation, reflecting variation in soil microbial activity and possibly diversity. Rapid cycling and lower nutrient levels tend to be associated with greater microbial diversity, but not always density.

Goodlass & Johnson (1997) have suggested that a reduction in nitrogen supply, in response to IFS fertiliser practices, may result in a loss of soil organic matter with a consequent negative impact on soil structure, invertebrate and microbial activity and density. Under IFS regimes, some crops may be managed with lower inputs than optimum to reduce disease problems. The result is a depletion of soil nutrients which may adversely affect subsequent crops unless sufficient additional nutrients are supplied. Sometimes this application rate will need to be higher than in a comparable arable system if the soils are not to be depleted for subsequent crops, and if long-term damage to soil microbial diversity and density avoided (Goodlass & Johnson, 1997).

i) Impacts on micro-organisms

There are many papers on the effects of soil management practices on soil micro-organisms (see ADAS, 1995a). Pesticides, cultivation and fertilisers are particularly important. In soils treated with organic manures including farmyard manure (FYM), soil bacterial and fungal counts and dehydrogenase levels (a measure of the overall rate of microbial metabolism) were higher than in soils supplied with inorganic fertilisers (Madar *et al.*, 1996). Untreated plots had lower microbial populations than those treated with inorganic fertilisers, which in turn had lower populations than plots treated with organic manures (Madar *et al.*, 1996). Work by Reddersen (1995a, 1995b) and Macdonald & Smith (1991) suggested that mycorrhizae are suppressed by application of fertiliser, although many other factors have an influence. Mycorrhizal fungi infect the root surface of plants and are critical in enabling the uptake of nutrients by plants.

ii) Impacts on soil meso-fauna

Yeates *et al.* (1997) studied bacterial, fungal and soil fauna relationships on three Welsh soils under organic and conventional regimes. Tardigrades and Acari (mites) were found to be more abundant under organic management on some soils, and nematodes were greater on all soils under organic management. The soils were pasture soils and the authors indicated that differences between farming regimes were not as marked as in arable cropping regimes. In the latter, diversity is generally much greater on organic management regimes, but densities of a few key species are frequently greater on conventionally managed soils (Brown, 1997a). Well-rotted farmyard manure (FYM) applied at low levels appears to stimulate earthworm and organic matter dependent groups such as some of the Cryptostigmatid mites and springtails (Brown, 1996). However, no quantitative assessment is available at present. The impact of over-application on dicotyledenous and grass communities suggests that there may be a negative knock-on effect on fauna (Simpson & Jefferson, 1996).

iii) Impacts on the plant community
The conflict between synthetic fertiliser use for agricultural production and the maintenance of botanical diversity for nature conservation, is suggested from studies of fertiliser use on flower-rich hay meadows in the Somerset levels (Tallowin & Smith, 1994). These demonstrated that three years after cessation of fertiliser input, there was no significant change in soil status and that there was a persistence of enhanced residues of available nutrients, especially phosphorus. Variation in cutting dates had little effect on soil nutrient status. Within organic regimes, Frieben & Kopke (1996) have suggested that the occurrence of lower nitrogen levels is one of the factors that have a positive effect on plant species diversity

Simpson and Jefferson (1996) reviewed the effect of farmyard manure on semi-natural (meadow) grassland. FYM is commonly used in organic systems, in some conventional, mixed lowland regimes and sometimes in integrated production regimes. It is rarely used in conventional arable, although some slurry products are, but the overall reliance is on synthetic fertilisers. In their review, Simpson & Jefferson (1996) emphasise the importance of the use of well rotted FYM, and suggested that applications of 20 t/ha every 3-5 years may be too high to maintain species rich meadows of high nature conservation value. Rates and frequency of application which are too high result in the reduction of richness and abundance of dicotyledonous herbs and an increase in competitive grasses resulting in an overall reduction of species richness and diversity. Rates greater than 30 t/ha can cause scorching and bare patches on re-seeded grassland.

2.3.2 Intercropping (green manures)

Because mixed ground cover presents more niches, it is argued that intercropping will encourage a greater diversity of faunal species, including beneficial arthropods, because it retains some of the structural and botanical diversity of a weedy crop. From an agricultural viewpoint, this is important as weedy crops tend to have a lower density of invertebrate pest species than weed free crops (Younie & Armstrong, 1996). Greater diversity of polyphagous predators has been recorded by Altieri & Letourneau (1982) in intercropped fields compared to conventional wheat monocultures. In a study of cabbages under-cropped with clover in Scotland, Armstrong & McKinlay (1996) found more species of carabid in natural weed cover than in intercropped plots. Specifically, the carabid species *Bembidion tetracolum, Trechus quadristriatus, Amara apricaria* and *Notiophilus biguttatus* were recorded in larger numbers in mono-cropped cabbages than intercropped plots. By comparison, *Pterostichus melanarius* and *Loricera pilicornis* were more common in intercropped plots, even when natural weed areas were available. Such variation in species response may reflect species habitat preference for open or shady habitats, as has been demonstrated in studies of carabid species distribution in semi-natural habitats (*e.g.* den Boer, 1977; Gardner, 1991; Gardner *et al.*, 1997). Biogeographical variation in species composition will also have an impact on species response in different areas of the British Isles. Intercropping is common practice in organic regimes (Table 2.1) and also occurs within conventional mixed lowland, LEAF and IFS-experimental regimes.

2.3.3 Irrigation

There are few specific references on the effects of irrigation on biodiversity, although issues of raising, manipulating water tables on pasture to encourage particular communities (*e.g.*

Somerset Levels ESA) have been investigated in a practical way (Mountford & Chapman, 1993; Mountford *et al.*, 1997). Irrigation tends to be used mainly on root crops *e.g.* sugar beet, potatoes, and occasionally in cereals on light soils in dry conditions. Soil moisture content has a significant impact on microbial activity and some soil invertebrates *e.g.* nematodes. Thus irrigation may be expected to enhance the activity of these groups (Jones & Johnson, 1994, 1995).

2.3.4 Crop production and biodiversity impacts in different farming regimes

In conventional systems, intensive crop production involving continuous manipulation of the soil, high (synthetic) input into crops/soils and restricted rotations, often with limited margin/non-cropped habitat, results in a lowering of biodiversity (Tilzey, 1996), although densities of some species (*e.g.* some staphylinids) may be greater. Under organic regimes, the removal of synthetic inputs, the use of longer rotations with grass leys and sympathetic margin management generally favour both faunal and floral diversity and soil microbial activity (Frieben & Kopke, 1996). Integrated production incorporates some of the elements, intrinsic to the organic system, which favour biodiversity (Glen, 1997) and adopts, where possible, cultivation practices which are more sympathetic to communities of soil organisms (see Tables 2.1 and 2.2).

2.4 Crop protection

Agricultural pesticides are designed to impact directly on specific, and sometimes on a broad-spectrum of, groups of fungi, higher plants and invertebrates. There appears to be little information available on the overall impact of pesticides (specifically fungicides) on fungal diversity. Herbicide impact on plant species abundance and diversity is reviewed in section 2.4.2. There is little doubt that pesticides have a direct impact on invertebrate diversity. Holland *et al.* (1996) identified the impacts on arthropods of the following pesticide groups.

- Insecticides - were shown to cause direct mortality and to have indirect effects, for example, by depriving predators of prey.

- Herbicides - may affect arthropods by reducing the abundance of their host plants or by altering ground cover and microclimate.

- Fungicides - only those containing pyrazophos, which are no longer used in arable crops, were found to have any direct toxicity.

- Molluscicides - were not included in the review of Holland *et al.* (1996), but other work has suggested that small mammals may be affected by their use (Johnson *et al.*, 1992).

Similarly, Campbell *et al.* (1997) identified that pesticides may affect birds in various ways.

- Insecticides by reducing the abundance of invertebrates, which are an important food resource for breeding birds.

- Herbicides by reducing the abundance of host plants for invertebrates and hence, reducing invertebrate abundance.

- Herbicides by reducing the abundance of weeds and seeds, which provide a food source for birds in winter and for some species during the breeding season.

The use of pesticides on cereal crops in the UK has changed markedly (Campbell *et al.*, 1997). In particular, the advent of more specific active ingredients and more efficient spray technologies has led to a drop in actual application rates per unit area, although the geographical area over which pesticides are applied has increased substantially (Campbell *et al.*, 1997). Specifically, Campbell *et al.* (1997), using information from the Pesticides Trust (1996), indicate that herbicide use in cereals has increased in the 1990s to 200% of the area sprayed in the 1970s. Insecticide use in cereals in the early 1970s, was low, just a few percent, but increased to 100% in 1990, dropping back to around 60% in 1992 and 1994 (Campbell *et al.*, 1997). These changes apply primarily to conventional arable, conventional mixed lowland, LEAF and to a lesser extent to IFS-experimental regimes.

2.4.1 Weed control - mechanical

This process which involves dragging tines across the soil surface to remove young weeds (Brown, 1995a) is used in both integrated production and organic regimes (Table 2.1). Whilst generally effective, it can have a serious negative impact if undertaken at a time when ground nesting birds are present. Attention to timing of operations is highlighted in the standards set by some sector bodies (*e.g.* Soil Association, 1997) but adverse impacts have been recorded under a small percentage of IFS-experimental operations (Brown, 1995a).

2.4.2 Weed control - chemical

This is common practice in conventional arable and conventional mixed lowland farming and widespread on LEAF and IFS-experimental regimes (Table 2.1).

i) Effects on arable weed communities
The short and longer-term impacts of herbicide use on arable weed communities have been comprehensively reviewed in Campbell *et al.*, (1997). Whilst weed populations have been shown to be more abundant on cereal rotations receiving lower inputs of herbicides (*e.g.* El Titi, 1991; MAFF, 1998), the actual effects of herbicides on plant community composition are frequently difficult to disentangle from effects such as nitrogen use, crop type, seed-bank productivity and germination period (Froud-Williams & Chancellor, 1982; Green *et al.*, 1995; Greig-Smith, 1992; Wilson, 1994). Comparisons of weed communities within organic and conventional cereals (equivalent to the conventional arable defined in this review), have indicated a significantly greater abundance and diversity of weeds within organic systems (Brookes *et al.*, 1995; Halberg, 1997; Moreby *et al.*, 1994). Similarly, comparisons of sprayed and unsprayed field headlands have indicated that weed biomass, density and species richness are reduced on sprayed headlands (Chiverton & Sotherton, 1991; Sotherton *et al.*, 1985). Both of these comparisons, organic v. conventional cereals and sprayed v. unsprayed headlands, suggest a negative impact of herbicide spraying on arable weed communities.

Long-term declines in the abundance of several arable weed species have been reported (*e.g.* Smith, 1989; Stewart *et al.*, 1994; Wilson, 1994), but the role of herbicide usage in effecting these declines has proved difficult to establish. This is because past management strongly influences the diversity and abundance of weed communities each year. That herbicides have had some impact is likely, given the evidence from short-term studies, the question is how large this impact is.

ii) Effects on animal communities
As indicated above, herbicides may impact on vertebrates and invertebrates indirectly, by influencing both food and breeding sources (Campbell *et al.*, 1997). The strongest support for such an impact emerges from work on the grey partridge, where experimental reduction in the spraying of pesticides - particularly broad-leaved weed herbicides resulted in increased brood size and chick survival (Rands, 1985, 1986; Sotherton *et al.*, 1993). Herbicide use is also implicated in the population decline of at least two other farmland bird species, corn bunting and linnet (reported in Campbell *et al.*, 1997). For the linnet, the loss of preferred weed seeds appears to have been compensated, at least in one study area, by a switch to oil-seed rape (Campbell *et al.*, 1997). The increased incidence of weeds and higher densities of birds reported for organic regimes (BTO/IACR, 1995) lends some support to the argument that herbicides can have a negative indirect impact on farmland birds. Indirect effects of herbicides and the impact of fungicides on fungivores, were also issues identified by Reddersen (1994) in relation to Lauxanidae (Diptera) and other species which depend on fungal material at some stage in their life cycle.

2.4.3 Pest control - chemical

The use of synthetic chemical is only permitted in conventional and IFS regimes. Within organic regimes, pest control is achieved using cultivars, rotation, natural products *e.g.* pyrethrum, or by biological or cultural means. There is a significant amount of literature on the impacts of synthetic pesticides on species occurrence and biodiversity and only recent reviews, based on studies undertaken primarily on arable farmland, are given here.

i) Effects on arthropod diversity
Two long-term projects have been funded by MAFF to examine the environmental impacts of contrasting pesticide regimes (Greig-Smith *et al.*, 1992; Green *et al*., 1995). The first of these, the Boxworth project, compared three pesticide treatments, namely full insurance, supervised and integrated (Greig-Smith *et al.*, 1992), over a period of five years. Results from the project indicated that some invertebrate species were susceptible to intensive pesticide use in winter wheat, whereas others appeared to benefit. For example, on the full insurance treatment species such as lucerne fleas disappeared immediately and spiders became less frequent; specifically, deltametharin used for aphid control had a negative effect on spiders (Frampton *et al.*, 1992). Similarly, the ground beetle *Bembidion obtusum* was virtually eliminated by deltametharin and chlorpyrifos, whilst another species, *Trechus quadristriatus* (Carabidae) disappeared initially, but re-established after several months and increased in abundance. Soil invertebrates were affected to different degrees. Collembola were taken as an indicator group, as these species are not very mobile and are directly influenced by environmental change. Both Arthopleona and Symphypleona sub-orders of Collembola were depleted by spraying, especially *Entomobrya multifasciata, Isotoma viridis, Sminthurides signatus* and *Sminthurus viridis. Folsomia*

quadrioculata was reduced in the full insurance treatment, but other Entomobryids were favoured perhaps through lack of competition.

Some of the variation in species response, outlined above, can be attributed to differences in species' ecology. Species that left the crop in late summer to over-winter in neighbouring habitats, species that were active on the ground or lower crop canopy or species that over-wintered underground, were less susceptible to the treatments than species that remained above-ground in the crop or field throughout the year (Greig-Smith *et al*., 1992). Species dispersal ability appeared to have an important effect on their persistence within the treatments. Thus some species, although significantly reduced in numbers on the full insurance treatment, managed to persist on the treatment throughout the five-year study due to their ability to recolonise from neighbouring areas. *Bembidion obtusum,* a ground beetle with poor dispersal ability was not able to recolonise rapidly and Frampton & Cigli (1992) suggested that it was therefore a useful species to use in assessing the impact of insecticides.

A second project SCARAB (Seeking Confirmation About Results After Boxworth), was established in 1990. The overall objective of this project was to establish the ecological consequences of applying two different pesticide regimes to six-course arable rotations (Cooper, 1990). Two pesticide management practices were explored.

- Current Farm Practice (CFP), designed to represent general pesticide usage in comparable farming situations;

- Reduced Input Approach (RIA), based on minimum usage of fungicides and herbicides necessary to avoid more than 10% loss in yield/crop value. Insecticides were only used in this regime in an emergency, in response to a crop threatening situation (MAFF, 1998).

Preliminary results are reported in Green *et al.,* (1995) and summarised in MAFF (1998)**.** These indicated the following.

- Polyphagous predators showed no irreversible and adverse long-term effects under the CFP treatments, although winter use of chlorpyrifos did cause major reductions in several groups that persisted for several months (Cigli & Frampton, 1994).

- Detrimental effects of pesticides were recorded for Collembola, the effect being most pronounced where organophosphorus insecticides were applied in consecutive seasons (MAFF, 1998).

- Synthetic pyrethroid insecticides resulted in a short-term reduction in spider abundance (MAFF, 1998).

- Soil microbial biomass fluctuated more widely within the CFP regime than within the RIA one (Green *et al*., 1995). Fungicides had a short-term negative effect on soil microbial activity and biomass, and multiple applications of fungicide were often seen as inhibitory to microbial activity (MAFF, 1998).

- Earthworm biomass and abundance differed significantly between sites, but no consistent differences were detected between treatments (Green *et al.*, 1995).

By comparison, a long term study by Heydermann & Meyer (1983) showed a 95% decrease in activity-biomass of ground beetles over three decades in Switzerland in response to agricultural intensification, especially increased use of pesticides (Lys *et al.*, 1994). Similarly Moreby *et al.* (1994) demonstrated a reduction in polyphagous and other arthropod groups on farms where summer insecticides had been used on conventionally managed arable land compared to farms without summer insecticides.

In a series of studies on the effects of conventional and organic management on arthropods in Danish cereal fields, Reddersen (1995a) demonstrated that three common species of Lauxaniid flies were negatively influenced by normal pesticides, as well as fungicides alone and combinations of herbicides and fungicides. He had already suggested these as a possible indicator group for pesticide response (Reddersen, 1994). The same author (Reddersen, 1993, 1995b) identified uniformly lower densities of predatory arthropods in conventionally sprayed plots, especially those with a high fungal element in their diet.

In Germany, Basedow (1995) carried out a study on an ecological (organic) wheat farming area where there was high abundance and diversity of arthropod faunas following the discontinuance of insecticide and herbicide input. Here the management regime encouraged the diversification of the fauna, but the results could not be achieved on all soil types. Consequently Basedow (1995) concluded that while much modern farming is seeking to reduce external inputs, especially synthetic pesticides and fertilisers, total elimination would appear to be unlikely as an achievable goal.

ii) Impacts on birds

In a major review of the indirect effects of pesticides on farmland birds Campbell *et al.* (1997) highlighted the significant decline in 59% of species breeding on farmland over the last 30 years. This was thought to be linked partly to pesticide use, although for some species, populations within woodlands also show a parallel decline to their farmland counterparts. Excluding rare species, the most severe declines were recorded for tree sparrow, grey partridge, turtle dove, bullfinch, song thrush and spotted flycatcher (over 70% decline in the last 20-30 years). Lapwing, skylark, linnet and reed bunting also showed a 50% decline. In most cases, the populations of these species had been increasing in the period up to 1974.

Although the majority of birds feed on a wide range of foods, there are indications that Lepidoptera, Coleoptera and Orthoptera are especially important in the diets of the declining species (Campbell *et al*., 1997). Various studies of the food of farmland birds have indicated a decline in invertebrate sources, but the information on plant foods is less clear cut. There is clear evidence that pesticides result in short term reductions in the abundance of target and non-target invertebrate species which could impact on birds (Campbell & Cooke, 1997).

Campbell *et al*. (1997) recognised that there were many factors involved in bird species decline and that there was an absence of clear cut relationships between pesticides and bird food. Temporal associations were established between the increasing trend in pesticide use and the period of rapid decline of eleven bird species, which suggested that pesticides could not be ruled out as a major factor in the decline of these species. It was acknowledged that the occurrence of rotational set-aside had reduced the impact of some of the problems of crop management change, by providing stubble and winter food for some seed-eating species. Campbell & Cooke

(1997) summarise some of the changes that they consider might help to reverse the decline in farmland bird populations. These include the following.

- Increased use of Integrated Crop Management (ICM), narrow-spectrum pesticides and similar techniques, to minimise the use and impact of pesticides.

- Widescale introduction of an integrated package of prescriptions in an agri-environment scheme. These might involve reasoned and targeted reductions in pesticide use and non-chemical changes aimed at promoting species diversity and richness.

- The introduction of a successor to set-aside designed to encourage farmland birds.

- A switch to organic farming.

- A reversion to farming techniques used several decades ago.

Campbell & Cooke (1997) recognised that the latter reversion is not realistic on a large-scale, and that none of the proposed options alone would allow farmland birds to return to their former abundance. A combination of measures would, therefore, be necessary. The Pilot Arable Stewardship Scheme may go some way towards dealing with some of these issues.

Detailed studies of the impacts of pesticides on bird diversity were also included in the Boxworth experimental project (Greig-Smith *et al*., 1992) and the BTO/IACR (1995) survey of organic farms. The latter demonstrated higher density and reproductive success on organically managed areas, but because these were whole farm studies the identification of the specific role of pesticides on bird populations was not possible.

Results from the Boxworth project indicated that starlings were affected by food loss, *e.g.* of cranefly larvae on the full insurance treatment (Greig-Smith *et al.*, 1992). There was, however, no evidence of direct impact of pesticides on any bird species and no overall impact on small mammals, although the death of adult bank voles and wood mice as a result of the use of slug pellets containing methiocarb was recorded. Population recovery was rapid and it was not clear if the deaths were a result of direct poisoning or eating contaminated food. The buffering effect of woods and thick hedges was again seen as a key factor. Shrews may also have suffered as a result of food loss (Johnson *et al.,* 1992).

2.4.4 Pest control - biological

Enhancement of natural enemies for controlling animal pests has been explored quite widely within UK and European agricultural systems (IOBC, 1993). It is a major element of organic regimes and a key principle for integrated production (IOBC, 1993) and can involve habitat manipulation to create favourable conditions (*e.g.* planted strips for over-wintering beetles) for natural enemies. Biological methods may be incidentally important within conventional mixed lowland regimes. Biological control may involve the selective breeding or genetic engineering of the plant or animal at risk from a pest or disease, or the introduction of a natural enemy or control agent. It is important to note that the use of genetically engineered organisms is not permitted in organic regimes.

Recently, concerns have been raised about the use of introduced species or organisms, and the potential risk to non-target organisms, as these have been adversely affected in some cases. Many countries in Europe, North America and Australasia are considering legislation in relation to biological control initiatives. The nature of the problem in Europe was highlighted by Isart *et al.* (1996) in relation to using pheromone traps against *Zenzera pyrina* (Leopard moth) in hazelnut systems being managed on an organic regime in Tararagon. Although the technique had been used successfully in Mediterranean regions of southern Spain since 1995, in different fruit tree crops, it also attracted other non-target moth species, resulting in their destruction and a consequent reduction in biodiversity.

Work is currently underway to encourage larger beetle populations through manipulation of breeding in relation to apparent food availability. This may stimulate biodiversity by providing increased food sources to mammals such as shrews, woodmice, badgers and birds such as little owl. There is clearly potential in such manipulative approaches of utilising existing resources in terms of resident species, but introductions and supplementation of natural enemy populations must be managed with caution at national and international level (Isart & Llerena, 1996).

2.4.5 Crop protection and biodiversity impacts in different farming systems

Pesticides used in conventional and integrated production regimes can have a direct impact in reducing both plant and invertebrate abundance. Such reductions may be short-lived if suitable non-cropped reservoir areas are available. Longer-term indirect effects, particularly on farmland birds, are also evident (Campbell *et al.*, 1997), although the specific effects due to pesticides are frequently difficult to pinpoint. Natural pesticides, used in organic regimes, can be a problem if, for example, they enter wetland or aquatic systems. Mechanical weed control used in IFS-experimental regimes can affect soil fauna and ground nesting birds, although the extent of the effect has yet to be fully evaluated.

2.5 Post-cropping practices

2.5.1 Crop residue (straw) management.

Although straw burning is no longer permitted in the UK, apart from linseed which occupies a very small area of arable land, this is not the case in some other countries.

The implications of straw burning for soil biodiversity have been differently interpreted. Biederbeck *et al*. (1980) established that bacterial populations in the top 2.5 cm of burned sites were permanently reduced by 50% (Saskatchewan, Canada). In Greece, Kaliburtji (1996) found only slight decreases in fungal populations on burnt sites, whilst bacteria appeared to increase. The long term effects of burning may lead to reduced water infiltration, greater soil compaction, greater susceptibility to water erosion, lower available nitrogen and to lower microbial activity, which, in turn, will lead to the gradual loss of soil organic matter.

A survey of crop residue management practices on 868 farms indicated that 88% of farmers baled and carted residue (mean area 65.6 ha/farm), whilst 62% chopped and incorporated residue on site (mean area 69.5 ha/farm). Less than 4% of farmers burned linseed (mean area 15.7 ha/farm). Although chopping and incorporating can cause short-term disturbance to the soil fauna, the direct injection of organic matter is likely to have a beneficial impact on groups such as the earthworms and microbes. Residue removal may, however, help to maintain species diversity by limiting the build up of density or biomass in any one group of organisms. The return of residues also helps to minimise nutrient off-take and reduces the need for fertiliser replacement. The practice is widely used in all five regimes (see Table 2.1). Farmers frequently use more than one technique, and the choice of technique will be determined, to some extent, by soil conditions and crop type.

2.5.2 Set-aside and stubble retention vs cropping

The value of stubbles for birds has been well-established (Wilson *et al.,* 1996). In this respect, the introduction of set-aside has been of particular benefit to biodiversity on farmland partly through stimulating the regeneration of the previous (normally cereal) crop which provides additional food (Moreby & Aebischer, 1992; Wilson & Fuller, 1992; Wilson *et al.,* 1996). The area of rotational set-aside fluctuates annually but is typically between 5-15% of UK arable land (Clarke, 1992; ADAS/SRI, 1996; Clarke, 1998: pers. comm.). The timing of sowing is important in that spring cultivation and sowing after a period of autumn or winter stubbles impact positively on biodiversity. Cosser *et al.* (1997) demonstrated that the timing of cereal sowing also had an impact on the composition of the weed community, including the rarer species. In particular they suggested that spring sowing of wheat significantly increased weed germination and performance.

Stubbles and set-aside occur widely in all regimes. Autumn sowing is commonly practised in conventional arable, conventional mixed lowland and LEAF regimes. IFS-experimental and organic regimes tend to maintain a better balance between spring and autumn sowing, where soil type permits.

2.5.3 Crop rotation

Agricultural intensification has tended to polarise crops geographically rather than maintaining a mixed system. In organic regimes, crop rotations that include grass leys, are a key element except on permanent pasture farms. Organic regimes also tend to support a wider variety of crops (which is also a characteristic of IFS-experimental regimes) which provide greater structural diversity and habitat diversity for flora and fauna. Two- or three- year leys are particularly important for many elements of biodiversity (see grass and pasture section in 3.3)

Holland *et al*. (1994) assessed the effect of crop type and introduction of IFS on predator populations. Crop type exerted the greatest influence, although differences between conventional and integrated systems were not marked. The effect of crop rotation on invertebrates was investigated as was crop preference. Nineteen taxa of Carabidae, 13 taxa of Staphylinidae and 8 taxa of Araneae were used to provide an indication of diversity. Winter oilseed rape contained the greatest number of predatory species, followed by winter wheat (2nd crop), which had three times more activity than winter wheat (1st crop) and fourteen times more activity than spring barley. This conflicts with findings elsewhere in relation to the barley (Frampton *et al.*, 1992). *Bembidion obtusum* and *Trechus quadristriatus* were more common in peas but absent from cereal crops. Potatoes had a negative effect in the rotation as a result of intensive cultivation, poor ground cover in spring and high pesticide input. The importance of matching crop types (in relation to plant families) to the plant community composition of the margins to maximise predator performance was stressed.

Holland *et al.* (1996) reported on a study of the impact of wheat production on carabids in the LINK Integrated Farming Systems project. They looked at insecticides, crop types and rotations on several sites. Carabid activity differed the most between research sites and individual fields rather than treatments. Often a few species dominated the carabid community *e.g. Nebria brevicollis* and *Pterostichus melanarius*. Seed potato crops reduced carabid activity, and this effect persisted in following crops for at least two years. No significant differences in carabid activity between conventional and integrated production regimes were detected. In the same study, the assumption was made that the less mobile species were most susceptible to disruptive or disturbance practices. Spring breeders overwintering as adults were found to be sensitive to autumn ploughing, and the occurrence of bare soil over winter may have further reduced numbers resulting in a decline in numbers in spring crops unless stubble is left. Reddersen (1994) reported carabid activity as being lowest in pea and root crops and highest in winter wheat. No evidence of spring barley being less favourable to carabid activity was reported in this paper, although this was not the case elsewhere (see Frampton *et al*., 1992).

A study of significance of crop type to Araneae indicated that oilseed rape holds greater numbers of individuals than beans or wheat (Frank & Nentwig, 1995). Holland *et al.* (1994) identified that rotational set-aside may be valuable to predatory arthropods and, by implication, general invertebrate biodiversity.

2.5.4 Post-cropping practices and biodiversity impacts in different farming regimes

Key elements influencing biodiversity are the timing of sowing, the retention of stubble and occurrence of set-aside. Spring sowing of crops encourages biodiversity, whereas autumn sowing, most commonly used in conventional arable and mixed lowland regimes, tends to reduce biodiversity. Organic, LEAF and IFS-experimental regimes tend to adopt a wider range of post-cropping practices that are beneficial to biodiversity.

2.6 Grassland management and grazing regimes

Permanent grassland, whether extensively managed as in organic regimes, or intensively managed for high production silage in conventional systems, is an important element in the farmed landscape and can be significant in biodiversity terms.

Grassland is generally seeded with a grass mixture dominated by *Lolium perenne* and may include legumes, if it is not being used for silage. Organic regimes have an initially low input whereas conventional mixed lowland regimes are intensively fertilised. The main difference between organic and conventional mixed lowland grassland management is the use of artificial fertilisers and pesticides that are not allowed under organic management. It is to be expected that organic pastures might be more diverse with an increased range of unsown grasses and diversity in species and ground cover of broad-leaved species. However, Younie & Armstrong (1996) showed that the abundance of unseeded broad-leaved species was low in both systems, but there were differences in species composition. Frequency and timing of cutting have a significant impact, with single late cuts positively influencing both floral and faunal diversity. The invertebrate diversity of grassland systems is influenced by fertiliser and agrochemical inputs. In Younie and Armstrong's (1996) study, species richness was similar in both systems, although the number of individuals was greater in conventional systems reflecting higher herbage production. Earthworm activity was similar in both systems, although more evidence of breeding was found under organic grassland. Although there was an increase in herbage legumes compared to grass species in grasslands converting to organic management, this did not increase species richness in the short- or apparently long-term (Section 3) since soil fertility status and cutting or grazing regimes were maintained at levels optimal for production.

The key elements influencing the biodiversity of grassland are fertiliser use, cutting and grazing. Where the farming regime focuses on low consistent herbage production, biodiversity will be enhanced (Frieben & Kopke, 1996). On the other hand, high-output intensive silage systems, supporting heavy stock activity, frequently show reduced floral and faunal diversity.

2.7 Conclusions on impacts of agricultural practices within different regimes

This section has identified the principal agricultural practices adopted within five farming regimes, conventional arable, conventional mixed lowland, LEAF, IFS-experimental and organic, and has reviewed the published and reported literature on the effects of these practices on biodiversity. Much of the literature on individual practices focuses on their impacts on particular species groups, rather than biodiversity as a whole. We have therefore based our assessment of impact on those groups where information is available.

Our assessment of impact of different agricultural practices is summarised in Table 2.2. The assessment is based on actual or possible impacts reported in the literature for five broad organism groups, namely soil organisms, higher plants, invertebrates, birds and mammals. Key studies and review papers on which the assessment is based are listed at the end of Table 2.2. These and other studies are discussed in the preceding sections and listed in the bibliography. Actual impacts on individual groups are recorded as neutral (0), positive (+), or negative (-) in Table 2.2, and are assigned scores of 0, +1 or -1 respectively. Possible impacts, indicated as ?+ or ?-, are given a score of +0.5 or -0.5 respectively. Unknown impacts indicated as (?) are assigned a zero score. The overall impact awarded for each agricultural practice, is the sum of the scores for the actual and possible impacts for each species group.

The most well-researched practices are those relating to crop protection. Unsurprisingly, the use of synthetic chemicals for weed and pest control is most widely reported as having a negative impact on biodiversity. Other practices that are reported as having a particularly negative impact are the use of artificial fertilisers or slurry, winter planting of crops and inversion ploughing. All of these are commonly associated with conventional arable farming.

Several practices are reported as having a positive impact on biodiversity. These include the occurrence of grass leys and permanent pasture, green manures or intercropping, spring sowing. All of these practices are associated with organic regimes and several occur in conventional mixed lowland, LEAF and IFS-experimental regimes An overall evaluation of the impact of the practices associated with each farming regime is given in section 4.3.

3. MANAGEMENT AND SIGNIFICANCE OF CROPPED AND UNCROPPED AREAS FOR BIODIVERSITY IN DIFFERENT FARMING REGIMES

3.1 Introduction

This section reviews the importance of different elements of cropped and uncropped areas for maintaining or enhancing biodiversity under the five different farming regimes. As indicated in Section 1.3, cropped areas are defined in this review as all the areas managed for arable or livestock production, whereas uncropped areas are defined as the areas and features not subject to the agricultural practices listed in Table 2.1. Each element of cropped and uncropped area is discussed in relation to its value as a habitat or resource for plants, soil organisms, invertebrates, birds and mammals. Distinguishing between the effects of cropped and uncropped elements is important as many studies have focused on the significance of uncropped areas for the biodiversity of agricultural land. The impact of farming landscapes on biodiversity, particularly the balance between cropped and uncropped areas is considered and the role of agri-environment schemes in contributing to biodiversity is discussed.

3.2 Cropped areas

3.2.1 Introduction

Cropped areas vary greatly in their importance for farmland biodiversity. This is related to the wide variety of crops present (ranging from arable to permanent grassland) and their interaction with particular management practices. Crop rotations that include grass leys and set-aside areas add considerably to the diversity and activity of some groups within cropped areas. The value of cropped areas for biodiversity is also strongly influenced by the type, proximity and quality of adjacent uncropped habitats.

Cropped areas are the dominant elements in terms of area in conventional arable and LEAF regimes. Organic farms also carry extensive cropped areas, although, as with some IFS-experimental regimes, there may be significant areas of uncropped land. Mixed lowland farms include a significant proportion of grassland, and the occurrence of permanent pasture, particularly if it is unimproved, is important in providing less-disturbed areas that benefit biodiversity. The following sections review the potential of arable, grass and pasture areas for supporting and enhancing biodiversity on farmland.

3.2.2 Arable

The value of arable land for particular species or groups has been examined in many studies. This section draws out the principal conclusions and readers are referred to the original publication for full details.

i) Plants

Moreby (1996) examined the flora and arthropod fauna of conventionally and organically grown winter wheat and demonstrated a greater percentage weed cover in organic fields than on conventional. This is corroborated by several other studies (*e.g.* Brown, 1995b; IACR, 1997). As indicated in section 2.5.2, the timing of cereal sowing has a significant impact on the diversity and vigour of the weed community (Cosser, *et al.*, 1997), and is used as a management tool to control black grass in both agricultural crops and arable weed communities (Moss & Clarke, 1994).

ii) Soil organisms

A long term study of soil microbial and faunal activity was reported by Madar *et al*. (1996) as part of a larger programme looking at biodynamic, organic and conventional farming regimes near Basle. Crop rotations were the same in all systems and included a two-year ley. Microbial functional diversity was lowest in soils treated with mineral fertiliser and earthworm biomass, density and species diversity were significantly higher in biodynamic and organic regimes. Such results would be expected from the build up of organic matter associated with biodynamic and organic management and the relatively limited inversion ploughing depths (less than 20 cm) applied in this particular study.

The importance of a varied earthworm fauna as bio-indicators, and in influencing soil structure is well-recognised (Christensen, 1998; Edwards & Lofty, 1982). Vanvliet *et al*. (1995) demonstrated that, despite low densities, enchytraeid worms have a major role to play in the structure of arable and pasture soils especially in less intensive systems. The occurrence of grass leys within a rotation, a common feature of organic regimes and present in conventional mixed lowland and some IFS-experimental regimes, is important for enhancing the biomass and activity of the soil fauna (see Appendix 1).

iii) Invertebrates

Moreby (1996) carried out one of the few above ground studies on Hemiptera-Heteroptera examining the densities in winter wheat under conventional and organic management. This study was important as Heteroptera are normally neither pest nor beneficial in agricultural terms, but are important as food sources for birds (*e.g.* lapwing, grey partridge, tree sparrow, linnet, corn bunting and skylark) and are significant prey items for predatory invertebrates. Their presence contributes directly to biodiversity and is important in maintaining the persistence of other species groups. Greater heteropteran activity was recorded in organic fields, probably associated with the greater abundance of weeds, although the differences were not statistically significant. In an earlier study (Moreby *et al*., 1994), found significantly greater densities of aphid-specific predators, parasitic Hymenoptera and some Coleoptera in conventional fields, whilst weevils, spiders, springtails and plant hoppers were more prevalent in organic fields. These results were clearly linked to the relative availability of food items within the two systems.

Madar *et al*. (1996) confirmed higher levels and greater diversity of epigaeic arthropods on biodynamic and organic areas, (18-24 species in biodynamic areas, 13-16 species in conventional) together with a more diverse carabid community. Carabids are important indicators of invertebrate diversity as the group is widely distributed among different habitats and feeds on a wide variety of prey (Armstrong & McKinlay, 1996). The relationships between carabid diversity and the occurrence of field margins and wildlife strips have been well researched, but the relationship between diversity and cropping pattern is less clear. Helenius (1990) established that some species were less active in the dense crop cover associated with conventional barley management and that species, such as *Carabus granulatus* and *Bembidion obtusum* were slow to recolonise after disturbance caused by cultivation (Frampton & Cigli, 1992). Current studies indicate that there are more complex patterns within crops and that variability within a field under the same crop may be greater than the variability between fields under different management systems (Green *et al.,* 1995; Long Ashton, 1998: pers comm.).

Variation in overall arthropod populations in mid-field situations was examined by Reddersen (1997). Density, species diversity, total biomass and bird food species were consistently and often significantly greater in organic than in conventional fields. However, density, species diversity and biomass decreased with increasing distance from margins, emphasising the importance of uncropped areas in maintaining in-field invertebrate populations (Lys *et al*., 1994). Differences in arthropod populations between organic and conventional regimes were most marked mid-field and decreases from the margin were most obvious in conventionally managed fields. In all cases, the edge effect from the margin disappeared after 9 m. This principle applies to all systems and those which employ wide margins, seeded strips and good edge management, such as the organic, IFS-experimental and LEAF regimes, will favour arthropod biodiversity on a farm-wide scale.

iv) Birds

Arable areas are important as food sources and nest sites for some species provided the management is appropriate. Organic fields have been identified as more beneficial to birds because of their greater seed and invertebrate food availability (Christensen *et al.*, 1996; Fuller, 1997; Brown, 1997b; Redersen, 1997). The reasons suggested include exclusion of synthetic pesticides, crop rotation with leys, weed control by crop management or mechanical means and sympathetic management of uncropped areas. Ironically, some of the crops that are beneficial to birds (*e.g.* oil-seed rape which provides food for linnets and nesting sites for reed buntings) are not grown under organic regimes due to the current lack of a market. A study of the decline of the corn bunting, a species of rotational grassland and spring barley on mixed farms, highlighted intensification of cropping, as opposed to pesticide application, as a key factor (Ward & Aebischer, 1994). This study highlights the importance of variety in cropping and diversification of the landscape structure for maintaining diversity in vertebrate communities. It is this loss in variety of habitats in relation to intensive crop production which has had a major impact on many bird species and which has arisen primarily as a result of modern conventional post-war agriculture.

v) Mammals

Almost all mammals, except the larger free ranging ones such as deer, are dependent on cropped and uncropped areas, with only field vole and some shrews spending most, if not all, of their lives in the open field (usually grassland) situation. Brown (1997c) found no overall differences in small mammal populations between organic and conventional systems, but other studies have indicated that woodmice are encouraged by the more weedy fields and margins associated with organic management (Tew, 1987). Harvest mouse and yellow-necked mouse are encouraged by planted strips and banks, which are integral to organic and IFS-experimental regimes. Cultivation practices employed under the five different regimes and their effects on small mammal activity have been discussed in section 2.2. Frylestam (1986) identified the importance of arable weeds in the diet of brown hares and pointed to the effects of herbicides on food plants in influencing the health of animals. This study provides another example of the effects of intensification of crop production and simplification of the landscape fabric on the population dynamics of a key farmland vertebrate species.

In summary, many studies have concluded that biodiversity in the cropped areas of conventional arable farms, has been reduced as a result of changing agricultural practice and simplification of the landscape fabric. The evidence presented indicates the value of cultivating arable land at a lower external input level and enrichment of the landscape by the development of field margins, hedges and features such as uncropped wildlife strips, conservation headlands and sown grass strips, to enhance biodiversity. Such elements are present in conventional mixed lowland regimes, and are present and widely encouraged within organic and integrated regimes such as LEAF and IFS-experimental. They are also being encouraged within conventional arable regimes via agri-environment schemes such as the Arable Stewardship Pilot scheme, Countryside Stewardship and ESAs.

3.2.3 Grass and pasture

This section examines the value of grass and pasture areas for biodiversity within the managed farm landscape.

i) Plants

In botanical terms, short term leys and permanent swards associated with conventional high input regimes are intended for a high level of herbage output and livestock production, and are therefore less diverse. Permanent sward managed for nature conservation purposes (nutrient poor and low output) shows the greatest diversity of both flora and fauna (Younie & Baars, 1997). *Lolium perenne* and *Trifolium repens* dominate in intensively managed pastures and *Trifolium* is generally inversely correlated with plant diversity. Within such intensively managed pasture, botanical and faunal diversity are maintained largely by careful management of grass margins and boundaries, in the same way as arable fields. In their review, Younie & Baars (1997) focus on organic grassland as a resource for biodiversity. Organic permanent pastures contain more typical grassland species at greater densities than conventional pastures (Frieben & Kopke, 1996). Variation in grazing pressure is also a key factor and a moderate level of grazing is important in maintaining the diversity of many temperate grasslands (Montalvo *et al*., 1993). In this context, grazers, by selectively removing some species, can promote diversification within the sward (Cosser *et al.,* 1997). Several authors (Younie & Armstrong, 1996; Frieben & Kopke, 1996; Tallowin & Smith, 1994; Younie, 1992) have indicated that it takes a long time for previously intensively managed grassland to diversify. Younie & Armstrong, (1996) demonstrated that, after nine years, there was low species invasion in both conventional and organic grasslands in Scotland. Tallowin & Smith (1994) demonstrated that even sowing rare species into gaps created in formally improved sward did little to increase biodiversity after five years. Younie's (1992) study indicated that established organic pastures produced more early flowering species that are important for bumble bees, hoverflies, ladybirds and early butterflies. These pastures can produce later flowers also if not too heavily grazed, but conventional pastures do not show the same level of diversity.

ii) Soil organisms

Although responses to different organic management regimes are small compared to those reported in arable cropping systems, a study of Welsh soils by Yeates *et al.* (1997) suggested that fungal feeding nematodes in grassland soils could be sensitive indicators of change associated with conversion from conventional to organic pastures. It has been suggested that ammonium fertilisers may be detrimental to earthworms. Work by Younie and Armstrong

(1996) identified high nitrogen levels under both conventional and organic grasslands, the later being attributed to the effects of *Trifolium*. Earthworm diversity was similar under both systems, but the greater abundance of immature specimens present in the organic soils suggested that these pastures provided more reliable breeding conditions. Younie and Baars (1997) attributed the greater activity of earthworms under organic grassland to the larger volume of organic matter arising from FYM.

iii) Invertebrates
A nine-year study by Younie & Armstrong (1996) established that the carabid communities in organic and conventional grassland showed similar species richness, but greater numbers were recorded in conventional grassland due to greater herbage production. Seed-eaters were more prominent in organic systems, possibly due to greater weed production. Felton & Woodhead (1995) suggested that *Arrenatherum* meadows, characteristic of mixed and organic systems, were particularly good for invertebrates. Younie (1992) identified the following plant species in organic pastures as important as food or breeding resources for invertebrates. The species included: *Taraxacum officinale, Ranunculus repens, Cardamine pratensis, Trifolium repens, Cerastium holosteoides, Bellis perennis, Stellaria media* and *Veronica arvensis.*

iv) Birds and mammals
Very locally improved grassland can be important for winter feeding waterfowl, including internationally important populations of species such as Greenland white-fronted goose (*Anser albifrons flavirostris*), barnacle goose (*Branta leucopsis*) and widgeon (*Anas penelope*) (UK Biodiversity Steering Group, 1995). Where machine use is infrequent and stocking densities low, such grassland may also retain ground-nesting birds such as lapwing (*Vanellus vanellus*) and skylark (*Alauda arvensis*). Work by Evans *et al.* (1995) reported higher densities of skylarks and higher growth rates and productivity on an organic farm compared to its conventional pair. It has been suggested that this may be related to a greater abundance of prey items being present in the organic fields (Brooks *et al.,* 1995). Grasslands are important for providing food resources for birds and mammals and the loss and/or intensification in management of these has been implicated as a cause of decline in some species *e.g.* cirl bunting (*Emberisa cirlus*) and corncrake (*Crex crex)* (Campbell *et al.,* 1997).

In summary, grasslands are important in terms of their potential to provide more stable, less disturbed environments for biodiversity. Their value is, however, determined largely by management practices, particularly grazing, cutting and the level of external inputs. Such factors tend to override the effects of the farming regime to which they belong.

3.3 Uncropped areas

3.3.1 Introduction

Many workers have commented on the value of marginal and non-agricultural habitats for biodiversity on farmland. In Germany, Frieben and Kopke (1996) identified such areas as important in providing the following attributes.

- Refuges for endangered plant species, especially arable weeds.

- Overwintering sites for invertebrates and vertebrates.
- Areas of floristic diversity.
- Refuges for species after harvest.
- Areas with network links to other habitats.

In this section, various uncropped habitats are reviewed. These include sown grass strips, grass margins, conservation headlands, uncropped wildlife and flower strips, hedges, ditch and bank habitats. Uncropped areas vary in extent in conventional arable regimes but are generally not prominent. By comparison, they are more common in conventional mixed lowland regimes, integral in LEAF and IFS-experimental regimes - although the extent is variable, and intrinsic in organic regimes where their management is central to the regime.

3.3.2 Sown grass strips (beetle banks)

Strips are seen as important refugia for biodiversity, for stabilising unstable agricultural monocultural systems and for reducing the use of pesticides. Nentwig (1989) established the value of planted strips for many arthropods and as reservoirs for some rarer weed species. Significantly denser overwintering populations of carabids, staphylinids and Araneae have been recorded in assessments of weed strips in cereal fields (Lys & Nentwig, 1994; Lethmeyer *et al*., 1997). Fields with strips 1.5m wide and 24m apart showed 12 times the level of arthropod activity compared to fields with no strips. High biomass creating grasses such as *Dactylis glomerata*, *Holcus lanatus*, *Achillea millefolium* and *Arctium minus* have been shown to be valuable in grass strips. Thomas *et al.* (1991) and Nentwig (1996) demonstrated that strips showed a marked increase in arthropod diversity over a two-year period. They also favour a large number of beneficial groups such as syrphids (Hausamann, 1996) and are important for some small mammals. Strips were generated as a means of increasing the abundance of beneficial arthropods within arable systems and have been adopted into LEAF, IFS-experimental and organic regimes in the UK.

3.3.3 Grass margins

Various workers have established that the creation of diverse, perennial plant communities on arable field margins can offer low cost weed control and increase biodiversity of both flora and fauna (Smith & McDonald, 1989; Boatman, 1994). Generally, seeded margins show greater diversity than those allowed to regenerate spontaneously from field edge fallow. If natural regeneration is to be successful, neighbouring floras need to be rich. Generally, annual species give way to perennials as margins become established but these need not always be undesirables in agricultural terms. Hopkins (1997) concluded that field margins especially, although not exclusively, those under organic management are effective in enhancing floral and faunal diversity on farmland.

The value of margins for conserving rarer agricultural weeds has been highlighted by several authors (*e.g.* Grub *et al.*, 1996; Marshall, 1987; Wilson, 1994) who have found that many rare, including Red Data book species, can occur within 6 m of the field edge. Extended margins are important for butterfly populations as sown plots contain many food species (Feber *et al*., 1996; Hopkins, 1997). Cutting and sowing regimes can have an important impact on species occurrence. Feber *et al.* (1997) suggest that the impact of organic management on butterfly populations is related to the pattern of cropping rather than crop management. Hopkins and Feber (1997) confirmed that most butterfly species are associated with margins rather than cropped areas as they provide both adult and larval food as well as shelter. Organic practices are seen as important in maintaining grass margins, as also are those used within IFS-experimental regimes, and to a lesser extent the traditional structure of mixed lowland farm landscapes. The role of margins as buffer zones against spraying for both plant and invertebrate life has been reviewed in detail (*e.g.* Davis, 1992; Davis *et al.*, 1994, Davis, 1995; Longley & Sotherton, 1997 a & b; Longley *et al.*, 1997).

3.3.4 . Conservation Headlands

These have been developed and promoted by the Game Conservancy Trust, specifically to benefit gamebird chicks which depend on invertebrates in field margins for food. Sotherton (1992), studying the benefits of conservation headlands, concluded that reduced spraying resulted in a 10-fold increase in broadleaved weed diversity and increased invertebrate activity. Similarly Dover (1997) studying the activity and behaviour of Lepidoptera (butterflies) in sprayed and unsprayed headlands, demonstrated that while flying activity was recorded for both headland types, foraging activity was confined to unsprayed headlands. Conservation headlands are important in conventional arable regimes in countering the effect of autumn drilling and extensive areas of winter cereals, which are detrimental to rare arable weed conservation (Wilson, 1994).

3.3.5 Uncropped wildlife strips and flower strips

Work from the Breckland ESA has highlighted the value of uncropped wildlife strips for conserving floral diversity including rare arable weeds (Critchley, 1994). Factors such as soil pH, overhanging trees, broadleaved shelter belts and previous cropping were shown to be important in influencing community composition. Sites with infrequent cultivation led to a build-up of perennial grasses and annual species remained at a low cover (Critchley, 1996). Extension of the cultivation period and a reduction (to two years) in the interval between cultivations, appeared to be effective in promoting plant species diversity in this situation. Results from this work have been incorporated into the new Farmers Guidelines for the ESA.

Planted strips of *Phacelia tanacetiflia* have shown to have a positive impact on invertebrates such as syrphids, polyphagous predators, parasitoids and food species for gamebird chicks on a LINK IFS site (Holland & Thomas, 1996). Species diversity was low, but densities high. Work at ADAS High Mowthorpe indicates, however, that *Phacelia* is unable to maintain itself over several seasons, plants being lost from the sward towards the end of the third year (Griffin, 1998: pers. comm.). The possibility of planting native flower species in strips and their consequent impact on biodiversity requires further consideration.

3.3.6. Hedges

Hedges and their basal vegetation are important landscape and wildlife elements in mixed and pastoral farming systems in the UK. Intact hedges are important areas for flora and fauna that would otherwise be absent or poorly represented on farms (Lewis, 1969; Bunce *et al.*, 1994). The loss of hedges removes nest and feeding sites for birds (Parish *et al., 1994)*, reduces small mammal populations (Tew, 1994), removes overwintering sites for beneficial invertebrates and results in simplified floras both as a result of direct loss and the loss of buffering effects on herbicide drift. Hedge removal was prevalent in the 1960s and 1980s with rates of loss two to three times greater on arable as opposed to pasture sites. Hedges are retained as a matter of course in organic systems and are an integral part of IFS. Management operations to enhance the biodiversity of hedges has recently been reviewed by Barr *et al.*, (1995).

Stopes *et al.*, (1996) reported on hedges which were managed on a specific regime under an organic conversion programme (the same principles could be applied within any management system). They suggested that hedges should be maintained at 3 m wide and 4 m high, flowering and fruiting allowed with cutting on a 2- to 3-year cycle and coppicing on a 10- to 20-year cycle if possible. Other studies have demonstrated that most birds nest between 50 and 150 cm above the ground and indicate cutting should not be on less than a 15- to 20-year cycle (Frieben & Kopke, 1996). The role of hedges in stockless organic systems could be positive or negative depending on field size and hedge condition (Stopes *et al.*, 1996).

3.3.7. Ditch and bank habitats.

Greater vegetational diversity has been recorded on ditch bank habitats under organic regimes (Helenius, 1990). However, little has been published on the effects of different farming systems on bank-side habitats. Organic farming methods are generally expected to cause less erosion and thereby reduce sediment and nutrient pollution into water-courses. Wet margins, marshes and bogs are important for biodiversity and those remaining fragments and specifically created areas are of great value, irrespective of system. In reality, the impact of wetlands is less well researched in farmland areas than it should be in relation to biodiversity.

3.4. Impact of the farming landscape on biodiversity

3.4.1. Introduction

It has already been established that uncropped areas tend to be the major reservoirs for both floral and faunal diversity and therefore the nature and extent of these habitats are key in determining the overall biodiversity of agricultural areas. Kretschmer *et al.* (1992) demonstrated a continuous increase in biodiversity when the uncropped area increased and this trend has been corroborated by studies comparing conventional and organic regimes in the UK (Gaunt, 1997).

In assessing the impact of the farming landscape on biodiversity, it is important to consider the effects of scale. Soil fauna groups are clearly affected by local within field conditions and can show considerable heterogeneity within a single field (*e.g.* Goulding *et al*, 1997). Small mammals and birds are less dependent on local within-field variation, but are influenced by variation at the field level, *e.g.* crop type and the occurrence of uncropped areas within or surrounding the field. Larger species *e.g.* barn owls, hawks, brown hare are influenced by the extent, variation and balance of habitats across the whole farm.

This section looks at the balance between elements in different systems and briefly reviews the role of existing agri-environment schemes in promoting biodiversity, particularly through the manipulation of the uncropped areas. The broad objectives of the different schemes are given in Appendix 2.

3.4.2. Balance of elements within different farming systems.

Within conventional arable regimes, the proportion of uncropped areas varies but unless there is a game rearing interest, margins tend to be of limited extent and, on intensive arable farms, hedges are few and field sizes are generally large. In organic regimes, field margins, sown strips (beetle banks) and hedges are all encouraged. Within integrated production regimes, sown margins and strips are encouraged as part of the crop management programme but the field areas are of medium to large size, unlike organic systems where fields are generally smaller, and the impact of the uncropped areas on biodiversity as a whole is more limited. Conventional mixed lowland farms tend by definition to have moderate levels of uncropped area including hedges, although sown strips are not a feature. Often these farms contribute in a major way to the inter-joining uncropped fabric of the agricultural landscape.

In all systems the presence of broadleaved, mixed or scrubby woodland on or adjacent to the farm has a major impact on biodiversity as do ponds and streams. It is also important not to overlook the role of farm buildings. The older more traditional buildings often associated with conventional mixed, organic and some smaller integrated production units are valuable as resting or breeding habitats for bats and barn owls for instance. The existence of much uncropped land and low intensity grassland close by provides suitable conditions for these groups. Traditional buildings that have survived in intensively managed areas but have no uncropped habitats nearby, are of limited value. In some European countries, it is part of the national approach to incorporate more uncropped habitat into the agricultural landscape to increase biodiversity *e.g.* Switzerland (Van Bol & Peeters, 1996) and the Netherlands (Halberg, 1997).

3.4.3. The role of agri-environment schemes

Countryside Stewardship, ESAs and Tir Cymen are currently the principal agri-environment schemes within England and Wales focusing on the maintenance and enhancement of habitats for wildlife (Countryside Council for Wales, 1992; MAFF, 1994a, 1997c; see Appendix 2). Within these schemes, specific prescriptions for enhancing habitats on arable farmland are included, for example, the creation of uncropped wildlife strips in the Breckland ESA, conservation headlands in the Breckland, Clun and South Downs ESAs and extended field margins in the Somerset Levels and Moors and West Penwith ESAs.

However, ESAs in general, are targeted on more extensively managed farmland, for example the Lake District, North Peak, South-West Peak and Exmoor ESAs. Countryside Stewardship is more widely available to farmers on intensively managed land and the introduction of the Arable Stewardship Pilot scheme is aimed at encouraging the increased adoption of measures that benefit biodiversity on this land.

To date, habitat targets arising from the UK Biodiversity Action Plan (UK Biodiversity Steering Group, 1995), have not been formally incorporated into the environmental objectives of these agri-environment schemes. They have, however, been fed into proposals to modify ESAs at their five-yearly review. Ecological monitoring of Countryside Stewardship is in progress, and the evaluation of it effectiveness for biodiversity will be obtained on completion in the year 2000. ESAs have been regularly monitored since their instigation in 1987 (*e.g.* ADAS, 1997a,b & c). Where they have been monitored, for example in the Breckland ESA, the prescriptions that focus on arable land, specifically field margins, appear to be effective in promoting biodiversity, at least within plant communities (Critchley, 1994, 1996).

The Habitat Scheme includes, as one of its options, former five year set-aside (MAFF, 1994b). The latter has been shown to be effective in enhancing biodiversity and providing additional food resources for birds (Clarke, 1992; Wilson *et al.*, 1996). The retention of this land within the scheme may thus be seen as beneficial to biodiversity. The recently launched Arable Stewardship Pilot Scheme (MAFF, 1997d) specifically targets intensively managed farmland and focuses on several groups and species in decline *e.g.* farmland breeding birds (Campbell *et al.*, 1997; UK Biodiversity Steering Group, 1995). Monitoring of this scheme will commence in 1998.

An overall evaluation of these schemes, in biodiversity terms, has not been undertaken in relation to other agricultural management options. Until recently, the area on which they have been focused has tended to be pastoral rather than intensively managed land, and the opportunities for uptake by farmers in the latter areas have therefore been limited.

3.5 Significance of cropped and uncropped areas for biodiversity

The principal conclusion from Section 3 must be the high value of uncropped areas for maintaining and enhancing biodiversity on farmland. Such areas act as ‘reservoirs’ for species populations and help to mitigate the negative impacts of cropping, by enabling rapid recolonisation of cropped or disturbed areas by flora and fauna. The value of cropped areas for biodiversity should not, however, be dismissed, as many of the practices associated with these areas can have a positive benefit on biodiversity (see Table 2.2).

With respect to biodiversity, the key factor is the balance of cropped to uncropped land present on the farm. Within the existing literature, there is little quantitative information on the extent to which this balance varies between farming regimes. Based on the practices adopted and/or standards established for each regime, it is, however, clear that the proportion of uncropped area is higher on organic, integrated production and mixed farms than on conventional arable, with consequent benefits to biodiversity.

Agri-environment schemes potentially have an important role to play here. At present, most of these appear to have focused on semi-natural habitats and pastoral systems rather than on intensively managed arable land, and the uptake of schemes on the latter has been low. The new Arable Stewardship Pilot scheme may help to redress this balance.

4. EVALUATION OF IMPACTS OF REGIMES ON BIODIVERSITY

4.1 Introduction and approach

Much of the literature pertaining to the biodiversity of farmland has focused on the impacts of agricultural operational or habitat management practices on specific groups of organisms *e.g.* higher plants, insect families or orders and birds. Such a reductionist approach is inevitable when the focus of study is either the determination of factors underlying cause and effect in terms of change in biodiversity, or the identification of management practices that are effective in enhancing the persistence of particular organism groups. For the purposes of comparing the biodiversity of different farming regimes, this reductionist approach is less satisfactory, since it tends to overlook the effects of both the scale (the fact that organisms vary in the area and number of environmental components that they utilise) and interaction of different components on the farm. However, since little reliable information is available to enable a comparison of farming regimes at the whole-farm level, the approach adopted for the evaluation has focused on the following five steps.

Step 1: An assessment of the impact of the agricultural practices most commonly practised/ widely used within each regime, on the diversity of different organism groups.

Step 2: An assessment of the significance of the structural elements (cropped and uncropped land) present within the landscape of each regime, in maintaining and enhancing the biodiversity of arable land.

Step 3: An assessment of the overall impact of each regime, based on steps 1 and 2, in enhancing biodiversity at the whole-farm level.

Step 4: An examination of the extent of each regime within England and Wales.

Step 5: A final evaluation of the overall impact of each regime, based on steps 3 and 4 above, in enhancing national biodiversity.

To achieve an overall assessment of the impact of the five different regimes on biodiversity, each regime is evaluated according to its potential to enhance the status of biodiversity on arable farmland. The current status of biodiversity on arable farmland, which is used as the baseline for the final evaluation, is discussed in 4.2 below.

4.2 The status of biodiversity on arable farmland

Arable farmland is a managed landscape largely derived, in the case of lowland England and Wales, from deciduous woodland (Rackham, 1986). Over the centuries, this land has passed through multiple management changes, for example from strip farming to small hedgerow enclosed fields to large-scale intensive cropping (Rackham, 1986**.** Such changes have resulted in a significant re-distribution of wildlife species (UNEP, 1995**)**, and the replacement of a flora and fauna dominated by woodland species by those associated with woodland edge habitats, grass and open land (Rackham, 1986; Samways, 1994)**.** Since 1945, simplification of the landscape and the development of a high-input, high-yield intensive agriculture have led to a significant decline in species diversity within both the cropped and marginal areas of arable land (*e.g.* UK Biodiversity Steering Group, 1995; Campbell *et al.*, 1997) with relatively few species showing population enhancement (Campbell *et al.*, 1997**)**. Intensification of agricultural crop production has been documented as one of the prime causes of species loss and biodiversity decline (*e.g.* WCMC, 1992; UNEP, 1995; Tilzey, 1996).

Given this historical framework, it is evident that the biodiversity on farmland previously or currently subjected to intensive arable production, is considerably impoverished, in comparison to the semi-natural habitats from which it derived (WCMC, 1992)**.** Consequently, we have taken as the baseline for our comparative evaluation of farming regimes, the position that arable farmland represents an impoverished environment for biodiversity. Using this baseline, our final evaluation for each regime is based on its potential to enhance the impoverished biodiversity of arable land. The approach used in reaching this evaluation is outlined in section 4.1 above.

4.3 Effect of each regime on biodiversity at the whole-farm scale

4.3.1 Step 1: Effects of agricultural practices, used within each regime, on biodiversity

This section brings together information on the agricultural practices used within each farming regime (see Table 2.1), and the impact of each practice on the diversity of different organism groups (see Table 2.2), to determine the impact on biodiversity of the agricultural practices most commonly practised or most widely used within each of the five farming regimes. This information is summarised in Table 4.1 below.

The scores shown in Table 4.1 represent the overall impact of the named agricultural practice on the diversity of the five organism groups listed in Table 2.2. The scores allocated are based on the effects of each practice on the biodiversity of arable land, as these have been reported in the scientific literature. A summary of papers on which this assessment is based, is appended to Table 2.2. It is important to note that within this assessment, no attempt has been made to distinguish between the long-term and short-term effects of the different practices on biodiversity. Such information is scarce and varies considerably in quality and quantity between the different practices. Several of the practices indicated below (*e.g.* inversion ploughing, mechanical weeding, stubbles) have short-term impacts on biodiversity, which nevertheless are important in determining the long-term recovery and enhancement of biodiversity (Wilson *et* al., 1996). A further point to note in the interpretation of Table 4.1 is that the maximum and minimum score possible for each practice is +5/-5. The number of practices commonly or widely used varies between regimes, which limits the maximum and minimum scores achievable by each regime. The latter are indicated in the final line of the table.

Table 4.1 *Effect of the agricultural practices most commonly practised/widely used (CP & WU in Table 2.1) within different farming regimes, on biodiversity at the farm-scale.* Biodiversity impact: + positive, - negative, 0 neutral, ?unknown, ---- practice not widely adopted within the farming regime. The scores given represent the overall impact of each practice on the five different organism groups listed in Table 2.2.

Common/widely used practice	Conventional arable	Conventional lowland mixed	LEAF	IFS - experimental	Organic
Cultivation					
Inversion ploughing	-1.5	-1.5	-1.5	-------	-1.5
Minimal tillage	---------	-----------	-------	-------	--------
Direct drilling	----------	-----------	--------	-------	--------
Cultivation impact	***-1.5***	***-1.5***	***-1.5***	**------**	***-1.5***
Crop production					
Synth. fert./slurry	-2	-2	-2	-2	--------
Farmyard manure	-----------	+1	+1	+1	+1
GM/Intercropping	------------	-----------	------	--------	+3
Production impact	***-2***	***-1***	***-1***	***-1***	***+4***
Crop protection					
Mechanical weeding	---------	----------	---------		-0.5
Herbicide	-2.5	-2.5	-2.5	-2.5	--------
Chemical pesticide	-3.5	-3.5	-3.5	-3.5	---------
Protection impact	***-6***	***-6***	***-6***	***-6***	***-0.5***
Post-cropping					
Incorporation	+2.5	+2.5	+2.5	+2.5	+2.5
Set-aside/stubbles	+4	+4	+4	+4	+4
Autumn sowing	-2	-2	-2	-------	-------
Rotation with leys	---------	+2	+2	+2	+2
Permanent pasture	--------	+3	+3	+3	+3
Post-cropping	***+4.5***	***+9.5***	***+9.5***	***+11.5***	***+11.5***
OVERALL IMPACT	**-5**	**+1**	**+1**	**+4.5**	**+13.5**
Possible score range for each regime	-35 ....+35	-50......+50	-50... +50	-40.....+40	-40... +40

From the scores given in Table 4.1, the following conclusions can be drawn with regard to the agricultural practices most commonly used within each regime.

a) **Conventional arable:** the majority of practices commonly used within this regime have a negative impact on the diversity of at least one group of organisms. Some of the effects will be short-term, for example, the immediate impact of inversion ploughing is to cause a reduction in populations of soil organisms, but these may recover to former levels later in the year (see section 2.2.4). The overall effect in this example on soil organisms, would thus be to maintain the existing level of the population in arable soils rather than enable any enhancement of the population, either in terms of abundance or diversity. Some positive short-term benefits are associated with the occurrence of set-aside and crop residue incorporation. Overall the agricultural practices adopted within this regime are seen to be unfavourable to biodiversity. Some mitigation of these impacts may be expected from the occurrence of uncropped areas surrounding the crop, and enhancement of these could go some way to reducing the overall effect of the agricultural practices.

b) **Conventional mixed lowland:** overall the practices adopted within this regime appear to have the potential to enhance biodiversity on arable land. The practices include a mixture of those that disadvantage biodiversity, for example the practices commonly used for cultivation, crop production and protection, and those that enhance it, primarily post-cropping practices, such as rotations with grass leys. The actual benefits conferred will depend on the combination of practices adopted on individual farms.

c) **LEAF:** as in b) above, the practices adopted on LEAF farms have the potential to enhance biodiversity on arable land. Again this enhancement rises primarily from the adoption of post-cropping practices, which help to lessen the impact of practices that disadvantage biodiversity.

d) **IFS-experimental:** these regimes include several practices that benefit biodiversity and the overall effect is positive. Within this regime, the targeted use of products such as chemical pesticides (not explicitly accounted for in Table 4.1) and the replacement of herbicides by mechanical weeding, where practical, increase the value of these regimes for enhancing biodiversity.

e) **Organic:** these regimes include many practices that have a positive impact on biodiversity. Inversion ploughing is the prime practice that is seen as having a negative impact on biodiversity, but as indicated under conventional arable, this is probably short-term. Overall, the practices adopted on this regime clearly have the potential to enhance the biodiversity of arable farmland.

Table 4.1 provides a broad overview of the effects on biodiversity of the practices most commonly adopted within the five farming regimes. In reality, there is considerable variation in the range of practices available and the actual benefits conferred will depend on the balance of practices used on individual farms.

4.3.2 Step 2: Impacts on biodiversity of structural elements associated with each farming regime.

The literature review undertaken for section 3 highlights the importance of uncropped elements such as sown grass strips, hedges and conservation headlands, in providing ‘refuges’ for biodiversity on farmland. In view of the variation, in terms of biodiversity impact, in agricultural practices used on the cropped areas within each regime, it is evident that the uncropped areas have an important role in terms of the mitigation of effects of agricultural practices and the enhancement of biodiversity on arable land. To determine the importance of uncropped elements in enhancing biodiversity within each farming regime, the following factors need to be considered.

- The occurrence and proportionate balance of cropped to uncropped land present within each regime.
- The variety of uncropped elements present.
- The variety of crops present.

The impact of the variety of crops present on biodiversity is considered in section 2.5.3, and included in Table 4.1 as rotations with grass leys. Therefore no further consideration will be given to this topic here. Little quantitative information is available for the other two factors and, therefore, our assessment has relied on information on the occurrence of uncropped elements within each farming regime, and on the nature and adoption of standards for managing uncropped elements within each regime. The information used in this assessment of uncropped elements is based on the following surveys and information sources and is summarised in Table 4.2.

- Data from a survey of 480 farms (Brown, 1998: unpublished) in which the occurrence (but not area) of uncropped elements was recorded.
- Data from a survey of Farmland Cultivation Techniques (ADAS/SRI, 1996), in which the balance of different crop types, grassland and set-aside is recorded.
- Guidelines set out for LEAF farms and standards set by different organic sector bodies (e.g. Soil Association) on management and maintenance of uncropped elements.
- Information from the consultation exercise undertaken in March 1998 (see Appendix 3).

From the survey of 480 farms (Brown, 1998: unpublished, see Table 4.2) it is evident that the occurrence of uncropped elements on conventional arable farms is lower than on the other four regimes. This observation is also supported by the results of the ADAS /SRI (1996) report which indicated that only 17% of respondents had conservation headlands on their farms, and less than 5% of respondents had headlands wider than 4 m. This suggests that the enhancement of biodiversity on conventional arable farms via uncropped elements will be less than for the other four regimes. Conventional arable farms that are part of an agri-environment scheme *e.g.* Countryside Stewardship, may well incorporate a larger proportion of uncropped area which will be sympathetically managed for biodiversity. Similarly farms that maintain an active game interest (*e.g.* for pheasants or partridges) will maintain a higher proportion of uncropped area for game cover.

For the remaining four regimes, it appears that uncropped areas contribute significantly to the farm landscape. The reasons for this relate to farming practice, the use of land for livestock feed and shelter, and/or the implementation of standards to promote ‘environmentally friendly’ farming practice. Both factors ensure that the occurrence of uncropped land becomes enshrined within the farm management. Conventional arable farms that neither require uncropped land for production nor have required standards (noting the exception of the Hedgerow regulations) for the maintenance of such land, have rather less incentive (economic or otherwise) to retain such land within the regime. Conventional arable farmers who retain significant areas of uncropped land may do so voluntarily or as part of an agri-environment scheme.

Table 4.2 *Significance of uncropped areas within each farming regime*

Regime	**Percentage of farms with > 5% of uncropped land***	**Standards applying to each regime**	**Adoption of standards**
Conventional arable	45%	various prescriptions for ESAs & CSS, Hedgerow Regulations (1997)	Required if farm is part of agri-environment scheme, required for hedgerow regulations.
Conventional mixed lowland	80%**	various prescriptions for ESAs & CSS, Hedgerow Regulations (1997)	Required if farm is part of agri-environment scheme, required for hedgerow regulations.
LEAF	80%**	LEAF standards	Required to join regime
IFS-experimental	80%	Agreed standards for each experimental farm	Required to join experimental regime
Organic	95%	Sector body standards (e.g. UKROFS & Soil Association)	Required to join regime

* Based on survey by Brown 1998: unpublished.
** no specific assessments were made of these two regimes, but occurrence is likely to be similar to IFS-experimental regimes

4.3.3 Step 3: Effect of each regime on biodiversity at the whole farm-level

To achieve an overall assessment of the potential of each regime for enhancing biodiversity at the farm level, information on the agricultural practices and structural elements present within each regime has been combined. Within the overall assessment, the benefits derived from the occurrence of uncropped land within a regime are regarded as mitigating some of the negative impacts of agricultural practices on biodiversity. Thus, the impacts of inversion ploughing or pest control may be lessened where habitat is present that acts as a refuge or population reservoir to enable rapid recolonisation of cropped land. Such an effect may be significant for insects, birds and mammals but may be of more limited importance for plants. As noted in 4.3.2, conventional mixed lowland, organic, LEAF and IFS-experimental farms where the occurrence of uncropped areas is frequent, will show the greatest potential for mitigating negative impacts of agricultural practices. The overall effect of each regime on biodiversity at the farm level is assessed as follows.

a) **Conventional arable:** the agricultural practices used within this regime have an overall negative impact on biodiversity. Some of these impacts may be short-term (*e.g.* inversion ploughing) and will be offset partly by the areas of uncropped land retained on the farm. However, the occurrence of uncropped land on conventional arable farms appears to be significantly less than for the other four regimes, although definitive information on the balance of cropped to uncropped land is lacking for all regimes. This hampers the overall evaluation of each regime in terms of assessing its ability to mitigate the effects of agricultural practices on biodiversity. This mitigation would, however, appear to be least available within conventional arable regimes. Overall this regime effectively acts to maintain the impoverished status of biodiversity on arable land and may, in areas of particularly intensive management, act to further its decline. The potential for enhancement does exist where individual farmers adopt sympathetic management of uncultivated land or are part of an agri-environment scheme. Moreover there is considerable scope for improvement via the adoption of agricultural practices that benefit biodiversity *e.g.* direct drilling, use of farmyard manure, mechanical weeding and the inclusion of set-aside or stubbles, or by increasing the incidence and sympathetic management of uncropped areas.

b) **Conventional mixed lowland:** here the negative impacts of cultivation, crop production and crop protection are largely offset by post-cropping practices, for example the occurrence of crop rotations with grass leys, permanent pasture and by the occurrence of uncropped land. The occurrence and extent of these mitigating features provide the potential for this regime to enhance the biodiversity of arable land. This potential will strongly depend on the extent to which the management of these features, particularly the uncropped land, are sympathetic to the requirements of different organism groups.

c) **LEAF:** the balance of impacts from the agricultural practices adopted on LEAF farms appears similar to that on conventional mixed lowland farms. Again the negative impacts of cultivation, crop production and crop protection are largely offset by post-cropping practices and sympathetic management of uncropped land. The overall effect is a regime that has potential for enhancing the biodiversity of arable land.

d) **IFS-experimental:** this regime is essentially similar to the LEAF farms but adopts more stringent procedures for targeting the use of herbicides and pesticides and for managing or establishing structural elements that encourage beneficials and enhance the farm environment. The adoption of direct drilling lessens the impact of cultivation practice on biodiversity. In summary, this regime is assessed as one that can both maintain and enhance the biodiversity of arable land.

e) **Organic:** Both in terms of their agricultural practices and of the extent and management of uncropped land, organic regimes are seen to exert a positive effect on the biodiversity of arable land. The effect derives from the lack of synthetic inputs, the occurrence of post-cropping planting practices that benefit several organism groups (Table 2.2) and the widespread occurrence and sympathetic management of uncropped elements present within the regime. This combination of agricultural and structural elements is clearly one that can act to enhance the biodiversity of arable land.

4.4 Impacts on national biodiversity

4.4.1 Step 4: The extent of each regime within England

Up to 5 million hectares of agricultural land is cultivated annually (ADAS/SRI, 1996). The extent of each farming regime and the cultivation practices associated with it, may thus have a substantial impact on biodiversity at the national scale. To indicate the potential size of this impact, the biodiversity evaluation associated with each regime in 4.4.3 above, is reviewed in relation to the area of each regime within England.

Using figures from the Agricultural Census data (MAFF, 1997), the area occupied by conventional arable farms within England is estimated at 3.8 million ha. Much of this is concentrated within the eastern half of England where cereal farming is dominant. Conventional mixed lowland farms occupy just under 729,000 ha and are concentrated in the south and west of England. By comparison LEAF farms occupy around 142,000 ha (based on 1997 LEAF audit figures from the National Agricultural Centre at Stoneleigh), whilst IFS-experimental regimes account for less than 3,000 ha. The total area under organic farming is currently around 55,000 ha for the UK as a whole (UKROFS Committee 1998: pers. comm.). Around 28,300 ha, of organically farmed land are present in England, about half of which is in the uplands, leaving around 0.3% of arable land under organic regimes in the lowlands

4.4.2 Step 5: The impact of each regime on national biodiversity

Based on the figures given above, the overall potential of each regime for enhancing biodiversity on arable land is evaluated at both the farm and national scale, and indicated in Table 4.3 below.

In terms of impact at the national scale, it is evident that:

a) **Conventional arable**: occupying some 80% of arable land within England, is a key factor in influencing the current level of biodiversity present on arable land. As indicated in section 4.2, this level is one of an impoverished habitat in biodiversity terms. At present, the predominant agricultural and land management practices used within conventional arable act to maintain this baseline. Extreme examples can be found on either side of this maintenance line, for example, intensively managed farms that may further deplete biodiversity and sympathetically managed farms that try to enhance it. Insufficient quantitative information is available to enable an objective estimate to be made of the number of farms that fall within these categories.

b) **Conventional mixed lowland:** this regime has the potential for enhancing biodiversity on the 15% of arable land in England which it currently occupies. The extent to which enhancement may be achieved, will depend on the extent, condition and management of uncropped areas present on these farms.

c) **LEAF** farms, occupying 3% of arable land, have a high potential to enhance biodiversity over a small area. The overall impact on national biodiversity, at the present time, is likely to be small but positive.

d) **IFS-experimental** farms are likely to exhibit positive enhancement of biodiversity at the farm scale, but the total area occupied by this regime is so small that the national impact is likely to be insignificant.

e) **Organic** farms are also likely to effect positive enhancement of biodiversity at the local farm level, but their occupancy of just 0.3% of the arable land in England suggests that the overall impact on national biodiversity is currently very small.

Table 4.3 *Potential impact of each farming regime for enhancing the biodiversity of arable land at the local (farm) and national levels*

Regime	**Potential impact on biodiversity at the farm level**	**% of arable land occupied within England***	**Potential impact on the biodiversity of arable land at the national scale**
Conventional arable	Maintaining existing baseline	80%	Large area maintained at existing, species-impoverished baseline
Conventional mixed lowland	Potential to enhance biodiversity	15%	Reasonable area with potential for enhancing biodiversity
LEAF	Potential to enhance biodiversity	3%	Small area with potential for enhancing biodiversity
IFS-experimental	Enhancing biodiversity	<0.01%	Little impact as area is insignificant
Organic	Positive enhancement of biodiversity	0.3%	Very small area with positive enhancement of biodiversity

*Based on figures from Agricultural Census data in MAFF (1997b), IFS-LEAF 1997 farm audit (National Agricultural Centre, Stoneleigh), UKROFS (1998, pers. comm.)

4.5 Enhancing biodiversity on farmland

4.5.1 Identifying an appropriate approach

It is evident that organic farming regimes can provide significant benefits to biodiversity at the farm-scale, but their overall impact in enhancing the biodiversity of arable land at the national scale is currently small. Whilst it is important that this contribution is recognised and encouraged, it is clear that in biodiversity terms, efforts need to be focused on the 80% of arable land where biodiversity is still impoverished. Enhancement of biodiversity on these areas could be achieved by encouraging greater uptake of organic farming and/or the adoption of agricultural practices and elements that are known to benefit specific species groups. A number of alternative approaches have been discussed by Macdonald & Smith (1991). The success of any approach will, however, be determined by the readiness of conventional arable farmers to adopt it.

From a biodiversity viewpoint, the most successful approach is likely to be one that targets the requirements of specific species groups, and provides an effective mechanism for enhancing species population size and/or persistence. One of the conclusions from the Consultation Workshop (Appendix 3) highlighted that an approach that focuses on specific agricultural practices or landscape elements, rather than on the adoption of a particular farming regime, may prove more effective for enhancing biodiversity. Not all attendees were in agreement with this approach, and it is important to remember that several species require a combination of different elements to ensure their survival, such that concentration on single elements may not prove effective. Indeed it was suggested that the benefits of an organic regime arise from the interaction of a range of management practices that are greater than the sum of the benefits from each individual management practice.

Within organic regimes, much emphasis is placed on the adoption of a whole farm holistic approach. However, it is unclear what the specific benefits are to biodiversity of such an approach (*i.e.* what are the causal mechanisms that enhance biodiversity) and what benefits might be achieved when these are applied to land already impoverished in biodiversity terms. An assessment of such benefits might be most strikingly tested on farmland in East Anglia, which includes some of the most intensively managed arable land. Furthermore it remains unclear whether the adoption of the agricultural practices and/or the structural elements associated with organic regimes, into other farming regimes would deliver similar benefits in terms of enhancing biodiversity. Results from this review and from comparative studies of conventional arable and IFS-experimental regimes suggest that this could be possible, but replication of existing studies at a large (whole farm) scale is needed before such an approach could be advocated commercially.

4.5.2 Species response to management change

The response of different species groups to agricultural practices and structural elements on the farm has been fully discussed in sections 2 and 3 respectively. The sensitivity of species such as grey partridge, brown hare, and rare arable weeds, *e.g.* pheasant's eye (*Adonis annua*) and cornflower (*Centaurea cyanus*), to management change has been highlighted in the UK Costed Habitat Action Plan for Cereal Field Margins (UK Biodiversity Steering Group, 1995), and by studies such as that of Campbell *et al*. (1997) on pesticide use and farmland birds.

Species groups vary in their sensitivity to different agricultural and habitat management practices and respond at different scales. Thus bird diversity may be influenced by the availability of nesting sites, food resources for chicks, or predator cover, and as a group, birds will tend to respond to the balance of elements across the whole farm. The introduction of a single additional element may therefore, have little overall impact on bird biodiversity, but by comparison, may have a significant impact in terms of invertebrates. The scale and juxtaposition of structural elements within the farm landscape is therefore important in determining the overall effect of a farming regime on biodiversity

It is important to remember that change in species composition does not always herald a loss in biodiversity. It may simply reflect species preference for one habitat type over another. For example, ploughing will encourage carabid species such as *Pterostichus madidus* and *P. melanarius* that prefer open land. As the crop grows, these species may diminish in abundance and be replaced by species that prefer taller, shady vegetation. After harvest the species of open ground may dominate again. Shifts in community composition are common in semi-natural systems (*e.g.* Gardner, 1991; Gardner *et al*., 1997) and reflect change in the structure of the vegetation. The overall impact on biodiversity is limited so long as there are reservoir habitats present that enable recolonisation.

A further aspect that requires consideration in terms of species response is the impact of management change on the interactions between species (J.D. Wilson 1998: pers. comm. see Appendix 3). Most studies have focused on single species/species group responses and the knock-on effects for other species groups have not often been examined. A common reason for this is that studies often focus on a single management practice to determine its effectiveness in enhancing biodiversity. The need for information on interactive effects between species groups re-emphasises the requirement for studies to be conducted at the whole-farm level.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This section summarises the impacts of conventional arable, conventional mixed lowland, organic, LEAF and IFS-experimental regimes on biodiversity, including the key factors that influence biodiversity within each regime. The information gaps identified by the review are also highlighted and recommendations provided on additional research and monitoring studies to address these gaps.

5.2 Cropped areas

Cropped areas of arable farmland are seen largely as impoverished in terms of biodiversity (Tilzey, 1996). This impoverishment normally reflects past management history (Samways, 1994; WCMC, 1992) and is maintained largely by repeated disturbance due to cropping (Tilzey, 1996). Compared to the other four regimes included in this review, cropped areas within conventional arable regimes generally show greater fluctuation in the abundance/activity of soil organisms (*e.g.* section 2.3.1), the least diverse weed communities (*e.g.* section 2.3.1), the lowest diversity of invertebrates (although densities of individual species may be high *e.g.* section 3.2) and smaller populations of farmland birds (*e.g.* section 2.4.3). This situation appears to arise from the adoption of agricultural practices or inputs that either directly reduce populations of individual species, or that limit the availability of components (such as food items) that are essential to their persistence. Certain practices within conventional arable agriculture do have a positive benefit for biodiversity. For example, the widespread occurrence of set-aside has helped to enhance the food resources available to over-wintering species (Firbank *et al.*, 1992; Wilson, *et al*., 1996**).** However, the relative paucity of practices that benefit biodiversity within conventional arable, compared to the other four regimes, or that mitigate the impact of unfavourable practices, is a key factor behind the impoverishment of biodiversity on cropped areas within this regime.

Within organic farms, the absence of chemical inputs such as artificial fertilisers, pesticides and herbicides, coupled with the adoption of several practices that benefit biodiversity, enable these regimes to contribute positively to the enhancement of biodiversity on arable farmland. Practices that have a negative impact on biodiversity do occur within organic regimes, primarily associated with cultivation and weed control (see Table 4.1). However, mitigation of these would seem to be assisted by the infrastructure of organic farms, where uncropped areas occur frequently and are managed sympathetically for biodiversity.

Within conventional mixed lowland, LEAF and IFS-experimental regimes, the impact of unfavourable practices and inputs appears to be countered by the adoption of practices that have a positive benefit on biodiversity, and by the frequent occurrence of uncropped areas (see Tables 4.1 and 4.2). These counter-balancing elements provide the potential for these regimes to enhance the biodiversity of the arable land under their occupancy.

5.3 Uncropped areas

In all regimes, the uncropped areas are responsible for the bulk of all floral and faunal diversity within the agricultural landscape. These areas act as habitats in their own right and as species reservoirs for adjacent cropped or pasture land. They are also important buffer zones in limiting the effects of synthetic herbicides and insecticides in conventional arable regimes, and to some extent in LEAF and IFS-experimental regimes. The conservation and proper management of marginal features are therefore critical in all regimes for maintaining biodiversity.

The significance of uncropped areas for biodiversity is demonstrated by the impact of within-field planted strips or predator strips, which act as reservoirs and 'safe havens'. They are an integral part of the organic approach and have been adopted into IFS-experimental regimes where they are now a central principle of pest control management. Interestingly, they are being increasingly imported into conventional arable regimes (for example as an option within the Arable Stewardship Pilot scheme), where they, may have a positive impact on biodiversity.

5.4 Impact of different farming regimes

Evaluation of the five farming regimes, in terms of their ability to enhance biodiversity on arable land, indicates that organic regimes have the greatest benefit for biodiversity at the farm level. In terms of national biodiversity, however, the effect is small, since the total area of arable land under organic production in England, is less than one percent. Conventional arable regimes act primarily, at present, to maintain the impoverished status of biodiversity on arable land, although there are likely to be farms at either end of the scale; that is conventional arable farms that damage biodiversity and those that enhance it. The remaining farming regimes all have the potential to enhance biodiversity, although at the national scale, this potential is probably greatest for the conventional mixed lowland regime which is larger in extent than either LEAF or IFS-experimental regimes.

Many of the studies reported here have demonstrated that whilst organic farming enshrines principles that are beneficial to agricultural biodiversity, the specific farming practices that encourage this biodiversity can be adopted by both integrated production and conventional regimes. The range and balance of practices present within LEAF and IFS-experimental regimes are interesting and raise two questions. The first is the extent to which existing crop husbandry practices can be effective in reducing the impact of artificial inputs on biodiversity, whilst maintaining a viable commercial level of crop production. The second is the level to which artificial inputs need to be reduced, to achieve agricultural regimes that are sustainable in terms of both biodiversity and economic crop production. Such questions also identify the need to define the level of biodiversity that can be reasonably expected to co-exist alongside economically viable crop production and the economic benefits of enhancing this biodiversity.

In conclusion, all five regimes currently have the potential to maintain biodiversity, provided there is good management of uncropped areas, and enhancement of biodiversity is clearly possible under organic and integrated production regimes. Existing agri-environment schemes go some way to supporting biodiversity initiatives, but there is a need for an evaluation of management practices at the whole farm scale, to determine their impact on both individual species groups and on the interactions between species groups, and hence their overall effect on biodiversity.

5.5 Information needs and recommendations

5.5.1 Information gaps

A number of information gaps have been identified within this review which are outlined here, together with a suggested approach for tackling these gaps and recommendations for future work. With respect to information gaps, the following have been highlighted.

- A lack of quantitative information on the utilisation of and variation in different agricultural practices within the different farming regimes, and the extent and nature of uncropped areas associated with each regime.

- Information on the interaction of effects of agricultural practices and of structural elements at the whole-farm scale.

- Information on the proportion of cropped to uncropped land required to enhance biodiversity on arable land.

- Information on the effectiveness of different rotation cycles adopted under the different farming regimes in enhancing biodiversity on impoverished arable land.

- The identification of agricultural practices or approaches that are effective in enhancing biodiversity on species impoverished land.

- Information on the extent to which variation in artificial inputs influences biodiversity.

- Information on the economic implications of adopting measures to enhance biodiversity within the different regimes.

- An assessment of the overall effectiveness of current agri-environment schemes in enhancing biodiversity and in contributing to the UK Biodiversity Action Plan.

5.5.2 Suggested approach

In addressing these gaps, it is clear that there is a need for:

1. *Whole farm or large-scale studies:* to enable assessments to be undertaken at scales appropriate to the behaviour of different species groups and to enable the determination of interactive effects between different groups.

2. *Clear comparative studies:* to enable the determination of cause and effect in assessing the impact of different farming regimes on biodiversity. Consideration should also be given to monitoring farms under conversion (compared to those remaining under

conventional arable production), to assess the rate of recovery of biodiversity on land previously impoverished in species.

3. *Studies that focus on the enhancement of land impoverished in biodiversity terms:* this is allied to point 2 above. Most of the comparative studies undertaken in the literature have focused on comparison of established farming regimes. Such studies are useful in informing us of whether one regime is better than another in biodiversity terms, but rarely provide clear information on why a regime is better. This is because established farms may have started from a different baseline in biodiversity terms, have experienced different management practices, both existing and in the past, and may differ in the balance of structural elements present on the farm. As a result, it is difficult to pinpoint from these studies, the actual causal mechanisms that enhance biodiversity. Identification of these mechanisms is important, if we are to have confidence in advocating management practices to farmers. By undertaking comparative studies on land that is: i) already impoverished in biodiversity terms, ii) located within the same geographical region, iii) matched at the outset in terms of farm infrastructure, a clearer picture may be derived of the impact of different farming regimes in enhancing biodiversity. The individual effect of agricultural practices or structural elements on biodiversity would still need to be isolated, and this is discussed in 4 below.

4. *Studies that distinguish between the impacts of different management practices on biodiversity:* as indicated in 4.5.1, organic regimes have been identified as beneficial for biodiversity, but whether this is due to the adoption of the organic regime or the adoption of specific management practices remains unclear. Separating out the effect of different management practices is a difficult task and may only be done by manipulative experiments. Based on the scenario outlined in 3 above (points i-iii), we suggest that an exploration of the following could be informative:
    - experimental studies to assess the biodiversity benefits of areas with different proportions of cropped to uncropped land,
    - comparative study of the impact of different rotational systems (keeping inputs and structural elements constant) on biodiversity,
    - comparisons of cropping regimes that differ only in terms of agricultural inputs (*i.e.* are otherwise identical in terms of rotation and the balance of cropped to uncropped land). This would need to build on the work undertaken within SCARAB and TALISMAN which examined the effect of pesticide within different crop rotations.

Such experiments would help us tease out the relative merits/de-merits of uncropped land, crop management system and crop production practices in enhancing the biodiversity of arable farmland.

1. *Economic assessment* an economic evaluation of the costs and benefits to agricultural production (including the wider implications for consumers), and to biodiversity, of increasing the adoption of particular farming regimes. Whilst the costs and benefits of each regime, particularly in biodiversity terms, are not yet fully characterised, such an exercise may be possible based on best-case and worst-case scenarios. Economic assessments could also be linked to demonstration farms undergoing conversion from conventional arable to organic or integrated production. On such farms, monitoring of both biodiversity and production would have the advantage of providing quantitative information on change in these two parameters. The farms would also act as a focus for

technology transfer and dissemination of information to the wider agricultural and consumer community.

5.5.3 Recommendations

In conclusion, we would recommend the following issues for consideration.

- Monitoring of biodiversity on farms pre- and post- conversion to organic farming.

- Comparative studies that focus on the effectiveness of different farming regimes or agricultural practices, in enhancing biodiversity on species-impoverished intensively managed arable land.

- Manipulative experiments to determine the optimal balance of cropped to uncropped areas for enhancing biodiversity.

- Manipulative experiments to examine the separate impacts of rotational regimes and agricultural inputs on biodiversity.

- An economic assessment of the costs and benefits of conversion to organic, integrated production or uptake of available agri-environment schemes, in both production and biodiversity terms.

Distinguishing whether the benefits accrued for biodiversity are optimised by the adoption of a specific farming regime or from the incorporation of specific elements within a regime is critical for enabling cost-effective policy decisions. The task is not simple and is only likely to be achieved by manipulative experimentation at a large, if possible whole farm, scale. The suggested solutions must also be readily adopted by conventional arable farmers, responsible for managing 80% of the arable land in England, in order for the desired biodiversity benefits to be realised.

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* Note reference not cited in the text but provides useful additional information in support of this review.