REDUCING AGROCHEMICAL USE
ON THE ARABLE FARM

THE TALISMAN & SCARAB PROJECTS

Edited by

J E B Young
M J Griffin
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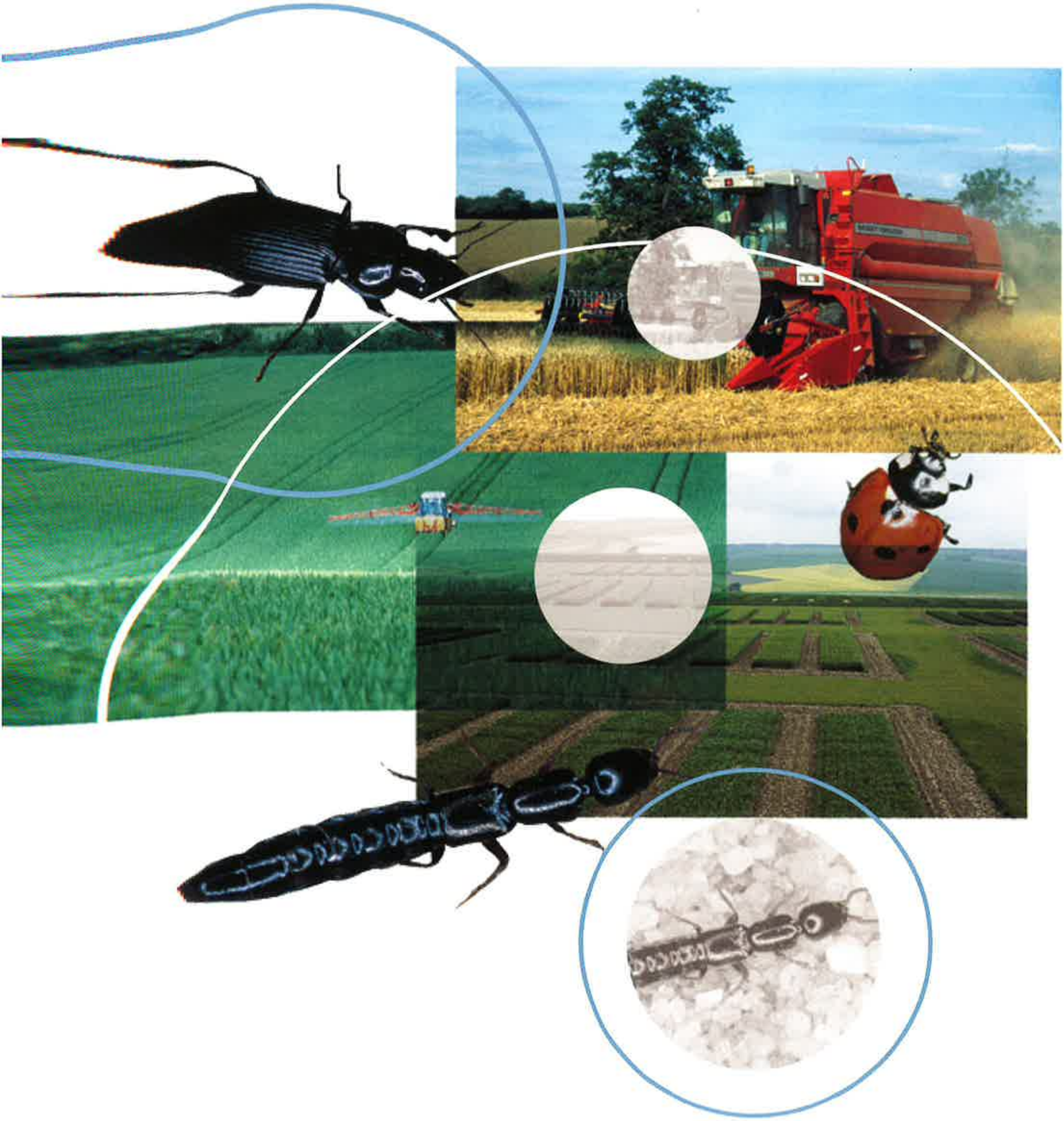
Published by

DEFRA
Department for Environment, Food & Rural Affairs



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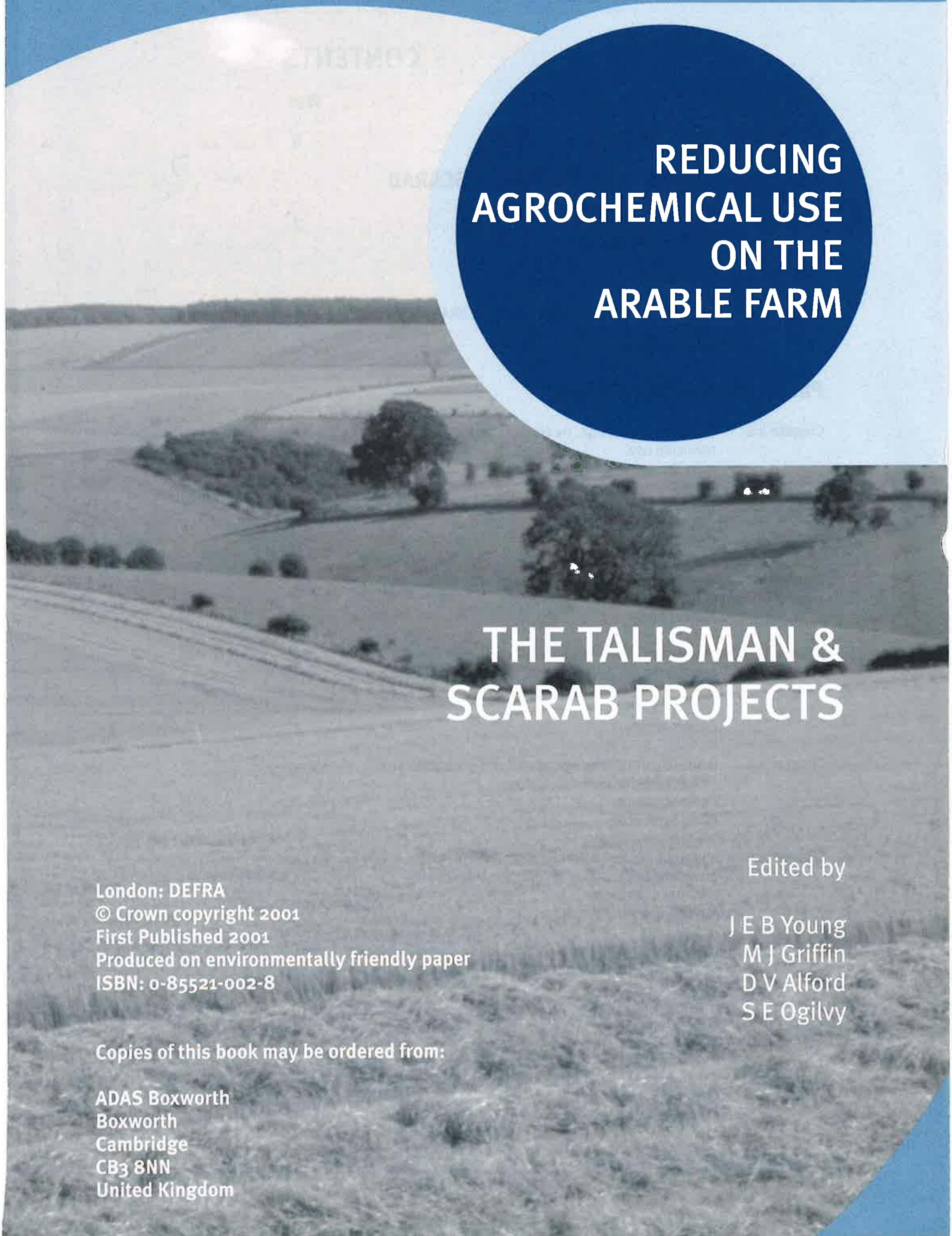

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London: DEFRA

First Published 2001
Produced on environmentally friendly paper
ISBN: 0-85521-002-8

Copies of this book may be ordered from:

ADAS Boxworth
Boxworth
Cambridge
CB3 8NN
United Kingdom

Part 3: The SCARAB Project

Part 4: The RISC Project

Part 5: TALISMAN and SCARAB: summary and conclusions

FOREWORD

The closing decades of the late twentieth century have witnessed great changes and advances in the UK agricultural industry. The drive for increased productivity following the second world war, allied to rapid technological advances in all aspects of farming, has led to tremendous increases in yields over the past thirty years. Farmers have been quick to adopt the latest agronomic tools, including advances in plant breeding and the use of efficient fertilisers and pesticides.

Today, arable farmers are faced with the new challenge of maintaining their profitability against a background of increasing costs plus falling output values for their produce. There have also been increasing environmental demands; the wisdom and effects of modern, intensive, farming methods have been widely questioned. Consequently, environmental protection and food safety issues have now assumed major importance in the production and management of arable crops.

The MAFF-funded Boxworth Project (1981–1991) broke new ground by being the first long-term, farm-scale project to investigate the ecological side-effects of intensive farming practices and to evaluate more environmentally friendly approaches to crop production in the UK. The TALISMAN and SCARAB research projects (1990–1998) described in this book, were also commissioned by MAFF and were specifically designed as follow-on studies to address, in more detail, many of the issues raised by the Boxworth Project. These projects demonstrated a continuing commitment from MAFF (became part of DEFRA in 2001) to support environmental research and to ensure that arable farming remains both profitable and environmentally aware.

TALISMAN and SCARAB complemented each other in their aims and objectives; TALISMAN focused primarily on the economic issues of reducing pesticide and fertiliser use, whilst SCARAB was driven by the need to examine in detail many of the questions surrounding the ecological side-effects of pesticides. TALISMAN commenced in 1990 and involved study sites at ADAS Boxworth, Drayton and High Mowthorpe. In addition to the ADAS input to TALISMAN, scientists from the Scottish Crop Research Institute (SCRI) studied two specific areas: nematodes and weed seedbanks. SCARAB also began in 1990, with study sites located at ADAS Drayton, Gleadthorpe and High Mowthorpe. The SCARAB sites were managed by ADAS and the detailed programme of monitoring and investigation included inputs from specialists at Southampton University (on arthropods), the University of Wales, Bangor (on soil microbiology) and the Central Science Laboratory (on earthworms).

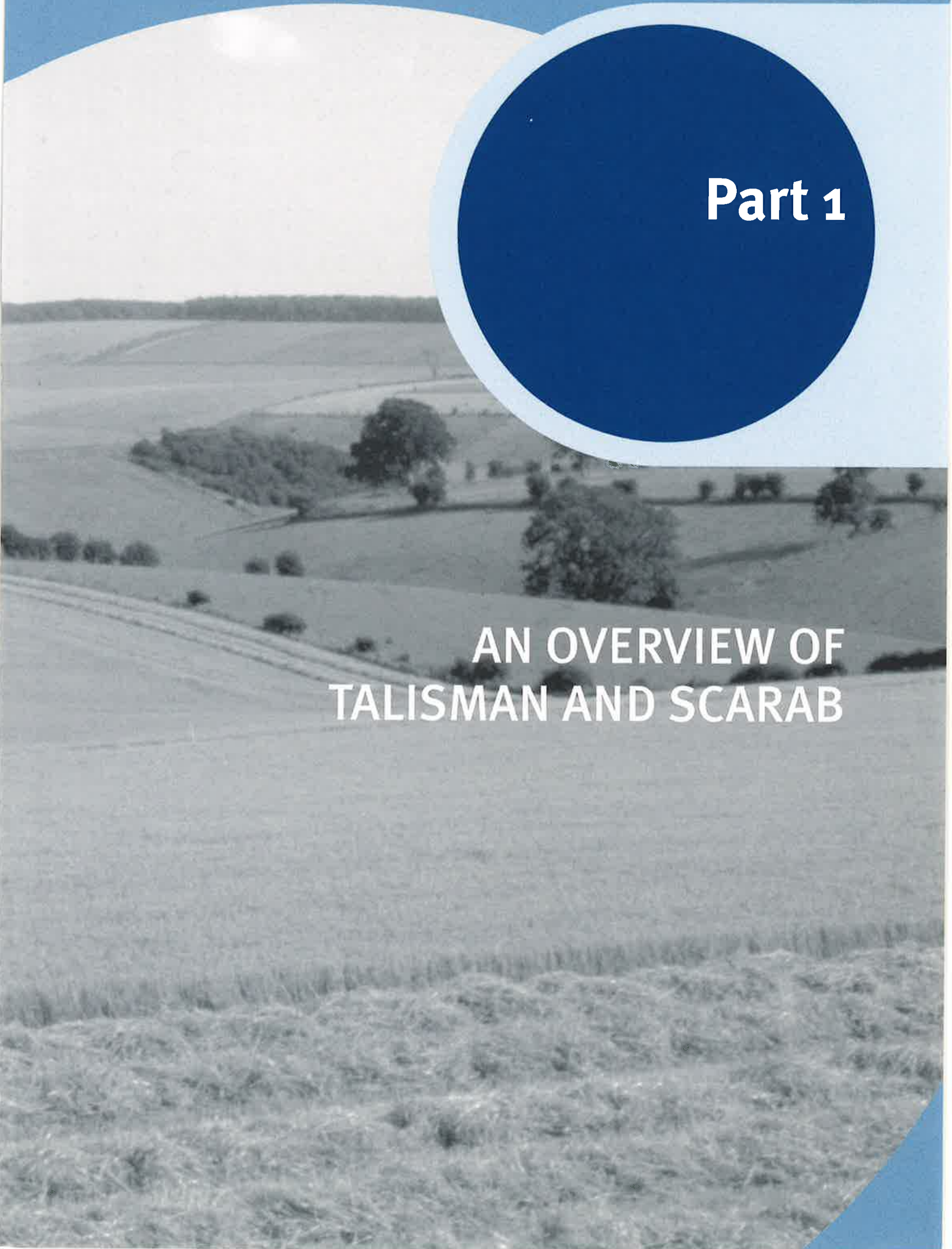
This book brings together a unique and comprehensive account of TALISMAN and SCARAB methodology and results plus key implications and messages for the arable farming industry in the UK. Information on the related RISC project, managed by the Agricultural Research Institute of Northern Ireland, is also presented.

The combined results of the TALISMAN and SCARAB projects have built solidly on the findings of the Boxworth Project and have provided a wealth of information which will contribute to the development of sustainable farming systems which aim to maintain profitability with minimal environmental impact. Looking to the future, the knowledge gained in TALISMAN and SCARAB now forms an important foundation of economic and environmental information of great value to policy-makers, environmentalists and farmers alike.

Dr M J Griffin
Research Director
ADAS Consulting Ltd

Part 1

AN OVERVIEW OF TALISMAN AND SCARAB



ORIGINS AND AIMS OF THE TALISMAN AND SCARAB PROJECTS

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Introduction

At the start of the 21st century, arable farming in the UK is under greater economic and environmental pressures than ever before. Arable farm businesses have had to contend with increasing production costs and decreasing 'farm-gate' prices for their produce, the net result of which has been a fall in farmers' gross margins – the money left from the sale of a crop after deduction of variable costs such as seed, fertiliser and pesticides (Murphy, 1990). The progressive decline in the output value of arable crops over the past decade was triggered by reforms to the European Union (EU) Common Agricultural Policy (CAP) and the influence of the General Agreement on Tariffs and Trade (GATT), both aimed at curbing over-production within the European Union and bringing European prices more in-line with world market prices (Hughes, 1994; Anon., 2000).

In parallel with the economic challenges facing the farming industry, environmental and food safety issues are also of major importance. However, questions surrounding the potential environmental repercussions of modern farming methods have been in existence for at least 40 years and were marked, notably, by the publication of Silent Spring (Carson, 1962), which highlighted the undesirable side-effects of the insecticide DDT and triggered the debate and ongoing concern over the safety of pesticides.

The 1970s marked a period of expansion in arable crop production in the UK, and the use of pesticides (fungicides, herbicides, insecticides, molluscicides and nematicides) generally increased (Sly, 1981). During this time, an overall decline in cereal invertebrates was observed in southern England (Potts, 1986; Aebischer, 1991). Although there was no proof that these trends were connected, the increasing frequency of pesticide application raised concerns that intensive use may be causing harm to the environment. Furthermore, the need to apply pesticides in rigid, routine programmes to insure against crop losses was being challenged in the best interests of sustainable and cost-effective crop production.

Against this background, the Boxworth Project was conceived in the late 1970s and was subsequently commissioned by the Ministry of Agriculture, Fisheries and Food (MAFF) in the early 1980s. An introduction to the origins, objectives and results of the Boxworth Project is, therefore, essential to fully understand the evolution and purpose of the TALISMAN and SCARAB projects, which followed-on in the 1990s after the Boxworth Project was completed.

It should be noted that MAFF became part of the Department for Environment, Food and Rural Affairs (DEFRA) in June 2001.

Reducing Agrochemical use on the Arable Farm: The TALISMAN and SCARAB Projects.

Young J E B, Griffin M J, Alford D V, Ogilvy S E. [*eds*] 2001. London: DEFRA.

The Boxworth Project (1981-1991)

The Boxworth Project was designed to investigate the effects of pesticide use in cereals on a range of wildlife, including plants, birds, small mammals, and arthropods (e.g. insects, mites and spiders). The Project broke new ground as it was the first large-scale, multi-disciplinary study in the UK to involve a long-term comparison of different farming systems (Greig-Smith *et al.*, 1992). The Project was, therefore, primarily an ecological study, with economic inputs and outputs monitored incidentally. The following three main aims were central to the Project:

- to examine and compare the environmental and ecological side-effects of contrasting pesticide regimes;
- to monitor the economics of crop production under contrasting pesticide regimes and to establish the commercial viability of reduced-input farming;
- to identify any difficulties that might arise in the practical management of reduced-input farming systems, with particular reference to pesticide use.

The ADAS Boxworth Research Centre (formerly Boxworth Experimental Husbandry Farm) provided a whole-farm study area in which the various effects of the contrasting pesticide regimes could be investigated. The farm was divided into three areas, each a block of contiguous fields. After two years (1981–1983) of baseline monitoring of flora and fauna, the following three pesticide regimes were applied to contiguous groups of fields on the farm for a period of five consecutive cropping years (1983–1988).

1. A 'Full Insurance' regime which involved high inputs and prophylactic treatments, imitating an intensive cereal production system of the late 1970s.
2. A 'Supervised' regime whereby pesticides were applied only if weeds, diseases or pests exceeded economic thresholds.
3. An 'Integrated' regime using economic thresholds and husbandry practices which further reduce the need for pesticides.

In practice, in terms of pesticide inputs, there was little difference between the 'Supervised' and 'Integrated' treatment regimes.

Boxworth Project results

The following is a brief overview of the main results arising from the Boxworth Project. A full, comprehensive presentation of the findings of the Boxworth Project is available in the book 'Pesticides, Cereal Farming and the Environment. The Boxworth Project' (Greig-Smith *et al.*, 1992).

Pesticide effects on arthropods

Differences were observed in the response of various non-target arthropod species to the treatment regimes applied in the Boxworth Project. These responses were attributed to differences between species in their exposure to pesticides (predominantly to insecticides and molluscicides), their inherent susceptibility and the capacity of populations to recover after adverse pesticide events. The latter depends on the ecological characteristics of a species, including dispersal ability, reproductive potential, diet and number of generations per year.

Some surface-active arthropods virtually disappeared from the Full Insurance fields for long periods of the five-year treatment phase, e.g. the herbivorous springtail known as the lucerne flea (*Sminthurus viridis*) and the predatory ground beetle *Bembidion obtusum*. Effects of the Full Insurance regime on soil fauna were also mixed. There was no evidence for effects on mites (Acari) but within the springtails (Collembola), populations of certain species, such as *Lepidocyrtus* spp., were reduced by the Full Insurance regime. The springtails are an important order of soil-dwelling insects as many of their species are detritivores at the base of the food chain, feeding on fungi and decaying organic matter. Springtails form an important part of the diet of many beneficial arthropod species (e.g. ground beetles and rove beetles) and, as such, any disturbances to springtail populations could have a knock-on effect for species higher up the food chain.

Overall, the population densities of herbivores and carnivores (predators and parasitoids) were approximately 50% lower in the Full Insurance than in the Supervised and Integrated regimes. However, detritivores did not show an overall adverse effect as a result of the Full Insurance regime, although certain species were suppressed as previously discussed. Populations of some pest species, such as the grain aphid (*Sitobion avenae*) and the rose-grain aphid (*Metopolophium dirhodum*), were sometimes found to be greater in association with the Full Insurance regime. Furthermore, predator/prey studies using artificial pest baits (fly pupae) also indicated that the Full Insurance regime may have reduced the impact of predatory arthropods (e.g. ground and rove beetles) on the cereal aphid populations.

Pesticide effects on other wildlife

Other wildlife was also monitored at Boxworth. Acute effects of pesticide use were detected only in wood mice (*Apodemus sylvaticus*), which were killed by broadcast molluscicide pellets. However, immigration of juvenile mice from untreated areas allowed a rapid recovery in numbers, and there was no evidence of any long-term effects of pesticide use on wood mice populations. Additionally, there was no conclusive evidence from the Boxworth Project to suggest any long-term effects of pesticides on populations of birds, rabbits or wild plants.

Economic aspects of the treatment regimes

As expected, crop yields were higher in the Full Insurance regime, compared with the other treatment regimes. However, this apparent advantage entailed greater economic costs, as well as the environmental impact detailed above. Despite lower yields, the profitability of the Supervised approach was greater than the Full Insurance regime. The Integrated regime gave the lowest yields and economic returns because attempts to reduce pesticide use below that of the Supervised approach led to problems with grass weeds. However, the performance of the Integrated regime within the Boxworth Project was recognised to be unsatisfactory in many ways and not fully representative of how a low-input, fully integrated system would be designed.

Important conclusions of the Boxworth Project, that remain highly relevant today, were that very high inputs of pesticides are unlikely to be required in a well-managed crop, are likely to result in adverse environmental side-effects, and are unlikely to result in additional economic benefits. The Project also demonstrated the validity of the whole-farm approach for research on the long-term effects of pesticides as well as highlighting the scale of crop monitoring necessary to obtain meaningful results and the practical difficulties of operating low-input systems. The broad findings were also complemented by results from other farm system studies elsewhere in Europe (El Titi, 1986; Booij & Noorlander, 1988; Holland *et al.*, 1994).

Research following the Boxworth Project

The knowledge gained and the lessons learned from the Boxworth Project formed a sound basis for future research aimed at understanding and counteracting any undesirable effects from current farming practices.

Inevitably, the Boxworth Project was a compromise between the conditions required for long-term study of different aspects (**Table 1.1.1**). There were some criticisms of the Boxworth Project design: the lack of treatment replication and a lack of flexibility in the treatment regimes to adjust for changes and developments in 'conventional' farm practices. The lack of replication was due primarily to the large experimental area required to study and demonstrate the effects of pesticides on active, mobile species such as birds, small mammals and arthropods. No modifications were made to the treatment regimes in order to follow current trends in pesticide use or crop husbandry as the Project progressed. During the later stages of the Project, the inputs used in the Full Insurance regime were higher than had become standard practice for commercial cereal production. Furthermore, the continuous wheat cropping pattern adopted became less typical of current farming practice as the Project progressed. The restriction of the Project to a single crop rotation at one farm limited its immediate extrapolation for prediction of effects of pesticides on a wider scale. Nevertheless, the pre-planned high-input pesticide regime provided a consistent reference for comparative purposes throughout the life of the Project. Another shortcoming in the design was the lack of a nil insecticide/molluscicide treatment (nematicides were not used). Consequently, it was not possible to determine if there were any side-effects on non-target arthropods caused by the pesticide regime in the Supervised treatment.

In 1988, MAFF held a Topic Review of the Boxworth Project to consider the priorities for subsequent studies and how they should be designed (Anon., 1988). A wide range of interests in agricultural research and farmland ecology was represented at this meeting, which confirmed support for continuing research to extend the findings from Boxworth, taking into account its strengths and limitations. However, a limited continuation of the Boxworth Project was implemented (1988–1990) to monitor the extent to which the arthropod populations would recover once the high-input Full Insurance regime was replaced by a lower-input Supervised programme. This work showed that ground beetles, spiders and springtails recovered from the Full Insurance regime very slowly, indicating that effects of intensive pesticide use can last for several years after the intensity of pesticide use is reduced.

Consequently, in the wake the Boxworth Project, it was agreed that resources might be more usefully devoted to new projects. Rather than simply continuing the Boxworth Project, or repeating it elsewhere, further studies to follow up the key implications were planned. At the same time, there was also mounting interest from consumers, environmentalists and government within the UK, and throughout the EU, for farmers to be become more involved with environmental protection and food safety (Reus *et al.*, 1994).

Two new long-term projects, known by the acronyms of TALISMAN (Towards A Lower Input System Minimising Agrochemicals and Nitrogen) and SCARAB (Seeking Confirmation About Results At Boxworth) were subsequently commissioned by MAFF as follow-on studies to the Boxworth Project, and their initial 'baseline' work commenced in 1989/1990 (Cooper, 1990). These closely linked, six-year projects were designed to address in more detail many of the issues raised by the Boxworth Project. Furthermore, the new projects were designed to complement each other and to avoid the practical difficulties of studying economic and ecological aspects in appropriate detail in a single experiment (**Table 1.1.2**). TALISMAN was to focus primarily on the agronomic and economic effects of lower input farming whereas SCARAB was to address, in more detail, the environmental effects of pesticide use.

TALISMAN

As well as the follow-on from the Boxworth Project, wider policy issues also influenced the decision to go ahead with TALISMAN. At the time TALISMAN was conceived, there was a rapidly growing pan-European interest in pesticide minimisation and low-input farming, with suggested reductions of up to 50% of the then existing levels of pesticide use (Reus *et al.*, 1994). TALISMAN was subsequently planned in the wake of concerns within the UK about the possibility of EU-imposed reductions in overall pesticide and nitrogen usage on arable crops. TALISMAN was, therefore, designed with an underlying need to answer specific questions which were likely to surround the discussion of new policies relating to the use of pesticides and nitrogen fertiliser.

The main objective of TALISMAN was to provide MAFF with robust data on the economic and agronomic consequences of adopting cropping systems which used lower amounts of pesticides and nitrogen than conventional cropping systems (**Table 1.1.3**) (Cooper, 1990). As well as the primary agronomic and economic factors, non-target arthropods, soil nematodes and weed seedbanks were also monitored. Although the arthropod monitoring was subsidiary to the main objectives and design of the study, these data complemented the data generated by SCARAB. TALISMAN used a conventional replicated plot design, with plot sizes that enabled scaling up to farm level (Chapter 2.1). The small-plot design of TALISMAN was necessary to achieve the desired accuracy of yield measurement and a robust statistical analysis of the data. Experimental treatments followed a planned 50% reduction in pesticide and nitrogen input, achieved by either reducing rates or omitting applications.

A unique feature of TALISMAN was the inclusion of contrasting arable crop rotations of six-year durations. The economic and agronomic effects of reducing nitrogen and pesticide use could, therefore, be studied over a long and continuous period spanning the full term of each crop rotation. The experimental plots remained in the same field location at each site for the entire lifespan of the study. This design offered a major advantage in that the long-term and cumulative effects of reduced pesticide use on weed, pest and disease problems could be followed and assessed in detail across each crop rotation.

SCARAB

The purpose of SCARAB was to verify and to extend the environmental data gained in the Boxworth Project to a wider range of crops, including oilseeds, root crops and grass leys, and soil types ranging from clay to sand. SCARAB was driven by an overriding need to study the ecological impact of current pesticide use (essentially equivalent to the Supervised regime in the Boxworth Project) on arable crops in comparison with a low-input system (**Table 1.1.4**) (Cooper, 1990). To a lesser extent, SCARAB also investigated the economic and agronomic implications of a reduced-input system (although this was addressed in more detail in TALISMAN), once again emphasising the complementary nature of the two projects.

Experimental areas in SCARAB were based on half-fields, containing matched sampling areas running out into the field from a shared boundary (Chapter 3.1). Owing to the lack of replication, such a design has the drawback of not lending itself to accurate statistical analysis of conventional parameters such as crop yield. However, the large-scale design of SCARAB was dictated by the specialised ecological studies and was deemed particularly suitable for monitoring non-target arthropods. These species (e.g. spiders and predatory beetles) are often highly mobile and field margins and hedgerows are known to be important overwintering sites and reservoirs from which fields may be recolonised each year (Sotherton, 1985).

The experimental design of SCARAB was particularly important in that it introduced a nil-input treatment for insecticides, molluscicides and nematicides (a treatment not represented in the Boxworth Project), against which the possible impact on non-target arthropods, soil microbial activity and earthworms could be assessed. However, because of the ecological focus of the SCARAB project, it was necessary to accept at the outset that if invertebrate pest problems developed, greater yield loss might occur than farmers would normally tolerate (Chapter 3.6). This demonstrates the ecological priorities of SCARAB and highlights how this project effectively matched and complemented the design and purpose of TALISMAN.

RISC

The Reduced Input Systems of Cropping (RISC) experiment was initiated by the Department of Agriculture for Northern Ireland (DANI) and was done in Northern Ireland in parallel with the TALISMAN project in England. RISC shares the same objectives, core design and treatments as TALISMAN, although a number of additional treatments were included to widen the base of the project. Notable differences from TALISMAN were the inclusion of crop rotations typical of those found in Northern Ireland and also the inclusion of an integrated treatment in which crop cultivars, seed rates and choice of agrochemicals were varied to suit the use of reduced inputs. RISC began in 1991 at Hillsborough, Co. Down and the first six years of the project are reviewed in this book.

Book layout

The following chapters of this book are devoted to presenting the results and conclusions arising from the TALISMAN, SCARAB and RISC projects. The book has been divided into five distinct parts: Part One contains introductory and summary 'key findings' chapters; TALISMAN, SCARAB and RISC are dealt with in Parts Two, Three and Four, respectively; Part Five consists of an overview and conclusions chapter, plus a glossary and appendices.

Within the parts of the book dealing with TALISMAN and SCARAB, the chapters have been arranged to reflect the distinct areas of study and disciplines found within each Project. Therefore, each chapter has been designed to be relatively self-contained. In order to illustrate and to make important points readily accessible to the reader, all charts and diagrams have been included within the text. Tables also comprise a significant proportion of some chapters and will be required by those readers who wish to refer to supporting data in more detail. To preserve the continuity of text sections, the data tables have been included as clearly identified separate 'archive' sections at the end of each chapter.

Note that, in certain tables, because percentage values representing treatment changes have been calculated using source data, then they may differ slightly from the percentage values calculated using the data cited in the tables, owing to rounding to an appropriate number of decimal places.

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Table 1.1.1. Values and constraints of the Boxworth Project design (after Cooper, 1990).

Boxworth design	Reason for selection	Compromise accepted
Large experimental areas (whole fields and boundaries)	Essential for monitoring mobile species and minimising field edge-effects. Reflects scale of commercial operations	Replication not feasible for practical and financial reasons
Tight control over whole farming system	Distinguish pesticide effects from other changes in farm practice	Practical difficulties in operating research studies alongside realistic farming
Observations in continuous wheat	Pesticide inputs generally high; suitable system for initial study; monitoring techniques available	No crop rotation. Results not necessarily applicable more widely
Focus on pesticide effects	Minimise confounding effects on other variables	Exclusion of other environmentally important practices, e.g. fertiliser use
Long-term comparison of contrasting pesticide regimes	Stronger interpretation possible than from simple before/after contrasts of individual pesticide applications	Regimes chosen primarily for experimental reasons. Integrated regime not a true integrated farming system
Rigid Full Insurance pesticide regime	Representative of high-input farming to identify major effects; provide standard contrast to Supervised and Integrated regimes	Input levels not modified to reflect changing farm practices over experimental period
Broad range of ecological groups monitored	Opportunity to identify interactions and indirect effects	Treatment areas not equally suitable for all groups
Baseline monitoring for two years	Identify level of similarity between experiment areas	Differences still developing could affect results
Five-year experimental phase	Reveal effects that emerge relatively slowly	Longer-term effects not detected
Economic appraisal of inputs and outputs	Complement the environmental results	Economic and environmental objectives not readily compatible in the same design

Table 1.1.2. Comparison of the Boxworth Project, TALISMAN and SCARAB designs (after Cooper, 1990).

Design feature	Boxworth Project	TALISMAN	SCARAB
Dominant observations	Wide range of wildlife monitoring	Economic and agronomic aspects	Monitoring of arthropods, soil microflora and earthworms
Subsidiary observations	Economic and agronomic aspects	Monitoring of arthropod and soil nematode populations	Economic and agronomic aspects
Experimental areas	Whole fields; matched areas of farmland	24 m x 24 m plots; replicated trials	Large paired plots 84 m x 150 m in split fields; shared field boundary for each pair
Replication of sites	None	Three* sites: Boxworth, Drayton & High Mowthorpe	Eight sets: 3 at High Mowthorpe, 3 at Gleadthorpe & 2 at Drayton
Experimental treatments	*Pesticides:* 1. Full insurance – rigid 2. Supervised – regular crop monitoring 3. Integrated - additional husbandry Other inputs as required for specific fields	*Pesticide and nitrogen*: 1. Current Commercial Practice. Flexible 2. Low Input Approach – no more than 50% of CCP pesticide and nitrogen inputs	*Pesticides*: 1. Current Farm Practice – flexible 2. Reduced Input Approach – low-input pesticide use. Insecticides, molluscicides and nematicides excluded
Rotations	Intensive wheat; some fields with winter oilseed rape break in five-year rotation	Contrasting six-course rotations: 1. Standard Rotation – conventional winter crops 2. Alternative Rotation – included lower-input spring crops	Six-course rotations with combinable break crops, root crops and grass leys
Timescale	Two baseline years; five-year experimental phase	One baseline year and six-year experimental period	One baseline year and six-year experimental period

* Initially four but one site, Gleadthorpe, was abandoned in the first year owing to unacceptable soil variation.

Table 1.1.3. Objectives of the TALISMAN Project.

TALISMAN main objectives:

To measure the economic and agronomic impact of adopting cropping systems which use lower levels of pesticides and nitrogen fertiliser than conventional cropping systems, and to provide information of value to MAFF Policy Divisions on the yield and economic penalties of adopting such low-input systems.

TALISMAN detailed objectives:

a) To compare the economic returns of winter-cropping-dominated compared with spring-cropping-dominated six-course rotations.
b) To examine the economic and agronomic effects of reducing pesticide and nitrogen use by 50% in winter- and spring-crop-dominated rotations.
c) To examine the effects of reducing nitrogen and pesticide use on weed, pest and disease incidence on each crop in the rotation.
d) To monitor soil nitrogen levels over the six years of each rotation and to examine how continued use of lower levels of nitrogen may affect soil nitrogen reserves.
e) To extend the work of the Boxworth Project by examining the effects on non-target arthropods of applying pesticides and nitrogen to a range of crops.
f) To examine if a reduction in pesticides and nitrogen over a six-year rotation leads to an increase in less common species of flora or weeds.
g) To monitor the changes in levels of weed seeds and soil nematodes in the soil over the six-year period of the project.

Table 1.1.4. Objectives of the SCARAB Project.

SCARAB main objectives:

To compare and contrast the environmental effects of two contrasting pesticide regimes in a range of six-course arable crop rotations and to confirm results obtained during the Boxworth Project on the long-term effects of pesticides on non-target arthropods.

SCARAB detailed objectives:

a) To monitor the within- and between-season effects of two pesticide regimes on numbers of the principal arthropod species and on the taxonomic composition and trophic structure of the arthropod communities at each site.
b) To examine any side-effects of pesticides on non-target soil microorganisms and to monitor any such effects in terms of their duration and the size, activity and composition of the soil microbial community.
c) To examine the short- and long-term implications of any changes in soil microbial biomass on soil fertility, e.g. carbon and nitrogen mineralisation.
d) To monitor the effect of the SCARAB treatments on earthworm populations, to investigate any such effects and to provide further information on the causes of any population changes.
e) To measure the effects of the two pesticide regimes on weed populations, floral diversity and distribution.
f) To monitor the agronomic and economic performance of a range of crops receiving reduced pesticide inputs and to monitor the long-term productivity of individual fields.

Ground beetles (Carabidae) featured prominently in the pitfall traps and are useful predators of pest species such as aphids and slugs.

Rove beetles (Staphylinidae) are a large family of active and often predatory species which can attack pests such as aphids.

Money spiders (Linyphiidae), although small in size (1-6 mm), can be particularly abundant in arable crops and prey on aphids and other small insects.

In 1991, a species of linyphiid spider new to science was discovered in the TALISMAN plots at ADAS Boxworth. This spider was named Centromerus minutissimus

Pitfall traps (9 cm diameter by 15 cm depth) were used throughout SCARAB and TALISMAN to monitor the numbers and activity of ground-dwelling arthropods, primarily insects and spiders.

D-vac suction samplers were used in SCARAB to assess populations of insects and spiders within the study fields.

In SCARAB, during summer 1995 at High Mowthorpe, sooty moulds developed on honeydew secreted by an attack of cereal aphids in the untreated reduced input area, visible as the dark area of crop on the right, compared with the insecticide-treated CFP area on the left. Inset: ears of wheat attacked by grain aphid.

On the left, a purpose-built plot sprayer applies a pesticide treatment to the TALISMAN plots at High Mowthorpe. On the far left, nitrogen fertiliser is applied to TALISMAN main plots using a pneumatic spreader.

Poppies flourished as a result of reduced herbicide inputs in the RIA area (left) of SCARAB at High Mowthorpe in 1995, compared with the conventional herbicide-treated area on the right.

An aerial view of the TALISMAN plots at ADAS High Mowthorpe, North Yorkshire.

The TALISMAN site at ADAS High Mowthorpe, showing layout of sub-plots within larger main plots, surrounded by grass buffer strips.

Poppies, shown here in a crop of low-input linseed of the Alternative Rotation at High Mowthorpe, were the predominant weed at this site and were not controlled by low doses of herbicides.

Grain aphids (Sitobion avenae) *attacked TALISMAN winter wheat at High Mowthorpe in the summer of 1992.*

On the heavy clay soil at ADAS Drayton, field slugs (Derocerus reticulatum) *gave rise to crop establishment problems in winter oilseed rape and winter triticale.*

The Project Team at the TALISMAN/SCARAB Conference held at Churchill College, Cambridge, December 1998. Back row L to R: David Green, David Alford, Steve Ellis, Geoff Squire, Michael Green, Heather Maher, Sue Jones, Sarah Cook, Sue Ogilvy, Mary Hancock, David Perks, David Harris, Barrie Johnson. Front row, L to R: Peter Gladders, Geoff Frampton, David Cooper, Lindsay Easson, Paul Bowerman, Brian Boag, Mike Griffin, John Young.

KEY FINDINGS OF THE TALISMAN AND SCARAB PROJECTS: A SUMMARY

This chapter presents a concise overview of the key results and conclusions arising from the TALISMAN and SCARAB Projects. The summary is arranged according to the various specialised areas of study within each project, further details of which can be found in the respective chapters referred to. A summary of Northern Ireland's RISC Project is also included.

The TALISMAN Project

The main aim of the TALISMAN Project was to measure the economic and agronomic implications of reducing inputs of pesticides and nitrogen fertilisers to arable crops. In addition, two contrasting six-course arable crop rotation systems were compared.

To reflect the recent trend towards the generally higher yielding and more reliable autumn-sown crops, the 'Standard Rotation' was based entirely on autumn-sown cereals and break crops such as winter beans and winter oilseed rape.

The 'Alternative Rotation' contained a high proportion of spring-sown cereals and break crops such as spring linseed. These tend to be lower yielding, but have an inherently lower demand for nitrogen and pesticides.

Pesticide regimes applied to these rotations were either:

- Current Commercial Practice (CCP), with nitrogen fertiliser and pesticides applied according to manufacturers' recommended rates, or;
- a Low Input Approach (LIA), in which nitrogen rates were applied at 50 per cent below CCP and pesticide applications omitted or applied at no more than 50 per cent of the rates used in CCP.

Additionally, the individual and combined effects of reducing herbicide, fungicide and insecticide use were studied in a series of pesticide sub-treatments. The experiment was designed to assess crop yields and economics at each level of agrochemical input over six years. The effects on crop pests and diseases were also evaluated, as were the long-term effects on weeds and weed seedbanks, soil nematodes and the environmental impact on non-target insects and spiders.

Results from the Project showed that reducing pesticide use in arable crops through low-input techniques can provide growers with the opportunity to maximise financial returns from conventional arable cropping. There is considerable potential for reducing the use of fungicides, followed by herbicides and insecticides but care must be taken to avoid the build-up of weed populations. However, the results have shown that low-input pesticide use strategies are not suitable for all sites and crops. Ultimately, to reap the rewards, local knowledge and management skill remain a vital factor in determining the scope, extent and financial viability of reducing pesticide use in arable crops.

Reducing Agrochemical use on the Arable Farm: The TALISMAN and SCARAB Projects.

Young J E B, Griffin M J, Alford D V, Ogilvy S E. [*eds*] 2001. London: DEFRA.

Nitrogen use in TALISMAN (Chapter 2.2)

- Yields were reduced, on average, by 11% where conventional nitrogen rates were cut by 50%.

- The arbitrary 50% reduction in nitrogen (N) use adopted in TALISMAN was unprofitable, resulting in an overall reduction of 9% (£64/ha). A more flexible and precise approach to reducing N use would prevent such losses.

- Low-input N use reduced the mean gross margin of the Standard Rotation (winter crops) and Alternative Rotation (mainly spring crops) by 10% (£79/ha) and 7% (£44/ha) respectively.

- Although spring crops were lower yielding and less profitable (by £118/ha or 18% overall) than winter crops, they have an inherently lower N demand and responded more favourably to low-input N use. Overall, gross margins of the low-input N treatment were reduced by 11% (£77/ha) and 4% (£20/ha) in TALISMAN winter and spring crops, respectively, compared with conventional N use.

- Unexpectedly high levels of nitrogen mineralisation from crop residues and soil organic matter can drastically alter conventional nitrogen requirements, e.g. by reducing the annual demand for additional nitrogen fertiliser, as observed at Boxworth in 1992.

- Few meaningful interactions were observed between nitrogen and pesticide use responses.

- There were few effects of nitrogen on crop quality, the main exception being the protein content of wheat grain at High Mowthorpe in 1992, which was reduced from 11.1% protein in the conventional N, to 9.3% protein in the low-input N regime, overall.

- Low-input nitrogen use reduced the apparent nitrogen balance in the soil and may also lead to lower losses of nitrogen to the aquatic environment. However, caution is required as, in the longer-term, low-input nitrogen use may well lead to a loss of soil organic matter and a reduction in soil fertility.

Weed control in TALISMAN (Chapter 2.3)

- Reducing herbicide rates to 50% of full label-recommended rates can be successful in agronomic and economic terms, if managed appropriately.

- Changing the crop rotations to include a wide range of spring-sown crops (Alternative Rotations) did not result in a marked reduction in herbicide use, compared with rotations comprising winter crops (Standard Rotations).

- TALISMAN indicated that, in some circumstances, weed numbers can increase in association with low-input herbicide use and this was generally unaffected by low-input or conventional rates of nitrogen.

- Reduced crop competition from poorly established crops often made weed control more difficult in a low-input situation.

- Low-input herbicide, achieved primarily through rate reductions, gave some yield reductions, especially in break crops (3–41%) and spring-sown cereals (5–11%).

- However, increases in gross margin (2%, £11/ha overall) often compensated for yield decreases by savings in herbicide costs.

- There is economic potential to reduce herbicide use, but there are certain exceptions:
    - * full-rate herbicides are required to maintain control of problem weeds e.g. black-grass at critical times;
    - * improved herbicide decision-making is required to reduce the risk of economic losses at critical periods in the crop rotation.

Weed seedbanks in TALISMAN (Chapter 2.4)

- Reducing herbicide inputs in the TALISMAN rotations was successful only when inputs and competition from the crop were already high. In rotations consisting mainly of winter-sown cereals (Standard Rotations), receiving about four herbicide active ingredient units annually, herbicide dose could be reduced by about half with little or no effect on the seedbank after six years.

- At Boxworth and High Mowthorpe, after six years, the seedbank populations in rotations consisting mainly of spring-sown crops (Alternative Rotations) were hundreds to thousands of times greater than corresponding above-ground weed populations, a result of the high reproductive capacity of the dominant species when allowed to complete their life cycle.

- Attempting to reduce herbicide inputs in rotations of mainly spring-sown crops or winter rotations with already low inputs was risky. At two of the three sites (Boxworth and High Mowthorpe), this left seedbanks in the range 10,000 to 100,000 seeds/m^2 that will give rise to large weed populations for many years into the future.

- Reducing herbicide inputs increased the number of species in the seedbank (e.g. an increase from seven to 20 species in the Alternative Rotation at Boxworth), but usually with a greatly increased number of total seed. To achieve a diverse but less abundant seedbank would seem difficult simply by cutting herbicide rates; a more targeted approach to a diverse and balanced seedbank, in which the rise of dominant species is curtailed, should be developed.

Disease control in TALISMAN (Chapter 2.5)

- Reductions in fungicide use were achieved mainly by reducing dose rate on winter wheat and other cereals, but by the omission of treatments in break crops.

- Fungicide use (units/crop) was reduced by 68% in the low-input regime and this resulted in a significant improvement in gross margins of 2% (£16/ha) over all crops.

- The reductions in fungicide use in TALISMAN were greater than those used in average farm practice. However, care is needed before extrapolating to crops under higher disease pressure than that experienced in these experiments.

- Disease control was impaired when fungicide dose was reduced and examples included powdery mildew (*Blumeria graminis*) on spring oats (Drayton, 1991), septoria (*Septoria spp.*) on triticale (Drayton, 1992) and winter wheat (Drayton 1992 and 1993) and leaf blotch (*Rhynchosporium secalis*) on spring barley (High Mowthorpe, 1993).

- Diseases tended to be more severe under high rates of nitrogen. Interaction between fungicide and nitrogen use was most apparent for powdery mildew on spring oats.

- Reducing fungicide inputs rarely resulted in significant effects on yield.

- In winter wheat, low-input fungicide use resulted in minimal impact on yield and a gross margin benefit of £24/ha (3%) overall, compared with conventional practice.

- In the break crops, low-input fungicide use resulted in a gross margin benefit of £15/ha (3%) overall, compared with conventional practice.

- The results from TALISMAN are consistent with recent developments in other projects on appropriate fungicide dose and Integrated Crop Management (ICM).

- There is clearly potential to reduce fungicide inputs safely provided risk of yield loss can be predicted reliably.

Invertebrate pest control in TALISMAN (Chapter 2.6)

- Insecticide and molluscicide use (units) was 72% lower in the low-input than the conventional regime.

- Minimisation of insecticide use was attained mostly through omission (52%) of applications rather than reduction (41%) in rates. No economic losses were experienced as a result of reducing the rates of insecticides or molluscicides.

- Omitting certain insecticides in the low-input regime resulted in economic losses (from £59/ha to £101/ha) in four (6%) out of 66 spray decisions. Overall, crop yields were largely unaffected by the low-input use of insecticides and molluscicides.

- Across all sites and years, the low-input use of insecticides and molluscicides resulted in a small increase of 1% (£5/ha) in the low-input gross margin, compared with the conventional regime.

- Results from TALISMAN have shown that profitable reductions in insecticide use are possible, provided they are targeted selectively. The generally low cost of insecticides and molluscicides, compared with other variable costs, dictates that the financial savings to be gained from reducing their use are likely to be small.

- The potential for small but consistent financial savings from minimising insecticide and molluscicide use in combinable arable crops has been demonstrated by the results from TALISMAN, and this should be exploited within the industry.

Monitoring the effect of pesticides on non-target arthropods and nematodes in TALISMAN (Chapter 2.7)

- The Collembola (springtails) were the most numerous order recorded at Drayton and High Mowthorpe, where they accounted for 81% and 42% of the total arthropod catch, respectively. At Boxworth, the Acari (mites) were most frequently trapped throughout the experiment (62% of total arthropod catch) but this was primarily due to very large catches in the first year. In all other years, Collembola were the most commonly caught order at Boxworth, and over all years they made up 31% of the total arthropod catch at this site.

- Over all sites, *Trechus quadristriatus* was the most numerous carabid beetle (18% of total carabid catch), *Tachyporus hypnorum* the most numerous staphylinid beetle (8% of total staphylinid catch), *Erigone atra* the most numerous linyphiid spider (24% of total linyphiid catch) and *Pardosa palustris* the most numerous lycosid spider (66% of total lycosid catch).

- A total of 66 insecticide or molluscicide applications was made to TALISMAN throughout the life of the study. Molluscicides (methiocarb only) were most frequently used, particularly on triticale at Drayton, followed by summer cereal aphicides (dimethoate only) and BYDV sprays (mainly cypermethrin).

- On the seven occasions where pesticides apparently affected pitfall trap catches, this was generally represented by a reduction in the number of carabid beetles or linyphiid spiders caught. However, catches recovered within three months. These effects were noted on three occasions in conjunction with methiocarb and on single occasions with cypermethrin, dimethoate, pirimicarb and triazophos, respectively.

- Multivariate analysis demonstrated that arthropod abundance was most significantly affected by year to year differences. Crop rotation also affected arthropod abundance. Furthermore, there were individual year effects of pesticide at Drayton and High Mowthorpe but these were not consistent across years or sites.

- Invertebrate monitoring in TALISMAN demonstrated limited effects of pesticide application on arthropods. Results suggest that the adoption of low-input pesticide use was less damaging to some invertebrates on some occasions but the effects were transitory and populations recovered. In general, variations between years and rotations appeared to have a greater effect on the invertebrate fauna than pesticide application.

- There was no evidence to suggest that the reduced use of herbicides or nitrogen fertilisers either increased or decreased plant-parasitic nematode populations, compared with conventional practice.

Impact of low-input pesticide use on yields and economics in TALISMAN (Chapter 2.8)

- Crop yields were generally reduced by the low-input pesticide regime e.g. by -6% in winter wheat. However, owing to savings in variable costs, gross margins were generally slightly higher in the low-input than the conventional regime, e.g. +1% (£9/ha) in winter wheat.

- In cereals, the average gross margin of the low-input regime was 2% (£17/ha) greater than the conventional. In break crops, an equivalent gain of 1% (£4/ha was noted). Across all crops, the average gross margin of the low-input regime was 2% (£12/ha) greater than the conventional regime.

- The average gross margins of the low-input regime exceeded those of the conventional regime in winter wheat (+1%), winter triticale (+16%), spring barley (+6%), linseed (+1%), spring beans (+1%) and winter beans (+5%). Break crops were more variable than cereals.

- The Standard Rotation (winter crops) was, as expected, more profitable than the Alternative Rotation (spring crops). Across all sites, the average gross margin from the Alternative Rotation (£626/ha) was 15% or £109/ha less than that from the Standard Rotation (£735/ha).

- The Alternative Rotation did not drastically alter the relative impact of the low-input pesticide regime. Although, at High Mowthorpe, there was evidence that some of the spring crops in the Alternative Rotation (e.g. spring barley) helped alleviate the relative impact of the low-input pesticide regime.

- Overall, High Mowthorpe had the highest gross margins (£807/ha) and Drayton the lowest (£559/ha). Drayton benefited the most (+9%, £50/ha) from adopting the low-input pesticide regime and High Mowthorpe the least (-2%, £15/ha). At Drayton, relatively more pesticides were used than at the other sites and the crops there were generally less responsive to pesticide treatment.

- Reducing fungicide use offered the greatest potential for financial savings, compared with herbicides and insecticides. Overall, low-input fungicide use resulted in a gain of £16/ha, whereas the equivalent values were £11/ha for herbicides and £5/ha for insecticides, compared with the conventional regime.

- Low-input pesticide use can be profitable but not all sites and crops are suitable. There is greatest potential with fungicides. Crop rotations may also need to be modified to grow crops more locally suited to low-input pesticide use.

- The financial incentives to adopt low-input pesticide use increase under more stringent financial conditions, e.g. higher pesticide costs and/or lower commodity prices.

- Local knowledge and management skill remain vital in the profitable implementation of low-input pesticide use.

The SCARAB Project

Following extensive studies in the Boxworth Project during the 1980s at ADAS Boxworth in Cambridgeshire, the SCARAB Project was set up to evaluate the wider effects of pesticides on the environment. The work was located on three different sites across the UK, with arable rotations typical for each area.

The main objective of SCARAB was to assess the environmental impact of typical current pesticide usage, compared with that of a low-input system. It aimed to quantify the ecological effects of pesticides on:

- non-target populations of insects and spiders associated with arable crops;
- the soil's microbial activity and biomass;
- earthworms.

The impacts of two levels of pesticide use were fully assessed over a six-year period. Current Farm Practice (CFP) mirrored the practices of a typical, technically competent and financially aware farmer, with pesticides for control of pests, diseases and weeds applied at the manufacturers' recommended rates.

With the Reduced Input Approach (RIA), no insecticides, molluscicides or nematicides were used. Fungicides and herbicides, at reduced or full rates, were applied only where required to avoid a significant reduction in crop yield or value. SCARAB was driven primarily by the need to make in-depth observations on the ecological effects of pesticides. Therefore, for the benefit of the ecological studies, rigid rules, notably the complete omission of insecticides, governed the use of pesticides in the reduced-input treatment.

Results from SCARAB demonstrated that the use of pesticides in arable crops had only a limited impact on the key organisms studied. The complete absence of insecticides and nematicides in the SCARAB reduced-input treatment gave a commercial disadvantage and led to reduced profits in some cases, most noticeably in the high-value crops of potatoes and sugar beet. In practice, however, a more flexible approach to reducing pesticide use would be adopted to prevent reductions in profitability.

The effects of pesticides on arthropods in SCARAB (Chapter 3.2)

- Short-lived effects of insecticide applications within the conventional regime occurred among different groups of arthropods in all fields and years. Following some broad-spectrum insecticide applications, catches of certain species declined to zero in all sample replicates, but recovery usually occurred within the same season.

- Long-term negative effects of the conventional pesticide regime on arthropods were detected only in one out of eight sites; this was 'Field 5' at Drayton, which was under a grass and wheat rotation.

- The long-term effects of the conventional regime in 'Field 5' were only evident when springtails (Collembola) were included in the analysis, and were related to the use of the organophosphorus insecticides chlorpyrifos and dimethoate.

- Counts of some springtail species that had declined to zero after the first organophosphorus insecticide application in 1991, failed to increase again during the Project; subsequent organophosphorus insecticide applications appear to have prevented recovery. In two species, recovery had not occurred two years after all use of insecticides had ceased.

- These findings imply that long-term effects of pesticide use vary with crop rotation and may not be detected if springtails are not monitored. However, not all springtails are equally vulnerable to insecticide use, as recovery rates differed considerably among species.

- The use of organophosphorus insecticides in consecutive seasons in a grass/wheat rotation (as in 'Field 5') is relatively uncommon in UK agriculture. However, these findings suggest that such a pattern of use should be avoided if possible.

The effects of pesticides on soil microflora in SCARAB (Chapter 3.3)

- Pesticide effects on the soil bacteria and fungi showed no clear-cut pattern and were highly dependent on soil type and soil condition at the time of application. Effects were most often found with the more persistent types of pesticide.

- Fungicides generally had a short-term negative effect on soil microbial activity and biomass. Multiple applications of fungicide were often inhibitory to microbial activity.

- The effect of herbicides and insecticides on soil microbes was variable and both positive and negative short-term effects were observed.

- For the first five years, the effects of conventional pesticide use on microbial populations were transient. Recovery of the microbial biomass to levels found under the low-input regime implied greater microbial population turnover under conventional treatments.

- In the sixth year of differential pesticide treatment, at one site (High Mowthorpe) the average microbial biomass was 25% lower under the conventional regime, compared with the low-input regime.

- At one site (High Mowthorpe), there was a suggestion that the potential for microbial recycling of organic matter was greater where reduced pesticide inputs were used. This may be an early indication of a site-specific reduction in soil fertility associated with conventional pesticide use.

The effects of pesticides on earthworms in SCARAB (Chapter 3.4)

- Some short-lived effects of pesticides were observed but these were small compared with natural variation found in the earthworm populations and were difficult to relate to pesticide use.

- There were no apparent long-term trends in earthworm populations, or individual species, which could be related to pesticide use.

- The results were consistent with the known toxicity to earthworms of the pesticides used in SCARAB.

The effect of low-input pesticide use on control of weeds, pests and diseases in SCARAB (Chapter 3.5)

- Weed populations increased over time and, in six out of eight fields, overall weed populations were found to be greater under rotations receiving low-input herbicide treatments, compared with conventional rates of herbicide treatment.

- Some site-specific weeds proliferated under the low-input regime, especially shepherd's purse (*Capsella bursa-pastoris*) and knotgrass (*Polygonum aviculare*) on a lighter soil type, and cleavers (*Galium aparine*) and poppy (*Papaver rhoeas*) on a medium soil type.

- Low-input herbicide use led to an increase in weediness at all sites, and therefore, needs to be selectively targeted to prevent localised, long-term, increases in problem weeds.

- In order to create treatment contrasts for the purposes of the ecological studies, no insecticides (including nematicides and molluscicides) were permitted in the SCARAB low-input regime and at least one commercially realistic insecticide was applied in the conventional regime of each crop. No molluscicides were applied as slugs were not a threat.

- Invertebrate pests were implicated in reduced-input regime yield losses in 13 out of 28 cereal crops and 10 out of 20 non-cereal crops. Notable pest problems associated with these yield reductions included cereal aphids (mainly *Sitobion avenae*) in ten cereal crops, potato aphids (*Macrosiphum euphorbiae*) in both crops of potatoes and migratory nematodes (e.g. *Trichodorus* spp.) in all three crops of sugar beet.

- In total, 30 reduced-rate applications out of 77 RIA fungicide applications resulted in disease control at least as good as that achieved by full-rate fungicide applications in CFP. No fungicides were used in sugar beet (reflecting industry practice) and only modest fungicide dose reductions of 25% were attempted in one out of two potato crops, owing to the risk of potato blight (*Phytophthora infestans*).

- Higher levels of disease were present in the low-input treatment of many of the cereal crops grown in SCARAB, compared with the conventional treatment. However, in only 30% of the winter cereal crops were the differences in disease incidence likely to have resulted in economically important yield losses.

- Little or no difference in disease development was seen in spring barley, spring wheat, oilseed rape, beans or grass from the adoption of a reduced-rate fungicide strategy, indicating the potential to successfully reduce the amount of fungicide currently used in these crops.

- Results from SCARAB have demonstrated that pesticide use can be reduced and, in many cases, it is profitable to do so. However, it is necessary to identify and understand areas of potential risk on the farm, where reducing pesticide use would incur major losses without careful pesticide management.

The effect of low-input pesticide use on crop yields and economics in SCARAB (Chapter 3.6)

- In comparing the economic results of SCARAB with those of TALISMAN, it should be borne in mind that the complete absence of insecticides in the SCARAB low-input treatment (to fulfil the ecological objectives of the project) gave rise to a substantial commercial disadvantage.

- The overall effect of the low-input pesticide treatment was a mean reduction in yield of 12% (1.5 t/ha over all crops), and a range of responses from +1 t/ha to -14.3 t/ha, with lower yields on RIA in 75% of the 48 comparisons with CFP.

- The largest yield reductions occurred in the sugar beet and potato crops (12.8 and 6.8 t/ha respectively). These effects appeared to be linked to the lack of nematicide and insecticide to control migratory nematodes (e.g. *Trichodorus spp.*) and aphids (*Macrosiphum euphorbiae*) in the sugar beet and potato crops, respectively.

- Wheat yields were reduced by 0.74 t/ha (8.8%) overall. Some of the yield losses could be attributed to specific problems such as aphids or weed competition. Reducing fungicide inputs appeared to have little effect on disease levels and would not be expected, in general, to have significantly affected yields.

- Yield losses on the other combinable crops (barley, beans and oilseed rape) were relatively small.

- Gross margins were less affected than yields but there was still an overall reduction of 5.5 % (£47/ha).

- Low-input pesticide use reduced gross margins in 52% of the comparisons, with responses ranging from +£128/ha to -£493/ha, with the majority of reductions between £0 and £150.

- The high value sugar beet and potato crops were most affected by the low-input pesticide regime (-£286 and -£426/ha, respectively).

- Wheat yields from the low-input regime were reduced by 9%, compared with the conventional regime. However, this yield loss was offset by savings in variable (pesticide) costs of the low-input regime, so that the gross margin of the low-input wheat was 4% (£33/ha) less than that of the conventional regime.

- In practice, however, a more flexible approach to reducing pesticide use than that used in SCARAB would be adopted to prevent reductions in profitability.

Reduced Input Systems of Cropping (RISC) in Northern Ireland (Chapter 4.1)

- Cereal crops tended to show improved gross margins ranging from £14/ha to £35/ha where all pesticides were applied at reduced rate, together with the use of full rate fertiliser.

- Where individual classes of pesticides were applied to cereals at reduced rate, the greatest financial benefits were from the use of reduced rate herbicide on winter barley (£46/ha), and reduced rate fungicide on winter barley (£24/ha) and spring barley (£12/ha).

- The application of reduced rate insecticide to cereal crops also improved gross margins, but this was based on only three instances of insecticide use.

- Weed seed numbers in the soil increased from 2,000/m^2 to over 13,000/m^2 where reduced rate herbicide was used in the arable rotation for six years, and to over 28,000/m^2 where no herbicide was used.

- Weed pressure tended to increase in the arable rotation more than in the arable/grass rotation.

- Reduced rate pesticides were not cost-effective in oilseed rape and potatoes, reducing gross margins by £33/ha year and £126/ha at full-rate fertiliser use.

- Reduced rate of a soil-acting herbicide resulted in poor weed control in potatoes under dry soil conditions, with a weed biomass at harvest of 82 g/m^2 with full-rate herbicide and 356 g/m^2 with half-rate herbicide in 1995.

- Half-rate nitrogen (N) fertiliser applications were not cost-effective, reducing gross margins by £43/ha to £82/ha in cereals, £73/ha in oilseed rape and £148/ha in potatoes, and appeared to contribute little to the reduction of mineral N losses over the winter.

- The two-year grass ley contributed to soil mineral N uptake in at least the following two years.

- In the two seasons following a grass ley, with reduced rate fertiliser and/or pesticide, gross margins were consistently higher (£40/ha to £538/ha) than for the same crops in the same years in the arable rotation.

- Extractable phosphate (P) concentrations declined from Index 3 to almost Index 1 in six years where no fertiliser N, P, potash (K) or slurry was applied, and K levels declined from Index 1 to Index 0 in four years.

- The soil P effect may be particularly important for environmental protection.

- Carabid beetle species diversity was affected more by duration and density of crop cover than by levels of pesticide or fertiliser use.

Part 2

THE TALISMAN PROJECT