HGCA

PROJECT REPORT No. 173

LINK INTEGRATED FARMING SYSTEMS

(a field-scale comparison of arable rotations)

VOLUME I: EXPERIMENTAL WORK

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VOLUME I: EXPERIMENTAL WORK

Edited by

S OGILVY

ADAS High Mowthorpe, Duggleby, Malton, North Yorkshire YO17 8BP

This is the final report of a five year research project which started in April 1992. The work was funded under the LINK 'Technologies for sustainable farming systems' programme with the following grants: £644,900 – Ministry of Agriculture, Fisheries and Food (CSA 2613); £125,000 – Scottish Executive, Rural Affairs Department; £455,100 – HGCA cereals (project 1518); £33,000 – HGCA oilseeds (project 1519); £50,000 – British Agrochemicals Association; £278,000 – Zeneca.

CONTENTS

Report I

Appendices

Report II

ABSTRACT

Sue Ogilvy, ADAS High Mowthorpe

The LINK Integrated Farming Systems (IFS) project commenced in April 1992 as part of the LINK Programme "Technologies for Sustainable Farming Systems". The project was funded by the Ministry of Agriculture, Fisheries and Food (MAFF), the Scottish Executive, Rural Affairs Department (SERAD), the Home-Grown Cereals Authority (HGCA), Zeneca Agrochemicals and the British Agrochemicals Association (BAA).

The project was established on six farms situated in the main arable farming areas in the UK: covering Hampshire (Manydown), Cambridgeshire (Boxworth and Sacrewell), Herefordshire (Lower Hope), Yorkshire (High Mowthorpe) and Midlothian (Pathhead). IFS was compared with local conventional practice on split field plots, occupying approximately 50 ha per site. The main practices adopted in IFS included: targeted and selective pesticide use; balanced nutrient inputs; resistant varieties; rotational weed control; crop diversity; and flexible cultivations. A locally-relevant, five-year crop rotation was adopted at each site, with all phases of the rotation present each year. The five-year study was completed in 1997.

Pesticide use was substantially reduced across most crops (30 % less cost and 18 % less active ingredient) on IFS, with no measurable increases in pest, disease or weed problems. Also, the IFS rotations used 20% less nitrogen overall than the conventional. Although yields were generally lower on the IFS, variable and production costs were also reduced, giving an overall lower cost of production per tonne from the IFS. Although, there was some variation between sites, IFS was as economically viable as the conventional system overall. Estimates of crop management time suggested that initially up to 50% more time was likely to be spent in crop walking and decision making on IFS, but this would ease with experience.

There was no evidence of any difference in direct environmental impact on beetles, spiders and earthworms, between the two systems, despite changes in rotation and cultivation practice and large reductions in inputs, particularly pesticides, over the period of the project. Potatoes and other spring crops were the least favourable for invertebrates. Over all sites, there was a small reduction in leachable soil mineral nitrogen on the IFS plots, with the spring crops leaving behind less residual nitrogen than their winter-sown counterparts. Reductions in the intensity of cultivations, fertiliser use and the incorporation of N-fixing legumes in the rotations contributed to the lower energy consumption of 8.5 % (equivalent to 34 l/ha of diesel) in IFS.

The aim of the project was to develop an integrated system that maintained profitability with a different balance of inputs and reduced environmental impact than current conventional systems. The integrated system was designed to grow crops in ways that minimised the need for fertiliser and pesticide inputs, and this was achieved. However, one of the main conclusions to arise from the project was the recognition that a single integrated system of production - a blueprint - would not be produced, as integrated practices had to be selected and adapted to meet the needs of individual sites. Potential benefits for farmers, supported by results from the project, include: lower costs from optimised inputs; potentially higher margins when economic conditions are difficult; improved knowledge and understanding of cropping and environmental risks; greater flexibility with soil management and reduced erosion risk; improved workload spread; reduced operator risks from fewer applications; and lower energy demands. Increased adoption of integrated farming could also make further legislation or mandatory schemes to reduce pesticide use unnecessary.

SUMMARY

Sue Ogilvy, ADAS High Mowthorpe

The LINK Integrated Farming Systems (IFS) project commenced in April 1992 as part of the LINK Programme "Technologies for Sustainable Farming Systems". LINK is a government scheme which supports collaborative research between industry and the research base. The LINK IFS project was funded by the Ministry of Agriculture, Fisheries and Food (MAFF), the Scottish Executive, Rural Affairs Department (SERAD) (formerly the Scottish Office Agriculture, Environment and Fisheries Department), the Home-Grown Cereals Authority (HGCA), Zeneca Agrochemicals and the British Agrochemicals Association (BAA).

The project was set up on six representative sites to develop arable integrated farming systems which concentrate on practical feasibility and economic viability, but also take into account level of inputs and potential environmental impact. The integrated system was compared with local conventional practice at each site. This work was seen as a development of integrated farming in different geographical and climatic locations in the UK, over a wide range of soil types. ADAS, IACR Rothamsted, Scottish Agricultural College and The Game Conservancy Trust were the main scientific collaborators in this project.

The project was established in autumn 1992 on six farms situated in the main arable farming areas in the UK: covering Hampshire (Manydown), Cambridgeshire (Boxworth and Sacrewell), Herefordshire (Lower Hope), Yorkshire (High Mowthorpe) and Midlothian (Pathhead). The five-year study was completed after harvest in 1997.

The aim of the project was to develop an arable integrated system of production that maintained profitability with a different balance of inputs and reduced environmental impact than current conventional systems. There were no specific reduction targets for nitrogen or pesticides. The integrated system was designed to grow crops in ways that minimised the need for fertiliser and pesticide inputs.

Project design

Approximately 50 ha of land, divided into five main blocks, were occupied at each site. Each block was sub-divided into two field plots so that the integrated system of production could be compared with a conventional reference. Partial replication was included via additional replicate fields at some sites, by partitioning fields into four plots at other sites, or by a blend of the two approaches. A five-year crop rotation relevant to the geographic location, including rotational set-aside at four sites, was adopted at each site. All phases of the rotation were present each year, so after five years, each block had completed a full rotation. Records of inputs, outputs and potential impacts on the environment were measured throughout the course of the project.

Integrated practices

Against a background of maintaining crop profitability, practices adopted in the integrated system included: targeted and selective pesticide use at appropriate rates based on crop monitoring; nutrient inputs balanced with crop requirements, soil reserves and offtakes; resistant varieties to minimise the need for pesticide inputs; planned, rotational approach to weed control combining mechanical weed control, stale seed bed techniques and delayed

drilling with appropriate herbicide use; crop diversity in a rotation to minimise disease, pest and weed problems, to manage nutrient resources and to provide diverse habitats and food sources for beneficial species; and flexible cultivation designed to meet crop needs, retain soil structure, minimise erosion, encourage invertebrates, control weeds and minimise energy use. At some of the sites, field margins were managed to encourage biodiversity of plant species, beneficial predators and parasites of crop pests, but the main thrust of the integrated practices was in the cropping area.

Yields

Generally, yields were lower on the IFS system, when compared with the conventional system across the whole project, although this was not significant on a site basis. Different crops and husbandry practices known to have some yield effects were incorporated into the integrated system to provide other benefits. Integrated first wheats yielded significantly less (0.71 t/ha) than conventional wheats overall. On three occasions, the loss was high because of poor weed control when residual soil-acting herbicides were not used in the autumn. In other situations, delayed sowing, used to minimise disease and help control blackgrass, and also choice of variety (milling on IFS v feed on CFP) on the integrated system resulted in lower yields. However, the difference in production margin between wheats in the two systems was only £1/ha, and this takes into account the problems noted above.

Yield differences between integrated and conventional for other combinable crops were varied, often because there were different crops in the same phase of the rotation, i.e. spring v winter crops or legumes v oilseeds, so lower yields were expected. Potatoes were grown at three sites with mixed responses, ranging from no yield difference at High Mowthorpe, lower yield on the integrated at Lower Hope, to higher yields at Sacrewell.

Profitability

Over all sites, years and crops, there was on average £51/ha less gross output (which included arable area payments) from the integrated system, but variable costs were £24/ha lower and operational costs £10/ha lower. This gave an average production margin (margin over variable and operational costs) difference of £17/ha, or 2 % less on the integrated, across all the sites. The picture did vary between sites, with a significant positive difference in favour of the integrated system of £128/ha at Sacrewell, influenced by the success of the potato crop, to a significant negative difference at High Mowthorpe of £129/ha, primarily caused by choice and performance of break crops (spring beans on the IFS and winter oilseed rape on the CFP). At the other four sites, the integrated performance was not significantly different from the conventional performance but it did vary from -£18/ha at Boxworth, -£103/ha at Lower Hope (at both sites this was a result of break crop choice on the integrated) to plus £1/ha at Manydown and £18/ha at Pathhead.

When compared against production efficiency standards, such as gross margin as a percentage of gross output (50% = poor and 80% = very good), the integrated system rated 79.9% and the conventional system 78.9%. Production costs per tonne were also generally lower on the integrated system.

The time and costs required to manage the integrated system were not specifically monitored during the project. However, as part of an associated economics bolt-on project to the main study, researchers at Reading University estimated that up to 50% more time was likely to be spent in crop walking and decision making on the integrated system, but this would probably decrease with experience. This study also considered the issue of risk. There was a general perception among the site managers that the integrated system was more risky because of changes in the rotation, choice of varieties, extending the autumn drilling period, reducing soil inversion, and using less fertiliser and pesticides. The perceived risk was likely to be most acceptable in a situation where integrated products accrued additional premiums, as the case with organic production. However, premiums are unlikely to occur in the current economic climate, but with the decline in commodity prices integrated farming becomes more attractive and high input conventional farming less economically sustainable.

Overall, the integrated farming system has been shown to be economically viable and both systems performed within an acceptable range of productivity and profit, although the variation between sites needs to be noted. Improved knowledge of the risks and the benefits should help enhance future performance.

Environmental impact

There was no evidence of any difference in direct environmental impact between the two systems, despite changes in rotation, cultivation practices, and large reductions in inputs, particularly of pesticides.

Invertebrates (beetles and spiders)

Overall, there were no significant differences in numbers of beetles and spiders between the integrated and conventional farming systems. The largest differences were found between sites, years and crops. Considerable variation was found in the numbers of invertebrates between the sites, with especially low numbers at High Mowthorpe and Pathhead, the most northerly sites. Potatoes and other spring crops were the least favourable for invertebrates.

Although farming practices may affect invertebrate activity and abundance, these effects were relatively small compared with other external influences. Insecticide usage was relatively infrequent within both the conventional and integrated systems, with the exception of the potato crops, and did not have any long-term effects. Minimum tillage has been shown to favour many invertebrate species in other studies, but no consistent differences were found between cultivation techniques in this project. Where differences were detected between the farming systems, these were usually a result of a different crop being grown in the integrated system, especially where this was a spring crop, which tended to be less favourable to the beetles and spiders.

Earthworms

No consistent significant effects of cultivations, pesticides or fertiliser use on earthworm populations or biomass were found over the course of the project. Numbers of worms in the deep soils at Boxworth and Pathhead (60 to 80 worms/m^2) were in the normal range for arable soils, whereas populations were extremely low at two of the sites, Sacrewell and Lower Hope. Both of these sites grow potatoes and the associated cultivation practices may have contributed to this result, although this was not the case at the third potato site, High Mowthorpe. Similar results were also found in other recent studies on earthworm populations in arable farming systems e.g. SCARAB.

Energy use

Results from the project show that savings of 8.5 % in total energy use (including direct energy used in fuel consumed and indirect energy involved in the production of all inputs and machinery) were made by implementing an integrated approach, and this was equivalent to 1239 MJ/ha or 34 litres of diesel. Actual fuel savings were equivalent to 20 l/ha. Ploughing and its associated seedbed cultivations were very energy intensive operations, and large savings in energy use were achieved by adopting less intensive cultivations. The manufacture of fertilisers requires high energy inputs, so the reductions in fertiliser use and the incorporation of N-fixing legume crops in the rotations contributed to the reduced overall energy consumption in the integrated farming systems.

Crop protection

Crop protection inputs were determined by regular crop walking, use of thresholds and crop monitoring systems, where appropriate. Crop rotation, variety choice, date of establishment and mechanical husbandry practices were used where possible to minimise the need for agrochemical inputs. When a need was established, the most selective chemical was applied at the appropriate rate to optimise the effectiveness and efficiency of the treatment whilst minimising the potential environmental impact.

Inputs of pesticides were measured in a number of ways, cost £/ha, units[1] of active ingredient/ha and weight of active ingredient/ha. The reductions achieved between each of these measures were 31 % less cost, 32 % fewer units and 18 % less active ingredient, [1]compared with the conventional inputs of £103/ha, 6.8 units/ha and 5.93 kg/ha. The number of times the sprayer had to go into the field was also reduced by 26 % (1.2 fewer passes per ha). Over the duration of the project, the conventional pesticide inputs were comparable with standard usage on commercial crops. The greatest reductions in pesticide use on the integrated plots were in fungicide and insecticide use.

There were no measurable increases in pest, disease or weed problems where inputs were reduced. However, weed control strategies did evolve to avoid the build-up of weeds associated with minimum tillage or delayed spring weed control. Care was needed with the adoption of some integrated practices to avoid this problem.

Crop nutrition

In the project, the use of inorganic nitrogen was optimised by the efficient management of inputs and the use of husbandry procedures to minimise the loss of nitrogen, whilst maintaining an adequate level of crop production and profitability. Rotation and cover crops were used to build up and retain soil nitrogen. At some sites, crops requiring less nitrogen were used to reduce the nitrogen inputs over the whole rotation. Nitrogen fertiliser recommendations for the conventional system were based on good farm practice using a fertiliser planning programme (ADAS Fertiplan). The recommendations obtained were modified for the integrated crop on the basis of measured soil mineral nitrogen.

The application of nitrogen averaged over both rotations was very similar at all sites ranging from 130 to 144 kg/ha/yr. The integrated rotations used 28 kg/ha/yr or 20% less nitrogen than the conventional. Most sites, except Sacrewell, showed a reduction in nitrogen input ranging

[1] A unit is defined as the maximum rate of active ingredient 'Approved' for application to an arable crop.

from 4 to 46 kg/ha/yr. Most of the reductions were made where less demanding crops substituted for demanding crops in the conventional rotation.

Other basal elements were usually applied on a rotational basis to maintain soil fertility at an acceptable level. Crop residues were incorporated in the soil where practicable at three of the sites (Sacrewell, Boxworth and High Mowthorpe) to minimise the offtake of nutrients in the integrated system.

Soil mineral nitrogen levels were measured in the autumn to assess leaching risk. Site means ranged from 61 to 103 kg/ha N (0-60 cm). Over all sites, the reduction was 3 kg/ha or 4 % less soil mineral nitrogen on the integrated plots. The largest reduction of 27% was achieved at the Pathhead site. At the sites where a comparison was possible, integrated spring crops left less nitrogen behind than their winter-sown comparisons in the conventional rotation.

Validation trials

At four of the six main project sites, Boxworth, High Mowthorpe, Lower Hope and Pathhead, additional, small plot, replicated trials were established on the integrated fields to check the validity of each major input decision within the integrated system. This work was funded by MAFF and the HGCA, as a separate project. Over five years, a total of 87 replicated experiments tested 757 treatments within the integrated crops, and the main IFS treatments were only significantly worse than the alternative treatments in 7% of cases.

The results of these experiments demonstrated the general success of the management strategies which were incorporated into the main integrated treatments, although there was scope for improvement in some cases. The use of autumn weed control, primarily through the use of residual herbicides in cereals, was a critical factor in most rotations. Delaying herbicide application until spring increased the risk of yield loss and reduced profitability. Mechanical weeding was most successful in potatoes, especially when soil conditions were dry at the time of the first weed flush, and when used in conjunction with low-dose post-emergence herbicides. Nitrogen rates calculated from soil nitrogen analysis were generally correct for winter wheat, but when incorrect, yield losses were severe and profitability decreased.

Operational costs

A full inventory was made of all operations undertaken on each site and in each crop and year. Standard costings were used to apply an appropriate cost to each operation, which included an element for fuel use, labour, depreciation, repairs, tax and insurance and interest on capital. The inventory took account of all operations from seed bed cultivation to drying of harvested grain and grading of produce. The total operational costs over all crops were lower in the integrated system than in the conventional system on four of the sites (Boxworth, High Mowthorpe, Manydown and Pathhead), and little different on the remaining two sites (Sacrewell and Lower Hope). However, the differences were relatively small and mask considerable seasonal variation in total operational costs. The highest operational costs (up to £500/ha) were associated with sites growing potatoes and lowest on the medium textured soil types growing combinable crops only (up to £220/ha).

Extra operational costs arose in the integrated system as a result of mechanical weeding, mechanical pre-harvest treatments (e.g. flailing of potato haulm), through additional costs incurred in establishing cover crops, and establishing, mowing and maintaining set-aside covers, particularly where set-aside cover was maintained beyond 1 May in the year of set-aside for wildlife or environmental benefits (e.g. maintenance of green cover to minimise nitrate leaching or to provide a habitat for farmland birds).

Highest cultivation costs were associated with sites growing potatoes because of the level of cultivations required in the destoning, ridging and planting process. The greatest difference in cultivation costs between the conventional and integrated systems was observed at Boxworth, where the adoption of 'one-pass' non-inversion cultivations to establish wheat reduced costs by £21/ha/year on average. Other IFS studies have shown that large savings can be made in establishment costs by adopting direct drilling or non-inversion cultivations. For all sites, total costs of input application (agrochemicals and fertiliser) were always lower in the integrated system.

Comparisons with other studies

The results from the LINK IFS project complement those found in other UK integrated farming studies, and common messages from all the projects have been presented to the industry at a conference, in a summary booklet, and are being developed into a technical guide for farmers. The results from the project are also comparable with those from other European studies, especially in terms of reduced inputs and maintenance of profitability.

Uptake of integrated farming systems has been slow in the UK because the drivers for change have not been as strong as in some other European countries, especially Germany, the Netherlands and Denmark. In the UK, any change towards an integrated system is likely to be market-led rather than by statutory control. Already, increasing consumer demand for safe healthy food produced by environmentally friendly methods is likely to influence the uptake of such farming systems, alongside or in preference to organic production in the future.

Farmer uptake will be assisted by the provision of sound technical and practical advice arising from the current research projects. To make best use of the results from this project, farmers would need to identify which of the six sites was most appropriate to their own farming situation, to identify the issues and which successful integrated techniques they could adopt. Further assistance will be provided by an IFS practical guide to be produced by the members of the Integrated Arable Crop Production Alliance (IACPA).

However, it should be recognised that the continuing downturn in the economic situation in farming, especially in relation to changes to the CAP under Agenda 2000, proposed pesticide and fertiliser taxes, combined with the environmental and consumer demands, increase the need for sound research to continue to develop integrated systems for the future. New research, which builds on the results from the LINK IFS and other IACPA research projects, is needed to underpin the development of sustainable agricultural systems, the production of safe, affordable food, and the continuation of a viable agricultural industry.

KEY MESSAGES

Sue Ogilvy, ADAS High Mowthorpe

Profitability

- Integrated farming can be as profitable as conventional farming, provided the rotation and integrated practices are selected with care, and adapted to the specific needs of the farm.

- Yields and gross output are likely to be lower with an integrated system; but these reductions should be offset by lower input and cultivation costs, giving lower production costs per tonne of produce.

- The production efficiency of an integrated system can match that of conventional farming.

- Pesticide use can be substantially reduced across most crops, with the greatest reductions in fungicide and insecticide use, without measurable increases in pest, disease or weed problems. Potential logistical and operational benefits may also occur.

- Nitrogen inputs can also be substantially reduced, by matching nitrogen supply to soil reserves and crop needs; and replacing high N demand crops with low N demand or nitrogen-fixing crops.

- Initially crop walking and decision-making are likely to take up to 50% more time, although this eases with experience.

Environment

- There is no evidence from this study that changing to an integrated system with a different rotation, cultivation practices and lower inputs will have direct benefits on numbers and diversity of beetles, spiders and earthworms.

- Potatoes and other spring crops are the least favourable for invertebrates.

- Leachable soil mineral nitrogen can be reduced from an integrated system, especially if spring crops are used in the rotation.

Energy use

- Ploughing and seedbed cultivations are very energy intensive operations, and large savings in energy use can be achieved by adopting less intensive cultivations.

- Reductions in fertiliser use and the incorporation of N-fixing legume crops in the rotation can contribute to reduced overall energy consumption in an integrated system.

CHAPTER 1 - Introduction

Sue Ogilvy, ADAS High Mowthorpe

Background

During the past decade, output values for agricultural products in the UK have progressively decreased in real terms, while at the same time input costs have increased. The reform of the Common Agricultural Policy and the influence of the General Agreement on Tariffs and Trade (GATT) have resulted in lower support payments linked to farmed land area rather than production. The reality of reduced grain prices has accelerated the process of reducing costs per unit of output to maintain profitability.

There has also been strong pressure from the EU, the national government, non-government organisations and consumers, for farmers to become more concerned over environmental protection, food traceability, quality and safety. Pressures on UK farmers to reduce inputs of agrochemicals have generally been less than in some European countries, where particular environmental problems associated with intensive pesticide use and nutrient leaching have had to be addressed. Within the EU Fifth Environmental Action Programme (FEAP), launched in 1992, targets were set for a significant reduction of pesticide use per unit of land under production and conversion to agricultural methods of integrated production, especially in nature conservation areas (Reus *et al*., 1997). Policies relating to FEAP were set by individual member states with some defining plans to minimise the use of pesticides or to reduce pesticide emission.

In the UK, the preference has been for self-regulation by responsibility and accountability, rather than by statutory control or specific financial inducements. However, specific EU directives have been implemented which place controls on the quality of ground, surface and drinking water in relation to pesticides and nitrates which impact on agricultural practices, and Codes of Good Agricultural Practice have been produced by MAFF (Anon., 1999a, b, c) to help minimise these problems. Numerous voluntary schemes have also been introduced such as the Nitrate Sensitive Areas (1992), Nitrate Vulnerable Zones (1995), Environmentally Sensitive Areas (1987), Countryside Stewardship Scheme (1991) which aim to improve the environmental management of land. At the moment, there is no general scheme in the UK requiring the minimisation of pesticide use on mainstream agricultural land, although the imposition of a Pesticides Tax is currently being considered by the UK Government, and issues relating to pesticide minimisation are being considered by a Government-led committee, the Pesticides Forum (Anon., 1998d). Taxes on fertilisers and energy are also under consideration.

Farmers are responding to these numerous pressures, particularly those relating to consumer and environmental concerns about pesticide residues in food and production systems, in different ways. A small percentage have converted to organic farming, and interest in this type of production is likely to increase as consumer demand rises. Some farmers will continue with high input intensive farming methods to remain economically viable. Others are already moving away from using high rates of inorganic fertilisers and from using prophylactic and insurance pesticides at full recommended rates, and are basing treatments on managed inputs, thresholds and appropriate rates (Burnhill *et al*., 1996, Thomas *et al*., 1996) - effectively moving towards an integrated system - as a means of coping with these pressures. Although reduced fertiliser and pesticide use will save costs, yields and profitability will be maintained only if husbandry practices are also modified to help limit nutrient losses, leaching risk, soil erosion, pest, disease and weed problems, to develop a truely integrated system on the whole farm.

Definition of integrated farming

The concept of Integrated Farming Systems (IFS) or Integrated Crop Management (ICM) has several definitions, some of the main ones are listed in Appendix D. Whatever definition is used, the aims of integrated farming, in America and a number of European countries including the UK, are broadly similar but vary in the degree to which agrochemical inputs, both of pesticides and fertilisers, are replaced by alternative practices. An overriding principle of integrated farming is the consideration of all inputs and practices within a crop, within a farm and how they interact with each other. By understanding where, when and how these interactions occur, farming practices can be adopted to mitigate some of the actions that may cause adverse effects, such as effects on non-target species, pollution caused by leaching and run-off, loss of habitats, soil erosion and other issues associated with intensive arable farming practices.

European research

Much previous and current agricultural research has been orientated towards single factors or problems, and short-term studies. Alternative research methods have been adopted which look at farming systems over rotations to measure cumulative effects over five or six years, and to express the interactions between husbandry techniques, agrochemical inputs, pests, diseases, weeds and crop performance on large field areas over longer periods of time. Such integrated farming has been researched in several European countries and the UK (Holland *et al.*, 1994).

Expertise in IFS research has accumulated gradually since 1979, when the first three projects were started at Lautenbach in Germany, at Nagele in the Netherlands and at Ipsach in Switzerland (El Titi, 1989; Vereijken, 1989; Hani, 1989). A working group was set up in 1986 within the framework of the International Organisation for Biological Control of Noxious Animals and Plants (IOBC) which brought together interested researchers from a number of European countries (Vereijken & Royle, 1989).

In 1992, the European Commission financed a Concerted Action to develop a representative European network of research teams working on Integrated Arable Farming Systems (IAFS), to produce a common methodology and provide effective dissemination of the results (Vereijken, 1992, 1994, 1995, 1996, 1998). Two research projects in the UK joined this European network; the Less Intensive Farming and Environment (LIFE) project (Jordan *et al.*, 1995) and the LINK Integrated Farming Systems (LINK IFS) project (Ogilvy *et al.*, 1995). The methodology comprised four steps:

(1) to draw up a hierarchy of general and specific objectives;
(2) to quantify what has to be achieved with a set of parameters related to the objectives, and establish the farming methods needed to achieve the quantified objectives;
(3) to design a prototype to link the parameters and methods;
(4) to test and improve the prototype, in particular the farming methods, until the quantified objectives have been achieved.

The hierarchy of objectives for the LINK IFS project (UK2) are shown in Table 1.1.

Table 1.1 - Hierarchy of objectives for the LINK IFS project

Major objectives	**Priority***	
	UK2	**EU**
Basic income and profit	6	4.6
Abiotic environment	5	4.8
Food supply	4	4.4
Nature and landscape	3	3.6
Employment	2	1.7
Health and well-being	1	1.8

* Highest number indicates the highest priority.

In the LINK IFS project, basic income and profit was the main objective ahead of abiotic (soil, water, air) environment and food supply. Financial viability at the farm level was seen as being crucial to ensure the success and continuity of farming businesses, the adoption of environmentally sound farming practices and the successful uptake of integrated systems. The specific objectives of the LINK IFS project were similar to the average of the 13 European prototypes, although in the European average, abiotic environment was considered to be the main objective just slightly ahead of basic income and profit. Further details of the parameters, methods, desired and achieved results and the theoretical prototype are given in Ogilvy (1996) and Vereijken (1996).

UK Research and demonstration projects

In the UK, there are four main, large field-scale integrated farming research projects based on commercial or research farms. These include the LIFE, LINK IFS, Focus on Farming Practice (FOFP) and Rhône Poulenc Farm Management (RPMS) projects (see Appendix D, Table 1.2 for more details) covering a total of nine experimental sites in England and Scotland. The LIFE project started at Long Ashton in 1990, followed by the LINK IFS project on six sites in 1992, FOFP at Stoughton in 1993 and RPMS in Essex in 1994. The projects complement each other rather than duplicate effort, as they cover a wide range of soil types, geographical and climatical areas and different crops.

The projects have all been designed to develop practical integrated arable farming systems on a field scale, and are compared with local conventional practice at each site. The aims of these projects are therefore different to those of the Boxworth, SCARAB and TALISMAN projects which specifically looked at the agronomic, economic and environmental effects of different levels of agrochemical inputs rather than developing systems that required lower levels of inputs (Cooper, 1990; Young *et al.*, 2000).

The Balancing Environment and Agriculture in the Marches (BEAM) demonstration project started in 1996 looking at implementing integrated farming on a farm scale (285 ha) with a mix of arable, beef and sheep enterprises.

The integrated farming research and demonstration projects are co-ordinated in the Integrated Arable Crop Production Alliance (IACPA) along with Linking Environment and Farming (LEAF), Targeted Inputs for a Better Rural Environment (TIBRE) and Farming and Wildlife Advisory Group (FWAG) (Appendix Table 1.2). IACPA was set up in December 1994 to ensure that the members of the Alliance work together so that a range of common cropping problems are addressed in their research; that literature and research and development findings are exchanged on a regular basis so that unnecessary duplication of work can be avoided; and that more effective dissemination of the results and formulation of common messages are passed onto the industry as soon as possible. Messages from all the IACPA projects were published in October 1998 and presented at a conference to farmers and their advisors (MAFF, 1998).

Integrated farming practices

The replacement of external farm inputs (mineral fertilisers, pesticides and energy) by means of on farm produced substitutes and better management of inputs is a major objective of integrated farming to reduce the environmental impact of agriculture (El Titi *et al.*, 1993). Partial substitution of inputs can be achieved by the use of natural resources, the avoidance of waste and the efficient management of purchased materials. This can lead to reduced production costs and less pollution. Integrated farming requires the sequential consideration of a number of integrated practices on a whole farm basis, against the background needs of providing a profitable income and the demands of the markets for crop produce. Some of the practices described below are not ignored in conventional farming systems. However, the essential difference between conventional and integrated farming lies in the basic philosophy of integrated farming which aims to grow crops in ways that collectively minimise the need for external farm inputs, and protects and improves the environment; the general conventional philosophy is more one of maximising production and profitability within permitted limits and environmental controls. However, it is perhaps inevitable that as farmers gain experience of the results of new research that tomorrow's 'conventional' tends to drift towards today's IFS.

Detailed integrated farming practices are described by Vereijken (1995) and El Titi *et al.* (1993), key practices are:

Crop rotations - Used to increase the diversity of crop species to prevent disease and pest carryover from crop to crop and the development of persistent weed problems; to ensure effective nutrient uptake by scheduling crops with different nitrogen demands and transfers in the correct sequences; to preserve physical soil fertility by ensuring there is a balance of crops which cover the soil well, produce good rooting structure and reduce compaction, with crops that may result in soil erosion or compaction. Resistant cultivars are used to minimise the need for chemical inputs.

Soil protection - Cultivations should be minimal to reduce energy inputs, the risk of soil erosion by water or wind and adverse effects on soil invertebrates such as earthworms and predatory beetles and spiders, but should ensure effective seedbed preparation and crop establishment, weed control, incorporation of crop residues and restoration of physical soil structure, where compaction or erosion cause problems. Cultivations are subject to the constraints of soil type, crop requirements, weed problems and climate and need to be planned over a rotation, incorporating inversion and non-inversion techniques.

Crop nutrition - Nutrient inputs should be carefully calculated to balance with individual crop requirements, crop offtakes, existing soil residues and residues from previous crops, without leaving excess residues which could be lost by leaching or run-off. Regular soil analysis is recommended so that inputs of chemical fertilisers and organic manures can be adjusted. Crop residues should be incorporated in the soil where practicable to minimise offtake of nutrients, and cover crops/green manures can be used before spring crops to minimise leaching and erosion, where weather and soil conditions permit their establishment.

Crop protection - A fundamental feature of integrated farming is integrated crop protection which is the prevention and control of pests, diseases and weeds to maintain quality production and output with the minimal use of well-selected pesticides which have minimal off-target effects. Alternative husbandry techniques such as time of establishment, method of primary cultivation and mechanical weeding are used where appropriate to minimise the need for pesticide interventions. In-crop monitoring systems and trapping techniques are used to determine disease and pest levels, and appropriate rates of pesticides are used relative to the size of the problem to be controlled, crop and environmental conditions. Precision farming techniques will be used increasingly to target pesticide use more accurately. Habitats for predators and parasites of crop pests are improved to increase the natural level of biological control.

Wildlife & landscape - Integrated farming involves planning a programme for the whole farm, including the cropped areas as well as the non-farmed land, to enhance biodiversity and landscape features. This may include developing and maintaining a network of hedges, ditches, field margins, beetle banks and conservation headlands, which enable wild species to establish and migrate, and to provide recreational areas for people. A greater diversity of broad-leaved weed species may be left within crops to provide food sources for birds and insects, provided the numbers of aggressive, crop-damaging weeds are contained.

Energy efficiency - It is important that energy consumption, especially of fossil fuels is efficient. This can be best achieved by detailed analysis of energy use on farms with remedial action to minimise waste, consideration of alternative energy sources, changes in conventional farming practices such as soil cultivation, replacement of high fuel consumption machinery with more fuel efficient alternatives and rationalisation of vehicle movements.

Pollution and waste - Pollution of water, soil or air is a risk on any farm, and integrated farming requires that farmers fully comply with the relevant codes of practice. Recycling of crop residues is required and recycling or safe disposal is required for non-organic wastes such as plastic.

These principles and practices have been considered in relation to the representative sites and crop situations, and built into the LINK Integrated Farming Systems project. The results are described and assessed in the rest of this report.

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CHAPTER 2 - Method

Sue Ogilvy, ADAS High Mowthorpe

The LINK Integrated Farming Systems (IFS) project commenced in April 1992 as part of the LINK Programme "Technologies for Sustainable Farming Systems" (Wall, 1992; Prew, 1993). LINK is a government scheme which supports collaborative research between industry and the research base. Government provides 50 % of the financial support with the remainder coming from industry.

The LINK IFS project was funded by the Ministry of Agriculture, Fisheries and Food (MAFF), the Scottish Executive, Rural Affairs Department (SERAD) (formerly the Scottish Office Agriculture, Environment and Fisheries Department), the Home-Grown Cereals Authority (HGCA), Zeneca Agrochemicals and the British Agrochemicals Association (BAA). ADAS, IACR Rothamsted, Scottish Agricultural College and The Game Conservancy Trust were the main scientific collaborators in this project.

The project was set up on six representative sites to develop arable integrated farming systems which concentrate on practical feasibility and economic viability, but also take into account level of inputs and potential environmental impact. The integrated system was compared with local conventional practice at each site. A wide range of soil types, geographic, climatic and cropping situations were chosen, but it was not possible to cover all farming types in the UK, for example, field vegetable production and sandy soils growing sugar beet were not covered by this study.

Mixed farming systems were considered but were not adopted due to the complexity of the experimental design, and also because the main users of pesticides and fertilisers, and the industry sponsors, were arable producers. It was recognised that mixed farming systems might be one of the most sustainable types of farming systems, especially if grass leys and organic manures were fully incorporated in a rotation. However, it would be unrealistic to expect many arable farmers to adopt livestock enterprises because of the lack of market demand and the lack of infrastructure on arable farms.

Location of sites

The project was done on six sites with a wide range of soil types and geographical situations in the main arable areas of the UK. Four of the sites were on commercial farms, and the other two sites were on ADAS Research Centres.

Fig. 2.1 - Location of sites

- 1. Sacrewell, Cambs
- 2. Boxworth, Cambs
- 3. High Mowthorpe, N. Yorks
- 4. Lower Hope, Hereford
- 5. Manydown, Hants
- 6. Pathhead, Midlothian

Table 2.1 - Locations, soil types and site management

Site no.	Site code	Site name	Location	Soil type	Site management
1	SW	Sacrewell	Scott Abbott Arable Crop Station, Sacrewell, Peterborough	Shallow stony clay loam over limestone	IACR Rothamsted, William Scott Abbott Trust
2	BW	Boxworth	ADAS Boxworth, Cambridge	Clay	ADAS
3	HM	High Mowthorpe	ADAS High Mowthorpe, Malton, N Yorkshire	Silty clay loam over chalk	ADAS
4	LH	Lower Hope	Lower Hope Farms, Ullingswick, Hereford	Silty clay loam	ADAS
5	MD	Manydown	Manydown Company, Basingstoke, Hampshire	Silty clay loam on chalk and flint	The Game Conservancy Trust Manydown Company
6	PH	Pathhead	Rose Mains and Turniedykes Farms, Pathhead, Midlothian	Sandy clay loam	SAC, Edinburgh

Duration

The project commenced in April 1992, when baseline monitoring was carried out on the project fields before the treatment splits were imposed. This baseline monitoring was limited at the Lower Hope site as the project fields were not allocated until harvest 1992. Differential treatments commenced in autumn 1992 as the new season's crops were established, and a total of five cropping seasons were included in the study. The main field treatments and monitoring finished after harvest in 1997.

Objectives

The working objectives of the LINK IFS project were:-

- to integrate the latest results coming from research into a production system which would optimise the use of inputs compatible with production needs, profitability and environmental concerns;
- to make valid comparisons between the integrated system of production and conventional practice for profitability, energy balance and environmental effects;
- to investigate scientifically the interactions between component parts of the systems.

Individual site aims are detailed in Table 2.2 in Appendix E.

Treatments

The integrated system was compared with a reference conventional system at each site.

The ***integrated system*** was defined as a husbandry system which maximised profitability with a different balance of inputs to that used conventionally, and aimed to achieve environmental benefits.

Conventional practice was defined as crop husbandry which maximised profitability using external inputs applied within permitted limits to overcome constraints on production.

Management controls were built in at the outset so that treatment decisions were based on clear guidance to ensure a common approach wherever possible, and also to ensure a clear distinction between systems. Detailed guidelines were produced by recognised crop specialists in conjunction with the project management team to aid the decisions for the integrated disease, pest and weed control and fertiliser use. Site managers had direct access to these specialists if particular guidance was needed for a specific treatment. In the first two years of the project, a regular conference call was held between site managers and the specialists to ensure that a common approach to the treatments was adopted where this was appropriate. However, the integrated and conventional approaches did vary from site to site as a result of different soil and climatic conditions, different pest, disease and weed pressures and different environmental problems. Guidance was also provided on the use of appropriate machinery for the integrated system for each site. (The specialist advisors are listed in Appendix B.)

Rotations

The experiment was based on five-course rotations with crops chosen to be appropriate to each site, details of which are given in Chapter 4.

Design

At each site, a minimum of five fields was allocated to the project, so that each phase of the rotation was present in each year. At the end of the study, each field had been through a full rotation. Each field was sub-divided so that comparisons could be made between the integrated and conventional treatments. One half of each field was managed on an integrated system, and the other half was managed according to local conventional practice.

In addition, at each site, a minimum of two fields was replicated, giving totals of 14 to 18 split field plots per site. The replication was done either by sub-dividing a large field into four split field plots or another field was included in the project. The minimum split field plot size was fixed at 2.5 ha with a minimum plot width of 72 m, but plot sizes ranged up to 13 ha, and approximately 50 ha were devoted to this project at each site (more details are given Chapter 3).

Validation trial design

At four of the six sites, Boxworth, High Mowthorpe, Lower Hope and Pathhead, small plot replicated trials were established on the integrated fields to check the validity of each major input decision within the integrated system. This work was funded by MAFF and the HGCA, in addition to the main LINK project (more details are given in Chapter 12).

Integrated practices

Not all integrated practices were suitable for adoption at all of the sites. Each site selected the practices appropriate for their locality, soil type, crops, their specific goals and aims and environmental issues to be tackled. The types of practices adopted at each site are detailed in Appendix E, Table 2.3.

Monitoring and assessments

This was a large-scale research project and all crops were monitored and assessed at a much higher intensity than would normally be required for commercial cropping. Details of the monitoring and archive assessments carried out are given below:

Monitoring

Weeds	Routine crop walking in autumn and spring to determine populations and species for herbicide selection and mechanical weed control options. Crops also monitored post-treatment to determine residual weed problems and to identify weed patches to improve control in the following season.
Pests & diseases	Routine crop walking to determine pest and disease problems, frequency dependent on time of year, crop growth stage and environmental conditions. Soil and crop sampling used to determine thresholds as appropriate, trapping techniques for slugs, weevils and pea moth also used. In crop weather monitors used at the three potato sites to determine blight risk periods at the field level. Forecasting systems for BYDV, aphids and blight were used where appropriate to trigger crop inspection and treatment if required.
Nutrients	Routine annual soil sampling to 15-30 cm for pH, phosphate, potash,

magnesium and organic matter content. Autumn and spring soil mineral nitrogen samples were taken from 0 to 90 cm from 10 sampling points in each field plot. The spring SMN sample was incubated, and hot potassium chloride was used to extract the nitrate mineralised from the soil organic matter.

Crop growth	Routine weekly crop walking in the main growing season recording crop growth stages and general appearance, including lodging and leaning.

Archive assessments

Weeds	Weed numbers and species were assessed on fixed quadrats (4 x 0.1 or 0.25 m^2 quadrats along a 12 m transect at each of 4, 30, 40, 50, 60, 70 m distances into the field) in the autumn, spring - before rapid crop growth, and in the summer - mid-June to mid-July. Spring crops were assessed before weed control was applied and before rapid crop growth. Weed seedbank samples were taken at the beginning and end of the project from one quadrat on each of the weed assessment transects. Each sample was taken from a 1 m^2 area which was cored to a depth of 0 to 10 cm and 10 to 20 cm. (Results from this assessment will not be available until 2000.)
Pests and diseases	Assessments for pests and diseases were triggered by spray decisions, but minimum assessments included:-

Cereals	GS 71, watery ripe: 25 plants and roots assessed for leaf, ear, stem-base and root diseases, green leaf area, aphids on ears and any other pest damage.
Oilseed rape	GS 1.9-2.1, end of rosette: 50 plants assessed for stem and petiole boring larvae. GS 6.3-6.4, seeds ripening: 50 plants assessed for stem and pod diseases, stem boring pests, shattered pods, pod midge and seed weevil larvae in pods.
Peas	GS 204, first pods: 25 plants assessed for aphids, thrips and weevil damage. GS 207, pod fill: 25 plants and roots assessed for pod and leaf diseases and foot rot.
Beans	GS 206, pod swell: 25 plants and roots assessed for stem, leaf and pod diseases, foot rot and nodule damage.
Potatoes	July: 25 plants and roots assessed for stem and leaf diseases, aphids and PCN cysts on roots. Harvest: 50 tubers assessed for surface and internal tuber diseases, slug damage and vascular staining. Out of store, Jan: 50 tubers assessed for surface and internal tuber diseases and vascular staining.
Linseed	Start of senescence: 50 stems assessed for capsule and leaf diseases.

Nutrients	Soil analyses and SMN sampling as detailed in monitoring. Plant samples of grain/straw, tubers/haulm were taken at harvest for harvest index assessment and nutrient offtake.
Crop growth	Combinable crops - autumn and spring plant populations, fertile tillers and harvest index. Crop yield assessed from a 1 ha yield sampling area mid field

plot. Grain samples were assessed for dry matter content, thousand seed weight, hectolitre weight, Hagberg, SDS and grain nitrogen where appropriate; oil content and glucosinolate for oilseed rape and oil content for linseed.
Potatoes - tubers were assessed pre-planting for sprouting, weight and size. Emergence counts, ground cover assessments, stem numbers and harvest index were done post-planting. Potato yields were assessed from five samples of two rows x 20 m per field plot. Tuber numbers and size grades were recorded and tubers assessed for skin finish, mechanical damage and greening.

Energy

Details and dates of all field operations were recorded, and the available machinery assessed at each site. Standard energy figures were determined for all inputs and operations, on the basis of data from published literature or actual usage on site.

Profitability

Records of fertiliser and pesticide use and all field operations were taken and the unit costs determined for each operation. Gross margins over variable costs, and production margins over variable costs and operational costs were calculated.

Climate

Rainfall and temperatures were recorded at each site.

Invertebrates

Pitfall trapping and D-Vac suction sampling for selected invertebrate species was done. Ten pitfall traps were installed in each field plot area on fixed points, in two transects 10 m apart at 30, 40, 50, 60 and 70 m from the field margin. Traps were opened for five sampling days per sampling occasion in summer and 10 days in autumn and spring. In autumn-sown crops, sampling occasions were before and after any insecticide application. If no insecticides were applied then two sampling occasions occurred in autumn and then monthly from March onwards. In spring-sown crops, samples were done monthly after drilling until harvest, additional samples were taken within one week after any insecticide application.
D-Vac samples were taken in cereals after mid-June and before any insecticide application, at three of the sites (Manydown, High Mowthorpe and Sacrewell).
Earthworms were sampled prior to the start of the differential treatments in autumn 1992; a mid-term sample was taken in spring 1995 and a final sample in 1997, from two 60 x 60 cm quadrats dug and sorted to plough depth, and then formalin-drenched to bring up deep burrowing worms (not at SW).

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CHAPTER 3 - Experimental design and statistical analysis

Peter Chapman, Eddie McIndoe, Mark Lennon, Zeneca

Introduction

This chapter discusses a number of issues relating to statistical design, analysis and interpretation of the results from the LINK IFS project. Because of the project's very large scale and because of the nature of the treatments, several aspects of this experiment are non-standard and present some interesting challenges. As a result, a great deal was learnt during the conduct of the experiment, and the lessons learnt are described in Appendix F of this report.

Experimental design

The LINK IFS project was carried out at six sites in the UK between 1992 and 1997. The 1992 harvest year was a pre-treatment year, with the main project starting in autumn 1992 and continuing for the following five harvest years. For a detailed description of the experiment see Chapter 2.

Prior to the start of the project, a feasibility study was carried out in order to consider the various options for the experimental design. The results of this study are reported in Pearce (1992).

The experimental layout at each site comprised between five and seven fields, each of which was split or quartered into smaller plots. The original proposal was for a design of five split fields but such a design allowed no degrees of freedom for estimation of within field (between plot) experimental error variance. At a relatively advanced stage in the study design, therefore, replication was included via additional replicate fields at some sites, or by partitioning fields into four plots at other sites, or by a blend of the two approaches. The number of fields and plots at each site are shown in Table 3.1.

Table 3.1 - Number of fields and total number of experimental plots at each of the six sites

Site	Number of fields	Number of halved fields	Number of quartered fields	Total number of experimental plots
Sacrewell	5	3	2	14
Boxworth	6	4	2	16
H. Mowthorpe	5	2	3	16
Lower Hope	6	5	1	14
Manydown	7	5	2	18
Pathhead	7	7	0	14
Totals	36	26	10	92

The two treatments, comprising the integrated and conventional farming systems, were allocated at random to plots within a field for the entire five-year period. A five phase, five year crop rotation was then implemented within each field, with each phase of the rotation present in each year, hence the minimum requirement of five fields at each site. Details of the rotations at each site are shown in Chapter 4.

The ANOVA table for the original design of five split fields is shown in Table 3.2. This demonstrates clearly that the design is nested, with phase, year and the phase*year interaction being between field effects, whilst system and all interactions with system are within field (between plot) effects. There are no degrees of freedom for estimating within field error variance but there are 16 degrees of freedom for the system*phase*year interaction which could have been used as a substitute for the error.

Table 3.2 - ANOVA structure for each individual site and for the original non-replicated design, showing the degrees of freedom for each source of variation in the fitted model from the within site analysis.

Source of variation	Original design	SW	BW	HM	LH	MD	PH
Phase	4	4	4	4	4	4	4
Year	4	4	4	4	4	4	4
Phase x year	16	16	16	16	16	16	16
Main plot error	0	0	5	0	5	10	10
Main plot total	24	24	29	24	29	34	34
System	1	1	1	1	1	1	1
Phase x system	4	4	4	4	4	4	4
Year x system	4	4	4	4	4	4	4
Phase x year x system	16	16	16	16	16	16	16
Split plot error	0	20	25	30	15	30	10
Split plot total	25	45	50	55	40	55	35
Overall total	49	69	79	79	69	89	69

The ANOVA table for each of the six sites is also shown in Table 3.2. These show that the degrees of freedom available for estimating within field (between plot) experimental error variance ranges between 15 and 30. This difference arose because (i) the total number of plots varied between sites and (ii) the balance between additional fields and quartered fields also varied between sites.

Treatments and responses

A very large number of experimental responses were measured at each site in each of the treatment years. A large number of variables are also required to describe each treatment because the treatments were complex strategies (i.e. combinations of crop variety, farm practices, fertiliser and pesticide applications etc.) which are different in each plot within a treatment group. A comprehensive list of both treatment descriptors and responses is given in the data handling protocol separate to this main report.

An interesting and possibly unique feature of this experiment is therefore that the conventional and integrated treatments are not fixed entities. For example, a conventional wheat plot may receive an application of an insecticide whilst a replicate plot in a different field might be left unsprayed. Thus when computing the mean response to the integrated or conventional strategy for a specific crop, for example, the levels of fertiliser, pesticide and so forth might be quite different for each component of the mean.

Another very unusual feature of this experiment is that whilst some measurements are clearly responses and some are clearly treatments, some variables possess characteristics of both. For example, yield and soil nutrient levels are clearly responses. In contrast, fertiliser inputs more clearly exhibit the characteristics of treatments because they are determined by a desire to reduce chemical input to the environment rather than as a response to developments within the trial. Pesticide input, however, exhibits characteristics of both responses and treatments. It is partially determined by a desire to reduce chemical input to the environment, but is also partially determined by such things as crop variety, poor pest control from earlier low applications and so forth. For purposes of statistical analysis, this situation was resolved in the following way: fertiliser inputs were classed as treatments and not analysed, whilst all other measurements were classed as responses and subjected to statistical analysis.

Statistical analysis

Methods

For those measurements that were classified as treatment components, rather than responses, and so were not statistically analysed at all, comprehensive tables of means were produced using the SAS© software (SAS Institute, 1998).

For purposes of initial reporting, all those measurements that were classified as responses or partial responses were analysed via a within site ANOVA according to the structure given in Table 3.2. Taking account of year in an analysis such as this is always a difficult decision, but in this case it was widely believed to be appropriate to designate system as a factor nested within year and phase. Again the software used was SAS©.

Cross site analyses were also carried out. The ANOVA table showing the structure of these analyses is given in Table 3.3. Because phase is meaningless as a between site entity, crop was used as a substitute in the between site analysis. For cross site analysis, it was found to be easier to use the GENSTAT software (Payne, 1989).

In very many of the analyses carried out, the data were transformed onto the log scale prior to analysis. This was mainly because of the presence of potatoes in rotations at three of the sites. The yield and margins for potatoes were usually both much larger and much more variable than for other crops which, without transformation, would have resulted in the assumptions of the analysis of variance being violated. To ensure consistency, data were transformed even when potatoes were excluded from the analysis. However, since de-transformed means often looked distinctly odd, raw untransformed means are presented throughout this report even when analyses are based on transformed means.

Table 3.3 - Statistical analysis across sites: ANOVA structure showing the degrees of freedom for each source of variation

Source of variation	**Degrees of freedom**
Crop	11
Year	4
Site	5
Crop x year	44
Crop x site	10
Crop x year x site	32
Between field error	53
Between field total	179
System	1
Crop x system	11
Year x system	4
Site x system	5
Crop x year x system	44
Crop x site x system	10
Year x site x system	20
Crop x year x site x system	32
Within field error	153
Within field total	280
Overall total	459

The statistical analyses produced for this report should be seen as preliminary. The data base created from this experiment is huge and highly complex, comprising many inter-correlated variables. There is much scope for applying more complex analyses, such as multivariate ordination techniques, to try and unravel patterns and relationships within the data. A more detailed description of the analyses carried out can be found in Lennon (1998).

Interpretation of results

Multi-factorial analyses of variance can be very difficult to interpret. The correct procedure for determining how to express the results involves testing the highest order interaction for significance in the first instance. If the highest order interaction is significant, then presentation of results should take the form of a table of means corresponding to this interaction, together with standard errors, confidence intervals and so forth. If the highest order interaction is not significant, then all of the interactions with one fewer dimensions should be tested. If one or more of these is significant then table of means corresponding to them should be presented. So the testing procedure carries on until the first significant interaction is found, and stops there.

In the analysis of single assessment such as yield from a single site, the highest order interaction is between phase, year and system. If this is significant then results should be presented as a three-way table of results. If this interaction is non-significant, the three two-way interactions should be tested and two-way tables presented for any that are significant.

The problem with this approach is that expressing the results can be a complex task. However, the temptation to present results in terms of two means, one for the conventional and one for the integrated should be avoided unless there are really no significant interactions. In the presence of high order interactions involving system, simple means for integrated and conventional treatments are meaningless and potentially misleading.

Precision

The purpose of the LINK IFS project is to compare the integrated and conventional systems. The precision of this comparison depends not only upon the measurement being analysed but also on the site, year, crop and will also very much depend on the effects that are significant in any given analysis.

As a very rough guide, Table 3.4 shows the LSDs for the overall mean difference between integrated and conventional treatments based on untransformed data at each of the six sites. For yield, the estimate of the overall difference is precise to within ± 0.5 t/ha, and for production margin to within ± 50 £/ha. These figures assume no significant interactions - if interactions are present, these figures would get worse.

Table 3.4 - Least square differences at the 5% level for comparing the two farming systems from analysis of yield (t/ha) and production margin (£/ha).

Site	Yield (t/ha)	Production margin (£/ha)
Sacrewell	*0.46	*33.14
Boxworth	0.26	31.78
H. Mowthorpe	*0.27	*29.52
Lower Hope	*0.19	*23.54
Manydown	0.26	46.60
Pathhead	0.47	48.82
Across all sites	*0.14	*16.84

*Results with potatoes excluded from the analysis.

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CHAPTER 4 - Rotations

Bob Prew, IACR Rothamsted

Introduction

The change in agricultural land use from balanced rotational cropping within mixed farming systems, to large areas of continuous arable production, has been one of the main responses to meet past policy requirements for increased production. However, intensive agrochemical and fertiliser use may well have contributed to current problems and impacts on environmental pollution (Ward, 1997). Crop diversification on the other hand, whether between fields or within fields, is likely to reduce demand for external inputs, thereby increasing the potential for sustainability (Jordan & Hutcheon, 1996).

Whilst crop choice is dependent upon location and soil type, choice is primarily market-driven, and conventional cropping patterns are usually determined by selection of the most profitable crops for the farm unit. Less intensive, integrated production systems also focus on the profitability of the farm unit but, to conform strictly with the Guidelines for Integrated Production (El Titi *et al.*, 1993), crop rotation is mandatory and must include at least four different crops. Within the multifunctional crop rotation (MCR) in the European prototypes (Vereijken, 1995), crop species frequencies are limited to 25%, and crop group frequencies (e.g. cereals) to 50% to prevent the transfer of pests and diseases from crop to crop.

For effective exploitation of all the potential benefits, crop rotation should be based upon a set of multifunctional demands. Whilst crop selection must be market driven to provide efficient economic production, it needs to be sufficiently diverse to limit the share of each crop species, so as to reduce the impact of diseases, weeds and most pests. A well-balanced selection of crops should be chosen that require minimal external inputs of nutrients, pesticides, machinery and energy to maintain soil fertility and crop vitality for quality production (Vereijken, 1995). Furthermore crop rotations should provide sufficient soil cover to minimise erosion and nutrient leaching, utilise biological N fixation and efficient N transfer from previous crop residues, and restore physical soil structure and fertility. Thus in integrated farming systems for environmental protection, a multifunctional crop rotation plays a central role in integrated nutrient management and crop protection to sustain profitable production with minimum need for external inputs (Vereijken, 1995).

Rotations in the LINK IFS project

There were small differences in the rotations of the two farming systems at each of the six IFS sites. The rotations in commercial practice on the farms were already suited to their soil type and climatic conditions, and in the main there were appropriate breaks between the crops for pest and disease control. Set-aside was included as a phase in the rotation at four of the six sites (Sacrewell, High Mowthorpe, Lower Hope and Pathhead). Oilseed rape was grown in the set-aside phase at Manydown in the first year, thereafter, there was no set-aside in the project area on this site. Boxworth opted for non-rotational set-aside on headlands. Overall, the project was based solely on arable cropping, although at the Lower Hope site, the grass/clover ley in the set-aside phase was cut for silage or grazed by sheep outside of the required set-aside period. The rotations for the sites are given in Table 4.1.

None of the sites meets the strict European MCR requirements for frequency of species (Ogilvy, 1996). Winter wheat is the dominant crop in all of the six rotations, as it is the most profitable combinable crop in the UK, and occurs at least twice in all the five-year rotations. Crop group frequency is met on three of the sites (SW, HM and LH).

Winter wheats were grown on both systems and so were always comparable; eleven of the thirteen phases with winter wheats were first wheats following a break crop. The two main differences in rotation between the systems were firstly, the introduction of a legume break into the IFS at two sites; three other sites had legumes on both systems. Secondly, the use of a spring sown crop on the IFS instead of an autumn sown crop on the CFP. This was originally introduced to the IFS on four sites, but because of establishment problems Boxworth abandoned spring-sown linseed in favour of the newly introduced winter-sown linseed cultivars after three years.

Table 4.1 - Crop rotations

Site	System	Rotational phase and crop				
		1	2	3	4	5
Sacrewell	IFS	W wheat	Set-aside	Peas	W wheat	Potatoes
	CFP	W wheat	Set-aside	Peas	W wheat	Potatoes
Boxworth	IFS	Linseed*	W wheat	W beans	W wheat	W wheat
	CFP	WOSR	W wheat	W beans	W wheat	W wheat
H. Mowthorpe	IFS	W wheat	Set-aside	S beans	W wheat	Seed potatoes
	CFP	W wheat	Set-aside	WOSR	W wheat	Seed potatoes
Lower Hope	IFS	W wheat	Set-aside	S beans	W wheat	Potatoes
	CFP	W wheat	Set-aside	WOSR	W wheat	Potatoes
Manydown	IFS	W wheat	W wheat	S barley	Vining peas	WOSR
	CFP	W wheat	W wheat	S barley	Vining peas	WOSR
Pathhead	IFS	SOSR	W wheat	Set-aside	W wheat	S barley
	CFP	WOSR	W wheat	Set-aside	W wheat	W barley

Boxed = Difference between systems.
* Linseed grown as spring crop 1993-1995 and as winter crop 1996- 1997

The benefit of the introduction of a legume break, was the overall lower input of nitrogenous fertiliser, as the legumes did not require any. However, soil residual N for the following crop was not increased compared with the crop following the winter oilseed rape in the conventional rotation. Spring cropping always followed a previous cereal crop or set-aside, thus providing greater overwinter feeding areas for birds and a greater variety of habitats, both overwinter and in the following spring.

At Pathhead, winter barley was grown to allow the early sowing of winter oilseed rape on the conventional area, while on the IFS, spring barley was followed by spring oilseed rape, thus providing two spring crops, with the additional benefit that the spring oilseed rape dramatically reduced the slug damage in the following winter wheat crop.

A third difference between the systems was the growing of an overwinter cover crop prior to all spring crops in IFS, to reduce the risk of nitrate leaching, either by sowing a cover crop or by natural regeneration. Sowing cover crops in September/October following the harvest of a cereal crop in most cases resulted in less, and sometimes much less, overwinter cover than would be obtained from natural regeneration. At Boxworth, minimally cultivating in wheat seed to boost the natural regeneration did give good overwinter cover; but caused problems in producing a good seedbed in spring for the linseed in two of the three years spring linseed was grown.

On three sites, the set-aside cover crop was allowed to continue through to the following spring. At Lower Hope, a grass clover mix was sown at the start of the set-aside phase on the IFS and was used for a silage cut and/or sheep grazing in the following autumn. At Sacrewell, natural regeneration was established on both systems, but on the IFS in August this was destroyed and Phacelia was sown as an overwinter crop. At High Mowthorpe, natural regeneration set-aside was allowed to continue through the winter on the IFS. In all three cases, extended set-aside covers on the IFS took up residual nitrogen overwinter, thus reducing the risk of nitrate leaching.

Summary

1. Rotations were not greatly different between systems, as the conventional rotation was already well suited to each farm and had appropriate breaks between crops to minimise disease and pest problems.

2. The IFS rotation included more leguminous and spring sown crops.

3. Where possible overwinter green cover was maintained on IFS prior to spring cropping.

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CHAPTER 5 - Yields

Bob Prew, IACR Rothamsted

Yields are important to any crop production system. Optimising crop yields is a crucial driver in achieving competitive production costs, especially for spreading fixed costs, such as machinery and labour. This is just as applicable for an integrated system as it is for conventional production. However, integrated farming aims to balance yield production with lower inputs, to produce a profitable outturn with a low unit cost, rather than maximising yields with high inputs.

Generally, yields were lower on the integrated system, when compared with the conventional system across the whole project, partly because different crops and husbandry practices known to have some yield effects were incorporated into the integrated system to provide other benefits. Sixty-six percent of the IFS crops yielded less than their conventional counterparts; the majority of the lower yield differences were between 0.2 and 2 t/ha (Fig. 5.1).

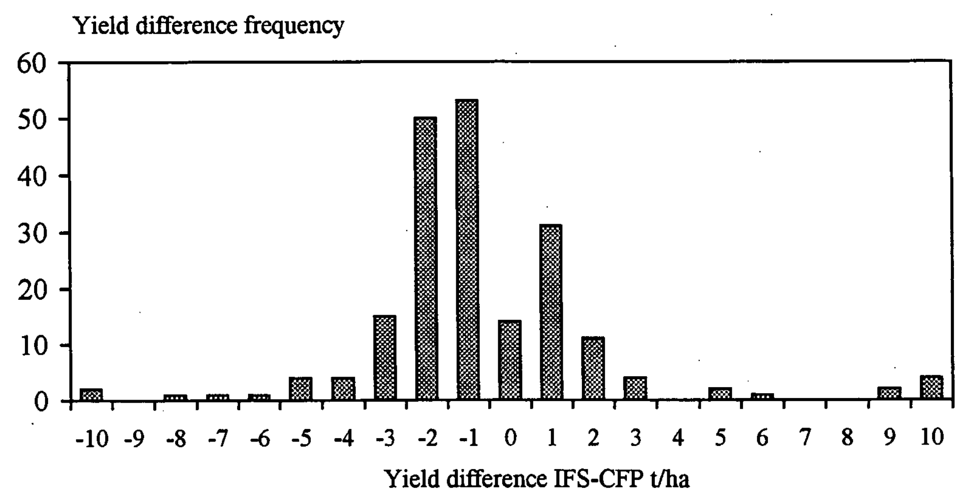

Figure 5.1 - Yield difference (IFS-CFP) distribution, all sites, years and crops (t/ha)

The reasons for the yield differences are described in more detail in this chapter and also in the chapters on crop protection, nitrogen use and the validation trials (Chapters 10, 11 and 12 respectively).

Overall site yields, meaned for each crop in each year are shown in Figure 5.2. None of the yield differences were statistically significant.

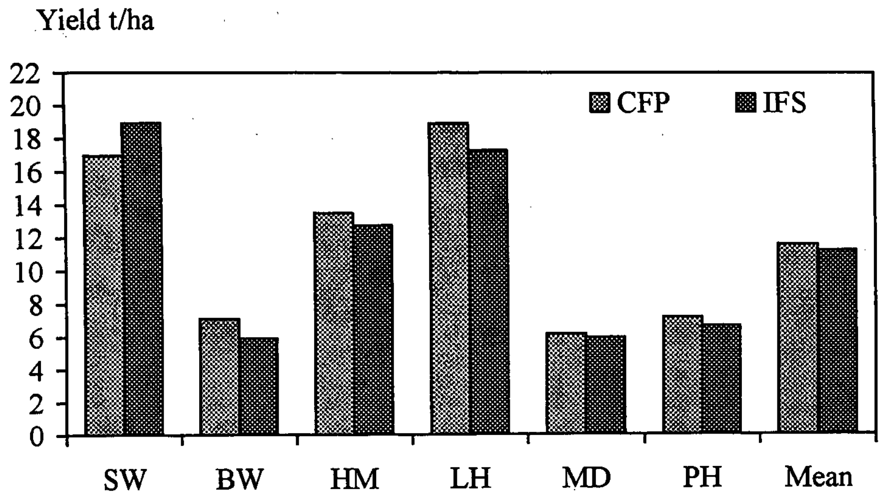

Figure 5.2 - Mean site yield for all crops, all years (t/ha)

Winter wheat

Yields of the first wheats are shown in Figure 5.3. Overall, they were consistently lower on the IFS, and the mean decrease of 0.71 t/ha was significant. On three occasions, severe losses (> 2t/ha) on the IFS compared with the CFP occurred (High Mowthorpe 4.30 t/ha in 1996; Sacrewell 4.12 t/ha in 1995 and 2.48 t/ha in 1994). In all three crops, this was probably related

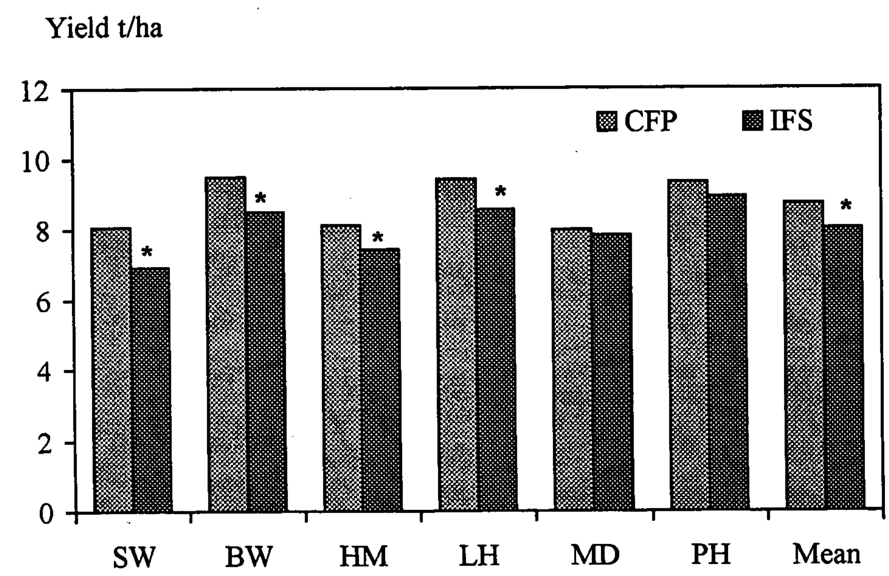

Figure 5.3 - Mean first winter wheat yields, by site all years (t/ha)
(* statistically significant result, $P<0.05$)

to poor weed control, that resulted from not using a residual soil-acting herbicide in the autumn; validation trial results confirm that the High Mowthorpe yield loss was from weed competition. There were no validation trials on the Sacrewell site, but weed levels indicate this could explain the result at this site as well.

The reasons for the generally lower yields on all sites were probably partly due to similar weed control problems, however in many situations specific decisions were taken which were known to have a lower yield potential, such as delaying sowing in order to decrease the reliance on pesticide inputs, choice of variety (milling v feed varieties), and lower nitrogen applications.

Yields of second wheats at Boxworth and Manydown were lower than respective first wheats (Fig. 5.4), and this difference was greater on the IFS than on the CFP.

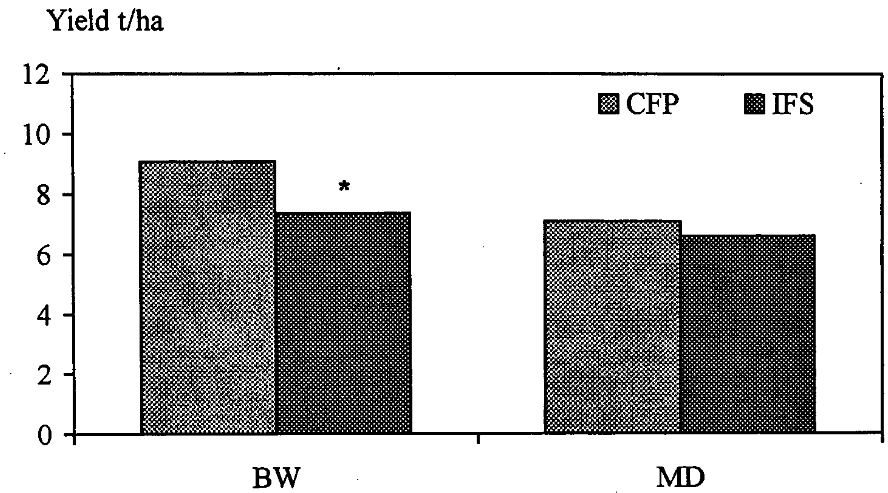

Figure 5.4 - Mean second winter wheat yields, by site all years (t/ha)
(* statistically significant result, P<0.05)

Barley

At Manydown, the yields of spring barley grown on the two systems were similar. At Pathhead, spring barley on the IFS yielded about 1 t/ha less than the winter barley on the CFP (Fig. 5.5), but this was more than compensated for by the premiums obtained for the integrated crop (see Chapter 6).

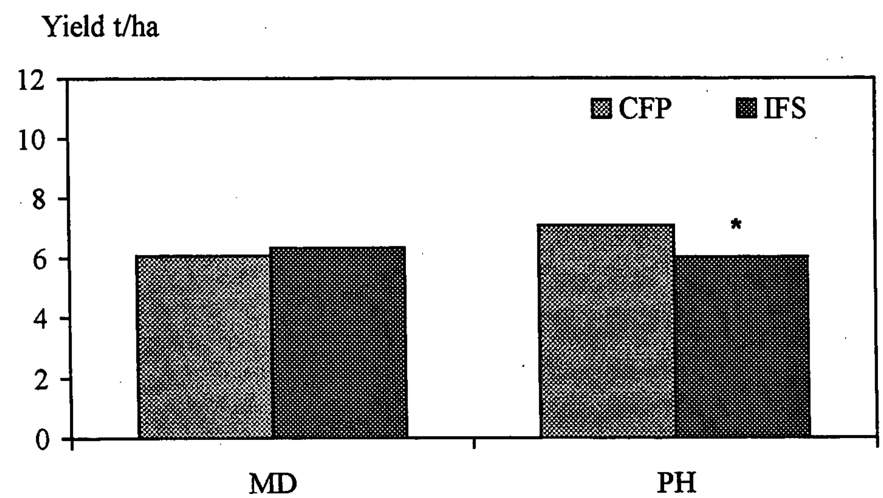

Figure 5.5 - Mean barley yields, by site all years (t/ha)
(* statistically significant result, P<0.05)

Potatoes

Potatoes were grown at three sites, Sacrewell, High Mowthorpe and Lower Hope, and showed mixed results between systems (Fig. 5.6). In the seed crop at High Mowthorpe, yields did not differ significantly. At Lower Hope, yields were about 10% lower on the IFS with no obvious consistent reasons for the loss. At Sacrewell, the variety Cara was grown on the IFS and Estima (1993) and Maris Piper (1994-1997) on the CFP. These earlier harvested varieties allowed the earlier sowing of the following CFP winter wheat crop. Yields were always better on the integrated, and much of this will have resulted from the varietal choice. The stronger canopy of Cara on the IFS helped smother weeds, and the longer duration of the canopy helped limit the laying of eggs by wheat bulb fly. The incidence of wheat bulb fly was also decreased on the IFS at High Mowthorpe following the potato crop, although the reason for this is unclear.

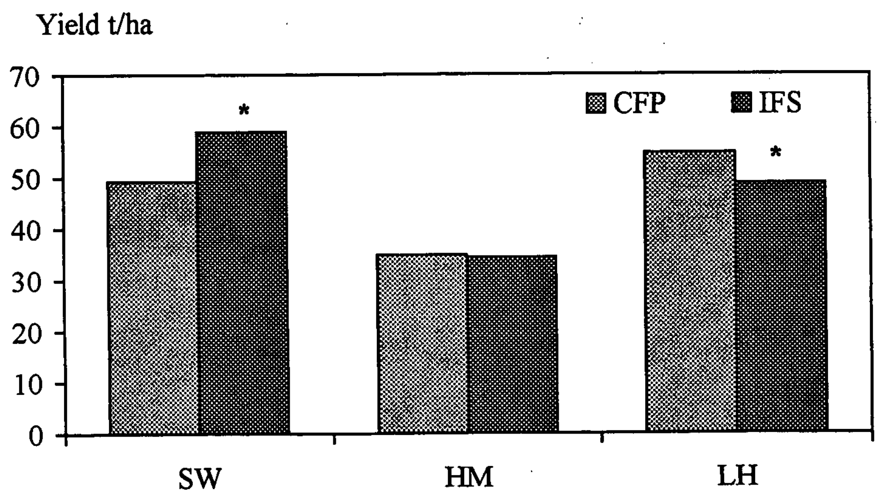

Figure 5.6 - Mean potato yields, by site all years (t/ha)
(* statistically significant result, P<0.05)

Other break crops

Where the same crops were grown on each system (Fig. 5.7) differences between systems were only large at Boxworth on the winter beans. The IFS yielded about 1 t/ha less than the conventional, mainly as a result of crop failure at Boxworth in 1993. The two pea crops showed small but consistent differences; the vining peas at Manydown yielded less and the dry peas at Sacrewell yielded more on the IFS than on the CFP. In the winter oilseed rape at Manydown, differences were small and inconsistent, resulting in no differences over the five years.

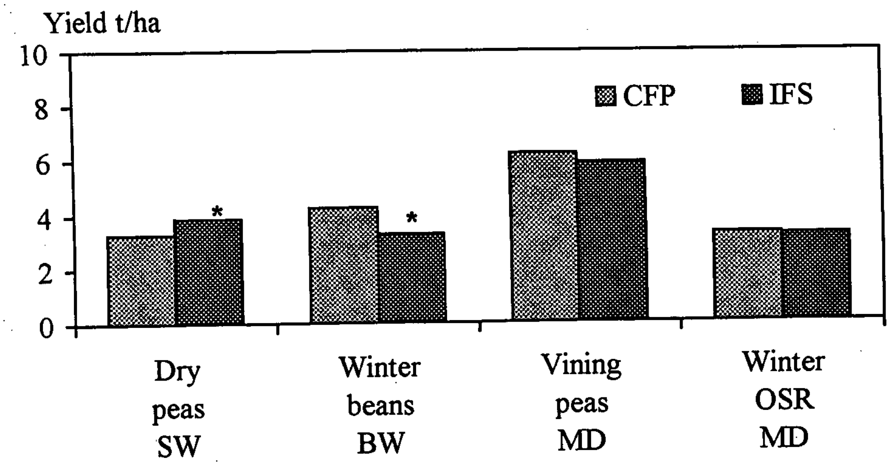

Figure 5.7 - Mean break crop yields (t/ha) - same crop on both systems, by site all years
(* statistically significant result, P<0.05)

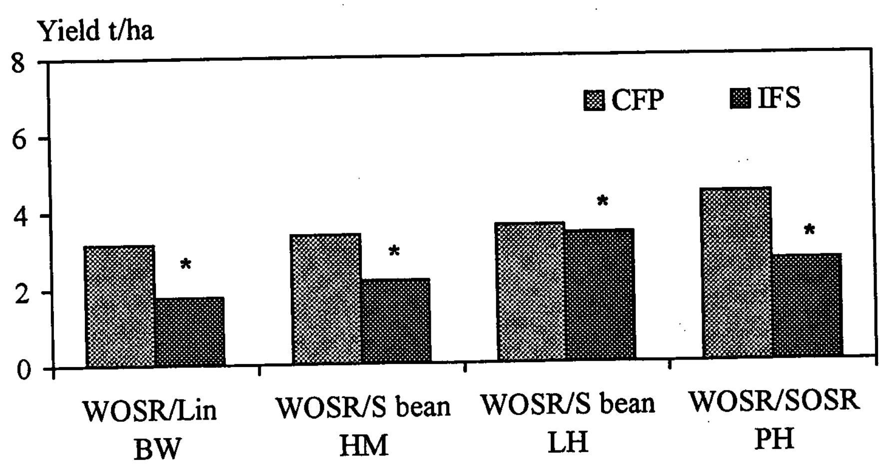

Figure 5.8 - Mean break crop yields (t/ha) - different crops on systems, by site all years
(* statistically significant result, P<0.05)

Where a spring crop was grown on the IFS in comparison with winter oilseed rape on CFP (Fig. 5.8) yields were less and more importantly, yields of the IFS spring crops were relatively poor compared with national figures (Nix, 1996) for those crops. Establishment of spring crops at Boxworth is always difficult, and in 1995 the spring linseed only yielded 0.57 t/ha. A change to winter sowing of linseed gave a yield of more than 2 t/ha in the two years it was grown.

At High Mowthorpe, spring beans yielded only 1.46 t/ha in 1993, and 0.90 t/ha in 1995, in both cases about 1 t/ha less than the oilseed rape on CFP. This was mainly due to poor weed control, as a result of relying on post emergence sprays and mechanical weeding, and also from patchy establishment after broadcasting and ploughing-in, as opposed to drilling after ploughing.

At Lower Hope, yields of spring beans on the IFS were variable; in 1993, they yielded over 6 t/ha in a favourable season, whereas in 1994 they failed completely, the likely causes being poor seed quality, a dry spring and soil capping.

At Pathhead, where spring oilseed rape was grown on the IFS in comparison with winter oilseed rape on the CFP, the spring crop yielded 1.4 t/ha less than the winter crop; this difference is only slightly greater than the expected difference between winter and spring oilseed rape in this area.

Conclusions

1. Integrated crops were lower yielding than their conventional counterparts in 66 % of comparisons.

2. Overall yield was lower on the integrated system at three of the six sites, but the results were not statistically significant.

2. Across sites, yields of winter wheat and beans were lower on IFS but those of potatoes, peas and oilseed rape were not.

3. A range of spring sown crops grown on the IFS was compared with winter oilseed rape grown on the CFP, and all yielded less.

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CHAPTER 6 - Economics

Bob Prew, IACR Rothamsted, and David Harris, ADAS Boxworth

Introduction

The economic viability of the IFS was one of the key questions for the project, and it needs to be viewed primarily as the viability over the whole rotation and over all sites. However, because of considerable variation between sites and crops, it is also necessary to consider the viability of individual sites and crops, to get a full picture of the systems strengths and weaknesses. A full assessment of the financial and economic impacts of adopting an integrated farming system is available in the report of the economics bolt-on project written by researchers at the University of Reading (Keatinge *et al.*, 1999; Appendix M).

In this report, IACS arable area payments were included in the output figures, and crop prices were taken either as those received locally or standard prices taken from the HGCA or the farming press. Standard prices were used for variable costs, and an operational cost was calculated for each operation on each crop, using standard figures based on contractor charges, data from the Nix Farm Management Pocketbooks and ADAS business management data. A production margin (gross output - (variable + operational costs)) has been used as the main measure of profitability. Management time has not been included in these calculations.

Over all sites and crops

Gross output of the IFS was lower than CFP on five of the six sites, with a mean difference (IFS-CFP) of -£51/ha or -3.5% per annum (Fig. 6.1). However, costs on the IFS were also down; variable costs were £24/ha lower (-7.8%) and operational costs were £10/ha lower (-3.2%). This resulted in no significant difference in the production margin of the two systems (IFS at £831/ha and CFP at £848/ha), with both margins well within acceptable levels.

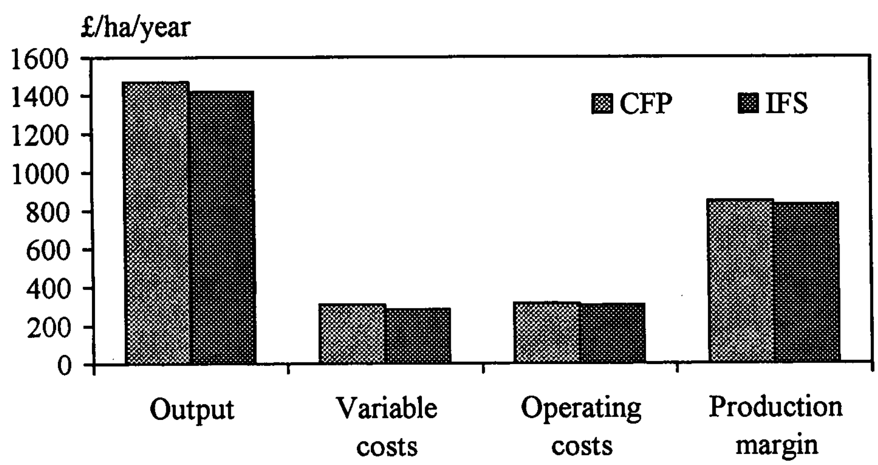

Figure 6.1 - Overall financial performance meaned for all crops, all sites and all years (£/ha/year)

A common measure of the overall efficiency of a system is the gross margin as a percentage of the gross output; on a poor farm this would be in the order of 50 % and 80 % on a very good farm. The figures for IFS and CFP were 79.9 and 78.8 % respectively. Thus overall, the results show IFS can be an economically viable system.

Over individual sites and all crops

There was considerable variation in financial performance between sites (Fig. 6.2). There was no evidence of a difference between the two systems in production margin on the three sites not growing potatoes (Boxworth, Manydown, Pathhead). On the other three sites which grew potatoes, there was evidence of a difference. The production margin at Sacrewell reflected the higher yield of potatoes on the IFS at this site, which influenced the overall site result, whereas at Lower Hope, it reflected the lower yield of potatoes on IFS. If potatoes are excluded from the analysis (Table 6.1) the positions are reversed, with the IFS at Sacrewell less profitable than CFP and Lower Hope more profitable. High Mowthorpe had the largest negative difference in production margin (IFS - CFP) of all the sites, whether potatoes were included in the analysis or not.

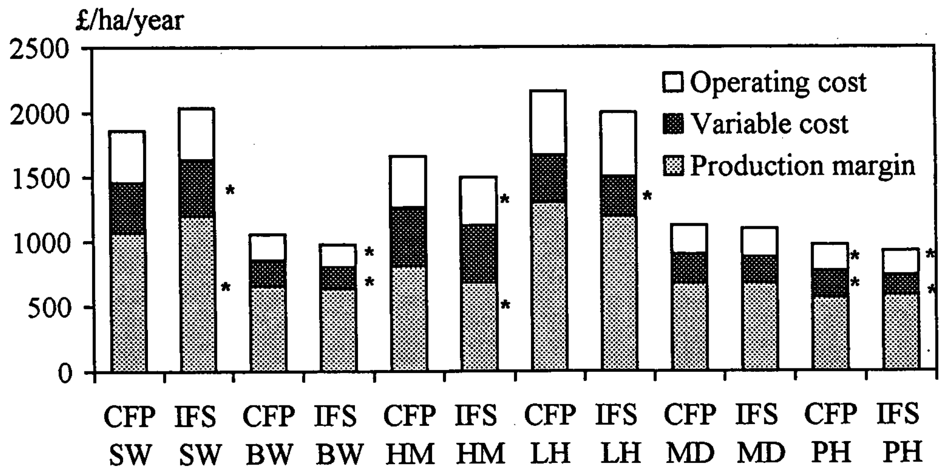

Figure 6.2 - Output and costs meaned for all crops and years at each site (£/ha/year)
(* Statistically significant result, $P<0.05$)

Table 6.1 - Change in production margin with and without potatoes.
Difference in production margin (IFS-CFP) (£/ha/year)

	With potatoes	Excluding potatoes
Six-site mean	-17	-23
Sacrewell	+128	-31
High Mowthorpe	-129	-147
Lower Hope	-102	+38

There was some variation in production margin between years, though it mainly followed the same pattern as the site means (Appendix G, Fig. 6.11).

The distribution of the differences in production margin between the IFS and CFP crops are shown in Figure 6.3. This compares with a similar figure for yield presented in Chapter 5 (Fig. 5.1). Forty-seven percent of the IFS crops had an equal or higher production margin (-10 to

2026 £/ha) than CFP, compared with the yield figure of 34 %, demonstrating that reduction in costs and obtaining premiums in the IFS compensated for some of the lower yields achieved. As with the yield data, crop responses were variable and are discussed in more detail below.

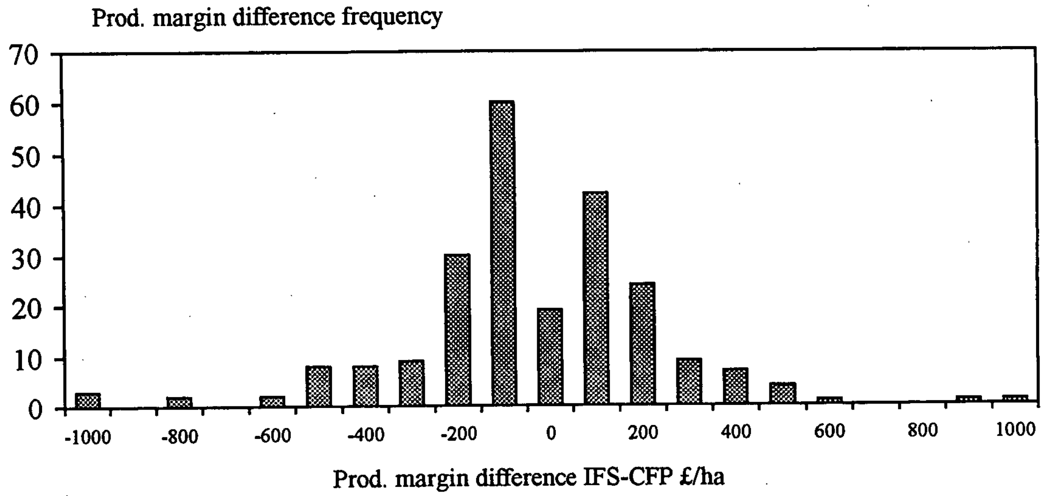

Figure 6.3 - Production margin difference (IFS-CFP) distribution, all sites, years and crops (£/ha)

Individual crops

With the exception of potatoes, where the same crop was grown on both systems, differences in the mean production margin over all years were inconsistent but meaned over all sites were very small. Production costs per tonne meaned over all sites and years, either did not differ between the two systems or were lower on the IFS (Table 6.2). Where different crops were grown on the two systems, the production margin differed much more, and in particular when a range of spring crops on IFS were compared with winter oilseed rape on the CFP, the IFS production margin was always much lower.

Table 6.2 - Mean crop production costs (£/t)

Crop (CFP/IFS)	**CFP**	**IFS**	**Difference (IFS - CFP)**
First winter wheat	55.7	53.4	-2.3
Second winter wheat	59.4	58.7	-0.7
Spring barley	68.3	67.0	-1.3
W oilseed rape	130.0	117.9	-12.1
Peas	86.7	76.4	-10.3
Winter beans	66.2	58.2	-8.0
Potatoes	65.2	65.2	0
W barley/S barley	65.0	60.1	-4.8
WOSR/Linseed	154.8	289.9	135.1
WOSR/S beans	130.0	122.7	-7.3
WOSR/SOSR	121.8	133.8	12.0

First winter wheats

The difference in gross output mainly reflected differences in yield, although at Boxworth and Lower Hope, a feed wheat was grown on CFP and a milling wheat on IFS, hence premiums were often obtained which compensated for the lower yield on the IFS (Fig. 6.4).

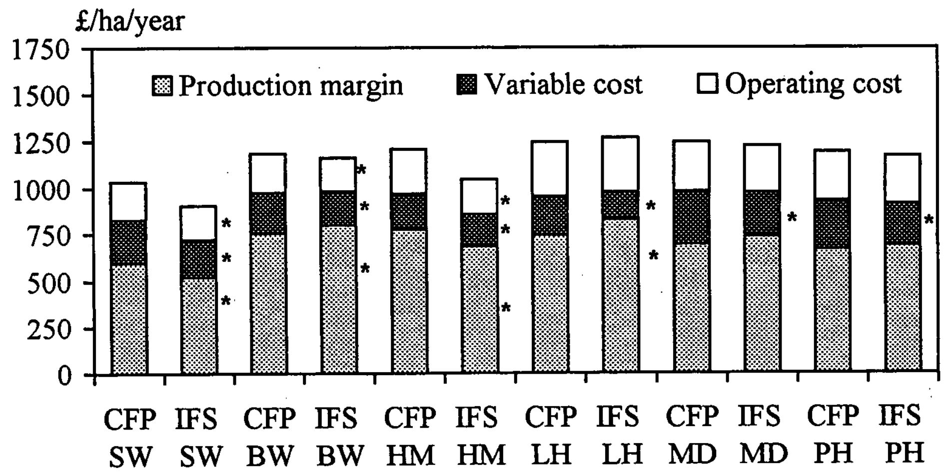

Figure 6.4 - Output and costs meaned for first wheats at all sites (£/ha/year)
(* Statistically significant result, P<0.05)

On all sites, variable and operational costs were lower on IFS resulting in no overall difference in production margin, with a positive difference in margin in favour of IFS at Boxworth and Lower Hope, a negative difference at Sacrewell and High Mowthorpe. There were very large differences in production margins between years at all sites ranging from -£286/ha at High Mowthorpe to +£241 at Lower Hope (Appendix G, Fig. 6.12).

Second winter wheats

These were only grown at two sites and the economic results were very similar to the first wheats at those sites (Fig. 6.5 and Appendix G, Fig. 6.13).

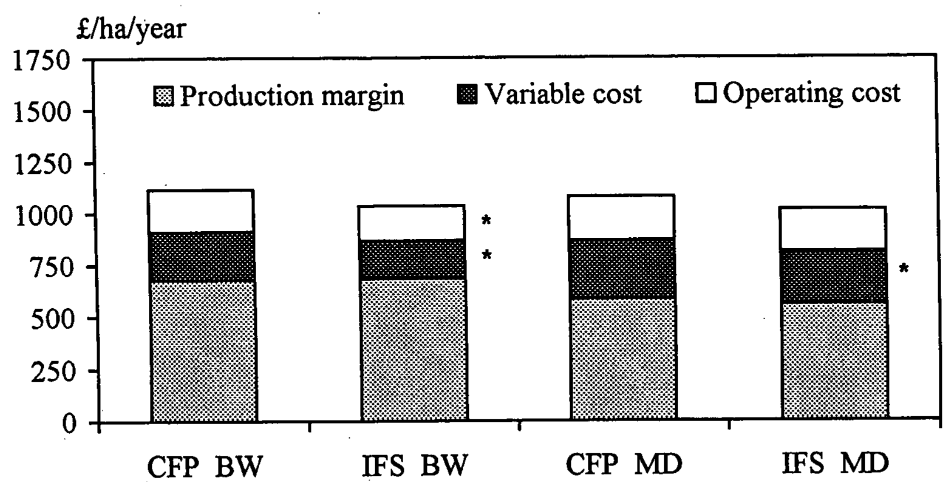

Figure 6.5 - Output and costs meaned for second wheats at Boxworth and Manydown (£/ha/year) (* Statistically significant result, P<0.05)

Spring and winter barley

Barley was only grown at two sites, Manydown and Pathhead (Fig. 6.6). At Manydown, spring barley was grown and showed no difference in costs or profitability between the systems. At Pathhead, the spring barley on the IFS was more profitable despite lower yields than the winter barley on the CFP. Variable and operational costs were lower and malting premiums were always obtained on the spring barley, but only in three years out of the five on the winter barley, and in two of those, the premium was smaller than that for the spring barley. The effects on production margins for the five years are shown in Appendix G, Fig. 6.14.

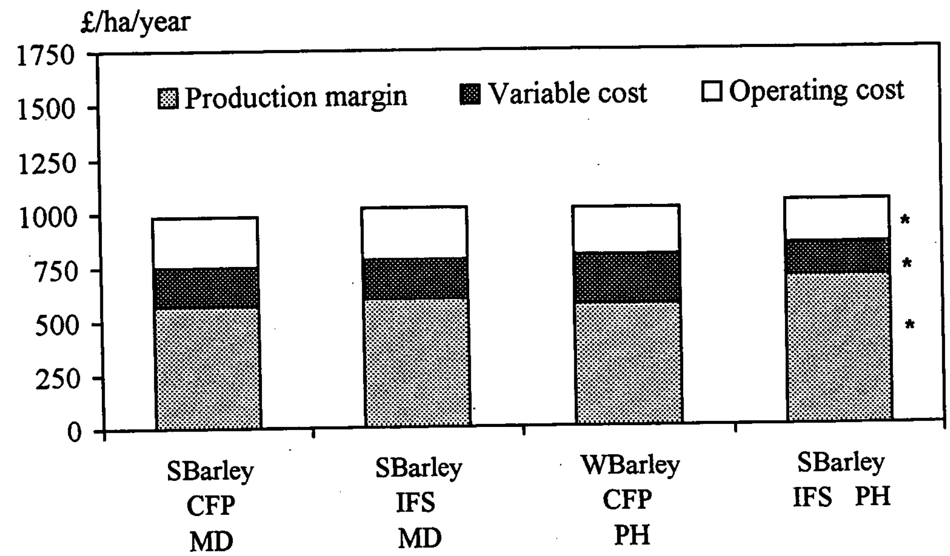

Figure 6.6 - Output and costs meaned for barley at Manydown and Pathhead (£/ha/year)
(* Statistically significant result, $P<0.05$)

Potatoes

Potatoes were grown as a seed crop at High Mowthorpe, and as ware crops at Sacrewell and Lower Hope. At these latter two sites, potatoes dominated the farm economics. At High Mowthorpe, there was no difference in production costs or margin (Fig. 6.7). Variable costs were greater on IFS at Sacrewell and smaller at Lower Hope where operational costs were slightly greater. The production margins at both sites reflected the differences in yield between the systems, resulting in a larger positive difference for IFS at Sacrewell, and a negative one at Lower Hope. These positive and negative differences in production margin occurred every year, but were largest in 1995 when potato prices were very high (Appendix G, Fig. 6.15).

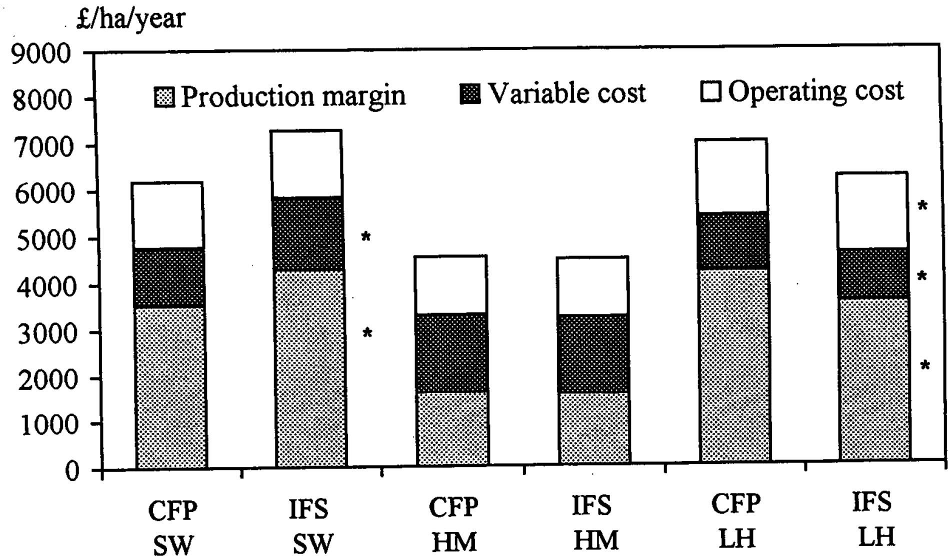

Figure 6.7 - Output and costs meaned for potatoes at Sacrewell, High Mowthorpe and Lower Hope (£/ha)
(* Statistically significant result, P<0.05)

Other break crops

Where cropping was the same on both systems, differences in both costs and production margins were small (Fig. 6.8). Production margin of IFS was poorer on winter beans at Boxworth as a result of the crop failure in 1993, and was better on dried peas at Sacrewell, where yields on IFS were much better in 1997 (Appendix G, Fig. 6.16).

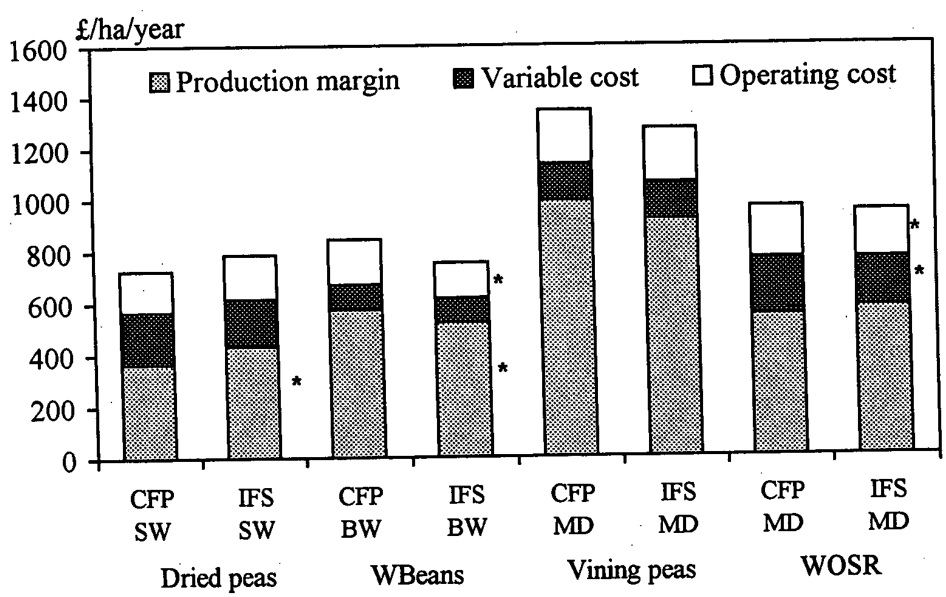

Figure 6.8 - Output and costs for break crops with the same crops on CFP and IFS at Sacrewell, Boxworth and Manydown (£/ha/year)
(* Statistically significant result, P<0.05)

Where break crops were different, winter oilseed rape was grown on the CFP, and a range of spring-sown crops were grown on the IFS (Fig. 6.9). The gross output and the production margin were much larger on CFP at all sites. Operational costs were considerably less on IFS at High Mowthorpe, Lower Hope and Pathhead, and variable costs were also much lower on IFS at Boxworth, Lower Hope and Pathhead, reflecting the considerably lower inputs in the spring crops. The pattern of difference in production margin in individual years was much less variable than other crop comparisons (Appendix G, Fig. 6.17), confirming that these crops together with potatoes at Lower Hope were the only real consistent failures of the system.

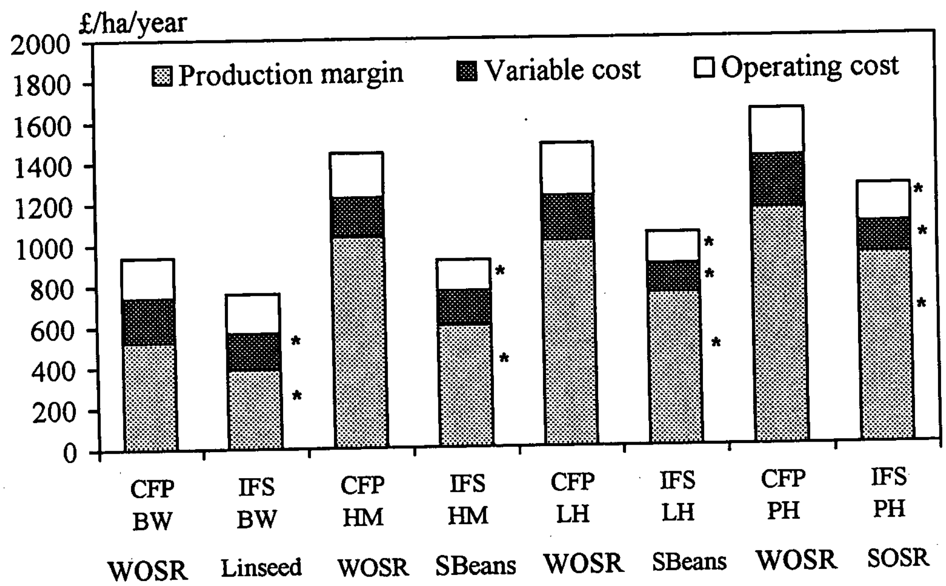

Figure 6.9 - Output and costs for break crops with different crops on CFP and IFS at Boxworth, High Mowthorpe and Pathhead (£/ha/year)
(* Statistically significant result, P<0.05)

Set-aside

Production margins were lower on IFS at Sacrewell and High Mowthorpe where additional operations to establish and manage cover crops were undertaken in the hope of environmental benefits. At Lower Hope, the production margin was greater as a result of improved gross output from the silage/sheep grazing of the grass/clover mixture on the IFS (Fig. 6.10).

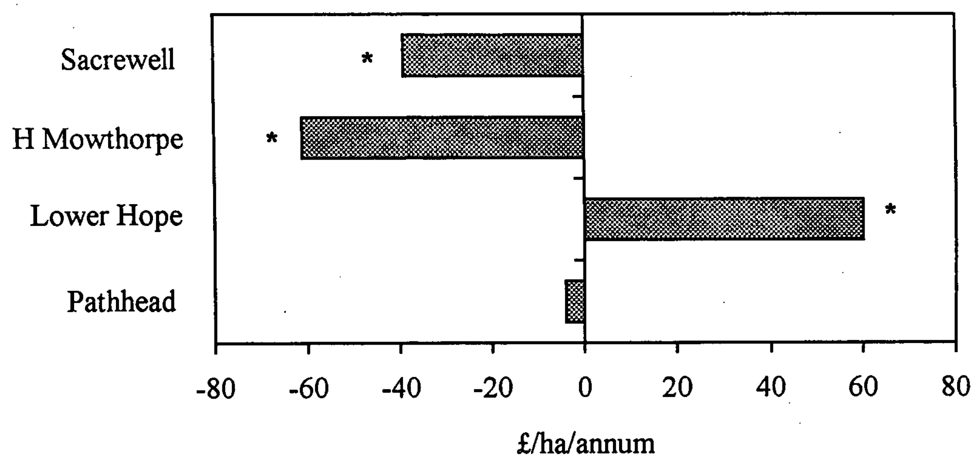

Figure 6.10 - Difference in production margin (IFS-CFP), set-aside
(* Statistically significant result, P<0.05)

Alternative economic scenarios

A range of economic scenarios have been applied to the production margins from the experiment. In each scenario, the annual difference in production margin (IFS-CFP) is shown for each site (Table 6.3), to consider how under different conditions, the relative performances of CFP and IFS will change. Also shown are mean annual production margins for the IFS and CFP, as it is important that the overall effect of the scenario on farm profitability is assessed.

Scenario 1 - generalised prices and premiums

This scenario takes out the effect of local variations in marketing and large seasonal differences in prices, by using generalised prices and premiums across all sites. At sites growing potatoes, there is a benefit to IFS from the smoothing of potato prices, particularly at Sacrewell. A uniform premium for wheat and barley benefited IFS at Boxworth but had a negative effect at Lower Hope and Pathhead. IFS at Lower Hope was also adversely affected by the generalised prices of spring beans compared to oilseed rape.

Scenario 2 - generalised prices, no premium

The lack of premiums compared with scenario 1 resulted in poorer performance of IFS at Boxworth, Lower Hope and Pathhead.

Scenario 3 - no arable area payment

This only affected sites with different cropping on the two systems, to the benefit of IFS at High Mowthorpe and Lower Hope, and to the detriment at Boxworth.

Scenario 4 - reductions of AAP by 50% for autumn-sown crops

The IFS benefited on the four sites, Boxworth, High Mowthorpe, Pathhead and Lower Hope, which had differential spring cropping between the systems.

Table 6.3 - Annual difference in production margin (IFS-CFP) for a range of economic scenarios (£/ha)

Scenario	Site						System		
	SW	BW	HM	LH	MD	PH	IFS	CFP	Diff. IFS-CFP
Actual figures	128	-19	-126	-102	0	17	831	848	-17
1. Generalised prices	160	12	-113	-99	0	3	761	767	-6
2. Generalised prices/no premium	160	-56	-107	-155	2	-8	713	741	-28
3. No AAP	128	-35	-113	-95	0	17	581	598	-17
4. Autumn crop AAP cut by 50%	128	20	-82	-62	0	88	768	752	16
5. No AAP, 25% price fall	108	12	-70	-46	7	18	241	237	4
6. Pesticides + fertiliser prices up by 50%	147	2	-106	-63	11	43	759	753	6

Scenario 5 - no AAP and 25% price fall

Only at Sacrewell, the site with the largest difference in production margin (IFS-CFP) in favour of IFS, was the effect on IFS negative. At all other sites, it was either beneficial to IFS or had no effect.

Scenario 6 - pesticide and fertiliser prices up by 50%

This improved IFS profitability on all sites, as less of these inputs were used than on CFP.

All scenarios effect on mean annual production margins

The actual production margin of IFS at £831/ha compares well with CFP at £846/ha. It is clear that the effect of all the other economic scenarios was to lower the overall production margin of IFS and hence profitability, relative to the actual prices achieved during the life of the project. In scenarios, 1, 2, 4 and 6 the margin fell by between 8 and 14%, in scenario 3 it fell by 30% and in scenario 5 by 70%. So while some of these scenarios are favourable to IFS relative to CFP, in real terms they are all detrimental.

Conclusions

1. IFS can be economically viable.

2. The production margin (output minus variable + operating costs) meaned over all sites, crops and years showed no significant difference between the two systems at £831/ha for IFS and £848/ha for CFP.

3. On a site basis, the IFS production margin was higher than CFP at Sacrewell, equivalent to CFP at Pathhead, Manydown and Boxworth, but lower than CFP at High Mowthorpe and Lower Hope.

4. When the same crop was grown on both systems, the production costs per tonne of produce on IFS were lower than or equal to the production costs on CFP.

5. The IFS production margin was always lower when a spring crop was compared with winter oilseed rape on CFP.

6. Overall, there was no difference in the production margin between the two systems for winter wheat, but on a site basis, the IFS production margin was lower than CFP at Sacrewell and High Mowthorpe, but higher at Lower Hope.

7. In potatoes, the IFS production margin was higher than CFP at Sacrewell, equivalent at High Mowthorpe and lower than CFP at Lower Hope.

8. Differences between the production margins for other crops were not great.

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CHAPTER 7 - Invertebrates (beetles and spiders)

John Holland, The Game Conservancy Trust

Background

Three of the most abundant and widespread invertebrate groups in arable crops are the ground beetles (Carabidae), rove beetles (Staphylinidae) and spiders (Araneae), of the latter money spiders (Linyphiidae) are often the most abundant. These groups include many predatory species important as bio-control agents, and because they are also relatively easily sampled and identified are often the most frequently used bio-indicators in agro-ecosystem research. Many farming practices such as type and timing of soil cultivation, pesticide usage, crop type and rotation, all of which are components of integrated farming are known to affect these groups. By measuring the abundance and diversity of beetles and spiders (hereafter referred to as invertebrates), some indication may be gained of the environmental impact of a farming system. Furthermore, if integrated pest management is to be a component of integrated farming, it is essential that predatory invertebrates are encouraged to maximise pest control by natural enemies.

Sampling methods and analysis

Sampling during the baseline year was used to determine the species most often found at the six sites and 19 ground beetle, 13 rove beetle and 8 spider taxa were then identified in all further sampling. Invertebrates were sampled using ten pitfall traps per plot during the autumn, spring and summer. A summary of the invertebrate data analysis is presented here. Data were analysed using the totals from April, May, June and July. Ground and rove beetle and spider numbers and number of species (which provided a measure of diversity) within each site, except for Pathhead, were analysed comparing the effect of farming system, crop and year of sampling. Data from Pathhead could not be analysed using this analysis because replicate fields were not sampled. To provide some reference, the means from Pathhead are presented in the figures. Individual species may, however, react differently to changes in farming practice depending on their life history, thus analysis at the species or genus level may be more revealing. This was carried out but only for those species where less than 25% of the counts were zero. Because of the low invertebrate numbers at many of the sites, this restricted the analysis to a few species, data from some of these are presented.

Results

Ground beetles (Carabidae)

The ground beetles are typically nocturnal and ground active although some species may climb the crop, they typically have relatively low powers of dispersal and usually complete their life-cycle within the field or its boundary. They are therefore likely to be responsive to changes in soil cultivation, cropping and pesticides.

There was considerable variation between the sites in total numbers of beetles. Comparing the five year average, numbers were highest in all crops at Boxworth, intermediate at Manydown and Lower Hope and lowest at Sacrewell and High Mowthorpe (Fig. 7.1). The most northerly sites had the fewest ground beetles suggesting a climatic effect on beetle distributions.
The type of farming system, crop or year had no effect on the numbers of ground beetles at three of the sites, Sacrewell, Lower Hope and Manydown (tables detailing the significant

interactions from the data analyses are presented in Appendix H, Table 7.2). Diversity differed significantly at three sites, Boxworth, High Mowthorpe and Lower Hope. At Boxworth, there were significantly fewer numbers and diversity of ground beetles in the integrated linseed crop (Figs. 7.1 & 7.2). The only other noticeable effect of farming system was at High Mowthorpe where a greater number and diversity of ground beetles were captured in the integrated wheat crop, but only in two years. At Lower Hope, beetle diversity was lower in the integrated spring beans compared with the conventional winter oilseed rape, but only in two years. Beetle numbers and diversity were lowest in potatoes and often in the following crop.

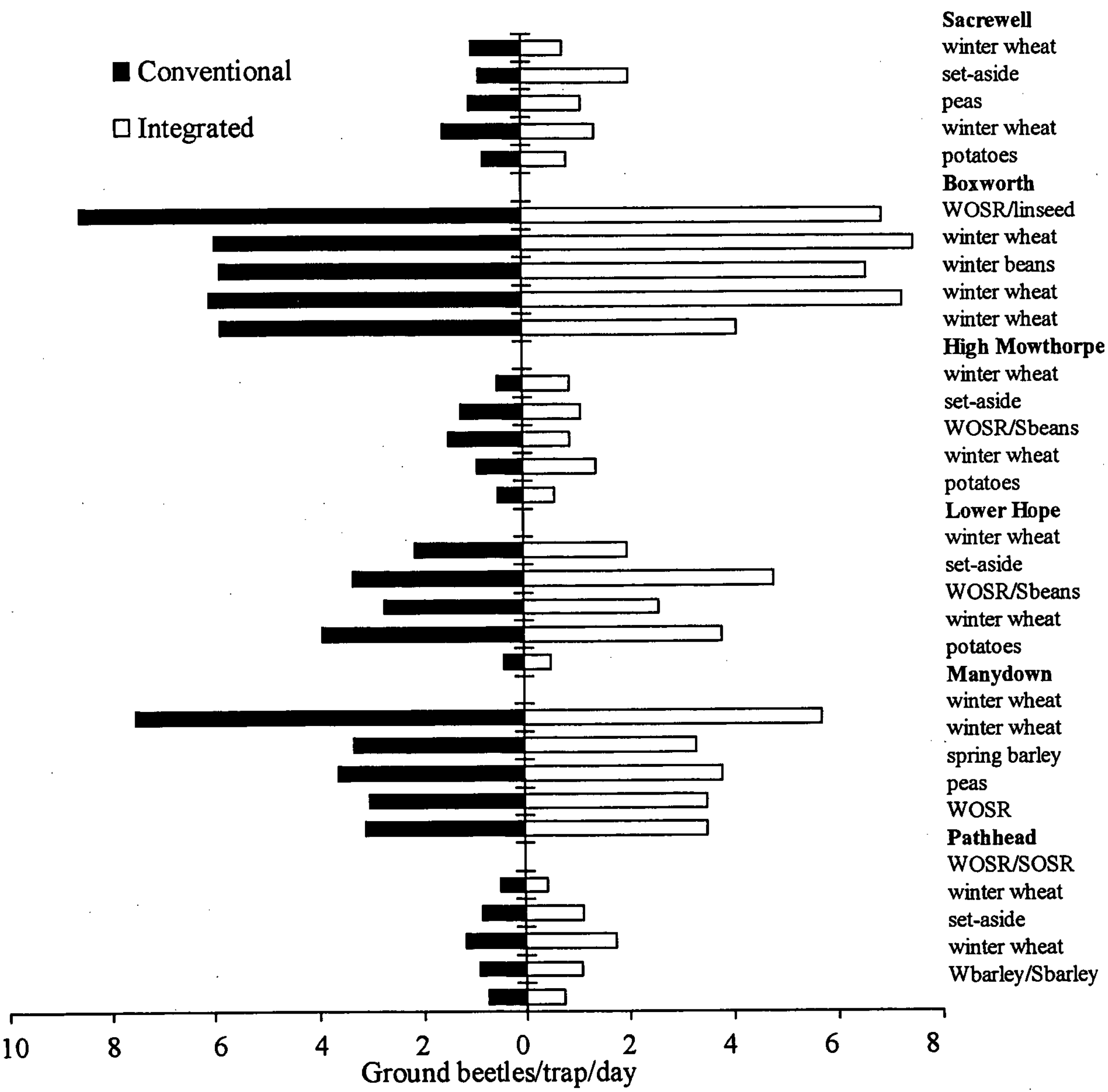

Figure 7.1 - Mean number of ground beetles for April to July over 5 years within each phase and system.

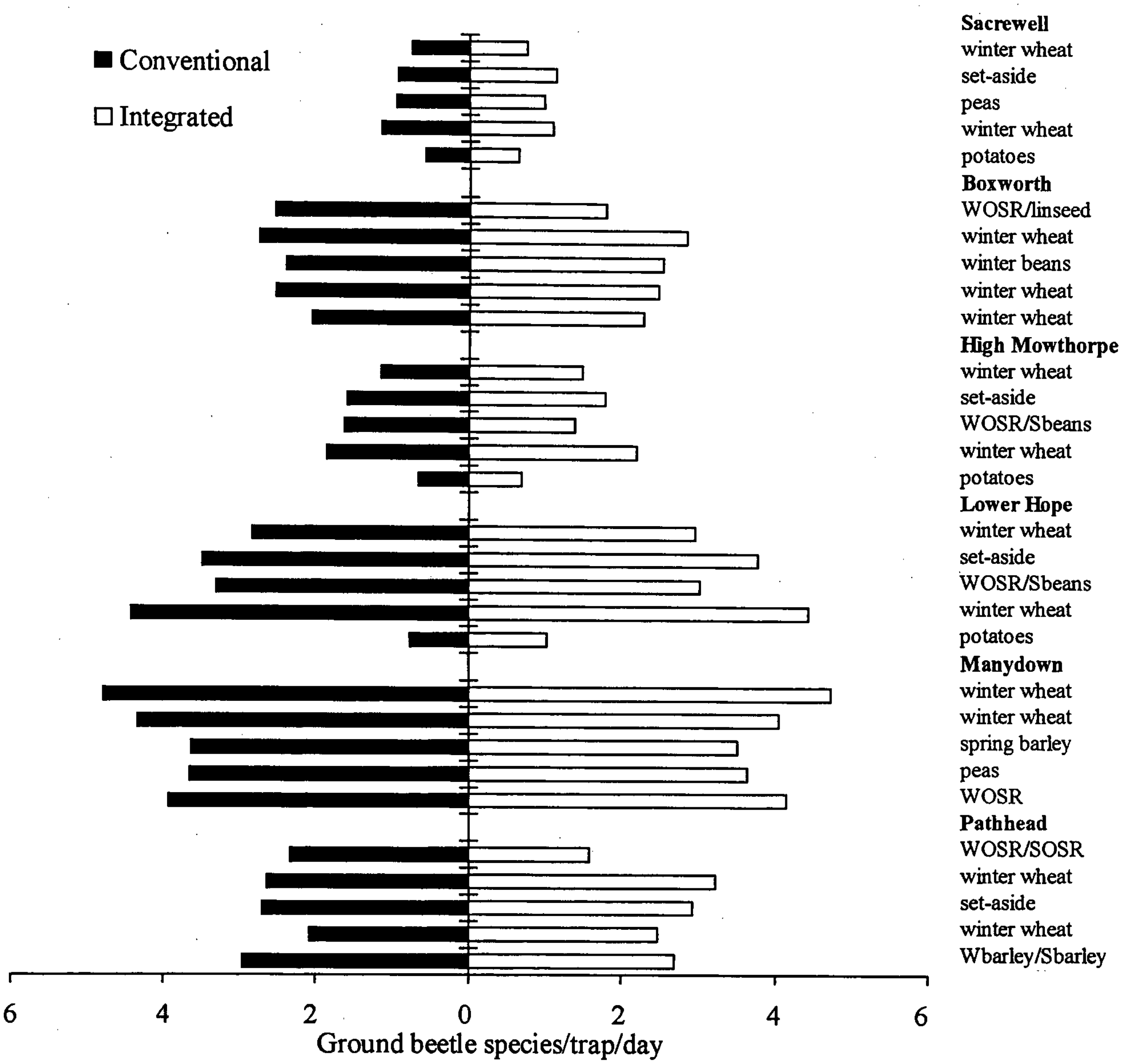

Figure 7.2 - Mean number of ground beetle species for April to July over 5 years within each phase and system.

By species

Pterostichus melanarius was the most ubiquitous ground beetle species and occurred in sufficient numbers during July for analysis at each site. The adults captured here are large, active predators of aphids and slugs, and therefore, are important for bio-control. Its lifecycle is completed within the field, but it survives ploughing and is relatively resistant to pyrethroid insecticides. At Sacrewell, Boxworth, and Lower Hope, there was a three-way interaction effect between the phase, year and system (Appendix H, Table 7.3). At Sacrewell during June, *P. melanarius* consistently favoured the integrated peas, however for July, there were no consistent differences. Similarly at Boxworth, numbers varied between the different crops, systems and years but with no consistent trend. During July at Lower Hope, numbers were significantly higher in the integrated winter wheat and spring beans and were lowest in potatoes, although this was not found every year (Table 7.1 and Appendix H, Table 7.3). Significantly more *P. melanarius* were caught on average in the integrated system at High

Mowthorpe when compared across all crops (Table 7.1). No differences occurred at Manydown.

Table 7.1 - Number of *Pterostichus melanarius* per pitfall trap per day during July at High Mowthorpe and Lower Hope in CFP and IFS, meaned over five years.

Rotation	**High Mowthorpe**		**Lower Hope**	
	CFP	**IFS**	**CFP**	**IFS**
Winter wheat	0.05	0.10	0.62	1.02
Set-aside	0.05	0.11	0.77	0.26
WOSR/Spring beans	0.10	0.52	0.66	1.06
Winter wheat	0.36	0.87	0.71	0.6
Potatoes	0.71	0.78	0.17	0.23

Bembidion lampros was found in sufficient numbers for analysis at three sites during April, May and June each year. This species overwinters in the field boundary and disperses into the field during spring. It is a small, ground active predator known to feed on aphids and fly eggs. Significantly higher numbers occurred in the integrated spring beans compared with the conventional winter oilseed rape, and especially low numbers were found in potatoes at High Mowthorpe and Lower Hope (Appendix H, Table 7.3). The predominantly seed-feeding *Amara* species were also less frequently captured in the integrated break crops of linseed and spring beans at Boxworth and High Mowthorpe, respectively.

No consistent trends were found across the sites for other individual species.

Rove beetles (Staphylinidae)

The species of rove beetle identified may overwinter in the field or the boundary but have greater mobility than the ground beetles, flying within the crop and field boundaries and feeding both on the ground and the crop. They may therefore respond more quickly to unfavourable conditions and may be more susceptible to insecticides because they often forage on crop foliage.

Numbers and diversity of rove beetles were very low at Pathhead, High Mowthorpe and Sacrewell, as found for the carabid beetles. There were significant differences in numbers of rove beetles at all sites (Appendix H, Table 7.2). At Sacrewell and Lower Hope, significant differences in the number of rove beetles occurred between the systems within individual crop/years but there was no consistent trend. At Boxworth, fewer rove beetles were caught in the integrated linseed (Fig. 7.3). There was a trend towards more in the integrated wheat crops at Manydown and to a lesser extent at High Mowthorpe. At High Mowthorpe and Lower Hope, fewer rove beetles were captured in the integrated spring beans compared with the conventional oilseed rape. Few rove beetles were captured in the potato crops. The same results were found for rove beetle diversity (Fig. 7.4).

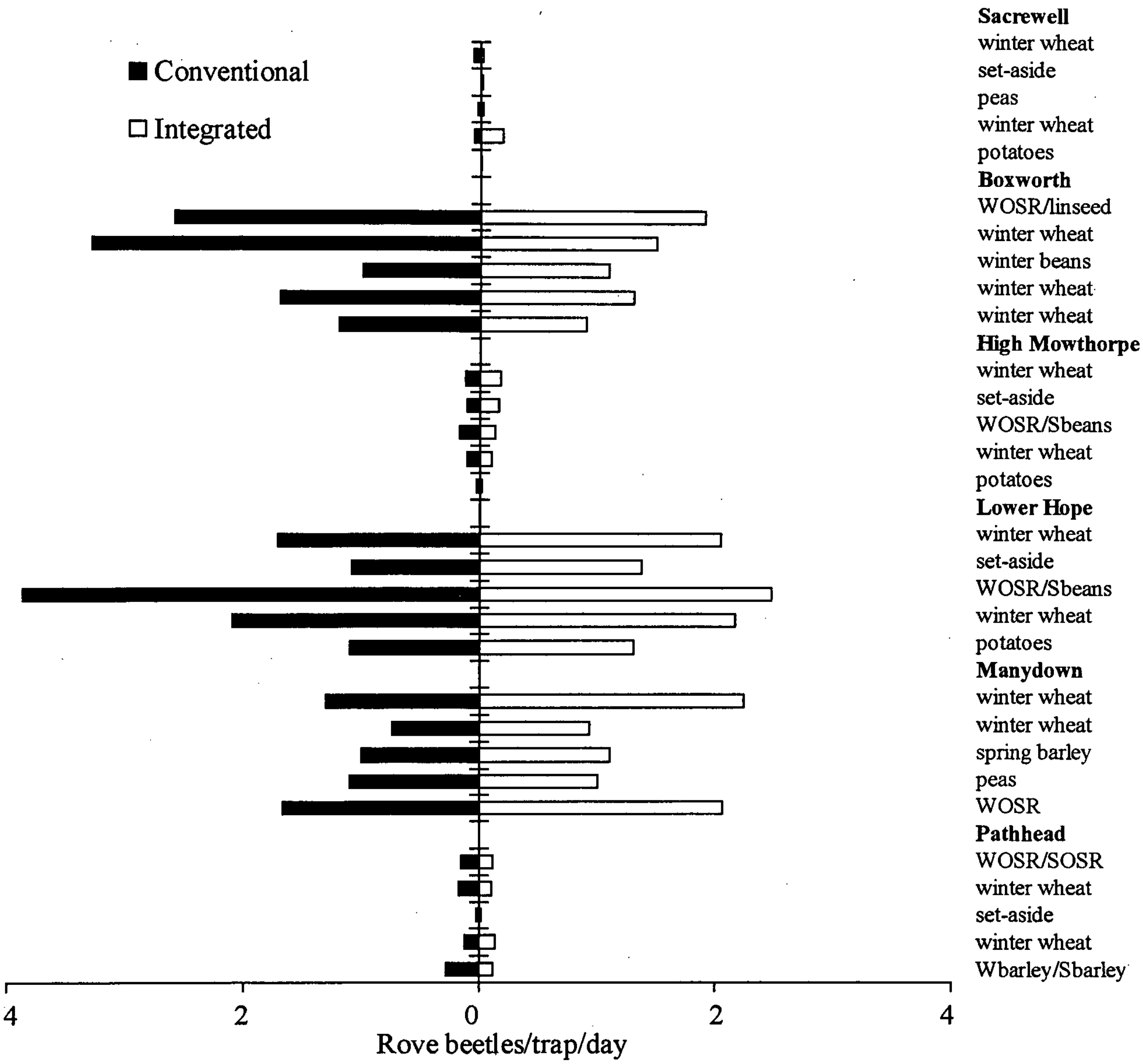

Figure 7.3 - Mean number of rove beetles for April to July over 5 years within each phase and system.

By species

There was only sufficient data for analysis of one rove beetle species (*Tachyporous hypnorum*) at Boxworth, Lower Hope and Manydown during May. This small, predatory beetle overwinters in field margins, dispersing into the crop by flight during the spring. It feeds upon fungal spores and aphids often inhabiting the upper parts of the crop. Numbers only differed significantly at Lower Hope where there was a phase by system effect, because few were captured in the integrated spring beans (Appendix H, Table 7.3).

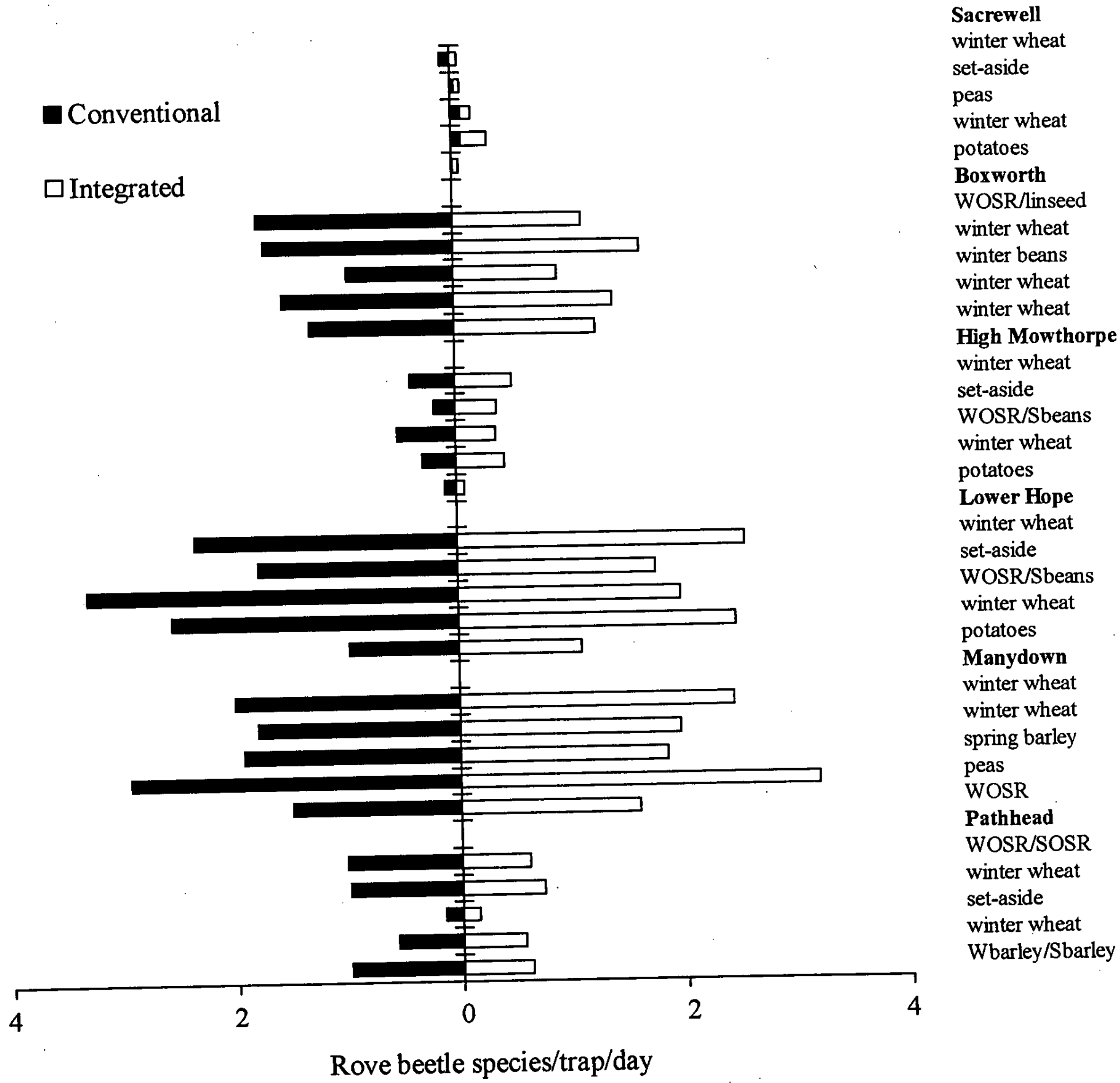

Figure 7.4 - Mean number of rove beetle species for April to July over 5 years within each phase and system.

Money Spiders (Linyphiidae)

Money spiders rely on wind dispersal therefore movement between fields is normal and they can reinvade crops quickly after disturbance. They inhabit the ground and lower parts of the crop except when dispersing. They exhibit a low tolerance to pyrethroid insecticides.

Numbers and diversity of money spiders differed significantly at three of the sites, Boxworth, High Mowthorpe and Lower Hope (Appendix H, Table 7.2). An explanation for the difference could only be found for Boxworth, where fewer money spiders were captured in the integrated linseed (Fig. 7.5).

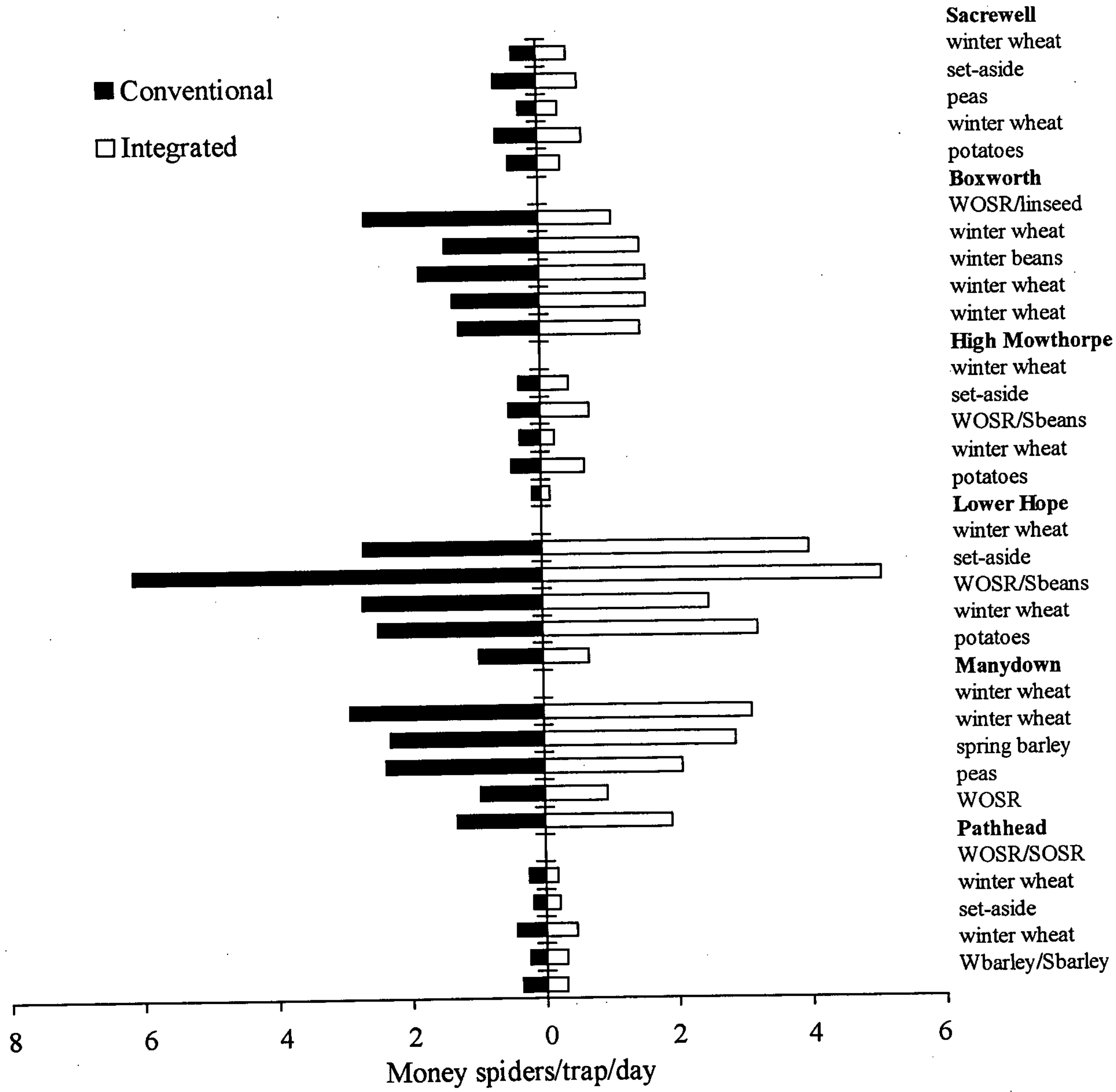

Figure 7.5 - Mean number of money spiders for April to July over 5 years within each phase and system.

By species

Erigone species were the most frequently captured money spider taxa and analysis was possible for April, May, June and July for Boxworth, High Mowthorpe, Lower Hope and Manydown (Appendix H, Table 7.3). Considerable differences in numbers was found between years and crops with some consistent trends. Overall, fewer were captured in the integrated linseed and second wheat crops at Boxworth, whereas at High Mowthorpe, more were found in the integrated wheat crops. No significant effects were detected at Lower Hope or Manydown. *Oedothorax* species were also found more frequently in the integrated winter wheat at High Mowthorpe.

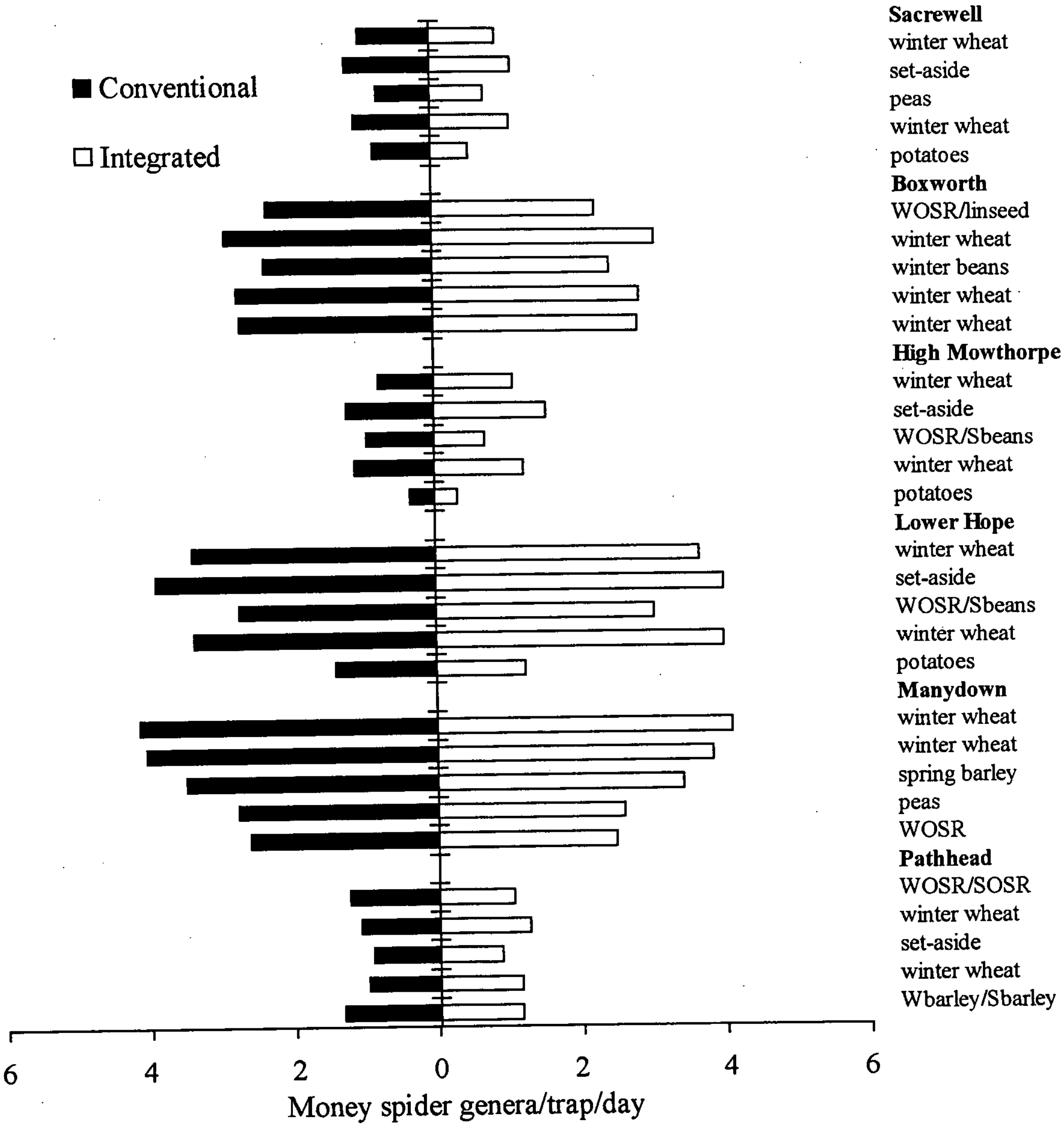

Figure 7.6 - Mean number of money spider genera for April to July over 5 years within each phase and system.

Discussion

Overall, the largest differences in numbers of ground and rove beetles and money spiders were found between sites and years, then crops and to the least extent between the farming systems. This was also confirmed by the analysis of individual species. Therefore, although it is known that some farming practices may affect invertebrate activity, in this study, these effects were relatively small compared with other external influences. Further analysis would be needed to identify the causes of short-term fluctuations. The main differences detected between the farming systems were usually a result of a different crop being grown in the integrated system, and often the choice of a spring crop was less favourable to the invertebrates.

Considerable variation was found between the sites with especially low numbers of all invertebrates at Sacrewell, High Mowthorpe and Pathhead. These are the most northerly sites indicating that this may be a climatic influence, although for Sacrewell and High Mowthorpe invertebrates were probably lower because of the husbandry practices associated with growing potatoes. No recovery was found in the integrated plots at the sites with very low invertebrate numbers and diversity, over the five years (Holland *et al*, 1998). Pest control by natural enemies is, therefore, likely to very low at the sites with few beneficial invertebrates. Even at Manydown, which had high invertebrate numbers, a bolt-on study (see Appendix C) revealed that aphid control by polyphagous predators was only detectable in those fields where the predators were most numerous (Holland & Thomas, 1997). Further measures are therefore needed if invertebrates are to reach sufficient densities to hold pest damage at acceptable levels without chemical intervention. In such a situation where mid-field populations have been depleted re-invasion from non-crop habitats is important, but what proportion of these areas is needed and where they should be located within intensive arable production areas remains to be resolved.

Insecticide usage was relatively infrequent within both systems, with the exception of potatoes, and did not appear to have any long-term effects, consistent with the findings from other arable crop studies e.g. SCARAB (Young *et al.*, 2000). Broad-spectrum insecticides were largely avoided in both systems. At Manydown, dimethoate was used, but only in the conventional vining peas, and no long-term differences were found. The intensity of weed control may also influence invertebrates because many species favour weedier crops. Herbicide use was reduced but this was to lower costs and the risk of leaching rather than preserve individual species for invertebrates. Differences occasionally occurred as a result of poor weed control and greater tolerance of for example *Poa anua* at Pathhead, and this resulted in a two-fold increase in invertebrates (Richards *et al.*, 1997).

Non-inversion tillage has been shown to favour many invertebrate species but no consistent differences could be identified in this project which were attributable to this practice. The timing of cultivations is also important, although the impact of this will depend very much on the life history of an individual species: for example whether it is present as a larvae, pupae or an adult at the time of cultivation.

Only the main results are presented in this summary, and the short-term impact of particular practices were not identified. Multivariate analysis has confirmed that few differences occurred between the systems but further analysis is needed to try and isolate the most influential husbandry practices so that further guidelines may be produced.

Conclusions

1. Numbers and species diversity of beetles and spiders differed most between the sites, years and crops and least between the farming systems.

2. Numbers and species diversity were very low at four of the six sites, and did not increase from a low starting baseline over the five years.

3. Spring crops and especially potatoes were the least favourable crops for the beetles and spiders.

4. Although there were large differences in agrochemical inputs between the systems, no impacts on the numbers of beetles and spiders or species diversity were detected.

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CHAPTER 8 - Earthworms

Eddie McIndoe, Peter Chapman and Mike Coulson, Zeneca

Introduction

It has been suggested that earthworms are excellent bioindicators of the relative health of soil ecosystems (Kuhle, 1983). They are important in providing soil fertility and improving soil structure (Edwards & Bohlen, 1996). They have a major role in the breakdown of organic matter, and the release and recycling of the nutrients that it contains. By turning over large amounts of soil and organic matter, they can increase the rates of mineralisation of organic matter, converting organic forms of nutrients into inorganic forms that can be taken up by plants. Earthworms have many complex interrelationships with microorganisms. They depend upon them as their major source of nutrients, they promote microbial activity in decaying organic matter by fragmenting it and innoculating it with microorganisms, and they disperse microorganisms widely through soils. Earthworms also have a critical influence on soil structure, forming aggregates and improving the physical conditions for plant growth and nutrient uptake. They increase soil macroporosity, aerate the soil and improve its water-holding capacity.

Earthworms possess a number of qualities needed in animals used for biomonitoring of terrestrial ecosystems. They are large, numerous, relatively easy to sample and easily identified. They are widely distributed and relatively immobile. They are in full contact with the soil in which they live and they consume large volumes of this soil.

Agricultural practices, such as cultivations, can affect the soil ecosystem and the state of balance between the living organisms in the soil and the physical soil environment. It is well established that tillage and cultivation practices generally destroy pores, burrows, holes and cavities in the soil (El Titi, 1995). This changes the water-holding capacity, conductivity and water permeability of the soil. Conversely, soil compaction can change habitat structure, resulting in serious effects on the composition of soil fauna and microflora, with consequent effects on the processes of mineralisation. Agrochemical inputs can also affect earthworm populations both directly and indirectly.

Integrated farming seeks to manage soils to the benefit of the earthworms, by returning crop residues to the soil to provide food sources and by taking a more considered approach to soil cultivations, such as minimising the frequency and intensity of major cultivations such as ploughing. Care is also taken in the use of agrochemicals that are known to have adverse effects on earthworms.

Method and data analysis

In the IFS project, earthworm samples were taken in 1992 (referred to as pre-treatment samples) then in autumn 1994 or spring 1995 (referred to as the 1995 samples) and after harvest at the end of the project in 1997. Samples were taken from two areas of one square metre selected at random from within each experimental plot, by digging and sorting to plough depth and formalin drenching to bring up deep-burrowing worms. Two taxonomic groups, tanylobous and epilobous, were identified within each sample. The number and total weight of adult and immature worms in each of these groups were recorded. However, all groups were not present in sufficient numbers to permit a separate analysis of each. Therefore, only the total number and weight of earthworms were analysed.

Results

Earthworm populations and biomass, averaged over the two treatment sample years 1995 and 1997, are shown in Figures 8.1 and 8.2 (data are also given in Appendix I, Table 8.1). Numbers were very low at Sacrewell, High Mowthorpe, Lower Hope and Manydown. The first three of these sites, all had potatoes in the rotation. Also Sacrewell, High Mowthorpe and Manydown, all have shallow stony soils which are not conducive to high earthworm populations. Numbers of worms in the deeper soils at Boxworth and Pathhead were in the normal range for arable soils (Edwards & Bohlen, 1996). Biomass results followed a similar pattern to the population figures.

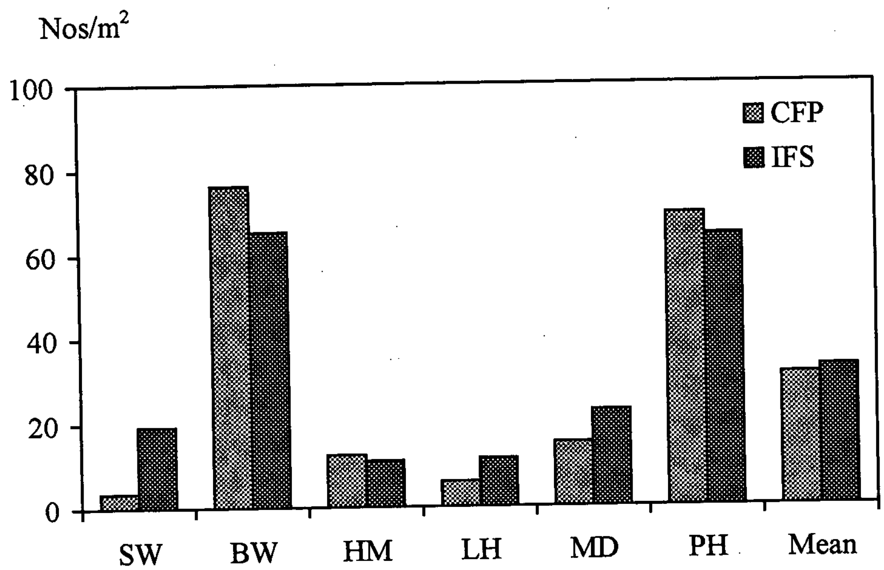

Fig. 8.1 - Total number of earthworms, meaned for 1995 and 1997 (no/m^2)

There were no statistically significant differences at any of the sites between the overall CFP and IFS cropping systems for either earthworm numbers or weights. At Boxworth and Pathhead, there were no statistically significant differences at all, whilst at Sacrewell and Lower Hope, the populations were so low that formal analyses were inappropriate and definite conclusions could not be drawn.

At High Mowthorpe, there was a statistically significant interaction between sample year and cropping system for both earthworm numbers and weights. In 1995, earthworm numbers were significantly greater on the conventional plots. However, by 1997, this had reversed when both numbers and weights were significantly greater on the integrated plots.

At Manydown, whilst no significant effects were observed on earthworms numbers, a significant interaction between phase of rotation, sample year and cropping system was observed on weights. This result was due to a significant increase in the weight of worms on the integrated oilseed rape plots in 1997. There was, however, no obvious reason for this apparent effect as cultivations and cropping were the same for both systems at this site.

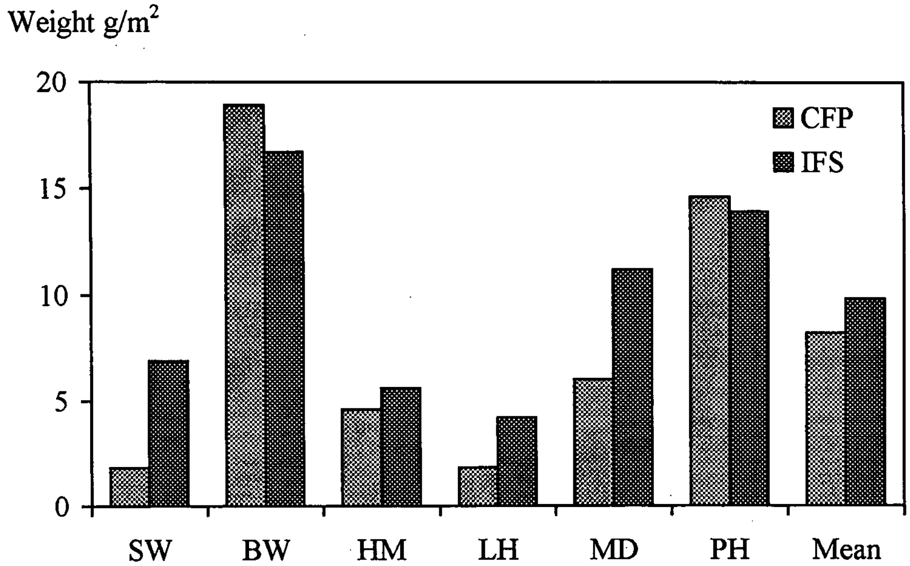

Fig. 8.2 - Total weight of earthworms, meaned for 1995 and 1997 (g/m^2)

Discussion

Overall, the analyses of earthworm numbers and weights yielded similar conclusions. Whilst some statistically significant effects were observed, these were all interaction effects which by their nature, indicate that there were no consistent effects of farming system on earthworm populations over the course of the study. Furthermore, when the levels of the significant interactions are examined, the number of significant results is consistent with the number that would be expected to arise by chance alone. Two of the sites, Sacrewell and Lower Hope, had such low earthworm populations that formal analyses were inappropriate and definitive conclusions could not be drawn. One common factor to these sites was that they both grew potatoes, a crop which requires the dramatic cultivation practice of soil destoning which is extremely disruptive to the soil structure.

The frequency of use of non-inversion tillage was 35% at Sacrewell, 56% at Boxworth, 35% at High Mowthorpe and 28% at Lower Hope, but none of the sites used direct drilling, which has been shown to be beneficial to earthworm numbers and biomass in an arable cropping situation. Results from the classic integrated farming project at Lautenbach in Germany (El Titi, 1995) show a greater incidence of worms in the integrated system in each of the 14 years of the study. Whilst reduced cultivations are thought to have contributed greatly to this effect, soil cover and organic matter availability were also key factors.

Inorganic fertilisers have been shown to affect earthworm populations but generally fertilisers were only detrimental when ammonia sulphate was used which was thought to be due to its acidity. Other nitrogenous fertilisers were found to increase earthworm populations (Edwards & Bohlen, 1996).

In their review of the effects of pesticides, Edwards & Bohlen (1996) list the pesticides which are known to be very toxic to earthworms, and these include chemicals such as phorate, benomyl, methiocarb, aldicarb, and carbofuran. In general, most organophosphate insecticides, pyrethroid insecticides, fungicides (except benomyl and carbendazim) and herbicides have been shown to have low toxicity to earthworms. In addition, the degree of exposure of earthworms to pesticides in soils depends upon a wide range of variable factors that may be associated with not only with the chemical, the route of exposure and the soil type, but also the environmental conditions, and the species and behaviour of the earthworms. Recent field studies on the effects of pesticides on earthworms in the SCARAB project (Jones *et al.*, 2000) have shown no major or transient adverse effects of some currently approved pesticides on the populations or weight of earthworms in three contrasting arable situations. Sample variability was also evident in this study which involved more frequent, intense sampling as well as pesticide residue testing. Unexplained differences between treatments were also observed.

Results from the LINK IFS study are consistent with the literature and other recent studies for arable cropping. More radical alterations to the integrated cropping systems would be needed to improve the earthworm populations in the study fields. Practices would need to include leys in the rotation, use of organic manures and much less soil disturbance.

Conclusions

1. Numbers of worms in the deeper soils at Boxworth and Pathhead were in the normal range for arable crops. Numbers at the other sites were much lower, which may have been the result of shallow stony soils and/or potatoes in the rotations.

2. There was no evidence that the differences in agrochemical inputs or changes in cultivations between the two farming systems had any impact on earthworm populations.

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CHAPTER 9 - Energy use

Bill Basford and Nigel Penlington, ADAS Gleadthorpe Grange

Introduction

Energy analysis of agricultural systems dates back to the early 1970s (Pimental *et al.*, 1973). Since then, there have been numerous papers highlighting the use of energy in agricultural production systems (Fluck, 1979; Panesar & Fluck, 1993; Taylor *et al.*, 1993; Bonny, 1993; Swanton *et al.*, 1996). The main focus of such papers was on the definition of the most appropriate techniques to use, and the trends in the energy efficiency of agricultural production over time. There has been a limited number of applications of energy analysis to the comparison of different methods of agricultural production, the most notable exceptions being in the field of organic farming (Lampkin, 1990) and a comparison by Donaldson *et al.* (1994) of energy usage for machinery operations of conventional and integrated farming systems.

Energy use calculation

The energy input for both the CFP and IFS systems at each site considered the total energy consumed in all processes up to but not including harvesting, crop processing or storage. The term total energy is used to include the direct energy in fuel consumed (diesel) and the indirect energy involved in the production of all other inputs from equipment to agrochemicals.

Direct energy use

Work rates (ha/hour) were calculated for all combinations of equipment on the basis of forward speed, width of working, and field efficiency for each task. Each operation was then assigned a fuel use in litres per hectare to calculate the energy consumed. Within the scope of the study, it was not possible to have the range of tractors at each site fitted with fuel monitoring equipment, so fuel use was assessed using published engine test data (Butterworth & Nix, 1983; DLG, Germany - OECD Tractor Test reports). Fuel usage was suggested for each power unit running at 80% full engine power, giving a mean value of 0.230g diesel per kWh, which converted to 37 MJ/l. (Conoco Ltd.).

Indirect energy

Many researchers have considered the energy required to construct equipment or contained within raw material inputs used in a wide range of industries (Leach, 1976; Fluck, 1979; Helsel, 1987; Swanton *et al.*, 1996). Within this study, energy requirements have been estimated for tractor and equipment construction, as well as the energy involved in seed, fertiliser and pesticide manufacture. This included all aspects of packaging, delivery and handling to the site.

The financial value of each piece of equipment was calculated based on its annual use, market value, depreciation and costs for spares and repairs (Nix, 1996). This value was then converted to an energy figure based on a conversion of 31.3 MJ/£ (Anon., 1991), and the indirect energy use was calculated for each hour of operation. The indirect energy per hectare for each operation was estimated using workrates as discussed above. Values used in all these calculations were based on many variables and reflected commercial use as far as possible.

Data analysis

As energy inputs were regarded in the main as an 'input' rather than a 'response' to treatment, it was considered that operational costs were not suitable for statistical analysis. Mean data are presented in this chapter.

Total energy

The direct and indirect energy values were combined to give the total estimated energy value for each piece of equipment. A wide range of equipment was employed over all sites, with additions and deletions during the life of the study. As far as possible, power units and systems were inspected and allocated into comparable groups for recording purposes. Power inputs were therefore assigned to the task, soil type and conditions at each site to permit comparison of the systems, rather than a comparison of the equipment available at each site.

Typical energy values, reflecting the complexity, capital involvement, draught requirement and work rate of each operation are given for some of the equipment in Table 9.1.

Table 9.1- Typical total energy values (MJ/ha) for a range of equipment including appropriate power units

Equipment	Direct Energy	% of total	Indirect Energy	% of total	Total
Plough	1160	57	890	43	2050
Heavy disc	860	55	700	45	1560
Power harrow	840	53	750	47	1590
Seed drill	280	58	200	42	480
Fertiliser spreader	32	64	18	36	50
Sprayer	51	60	34	40	85

Indirect energy values for inputs such as seed, fertiliser and sprays were included (Helsel, 1987). Mean values for pesticide active ingredients were used throughout due to the difficulty in obtaining information for the majority of pesticides used. This information was also not available to site managers to influence their choice of product. Herbicides used to calculate the mean included MCPA, diurone, atrazine, trifluralin, paraquat, 2,4-D, chloramben, arelon, propanil, propachlor, dicamba, glyphosate, diquat; fungicides included ferbam, maneb and captan; whilst insecticides included toxaphene, carbofuran, carbaryl and phorate.

Energy allocation between operations

An example of typical sector inputs in total energy use per ha are shown in Figure 9.1 for the production of winter wheat.

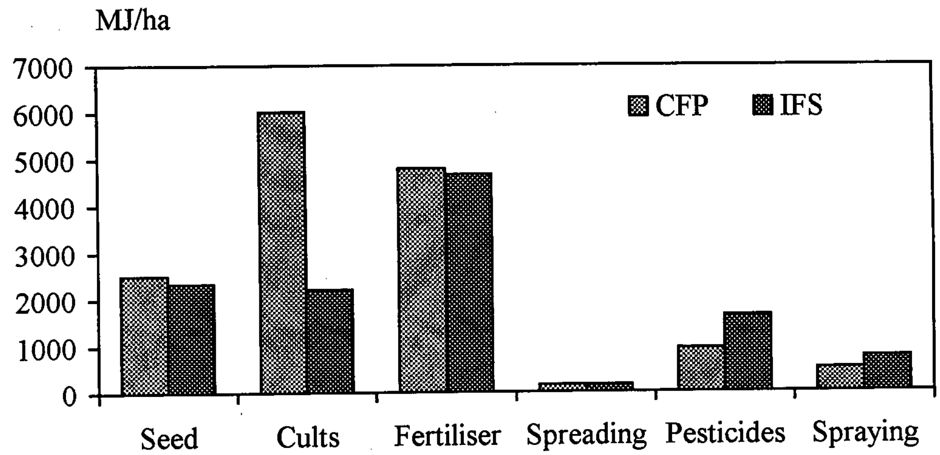

Figure 9.1 - Total energy Boxworth 1995, input sectors for one field of winter wheat, excluding harvesting (MJ/ha), (Cults = cultivations)

This example has been chosen since it demonstrates the difference in energy inputs in cultivation and crop establishment operations between the two systems. Only two passes were used on IFS, the first was a cultivator drill unit followed by simple harrowing. In contrast on CFP, five passes including a plough, power harrow, tined cultivator, seed drill and separate light harrow were used. The figure also illustrates the relativity of seed, fertiliser and pesticide energy inputs with operation energy inputs.

For comparison, typical sector energy inputs for potatoes are shown in Figure 9.2

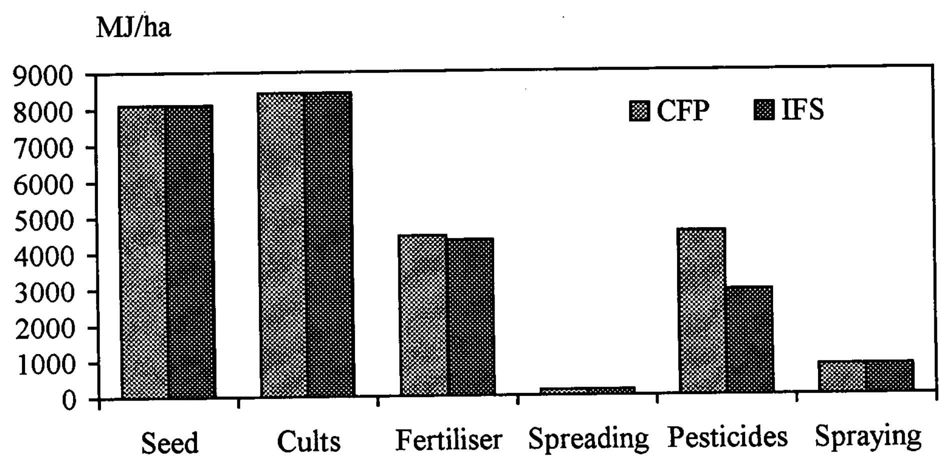

Figure 9.2 - Total energy High Mowthorpe 1994, input sectors for one field of potatoes, excluding harvesting (MJ/ha), (Cults = cultivations)

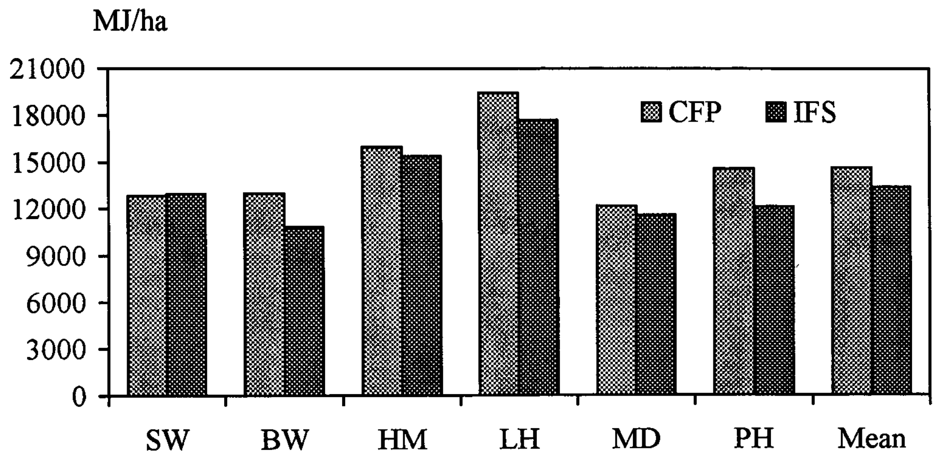

Figure 9.3 - Total energy use at each site (excluding harvesting), mean values for all crops all years (MJ/ha)

The mean values for total energy use were 14,667 and 13,428 MJ/ha for CFP and IFS respectively (Fig. 9.3). The mean difference in total energy of 1,239 MJ/ha between the systems was equivalent to 33.5 l/ha of diesel fuel using the standard conversion figure quoted earlier of 37 MJ/l. The difference in fuel actually consumed during work between the two farming systems was estimated to be 20 l/ha, as a result of the changes in cultivations, crops grown and reduced pesticide and fertiliser applications.

The percent change in energy input for all sites, all years for IFS relative to CFP is shown in Figure 9.4. Only one site, Sacrewell, expended more energy on IFS compared with CFP, which was probably due to the establishment of a cover crop on the integrated set-aside.

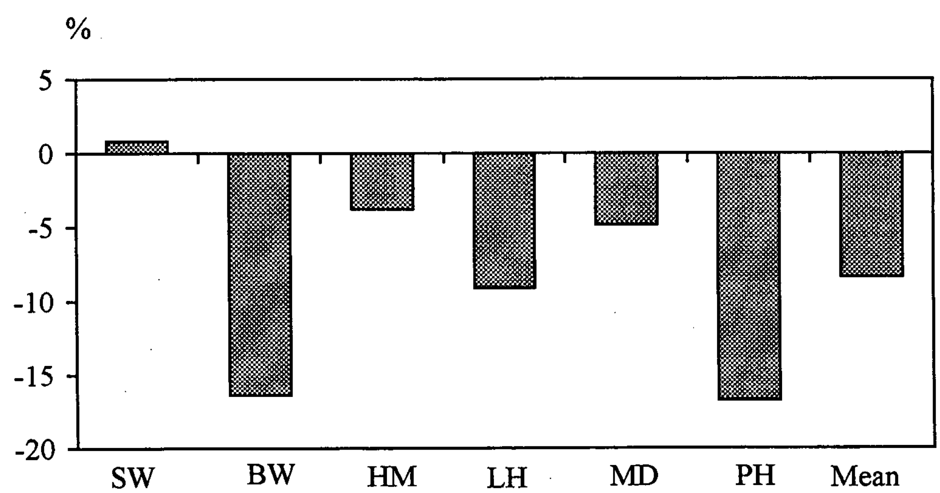

Figure 9.4 - Total energy use (excluding harvesting) for all crops all years
% change IFS to CFP

Harvesting

The inputs considered above excluded the harvesting operations, transport, processing, drying and storage. However, where desiccants were used pre-harvest, these and the operations to apply them, were included since some crops did not require them prior to harvest. There was insufficient data to judge whether harvesting was influenced significantly between the two systems studied. Some minor problems with weed growth were reported but not on all sites or all years.

Drying/Storage

Some crop records suggested that there could have been a slight increase in the amount of drying required for crops from the integrated plots. This could have been due to increased weed populations. It was indicated that this might have resulted in crops being harvested at 1.5 - 2 % points higher moisture content on occasions but no conclusive evidence was found for this. Calculations used to estimate the energy used in harvesting, transport to store, drier use and fuel to dry crops by 3 % points moisture content i.e. from 17% to 14 %, were on the same basis as other inputs. It was suggested that this would add another 5,150 MJ / ha to the mean figures presented earlier.

Energy use in relation to output

All detail discussed so far has related to inputs only; energy values per kilogram of crop produced are presented in Figure 9.5.

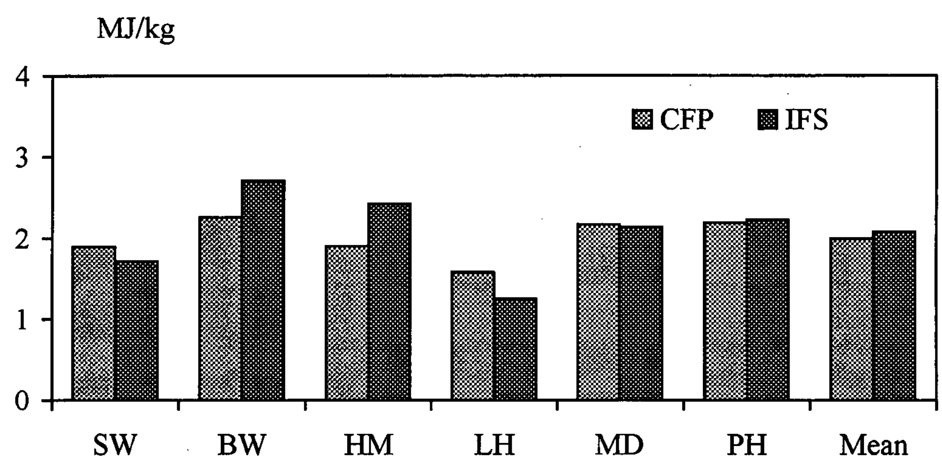

Figure 9.5 - Total energy (excluding harvesting) per kg yield at each site, for all crops all years (MJ/kg)

Overall, there was very little difference in energy values between the systems, when calculated on a yield basis. Slight increases were seen at High Mowthorpe and Boxworth, which was probably related to the lower mean yields at these sites.

Conclusions

1. Using the approach described in this chapter, it has been possible to estimate total energy inputs for the two farming systems. Overall, the integrated approach resulted in an 8% saving in total energy input, equivalent to 1239 MJ/ha or 33.5 l/ha of diesel fuel.

2. Actual fuel savings from changing or omitting field operations were estimated to be 20 l/ha or £3/ha (diesel price 15 p/l).

3. In general, cultivations required the highest energy inputs, but these could be substantially reduced by adopting a minimum tillage system

4. In cereals, fertiliser inputs resulted in higher energy levels than pesticide inputs, whereas in potatoes, energy levels were similar for both inputs.

5. There was little difference between the conventional and integrated systems when considered on energy input to kilogram of crop yield basis.

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CHAPTER 10 - Crop protection

John Coutts, Zeneca

Approach to integrated crop protection

The integrated approach varied from site to site to deal with local needs. However, some practices were adopted at most sites, with others at a few, with one or two which were site specific. The scale of adoption is described in Table 10.1.

Table 10.1 - Scale of adoption of practices into the Integrated Farming Systems

1. Widespread adoption	• Disease resistant cereal varieties • Treatment thresholds • Delayed drilling of winter cereals • Inclusion of spring crops in the rotation • Close monitoring of pests, weeds and disease incidence • Reduced rates of agrochemicals • Avoidance of residual herbicides.
2. Adoption at a few sites	• Mechanical weed control • Narrow spectrum agrochemicals • Integration of ploughing with reduced cultivations.
3. Site specific adoption	• Use of the Scottish Agricultural College low dose expertise to control broad-leaved weeds in cereals. • Avoid need for summer insecticides on cereals • Judicious application of herbicides (and desiccation where necessary) to maintain spring oilseed rape quality and minimise risk of seed admixture.

Crop protection inputs

Measures

Crop protection inputs were measured in £/ha, kg active ingredient/ha and pesticide units/ha (a unit is defined as the maximum rate of active ingredient 'Approved' for application to an arable crop). The pesticide unit was a concept specifically designed to allow comparison of inputs between IFS and conventional in this project. Whilst the size of the difference between IFS and CFP varies with the measure (Fig. 10.1), the direction is the same. Therefore, for simplification, results are presented here in £/ha with weight of active ingredient (kg/ha) and pesticide units (units/ha) in Appendix J (Tables 10.6-10.14). The term 'insecticide' also includes the use of nematicides and molluscicides

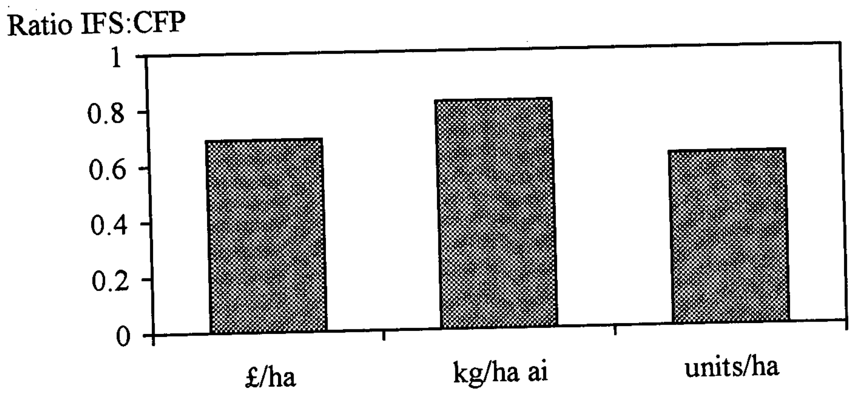

Fig. 10.1 - Pesticide measurements, mean of all crops, all sites and all years, ratio of IFS:CFP/ha

System comparisons

Crop protection costs were, on average, 31% (£32/ha) lower on the IFS compared with the CFP: corresponding reductions for weight of active ingredient and pesticide units used were 18% and 38% respectively (Fig. 10.1).

Herbicide costs were 23% (£9.75/ha), fungicides 42% (£17.57/ha), insecticides 20% (£3.52/ha) and plant growth regulators (PGRs) 55% (£0.94/ha) lower (Fig. 10.2). All the differences were statistically significant (P<0.01).

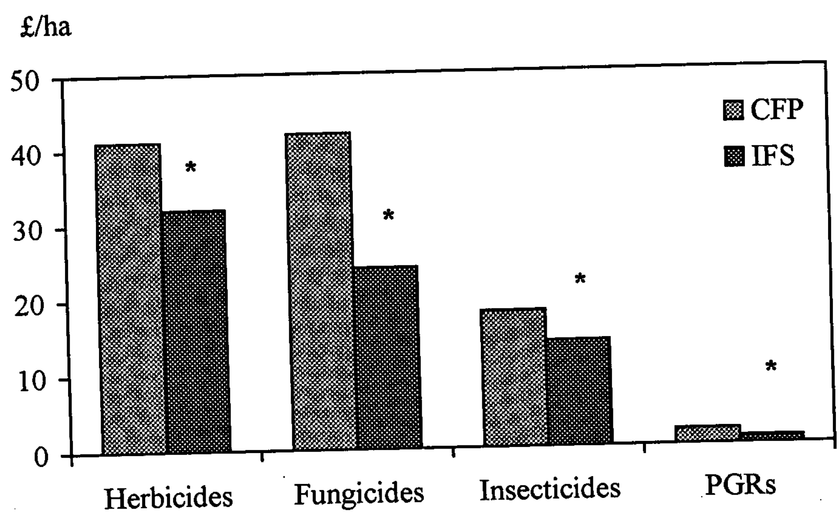

Fig.10.2 - Crop protection costs, mean of all crops, all sites and all years (£/ha/year)
(* Statistically significant result, P<0.01)

The costs were significantly lower on the IFS at all six sites (Fig. 10.3) and ranged from 55% of the CFP (£37.10/ha) at Pathhead to 20% (£33.62/ha) at Sacrewell.

Fungicide and PGR costs were significantly lower at all six sites; whereas herbicide and insecticide costs were lower at four sites, with no convincing evidence of a difference at the other two.

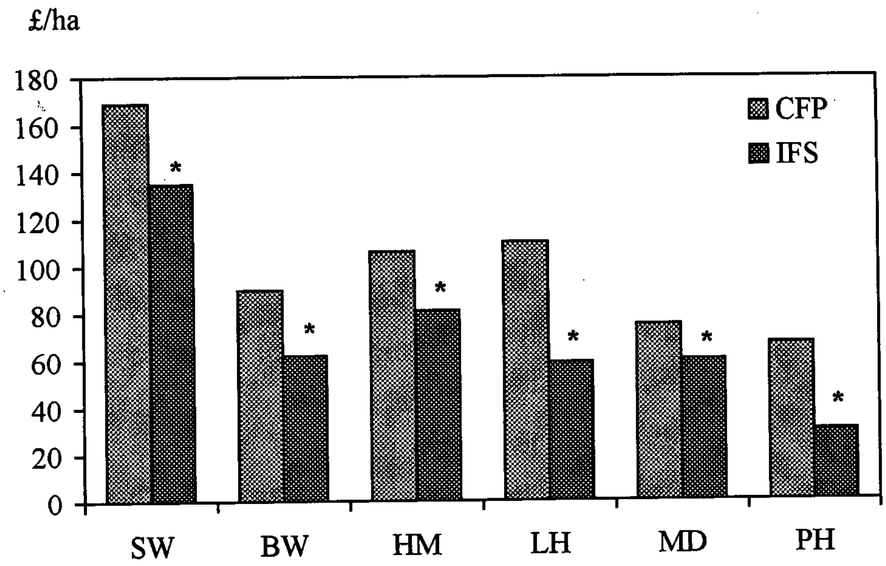

Fig. 10.3 - Crop protection costs at each site, meaned for all crops and all years (£/ha/year)
(* Statistically significant result, P<0.01)

The size of the decrease in average IFS costs was similar in each of the five years (Fig. 10.4). However, there were large yearly fluctuations in the herbicide, fungicide and insecticide differences at each site.

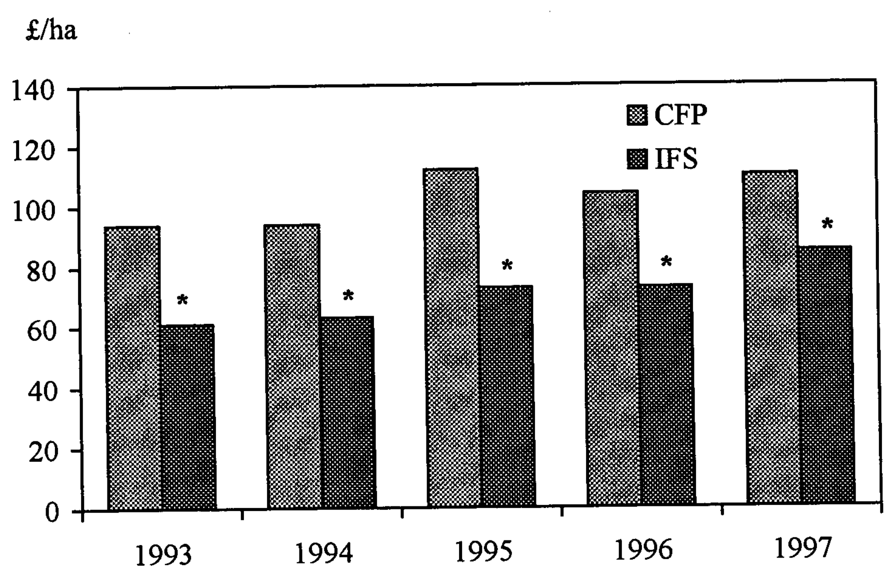

Fig. 10.4 - Crop protection costs in each of the five years, meaned for all crops and all sites (£/ha)
(* Statistically significant result, P<0.01)

Costs were lower in most crops grown in the IFS. The profile presented in Table 10.2 illustrates the individual contribution of herbicides, fungicides, insecticides and PGRs to the total. (Individual system cost by crop are presented in Appendix J, Table 10.12.)

Table 10.2 - Differences in crop protection costs by crop (CFP - IFS in £/ha)

CFP/IFS Crops	Herbicides	Fungicides	Insecticides	PGRs
1st W Wheats/1st W Wheats	4.8*	27.2*	5.5*	1.5*
2nd W Wheats/2nd W Wheats	7.9	22.7*	1.2	1.6*
S Barley/S Barley	2.0	5.4	0	0
W Barley/S Barley	8.3	29.3*	2.2	8.5*
Potatoes/Potatoes	31.7*	5.5	2.7	0
Peas/Peas	12.1*	3.5	-2.5	0
W Beans/W Beans	-16.8*	23.8*	0	0
Set-Aside/Set-Aside	4.5	0	0	0
W Oilseed Rape/W Oilseed Rape	4.8	11.8*	2.0	0
W Oilseed Rape/Linseed	0.3	17.9*	9.9*	0
W Oilseed Rape/S Beans	30.2*	15.6*	8.7*	0
W Oilseed Rape/S Oilseed Rape	31.8*	39.2*	7.8*	0
Mean	9.8*	17.6*	3.5*	0.9*

(* Statistically significant result, P<0.01)

Reducing the use of fungicides was the major contributor to the lower inputs in cereals; a result consistent with growing disease-resistant varieties and adopting practices such as delayed drilling for winter crops. In contrast, mechanical weed control was the major contributor to the lower pesticide costs in potatoes; the reductions were greatest at Sacrewell and Lower Hope. Where spring crops were adopted on the IFS, reductions in the use of herbicides, fungicides and insecticides all contributed to the lower costs.

Inputs compared with 'Standard Practice'

To help put the level of crop protection inputs applied in LINK IFS project into perspective, pesticide costs for wheat and weight of active ingredient applied are compared with standard figures in Tables 10.3 and 10.4.

Table 10.3 - Wheat crop protection costs (£/ha)

	LINK IFS (Mean over 5 years)			**J Nix***	
	CFP	IFS		1993	1997
1st W Wheats	102	63	Milling Wheat	115	135
2nd W Wheats	107	75	Feed Wheat	105	125

* Farm Management Pocket Books (Nix, 1992 and 1996).

Costs on CFP were comparable with standard figures for 1993, but lower than the 1997 costs. IFS costs were substantially lower than CFP and standard costs.

Table 10.4 - Weight of active ingredient applied to winter wheat (kg/ha ai)

	CFP	IFS	PUSR 1992*	PUSR 1996*
Herbicides	2.35	1.81	2.17	2.35
Fungicides	1.84	0.74	1.36	1.31
Insecticides	0.33	0.09	0.11	0.12
PGRs	1.10	0.53	0.91	1.02

* PUSR (Pesticide Usage Survey Reports), Davis *et al.* (1993) & Thomas *et al.* (1997).

CFP herbicide and PGR use were comparable with survey data, whereas the weight of fungicide and insecticide active ingredient was higher on CFP. Weight of active ingredient applied to the IFS was always lower than CFP and survey data.

Agrochemical spray applications

The lower agrochemical inputs led to a reduction of 26% (or 1.2 passes) in the number of spray applications required on the IFS at each site (Fig. 10.5). These results were not analysed statistically, mean data only are presented, as they were input rather than response data (see Chapter 3).

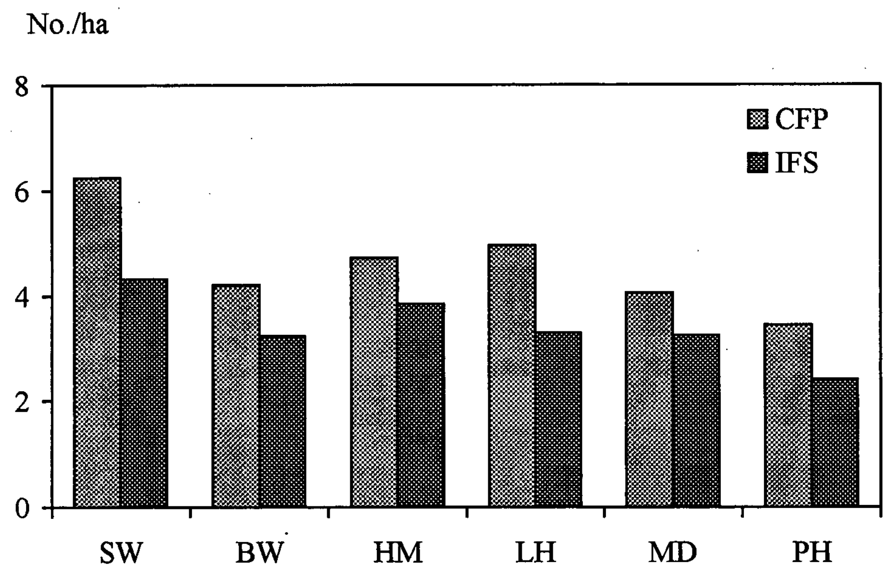

Fig. 10.5 - Number of spray applications per crop per year at each site

Avoidance of the need for fungicides and insecticides accounted for most of the reduction in the number of applications (Fig. 10.6).

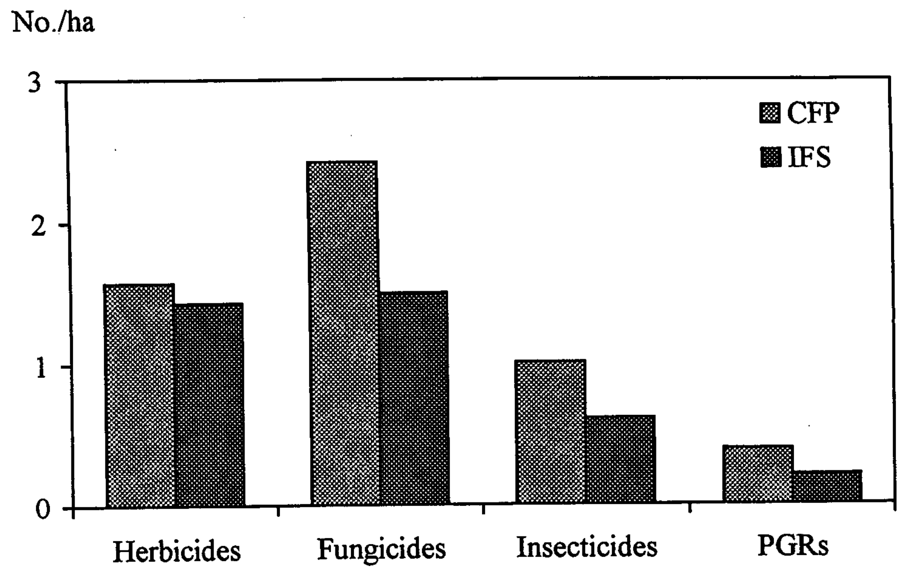

Fig. 10.6 - Number of spray applications per crop per year for herbicides, fungicides, insecticides and PGRs, meaned for all sites and crops.

Lessons learnt - weed, pest and disease control in cereals

There were no measureable trends in pest, weed or disease incidence over the five years of the experiment in either of the two systems (NB: weed seed bank results will not be available until 2000). However, there were specific differences which occurred as a consequence of practices adopted in each of the systems, and these are summarised in the following sections. Further detail on the effects of individual crop protection treatment decisions is given in Chapter 12 - validation trials results.

Weed control

At the start of the experiment, several sites adopted a policy of avoiding the use of residual herbicides for weed control in winter wheat, based on perceptions of overwinter leaching risks, and the integrated philosophy of treating a problem when the size and nature of it is known. As a consequence, grass weeds, notably black-grass and meadow grasses and occasionally broad-leaved weeds, such as chickweed, proved difficult to control in the spring. Primarily, this was because the weeds were too large for effective control with the available herbicides on those few occasions when spring weather conditions were suitable for spraying. Validation trials showed the size of yield loss at particular sites. In all cases, a return to residual herbicides applied pre- or early post-emergence solved the problem. However, it was not possible to demonstrate in this project, whether it was the residual activity of the herbicide or the early removal of weeds that had the beneficial effect. The value of pre-emergence weed control was also evident in some broad-leaved crops e.g. beans.

Delayed drilling had one of the most consistent effects on weed incidence (Table 10.5).

Table 10.5 - Effect of drilling date on weed populations in winter wheat at Manydown (weeds/m^2)

Weed species	Common name	CFP 26 October	IFS 24 November
Alopecurus mysuroides	black-grass	19	27
Galium aparine	cleavers	4	0
Papaver rhoeas	poppy	42	16
Stellaria media	chickweed	79	1
Veronica persica	speedwell	40	1
Viola arvensis	field pansy	537	40

The only pronounced change in species diversity has been the presence of volunteers, notably beans and oilseed rape from previous cropping. Neither has proved troublesome as they are simple to control in cereals.

Varying levels of success were achieved with mechanical weed control. Good control in potatoes was achieved at High Mowthorpe, Lower Hope and Sacrewell resulting in a large reduction in herbicide inputs; in most years a re-ridging was required afterwards with care needed not to bring up stones after stone separation. Peas at Sacrewell were weeded successfully, whereas beans have proved problematic; success in winter beans at Boxworth, but poor control in spring beans at High Mowthorpe. Mechanical weed control was abandoned at Pathhead mainly because of the lack of suitable conditions. When tried in spring barley at Manydown, it resulted in considerable yield loss. Overall, opportunities to mechanically weed winter cereals were few because soil conditions and crop and weed growth stages were rarely ideal for effective weed control.

Disease control

Diseases were controlled successfully in both CFP and IFS systems, even with the reduced level of fungicide inputs in most IFS crops, illustrating that the judicious selection of cultural practices can help reduce fungicide use. There was some evidence at Manydown that by delaying the drilling of second winter wheats in the IFS, the incidence of true eyespot (*Pseudocercosporella herpotrichoides*) was reduced.

Pest control

Insecticides were not routinely applied to any of the cereal crops, and pest incidences throughout the duration of the project were low. The incidence of slug damage was less at Pathhead where winter wheat followed spring oilseed rape in the IFS than where it followed winter oilseed rape in the CFP. At Sacrewell, wheat bulb fly (*Delia coarctata*) attack was less severe on the IFS in 1993 and 1997, but only in 1993 did the difference lead to an omission of a spray; whereas at High Mowthorpe, wheat bulb fly egg numbers were always lower and below treatment threshold on IFS than on CFP, which required routine treatment.

Conclusions

1. Crop protection inputs can be lowered significantly by the adoption of an integrated farming system.

2. The size of input reduction depends on the measure, the input (herbicide, fungicide, insecticides and PGRs), the site and the husbandry practices adopted. The largest potential reductions are in fungicides and herbicides - measured in absolute as opposed to percentage terms.

3. As the crops, husbandry practices and varieties employed at all of the sites in the LINK IFS project are well known, generally well understood and widely available, there are no technical barriers to adoption.

4. The reduction in crop protection inputs resulted in fewer spray applications, particularly fungicides and insecticides.

5. There were no measurable differences in pest, weed or disease trends between the two systems (NB: weed seed bank analysis still to be completed). Differences between the two systems were specific to the sites, and the result of adoption of specific practices in the IFS. The effects were consistent with 'general experience'.

6. The widespread adoption of post-emergence weed control in the IFS was unsuccessful and sometimes resulted in yield losses. The application of residual herbicides either pre- or early post-emergence solved the problem. It is important to know how many weeds and of which species in the overwinter period may cause yield loss, and have the ability to robustly remove them in the spring, if autumn residual herbicide use is to be decreased.

7. Results with mechanical weed control were variable. Mechanical weeding in potatoes was a successful and economically viable technique when soil conditions were dry at the time of the first weed flush. It was most successful in this crop when used in conjunction with low-dose post-emergence herbicides. Results in other crops were not as good, and lessons learnt about the limitations of mechanical weeding are consistent with previous experimental and practical experience.

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CHAPTER 11 - Crop nutrition

Neil Fisher, SAC Edinburgh

Introduction

In the IFS project, nitrogen inputs were carefully calculated to balance with individual crop requirements, offtakes and existing soil residues, without leaving excess residues after harvest, which could be lost by leaching or run off. The soil in every field was sampled in the spring, to estimate soil mineral nitrogen reserves from soluble nitrate and mineralisable organic matter, and chemical inputs were adjusted accordingly. More detailed studies on nitrogen utilisation and loss were carried out as part of the N bolt-on project, results from this are given in Appendix K. Other basal elements were usually applied on a rotational basis to maintain soil fertility at an acceptable level. Crop residues were incorporated in the soil where practicable at three of the sites (SW, BW and HM), to minimise offtake of nutrients. Cover crops were used before spring crops where weather and soil conditions permitted their establishment, and a green cover was maintained during the critical periods for leaching in the set-aside phase of the rotations, to retain nutrients in the top layer of the soil profile, to prevent soil erosion and the development of problem weeds.

Data analysis

As fertiliser applications were regarded in the main as an 'input' rather than as a 'response' to treatment (see Chapter 3), it was considered that they were not suitable for statistical analysis. Mean data are presented in this chapter.

Nitrogen fertiliser inputs

All sites except Sacrewell used less nitrogen fertiliser in the integrated farming system (IFS) than in the conventional farm practice (CFP) by an average of 28 kg/ha/yr (Fig. 11.1). The use in IFS was 80% of CFP (119 v 147 kg/ha N). The difference between systems was small at Sacrewell and Manydown where the same crops were grown on IFS and CFP.

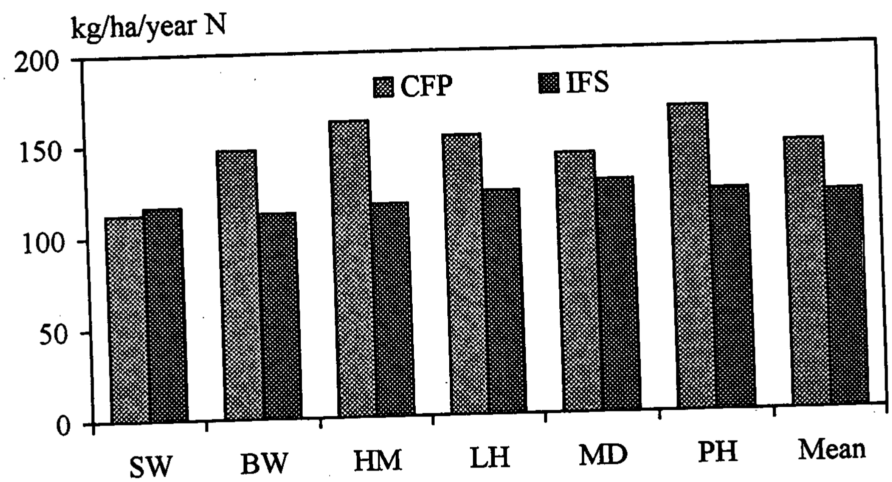

Figure 11.1 - Nitrogen fertiliser inputs at each site, meaned for all crops and all years (kg/ha)

Nitrogen use was less on IFS at the sites that opted for different break crops or where more spring-sown crops were grown. At Boxworth, less nitrogen was used on linseed than on winter rape. At High Mowthorpe and Lower Hope, spring beans were grown without nitrogen in comparison with winter rape which used 194 kg/ha N on average. At Pathhead, less was used on spring rape and spring barley than on their winter counterparts.

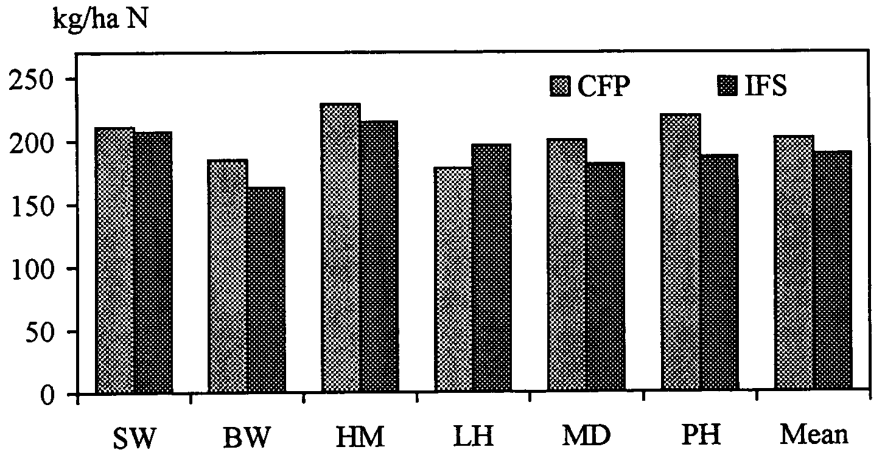

Figure 11.2 - Nitrogen fertiliser inputs on winter wheat at each site, meaned for all years (kg/ha)

At most sites, less nitrogen was used on the integrated winter wheat crops (Fig. 11.2). However at Lower Hope, more nitrogen was used to raise protein levels in breadmaking IFS wheat, compared with the feed wheats grown on CFP. The average nitrogen use on IFS wheat was 94% of CFP, or 13 kg/ha less (189 v 202 kg/ha N).

Soil mineral nitrogen in the autumn

At Pathhead and High Mowthorpe, measured soil mineral nitrogen (SMN) in the autumn was significantly less in IFS than in CFP (Fig.11.3). At Pathhead, high values in CFP occurred after winter rape and winter barley which were avoided in the IFS rotation. At High Mowthorpe, significantly lower values occurred after spring beans than after winter rape.

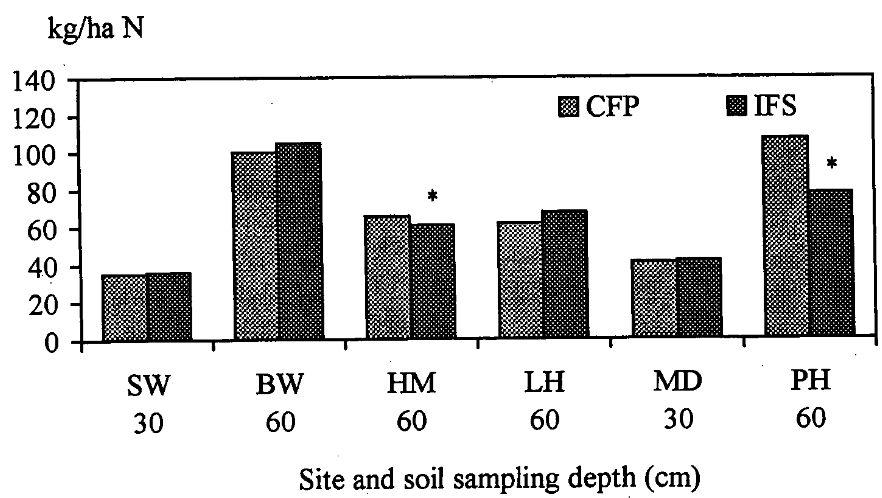

Figure 11.3 - Autumn SMN to stated depth at each site meaned for all years (kg/ha N)
(* statistically significant result, $P<0.05$)

There were five phases in all the rotations where a spring crop in IFS replaced a winter crop in CFP including Boxworth where spring linseed was used in the early years. In each case except for the linseed, the IFS spring crop left behind significantly less soil mineral nitrogen than the CFP winter crop (Fig. 11.4).

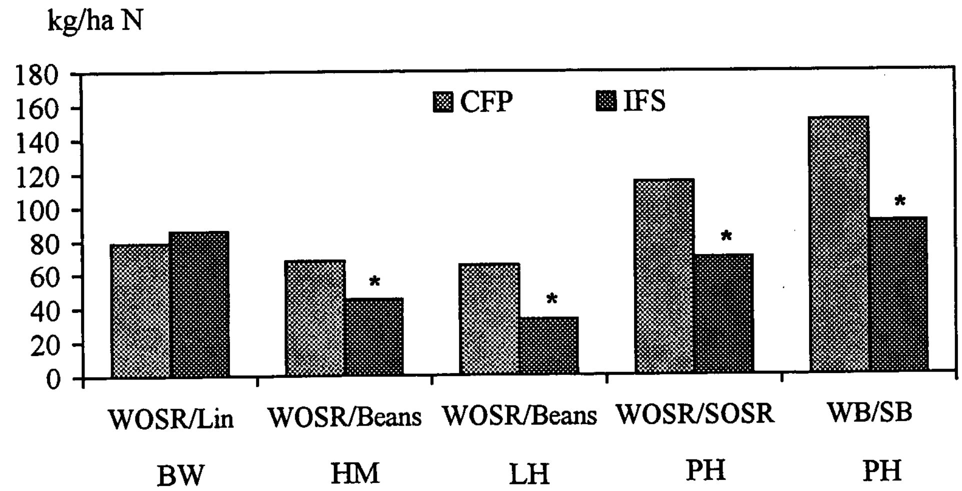

Figure 11.4 - Autumn SMN: winter/spring crop comparisons, meaned for all years (kg/ha N)
(* statistically significant result, P<0.05)

Phosphate and potash fertiliser inputs

Except for Sacrewell which adopted a deliberate policy of running down a very high phosphate status in the IFS, all sites had similar phosphate inputs with some economies for less demanding crops (Fig. 11.8). Overall, the phosphate input to IFS was 86% of CFP (50 v 58 kg/ha).

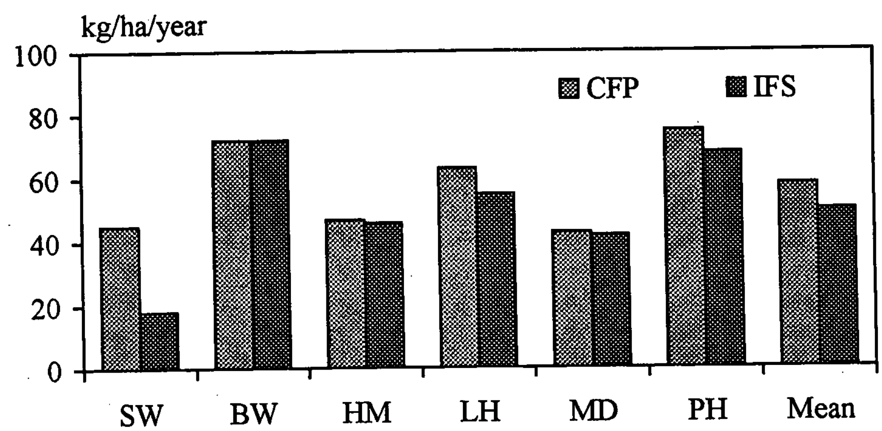

Figure 11.8 - Phosphate fertiliser inputs at each site, meaned for all crops and all years (kg/ha/year)

On the high status potash-releasing soil at Boxworth, no potash fertiliser was used but on the other sites similar inputs were used on the two systems (Fig. 11.9). Overall, the potash input to IFS was 95% of CFP (56 v 59 kg/ha).

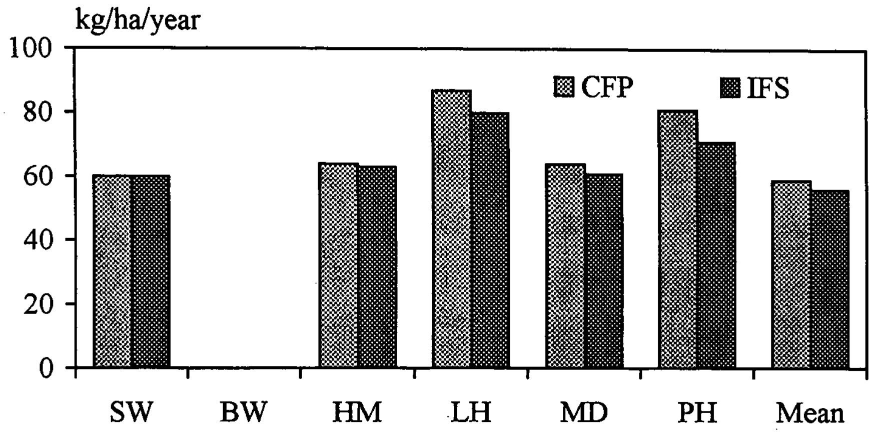

Figure 11.9 - Potash fertiliser inputs at each site, meaned for all crops and all years (kg/ha/year)

Phosphorus and potassium balance

With the exception of the IFS at Sacrewell, all sites applied more phosphate fertiliser than was removed in the crops (Fig. 11.10). Sacrewell and Boxworth applied less potash than was removed while Lower Hope, Manydown and Pathhead were in positive balance (Fig. 11.11). High Mowthorpe removed less than was applied in IFS because the straw was incorporated. On average, both systems had a very small negative balance.

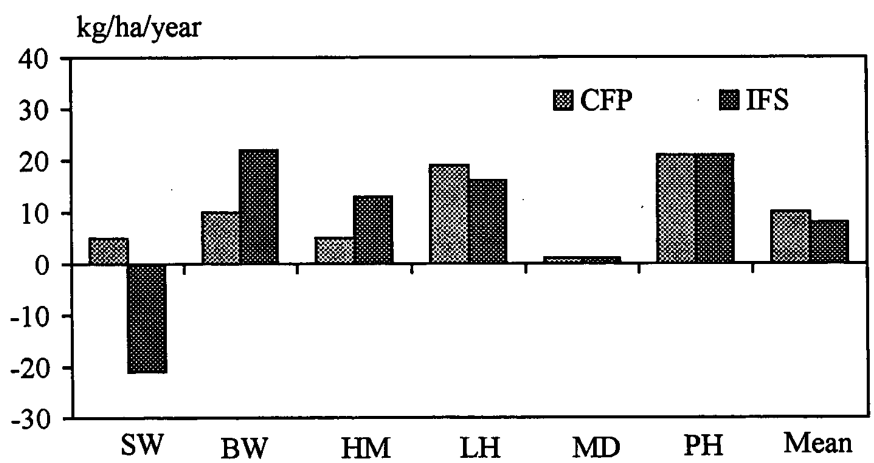

Figure 11.10 - Phosphorus balance at each site, meaned for all years (kg/ha/year)

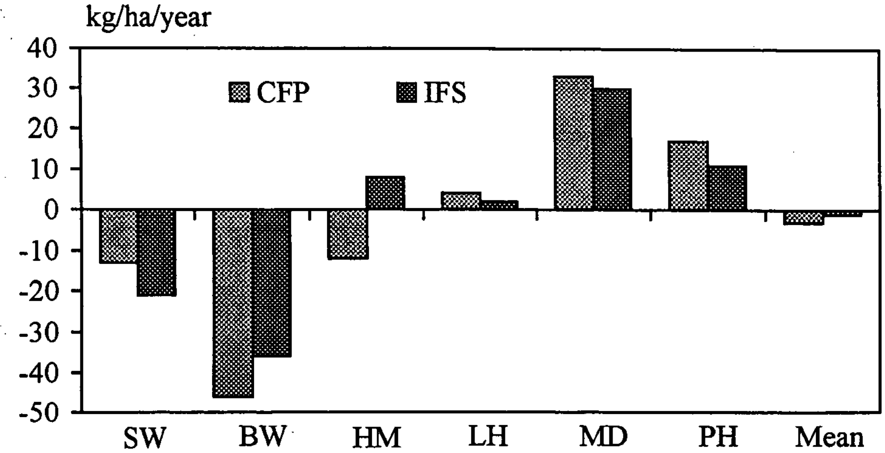

Figure 11.11 - Potassium balance at each site, meaned for all years (kg/ha/year)

Soil analysis and trends

Soil analysis trends for each system over the five year period of the project are presented in Figs. 11.12, 11.13 and 11.14. The data are compared with zero values which would imply that there was no trend in the soil nutrient status over the five years. At the start of the experiment, Manydown and Pathhead had low extractable soil phosphate values averaging about 20 mg/kg and Sacrewell was highest at 49 mg/kg. There were significant differences between systems at Pathhead with higher status on the IFS plots. The CFP at High Mowthorpe and the IFS at Sacrewell and High Mowthorpe had significant negative trends, and the overall effects were downward in both systems, though significant only in IFS (Fig. 11.12).

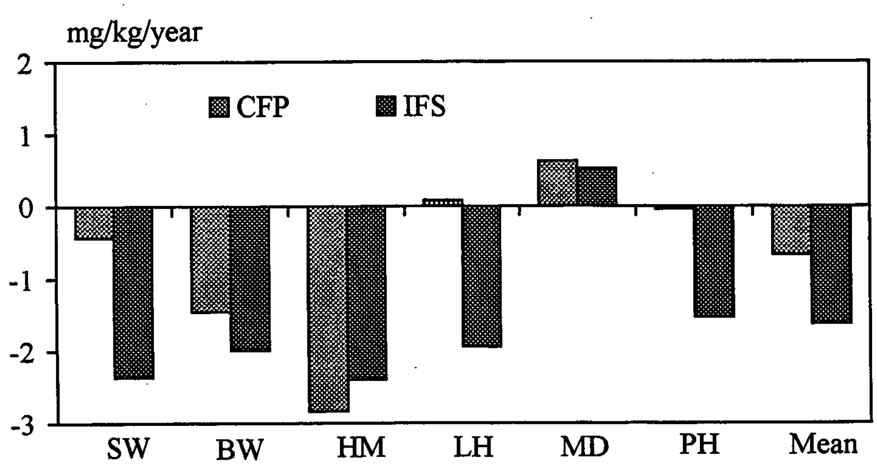

Figure 11.12 - Trends in phosphorus status at each site (mg/kg/year)

Pathhead had by far the lowest extractable potash values at 68 mg/kg while Boxworth had the highest at 270 mg/kg. The CFP at Boxworth and High Mowthorpe and the IFS at High Mowthorpe all had significant downward trends, and the overall trend was downward in both systems but significant only in the IFS (Fig. 11.13).

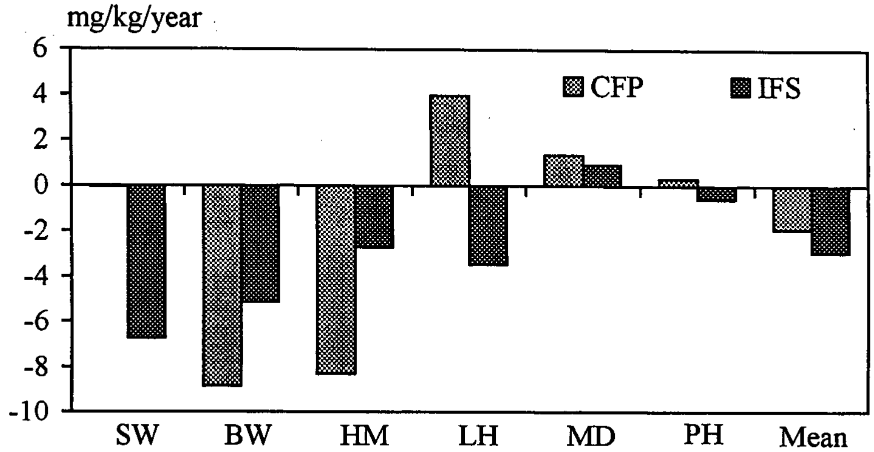

Figure 11.13 - Trends in potassium status at each site (mg/kg/year)

Lowest extractable magnesium values of 35 mg/kg were at Manydown and highest values were at Pathhead with 134 mg/kg. Sacrewell had a significantly lower status on IFS plots than on CFP but Boxworth had higher values on IFS. There were no significant trends in overall magnesium status but both systems declined on average (Fig. 11.14).

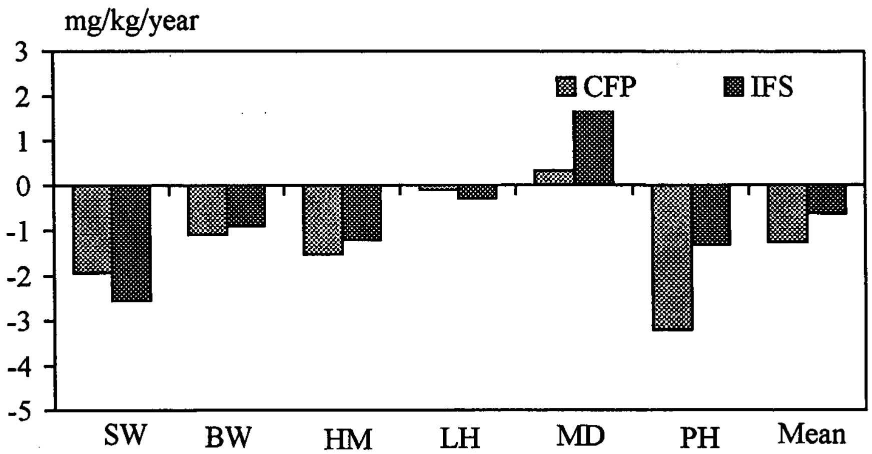

Figure 11.14 - Trends in magnesium status at each site (mg/kg/year)

Conclusions

1. All sites except Sacrewell used less nitrogen fertiliser for IFS and the overall average use was 81% of CFP. Some economies were made on winter wheat but most of the reductions were made by substituting less N demanding crops in the IFS rotations.

2. At Pathhead and High Mowthorpe, the IFS had less soil mineral nitrogen remaining in the autumn. Except for the linseed at Boxworth, there was less soil mineral nitrogen after an IFS spring crop than after a CFP winter crop.

3. All sites, except Sacrewell, applied more phosphorus than was removed in crops but nevertheless the overall phosphorus status tended to fall, especially at Lower Hope.

4. On average, the potassium input was in balance with offtake but there were considerable differences between sites. On average, there was a downward trend in potassium status, especially on the IFS.

5. Magnesium status tended to fall but the trends were not significant.

CHAPTER 12 - Validation trials

Sarah Cook, ADAS Boxworth

Introduction

At four of the six main project sites, Boxworth, High Mowthorpe, Lower Hope and Pathhead, small plot replicated trials were established on the integrated fields to check the validity of each major input decision within the integrated system. This work was funded by MAFF and the HGCA, and the full report is given in Part II of this main LINK IFS report.

Trial design

The validation exercise was designed to check the validity of each major input decision, and the comparisons generated were of two types:-

1. Where the crop was the same in both the CFP and IFS systems, an application made to the integrated crop was evaluated within the integrated system, by substituting the conventional input decision for the integrated input decision.
2. In other situations, or where the CFP and IFS crops differed in the same paired-field plots, the IFS decision was compared with possible alternative treatments. The aim of this was to test the effect of further minimising inputs, or evaluate alternative treatment effects on output. In some cases, the alternative treatment was a whole change in strategy, rather than a single change in one input.

Table 12.1 - Examples of treatment decisions

Possible IFS decision for field area	Validation experiment - small plot treatment
Disease resistant variety	Variety selected for conventional rotation
Nitrogen input modified according to soil mineral nitrogen level in field	Nitrogen applied according to Fertiplan alone (i.e. as conventional practice)
Autumn insecticide not needed due to delayed drilling and emergence	Pyrethroid applied as a routine spray
GS 32 fungicide delayed due to low disease pressure	Appropriate rate fungicide applied at GS 32
Flag leaf fungicide applied at appropriate dose based on latest product dose rate information	Recommended rate fungicide based on current local practice
Ear fungicide omitted (dry weather predicted)	Appropriate rate ear spray
No grain aphicide applied (i.e. just below threshold or high parasitic activity)	Grain aphicide applied
No autumn herbicide applied	Autumn residual herbicide

The validation trial plots were superimposed on all crops in the IFS rotation in each year (with the exception of the set-aside phase of the rotation). Plot sizes varied between 32m^2 and 72m^2, depending on site and crop. With the exception of the treatment under test, all other inputs for each plot were identical to the main IFS study.

For each major input decision made on the IFS rotation, a single factor comparison between the basic IFS and an alternative treatment was made (i.e. a change in dose rate, timing, product or specific strategy for disease or weed control). The IFS crop management strategy depended upon day-to-day decisions made according to detailed crop monitoring. Treatments under test in this supporting study could not be specified in advance but developed through the season in accordance with disease, pest and weed pressure, and crop fertiliser demand.

There were 87 experiments in total, and these were spread over six crop types. Details of the number of experiments and treatments are in Table 12.2. The number of comparisons in each crop is a function of the frequency of occurrence of the crop in the IFS rotations of the sites tested, and the normal range of inputs applied to the crop which offer alternative approaches to treatment.

Table 12.2 - Number of trials and treatment comparisons made in IFS crops

Crop	**Number of trials**	**Number of treatments in each category**							**Total no. of comparisons**
		Herbs.	**Fungs.**	**Insects.**	**PGRs**	**Nitrogen**	**Varieties**	**Other ***	
Winter wheat	45	99	198	41	51	51	6	2	492
Beans	17	20	34	11	0	0	0	4	83
Potatoes	9	18	10	1	0	5	0	6	48
Linseed	6	13	31	0	1	1	0	0	52
Spring barley	5	9	10	5	0	9	0	4	41
SOSR	5	10	11	7	0	5	0	3	41
Total	87	169	294	65	52	71	6	19	757

* includes micronutrients, SOSR = spring oilseed rape

Method and assessments

Sprays were applied using Oxford Precision Sprayers, nitrogen was applied by hand or toolframe-mounted spreader. The following assessments were done on the validation plots:

1. Disease or pest incidence at time of decision making and again at appropriate timing to establish the efficiency of the treatment, using appropriate methods for each crop and disease.
2. Yield and crop quality - combinable crops were harvested using plot combines, and potatoes were harvested by hand digging. Grain nitrogen content was measured in all combinable crops. In cereals, specific weight (all cereals), SDS and Hagberg Falling Number (quality wheats) were assessed.
3. Financial evaluation of each treatment - the final gross margin figures were calculated using actual crop selling prices achieved immediately after harvest. Area aid payments were not included but an allowance was made for application costs. The pesticide prices used were the same as those of the main LINK-IFS project, representing a mean UK price for inputs calculated from ADAS surveys.

Data analysis

From 1993 to 1995, the IFS validation trials were designed using randomised complete blocks i.e. each block contained one replicate of each treatment. For the trials in 1996 and 1997, their statistical design was changed to improve the precision (the power to detect significant differences between treatments). Improvements were made to both the blocking structure and the treatment structure. As a result, the trials were designed using incomplete blocks i.e. each block only contained a subset of the total number of treatments. The improved blocking structure consisted of between 4 and 6 plots per block. Most of the 1996 and 1997 trials were designed using α designs (Patterson *et al.*, 1978) which are an optimal set of incomplete block designs appropriate for these trials. A detailed discussion of these trials is provided by Lennon (1998).

As an alternative, a few trials were also designed with factorial treatment structures. In an experiment with a factorial structure, the effects of a number of different factors are investigated simultaneously. A factor is a set of treatments that can be applied to the experimental plots. A level of a factor is a particular treatment from the set of treatments which constitute the factor i.e. a factor could be herbicide and the different levels could be (1) none applied, (2) a half rate applied and (3) a full rate applied. The experimental treatment applied to a plot comprises one level from each factor in the experiment. Some of these trials took the form of fractional factorials, as there were more treatment combinations than experimental plots available.

Results

Of the total of 757 validation treatments on the integrated crops, the main IFS treatment was only significantly worse than the alternative treatments in 7% of cases (Fig. 12.1)

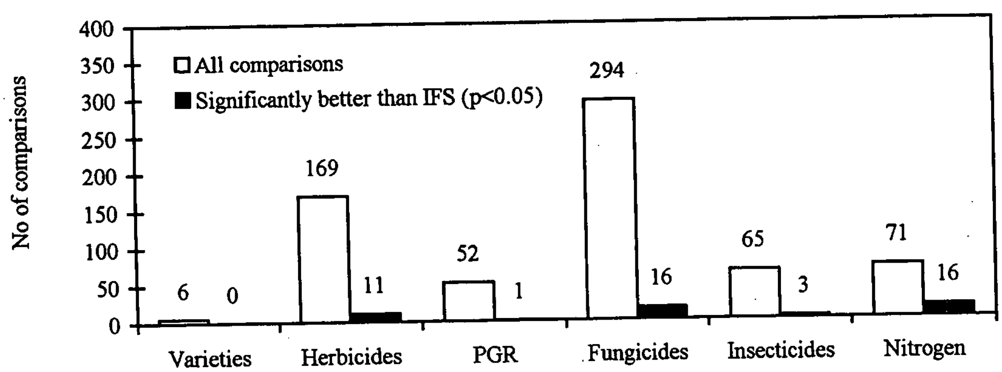

Figure 12.1 - Crop protection validation treatments for all crops, 1993-1997, and the number of treatments with a significant yield increase compared to IFS (P<0.05).

Weed control

In winter wheat, there were 99 validation weed control treatments, of these there were only seven in which the validation trial treatment resulted in a significantly higher yield than the IFS treatment. Overall, most of the yield increases (6 out of 7 occasions) were seen where a pre- or post-emergence residual herbicide was applied rather than a spring applied contact herbicide. If the alternative programmes had been followed in the integrated system on these seven occasions, the mean gross margin would have been £52/ha greater.

The validation treatments demonstrated that when early control of mainly annual grass weeds and sometimes broad-leaved weeds was required, autumn residual herbicides, generally produced better, more consistent weed control, higher yields and gross margins, than a sequence of purely contact products (predominantly spring-applied) and mechanical weeding. This was particularly apparent where weed populations were high, where there was an annual grass weed problem and where spring applications were delayed. In addition, herbicide programmes that relied on mechanical weeding and low dose spring herbicides were dependent on good ground conditions early in the spring for optimum weed control from the mechanical weeding. Previous cropping and soil type therefore assumed even greater importance in the IFS decision process, to maintain a good soil structure.

In the spring bean crop, the use of pre-emergence residual herbicides to control weeds resulted in higher yields and gross margins than where pre-drilling, mechanical weeding or post-emergence herbicides were used in the main IFS treatment. Post-emergence herbicide choice is very limited in the spring bean crop and often weather conditions were not conducive to maximum product activity. In later years, pre-emergence herbicides were increasingly used in the main integrated treatment at Lower Hope and High Mowthorpe.

Generally, mechanical weeding in potatoes was very successful in the integrated system at Lower Hope and High Mowthorpe.

Disease control

There were no set targets for fungicide reduction in the IFS rotation; all application decisions were based on detailed crop assessment, disease level, variety choice, weather conditions and the potential end market. The IFS approach took advantage of application rates at less than the manufacturers full recommended rate as did the conventional system, according to good local practice.

There were 198 comparisons of cereal fungicide strategies of which only 13 (6.6%) resulted in significantly ($p<0.05$) greater yields than the IFS treatment. If these decisions had been used in the integrated system then gross margins could have been, on average, £31/ha higher on these 13 occasions. Alternative treatments to the IFS fungicide strategy consisted of:-

a) Fungicide application at timings omitted in the main IFS approach.
b) The exclusion of fungicides applied to the main IFS plot.
c) The choice of a different product.
d) Alternative products at a rate and timing that is common conventional practice.

These alternatives allowed verification of most applications made to the main IFS treatment. Low disease pressure sites provided greater scope for large reductions in fungicide use within the integrated system where rotation, variety choice and drilling dates were optimised. A key selection criterion for all IFS wheat varieties was a good disease resistance profile. The use of Soissons and Hereward in particular allowed savings in fungicide inputs compared with conventional feed or biscuit varieties which, although higher yielding, usually required a higher fungicide input.

In the winter bean crops at Boxworth, no fungicides were applied to the IFS crops as disease was not considered to be a problem. However, when fungicides were applied in the validation experiments, yield increases of up to 0.57 t/ha and increases in gross margin of up to £45/ha were seen.

Reductions and alterations in the potato fungicide programmes were made but none showed any yield differences to that of the IFS system. In the IFS, an electronic blight monitor was used to monitor high risk periods. In the ware crop at Lower Hope, it was possible to widen spray intervals from 10 to 14 days during periods of predicted lower blight pressure. At High Mowthorpe, in a high value seed crop, although blight risk during the period of study was higher than that traditionally seen, sprays were maintained at maximum intervals.

Pest control

The low incidence of yield responses to insecticide treatment in these experiments, three significant responses to treatment in 65 comparisons, indicates that when pest pressure is low, there is considerable scope for reducing insecticide inputs on the basis of thorough and timely pest monitoring. Forty-one insecticide treatment comparisons were made on wheat in the validation experiments but only one of these resulted in a significantly higher yield than the IFS (0.25 t/ha). This was was due to the prevention of an aphid re-infestation.

Nitrogen use

Within the IFS project, nitrogen inputs for the integrated treatments were calculated to match crop and yield expectations. This was then amended according to the measured level of available soil mineral nitrogen present in the spring. Where the application rate was lower than the conventional system, the conventional rate was applied as a test treatment on the validation plots. Additional treatments to examine the effects of application rate, date and nitrogen source on grain protein content were applied to bread-making wheats.

In 78% of cases, the validation trials supported the nitrogen fertilisation strategy employed in the main IFS treatment, only 16 of the 71 comparisons gave significantly higher yields from the application of additional nitrogen. The nitrogen inputs were generally optimised in winter wheat, but were consistently 30 kg/ha too low in spring barley in Scotland, leading to significant reductions in gross margin by a mean of £53/ha.

Conclusions

1. The results from the small plot trials indicated there was scope for improving the gross margins of the IFS system up to the level of the conventional system, through optimising weed control, better prediction of nitrogen requirements and maximising production from break crops, although in the majority of cases the main IFS treatment was not bettered by the conventional or alternative strategies.

2. The use of autumn weed control, primarily through the use of residual herbicides in cereals was a critical factor in most rotations. Delaying herbicide application until spring increased the risk of yield loss and reduced profitability.

3. Nitrogen rates calculated from soil nitrogen analysis were generally correct for winter wheat, but when incorrect, yield losses could be severe and profitability decreased.

4. Mechanical weeding was most successful in potatoes, especially when soil conditions were dry at the time of the first weed flush, and when used in conjunction with low-dose post-emergence herbicides.

References

Patterson, H.D.; Williams, E. R. & Hunter, E. A. (1978) Block designs for variety trials. *Journal of Agricultural Science*, **90**, 395-400.

Lennon, M.G. (1998) *The design and analysis of multiple site, large plot, field experiments.* Ph.D. Thesis, University of Reading.

CHAPTER 13 - Operational and cultivation costs

David Turley, ADAS High Mowthorpe

Introduction

As part of the methodology of the LINK IFS project, a full inventory was made of all operations undertaken on each site and in each crop and year. Standard ADAS costings combined with those from Nix (1996) were used to apply an appropriate cost to each operation, which included an element for fuel use, labour, depreciation, repairs, tax and insurance and interest on capital. Standard costings were used to ensure commonality between sites. The inventory took account of all operations undertaken from seed bed cultivation to drying of harvested grain or grading of produce etc..

The International Organisation of Biological Control (IOBC) guidelines for integrated farming systems encourage the use of non-plough techniques to minimise soil disturbance (El Titi *et al.*, 1993). The aims of this are to:-

a) Reduce energy use and costs of cultivation.
b) Avoid burying weed seeds which could help prevent the buildup of weed seedbanks.
c) Flush weeds using sterile seedbed techniques.
d) Minimise the impact of cultivation on beneficial invertebrates.
e) Minimise the risk of soil erosion

Some the LINK IFS sites increased the proportion of non-inversion tillage used in the integrated crop rotation, with the aim of achieving some of these benefits.

Use of thresholds and better targeting of agrochemical inputs may reduce the number of applications to integrated crops, however, this may be offset by an increase in some operational costs such as those associated with establishment of cover crops, mechanical weeding and weed cutting or mowing (e.g. on set-aside). Costs of cultivation and input application are therefore of particular interest in the economic assessment of integrated farming systems which seek to minimise cultivation operations and crop inputs.

Data analysis

As operational costs were regarded in the main as an 'input' rather than as a 'response' to treatment, it was considered that operational costs were not suitable for statistical analysis (see Chapter 3). Meaned data are presented in this chapter.

Operational costs

The total operational costs averaged over all crops and years were lower in the integrated system than in the conventional system on four of the sites (Boxworth, High Mowthorpe, Manydown and Pathhead), and little different on the remaining two sites (Sacrewell and Lower Hope) (Table 13.1 and Figure 13.1). However, the differences were relatively small and mask considerable seasonal variation in total operational costs, as demonstrated by the range of year to year variation in Table 13.1. The highest operational costs were associated with sites growing potatoes (High Mowthorpe, Lower Hope and Sacrewell).

Table 13.1 - Differences in total operational costs (£/ha) between the IFS and CFP farming systems at each site, meaned for all crops and all years.

Site:	**% Occasions where annual operation costs in IFS < Conv**	**Range of annual difference (IFS - CFP £/ha)**	**Mean annual difference (IFS - CFP £/ha)**
Sacrewell	60	-12 to +39	+ 4
Boxworth	100	-49 to -13	- 27
H. Mowthorpe	80	-40 to +3	- 23
Lower Hope	40	-14 to +31	+ 2
Manydown	100	-10 to -2	- 7
Pathhead	100	-25 to -0.1	- 15

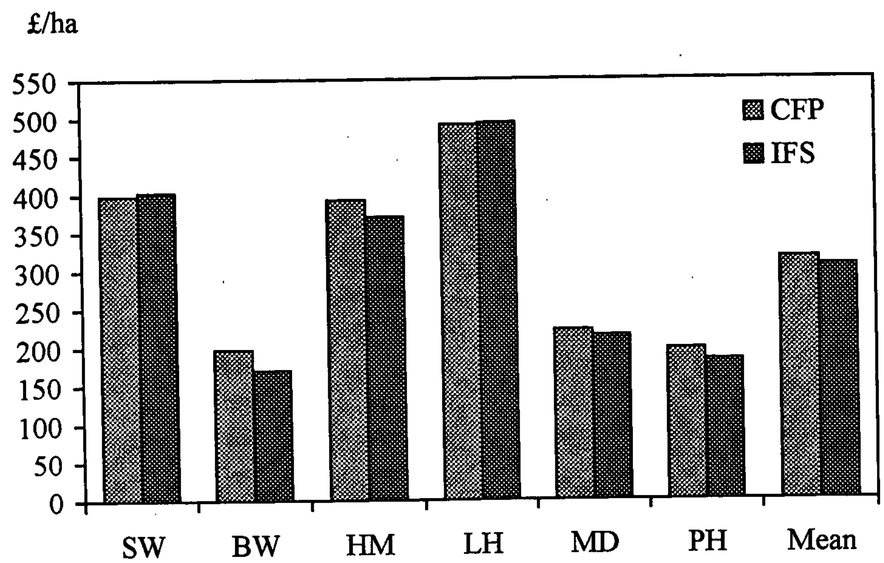

Figure 13.1 - Total operational costs, meaned for all crops and all years (£/ha)

Extra operational costs arose in the integrated system as a result of mechanical weeding, mechanical pre-harvest treatments (e.g. flailing of potato haulm), through additional costs incurred in establishing cover crops, and establishing, mowing and maintaining set-aside covers, particularly where set-aside cover was maintained beyond 1 May in the year of set-aside for wildlife or environmental benefits (e.g. maintenance of green cover to minimise nitrate leaching or to provide a habitat for farmland birds).

Cultivations

Cultivation operations in the conventional farming system were as commonly practised at each site, and this was predominantly annual ploughing. In the integrated system, some sites were able to adopt a greater proportion of non-inversion cultivations.

The Boxworth and High Mowthorpe sites regularly use minimal cultivations as part of the conventional farming system (Table 13.2). However, even on these sites further opportunities were found to adopt non-inversion cultivations in the integrated system. At the Boxworth site, this was achieved by adoption of the one-pass Rau system. At High Mowthorpe, a powered rotary cultivation (Rotospike), was introduced to bury surface trash after the spring bean break crop. Lower Hope incorporated disc/tine or powered non-inversion cultivations into one or two phases of the rotation where appropriate. Sacrewell used disc and tine cultivations to establish wheat crops during the early stages of the study, but found less opportunity to do this in later years. At Manydown, no suitable equipment was available on farm to adopt non-inversion cultivations, while at Pathhead, use of the plough to bury trash and weed seed was seen as a more important priority in the integrated system, so non-inversion cultivations were not utilised.

Table 13.2. Frequency of use of non-inversion cultivation for crop establishment (%)

Site	CFP	IFS
Sacrewell	0	35
Boxworth	28	56
High Mowthorpe	25	35
Lower Hope	5	28*
Manydown	0	0
Pathhead	0	0

* The integrated system at Lower Hope was also cultivated during the set-aside phase to establish a grass/clover cover

Cultivation costs

Highest cultivation costs were associated with sites growing potatoes (Sacrewell, High Mowthorpe and Lower Hope), and lowest on the medium-textured soil types growing combinable crops only (Manydown and Pathhead). When compared over all crops in the rotation, the greatest difference in cultivation costs between the conventional and integrated systems was observed at Boxworth (Figure 13.2). By adoption of 'one-pass' non-inversion cultivations to establish wheat crops in the rotation at Boxworth, cultivation costs were reduced by £21/ha/year on average. Small reductions in cultivation costs were made on the 'high cost' sites of High Mowthorpe and Lower Hope ranging from £7 to £11/ha/year. At Sacrewell, although small savings in cultivation costs were made in first wheat and pea crops, the additional costs of re-ridging following mechanical weeding, (which was recorded as part of the crop establishment costs for this site) pushed up cultivation costs in the integrated system by £3/ha/year on average.

With the exception of Manydown, where cultivations remained identical in each system, reductions in cultivation costs, with few exceptions, were consistent over season at each site. Whilst at Boxworth, these savings were made in numerous stages of the rotation, on other sites key savings were made where spring crops replaced winter-sown crops.

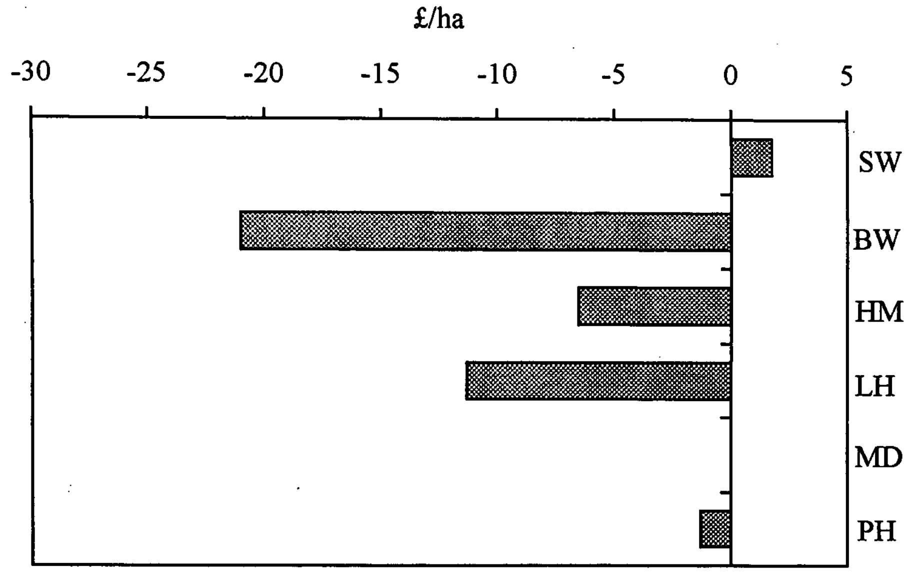

Figure 13.2 - Difference in crop establishment costs (excluding drilling) between IFS and CFP at each site, meaned for all crops and all years (£/ha/year).

Input application costs

For all sites, total costs of input application (agrochemicals and fertiliser) were always lower in the integrated system (Figure 13.3). Again these differences were small, the average saving over five years ranged from £6/ha/year at Manydown to £15/ha/year at Sacrewell.

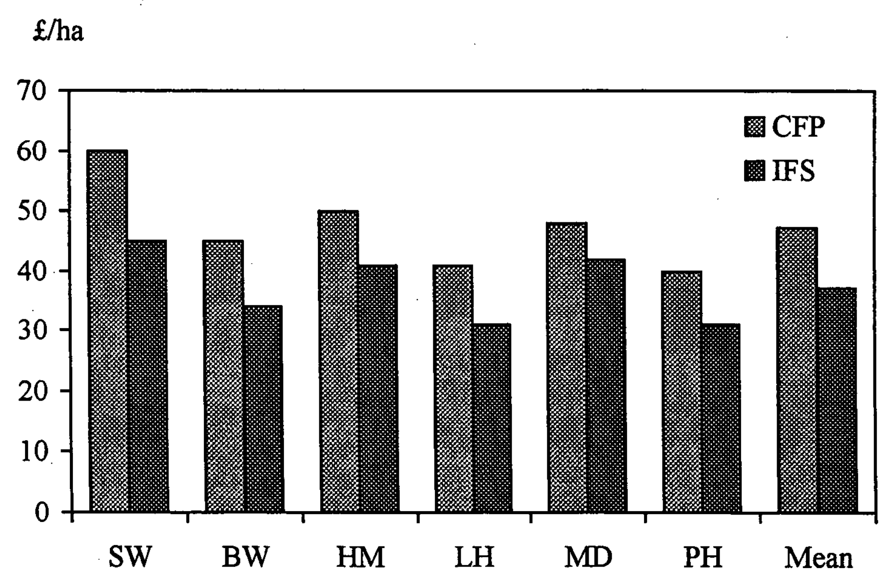

Figure 13.3 - Cost of agrochemical and fertiliser application at each site, meaned for all crops and all years (£/ha/year)

Other operational costs

Costs of crop establishment and input application represented a significant proportion of the total operational costs, particularly on sites where potatoes were grown (Table 13.3). A large part of the remaining costs categorised under 'other costs' which represented between a third and half of the total operational costs were made up of harvesting, drying, grading of produce and disposal of crop residue costs etc.. This represented a considerable cost on sites growing potatoes. High Mowthorpe was the only site where there was a difference in wheat straw disposal policy between the two farming systems. Straw was baled and removed on the conventional system, but chopped and spread in the integrated system. This added an average of £37/ha/year to the operational costs of wheat production in the conventional system through baling and carting of straw.

Table 13.3 - Breakdown of cost contributions to total operational costs for each site meaned for all crops and all years (£/ha/year).

Site	System	Operational costs						
		Cults	Inputs	Cover crops	Mech weed	Pre-harvest	Other costs	Total costs
SW	CFP	111	60	3	1	0	224	399
	IFS	115	45	14	7	0	221	402
BW	CFP	96	45	0	1	0	56	198
	IFS	75	34	5	3	0	54	171
HM	CFP	93	50	3	0	9	238	393
	IFS	86	41	15	1	2	225	370
LH	CFP	138	41	4	0	0	308	491
	IFS	127	31	27	7	4	297	493
MD	CFP	79	48	0	0	0	95	222
	IFS	79	42	1	0	0	93	215
PH	CFP	69	40	4	0	5	80	198
	IFS	67	31	4	0	0	82	184

Costs of cover crop and set-aside establishment and maintenance at Sacrewell, High Mowthorpe and Lower Hope also represented a significant, though small, proportion of the operational costs in the integrated system at these sites. At other sites, these additional costs were negligible. Additional operational costs associated with cover crop and set-aside establishment in the integrated system ranged from £5/ha/year at Boxworth, to £22/ha/year at Lower Hope (where a grass/clover cover was established on set-aside in the integrated system to provide limited grazing potential).

Mechanical weeding was used at Sacrewell, Boxworth, High Mowthorpe and Lower Hope, primarily in the potato crops grown in the integrated rotations but also occasionally in the wheat and pea crops (where present) on these sites, when soil and weed conditions allowed. However, this added little to the overall operational costs in the integrated system, ranging from an extra £1.50/ha/year at High Mowthorpe to £6/ha/year at Lower Hope.

A mechanical flail was used at Lower Hope to remove potato haulm from the integrated potato crops. This was the only site where pre-harvest operation costs were higher in the integrated system (by £4/ha/year). In contrast, use of a mechanical swather in conventionally-grown oilseed rape at High Mowthorpe increased operational costs by £7/ha/year. There were no differences in pre-harvest treatment costs at any other sites.

Conclusions

1. Savings in operational costs in integrated farming systems, where made, were modest.

2. Greatest savings in cultivation costs in integrated systems were made at Boxworth through adoption of a one-pass cultivation system.

3. Spring-sown break crops offer additional opportunities to reduce cultivation costs by adoption of non-inversion cultivations.

4. Integrated farming systems can increase total operational costs in some cases e.g. through operations such as mechanical weeding and flailing to remove potato haulm, where such costs are not balanced by savings in application costs.

5. Set-aside encourages ploughing to dispose of debris and therefore may prevent farmers optimising the utilisation of non-plough tillage methods in the rotation.

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DISCUSSION

Sue Ogilvy, ADAS High Mowthorpe

The main objective of the LINK Integrated Farming Systems (IFS) project was to develop arable integrated farming systems which concentrated on practical feasibility and economic viability, but also took into account level of inputs and probable environmental impact. The other two objectives were to compare the integrated system with conventional practice, and to investigate the interactions between component parts of the system. There were several drivers for this type of study; one being, to take forward the results and successful practices developed in other European countries, especially from the Lautenbach project in Germany (El Titi, 1995) and the Nagele project in the Netherlands (Wijnands, 1992). Both of these projects demonstrated that significant reductions in external farm inputs could be achieved and consequent environmental benefits followed, especially in soil protection, increased biodiversity, reduced pesticide and nutrient run-off and leaching, whilst remaining profitable.

A related study was established in the UK in 1990 at the Long Ashton Research Station near Bristol, the LIFE project (see Chapter 1 and Appendix D). In effect, this was the first integrated farming systems study in the UK to look at the development of a practical system designed to meet cropping needs and environmental objectives with lower inputs (Jordan *et al.*, 1995). Other studies, such as the completed Boxworth Project, and its follow-on studies, the TALISMAN and SCARAB projects, which started in 1991, were rotational studies with specific objectives to answer agronomic, economic and ecological questions in relation to current farming practices and lower input approaches (Cooper, 1990). They were not designed primarily to develop farming systems with lower input requirements. However, all three studies developed ideas and set important benchmarks against which the success of other studies could be measured. They also provide sound scientific information on the extent to which inputs can be lowered before yields and profitability are affected, and the ecological effects of current farming practices. Results from the Boxworth Project are available in Greig-Smith *et al.* (1992), and a book detailing the outcome of the TALISMAN and SCARAB projects is being compiled for publication in 2000 (Young *et al.*, 2000).

The LIFE project, the most relevant study to the LINK IFS project, was beginning to demonstrate similar results to those experienced in Europe but it was based on a single site in the south-west of England. It was proposed that this work was expanded to other arable areas in England and Scotland in the LINK IFS project (Wall, 1992).

A second driver was the need to address the concerns of farmers in the UK to meet the challenges and uncertainties of CAP reform, the GATT round, the predicted fall in crop prices and increasing environmental concerns. Could integrated farming provide farmers with a viable alternative to intensive arable production or at the other extreme, organic production, by reducing costs of production and reducing environmental impact? The success of the LEAF organisation in promoting the concept of ICM to farmers has demonstrated farmers' interest and their need for technical knowledge to implement the changes (Drummond, 1998).

A third driver was to provide government and the industry with information on the feasibility of meeting EU directives for water quality and environmental improvement, and the voluntary requirements under the Fifth Environmental Action Programme (Reus *et al.*, 1997), to minimise agrochemical inputs and encourage uptake of less intensive production systems without the need for statutory controls.

A fourth driver came from the environmental and research communities in the desire to look at the whole farming system and determine the interactions and conflicts, when best practices for individual components were put together in a whole package.

A fifth driver for the research, which has grown over the course of the project, is the increasing demand from food retailers, non-government organisations and consumers for safe, healthy, quality-assured food which has caused minimal environmental impact in its production, and results in pesticide-free end products. These pressures are likely to dominate in future, as currently demonstrated by the sharp increase in demand for organic food products in the last 12 months.

What were the outcomes from the LINK IFS project?

Results from the project have demonstrated that, overall, adopting an integrated system can be a viable economic alternative to conventional production, and that susbstantial reductions in inputs can be achieved; 20 % less nitrogen, 18 % less weight of pesticide (32 % fewer pesticide units), 26 % fewer passes of the sprayer and 8.5 % less energy. The reduction in the number of pesticide units applied will reduce the amount of pesticide entering the environment but there was no evidence of a difference between the systems in consistent specific environmental benefits, in terms of improved numbers and species diversity of beetles, spiders and earthworms. This mirrors the results from other recent long-term arable ecosystem studies, the SCARAB project (Young *et al.*, 2000).

Some reductions in potential nitrate losses were achieved, although one of the remedies for reducing leaching i.e. use of cover crops, has the potential to exacerbate the problem later in the rotational sequence.

There were site differences in the financial outturn from the integrated system, ranging from the successful to the less profitable, and the reasons for this will be discussed later in this chapter.

One of the main conclusions to arise from the project was the recognition that a single integrated system of production - a blueprint - would not be produced, as integrated practices had to be selected and adapted to meet the needs of individual sites, based on the crops grown, soil type, weather conditions, pest, disease and weed pressures, leaching and run-off risk and ecological infrastructure. A key development of this project in conjunction with the other research projects in IACPA (see Chapter 1) is to take forward the practices and results from the four projects and provide a technical guide on what integrated methods to use and when to apply them. Farmers and advisors will then be able to devise their own integrated strategies to meet their individual needs.

Integrated practices

Rotations and crop choice

The integrated rotations selected at the six sites were quite varied but did not meet the European requirements for frequency of crop groups (Vereijken, 1995) i.e. there were too many cereal crops in each rotational sequence. Choice of crop was limited not by the lack of suitable alternative crop species but by the need to maintain profitability in the rotation. Some farmers, at least in the short-term, may increase the frequency of cereals in their rotations, even more than the frequency in the IFS rotations, because of Agenda 2000 constraints on profitability.

Apart from the potato crop which was grown on three of the six sites, winter wheat was the most profitable crop, and it tended to dominate in all the rotations, especially on the clay soil at Boxworth. Length of rotation was also limited by the duration of the project, five years. This was not ideal in a situation such as at High Mowthorpe, where a seed potato crop was grown, and four years between crops was the minimum but not the desired interval between crops, the preference was for five to six years for hygiene reasons.

Rotational set-aside was included in the rotations at four of the six sites (SW, HM, LH and PH). This, in effect, provided an environmental benefit of improved habitats and feeding areas for farmland birds, especially where natural regeneration or ryegrass amended cover crops were left for longer periods on the integrated system than on the conventional system.

Although there were limitations on the rotations, no major pest or disease problems occurred as a direct result of a change in crop sequence, although grass weeds caused problems in the winter wheat dominated rotation at Boxworth. Choice of break crops such as spring beans, spring linseed or spring oilseed rape affected profitability when compared with the conventional winter oilseed rape alternative. The aim of growing the spring crops, usually with winter cover crops, was to reduce input requirements, especially nitrogen in the case of spring beans, to provide overwinter stubbles and to minimise overwinter nitrate leaching. Whilst these benefits were generally achieved, the loss in profitability from less consistent output, lower yields and lower arable area payments, significantly reduced the overall profitability of the rotation, especially at High Mowthorpe, Lower Hope and Boxworth.

Potatoes placed several constraints on the rotation and impacted on the integrated systems. Whilst these crops were very profitable, they had high demands for pesticides and fertilisers, even on the integrated system, because of their high value and associated financial risk. Any integrated system for potatoes, therefore still requires relatively high inputs. Potatoes also caused substantial soil disturbance, a particular problem at the Lower Hope site where soil erosion was a concern, and soil structure was not improved by the crop. Root crops have not been grown in any of the other integrated farming research projects in IACPA, and research relating to soil management and inputs to minimise their overall impact on the farming system is still needed.

Soil management

The approach to soil management varied between sites. Non-inversion tillage was incorporated into the rotational cultivations at Sacrewell, Boxworth, High Mowthorpe and Lower Hope. However, none of the sites adopted a completely non-inversion tillage system because of soil type, crop and weed control requirements, in contrast to the LIFE and FOFP projects, where one pass cultivation/drilling and direct drilling systems were frequently used at the two sites respectively. In general, use of non-inversion tillage was successful where it was used, although at Boxworth rotational ploughing was increased towards the end of the project, because of the increase in black-grass populations under the minimum tillage system.

Opportunities to change soil management were limited at two of the sites, Pathhead and Manydown, partly because of the lack of suitable equipment, and the requirement to retain ploughing for trash burial and clean seedbed preparation, especially for the seed wheat crop at Manydown. Integrated systems do not necessarily need to adopt non-inversion tillage e.g. as demonstrated by the Nagele project in the Netherlands. However, benefits from reduced energy consumption, reduced soil erosion and nutrient mineralisation and less disturbance of soil-living invertebrates need to be weighed against crop demands, machinery availability and weed management in the development of an integrated soil management system.

Integrated Nutrient Management

Within the LINK IFS project, there was no specific requirement to reduce fertiliser inputs by a predetermined percentage. Nutrient management was to be improved by balancing inputs with crop needs and soil reserves to maintain crop yields, without leaving excess residues. Overall, nitrogen use was reduced by 20 % across the sites, except at Sacrewell, which was a low user anyway. This reduction was mainly achieved by changing a high demanding crop such as winter oilseed rape in the conventional rotation to a low demanding crop, like linseed or spring rape or to an N-fixing crop like spring beans. As already mentioned above, these decisions had knock-on economic effects because of reduced profitability from these crops.

In general, the strategy of trying to predict what nitrate would mineralise from the soil organic matter and adjusting applied fertiliser was thought to be quite successful, as the IFS decision was only significantly improved on in 22% of the 71 nitrogen treatment comparisons in the validation trials. However, predictions tended to be too low on spring barley at the Pathhead site, indicating that mineralisation was less predictable in this situation. Also at Boxworth, after several dry years, soil N reserves exceeded 150 kg/ha in spring 1997. When fertiliser rates were adjusted down to take account of the soil reserves, wheat yields were reduced because the mineralisation failed to take place in a cold dry spring - demonstrating the unpredictability of N release from the soil.

Different N management strategies have been used in the other IACPA research projects to varying degrees of success. Incorporation of new techniques such as canopy management (pioneered in another LINK TSFS project), chlorophyll measurement, combined with improved understanding of the physiological state of the crop, have the potential to improve nitrogen management as detailed in the HGCA Wheat Growth Guide (Anon., 1997). However, routine reductions in nitrogen usage can potentially lower soil fertility and N supply to following crops (Sylvester-Bradley, 1996).

Results from the associated bolt-on study on nitrogen utilisation and loss, predicted from modelling (SUNDIAL) indicated that the nitrate leaching risk was lower in the integrated system, especially where cover crops were used before spring cropping or during the rotational set-aside phase. However, release of nitrogen from the cover crops was unpredictable and could result in problems later on in the rotation if N is released without a crop to take it up. At the High Mowthorpe and Sacrewell sites, there were particular concerns about the risks of nitrate leaching into groundwater from shallow soils, and the integrated practices adopted on these sites tended to reflect the need to retain nitrate in the soil profile, so practices such as early drilling and cover cropping were adopted.

Other soil nutrients, such as phosphorus, potassium and magnesium were managed by regular soil sampling and applications of fertiliser on a rotational basis. Crop residues were returned to the soil whenever possible, especially at High Mowthorpe, Boxworth and Sacrewell, to minimise loss of nutrients from the system, and also to improve soil organic matter content and workability, although it was recognised that these were long-term aims. Organic manures were not used in this project, and there was no specific objective to reduce phosphorus and potassium inputs, as seen in the work in the Netherlands. In general, P, K and Mg status tended to fall slightly on all the sites.

Integrated Crop Protection

Crop protection inputs were reduced on all sites, and in particular at Lower Hope and Pathhead. The largest reductions were in the use of fungicides and insecticides, and in general, decisions to reduce these inputs were supported by the results from the validation experiments. Similar success in reducing inputs was achieved in the TALISMAN project (Young *et al.*, 2000). Choice of resistant varieties played an important role in minimising the need for fungicide inputs in the integrated system.

The greatest challenges occurred in the use of herbicides, especially where decisions were taken to avoid autumn use of residual herbicides such as isoproturon in winter wheat, to minimise the potential leaching risk. Spring weed control treatments were generally much less successful on all sites than the autumn treatments, and often resulted in higher herbicide use than the conventional treatment, more weed problems, and in some cases significant yield losses as a result of weed competition. A return to low dose autumn herbicide use followed by spring treatments where necessary proved to be the most successful strategy. Results with mechanical weeding were variable and proved to be most successful in the potato crops, especially when combined with a low dose herbicide. Results in other crops, especially cereals, were not as good, and lessons learnt about the limitations of mechanical weeding are consistent with previous experimental and practical experience. Weed control is one of the most important issues in integrated farming systems, and further work is required on successful weed management strategies if the potential risk of water contamination by residual herbicides, the build-up of resistant weed species and yield losses are to be avoided.

Choice of pesticide products for particular tasks was determined by the individual site managers with assistance from a team of technical specialists. In most situations, the most cost-effective treatment was chosen for the specific task. Where information was available, informed choices were made on the basis of selectivity of the active ingredient for the intended target and leaching risk. In other integrated farming studies, pesticides have been selected on their environmental profile and potential environmental impact (Wijnands, 1997). A review of risk indices has recently been published (Edward-Jones *et al.*, 1999). However, none of the reviewed methods was found to be totally satisfactory, but they reflect the need for a usable subjective assessment method to determine the risks and hazards associated with pesticide use, to allow informed decisions to be made.

Making crop protection decisions in an integrated system can be more risky and time-consuming for growers until knowledge, experience and confidence are built up in the developed system. By its nature, integrated farming is knowledge intensive and greater technical support is required. Thresholds used must be well-established and robust, and decision support systems (such as DESSAC etc. being developed in the LINK TSFS and elsewhere) which give more information about the likely risk of decisions would help to encourage uptake.

Ecological management

The design of the project with its split field comparisons limited the extent to which ecological features such as hedges and field margins could be manipulated to improve habitats for beneficial species, because any effects as 'reservoirs' could influence both farming systems.

Nevertheless, the importance of improving the ecological infrastructure on the whole farm is recognised, and the European prototype recommends 5 % or more of the total cropping area should be uncropped (Vereijken, 1994), and the Integrated Production Guidelines also recommend that the lateral dimension of individual fields should not exceed 100m (El Titi *et al.*, 1993), and if they do beetle banks or equivalent uncropped areas should be created. Whilst it is recognised that provisions of such habitats can increase the numbers and diversity of invertebrate species, it is more difficult to demonstrate consequent reductions in crop pest numbers and improved crop yields. In-field integrated practices did not show any significant effects on numbers and species diversity of beetles and spiders on the LINK IFS sites. Site, year and crop had the greatest influences. This is confirmed by results from the SCARAB project, which has examined the ecological effects of pesticides in more detail. Findings from this work have shown that pesticide inputs in general use on arable crops do not have any major long term adverse effects on non-target beneficial insects (Frampton, 2000). Similarly, there was no evidence that earthworms were significantly affected by the farming systems in the LINK IFS project. Other studies (Jones *et al.*, 2000) and the literature would suggest that more radical alterations to the farming system would be needed, such as the inclusion of leys and organic manures, combined with less soil disturbance, for earthworm populations to be greatly increased (Edwards & Bohlen, 1996).

Management expertise and time

As already mentioned earlier, the skill level and time required to manage the integrated and conventional farming systems were not specifically monitored during the project. However, as part of the economics bolt-on study carried out by the University of Reading (full details can be found in Keatinge *et al.*, 1999 and summarised in Appendix M), site managers were asked to comment on the level of skill required and to estimate the time inputs for crop walking in an integrated system. Although site managers did not anticipate large differences between the systems, they indicated that possible changes in overall management tasks and their timing could result in additional effort because the integrated system was more complex to manage. In particular, the greater monitoring of inputs, crop changes and subsequent changes in timing of crop establishment, operations and harvesting, labour allocation, machinery type and use would all impact on management time. Site managers felt that IFS required a much higher level of skill than the conventional system, associated with the need for planning, monitoring, the use of thresholds and refining appropriate rates of inputs.

It was suggested that the integrated rotations would require a greater input in terms of management time due to increased crop walking to check on thresholds, extra record keeping and monitoring in the office, and a host of issues associated with the range of new approaches adopted. Site managers were asked to estimate the time spent with respect to managing the two rotations in terms of minutes per hectare. Estimates ranged from an extra 10 minutes to 60 minutes per hectare. In total, up to 50 % more time was likely be spent in crop walking and decision making on the integrated system. This is likely to be highest when an integrated system is first adopted and should decrease as knowledge, confidence and experience is gained.

Comparison between systems

The main aims of the project were to develop a feasible integrated system and to compare the integrated system with a reference conventional system at each site. This latter aim was important to provide a baseline against which the success of the integrated system could be measured. However, it was recognised through the course of the study that conventional practice was also changing at the same time as the integrated system was evolving, and there was potential for the two systems to converge. Some farmers were adopting IFS practices but often piecemeal, rather than as part of a truly integrated system. However, a difference was maintained between the systems by pushing parts of the integrated system to greater limits e.g. for weed control and nitrogen use, as shown by the reduction in inputs, and the conventional system remained representative of commercial practice (see Chapter 10 for details). In an ideal situation, the two systems might have been managed throughout by different site managers, to avoid situations in which decisions on one system influenced decisions on the other system. This was recommended by the statisticians at the start of the project (Pearce, 1992) but it was not practicable to implement at the sites. However, the treatments tested in the validation trials counterbalanced any unintentional convergence to some extent, as the integrated decisions could be tested against the conventional or alternative strategies, to determine whether they were successful or not.

Comparisons with other studies

The results from the LINK IFS project complement those found in the other IACPA studies, and common messages from all the projects have been presented to the industry at a conference, in a summary booklet (MAFF, 1998), and are being developed into a technical guide for farmers. The results from the project are also comparable with those from other European studies, especially in terms of reduced inputs and maintenance of profitability. However, the study at Lautenbach in Germany has demonstrated significant improvements in bio-indicators, such as beneficial arthropods and earthworms, increased floral diversity, reduced leaching and run-off and less soil erosion (El Titi, 1995). Results from Nagele in the Netherlands have also shown substantial reductions in pesticide and nutrient leaching (Wijnands, 1992; Vereijken, 1994). Both of these studies were in existence for more than 10 years (work at Nagele started in 1979 and is still continuing), which is a more suitable time period for the expression of cumulative ecological and agronomic effects.

Benefits to farmers

All farmers rely on the land for their livelihood, so it is in their longer term interests to farm it as effectively and sustainably as possible. Integrated farming takes that thinking further forward, and considers the impact of crop management practices on a wider range of environmental considerations. The benefits for farmers that might arise from adopting integrated farming were considered and discussed by the project site managers, and their output is recorded in Appendix L. Benefits supported by results from the project include: lower costs from optimised inputs; potentially higher margins from the integrated approach when economic conditions are difficult or in the scenario of imposed pesticide and fertiliser taxes; improved knowledge and understanding of the risks, both cropping and environmental on their farms; greater flexibility with soil management and reduced erosion risk; improved workload spread; reduced operator risks from fewer applications; and lower energy demands.

Site managers also felt that integrated farming would enhance the local environment, improve biodiversity and the countryside mosaic, reduce contamination of the environment, improve the image of farming, and satisfy market and consumer needs. Some of these benefits are supported by other projects in the IACPA group and by European research (MAFF, 1998; El Titi, 1998). It was also felt that increased adoption of integrated farming could make further legislation or mandatory schemes to reduce pesticide use unnecessary.

Farmers are beginning to adopt integrated farming systems but progress in the UK has been slower than in other European countries, especially Germany, the Netherlands and Denmark because the drivers for change have been less strong. In the UK, any change towards an integrated system seems likely to be market-led rather than by statutory control. Following the BSE crisis and the Genetically Modified Organisms (GMOs) debate, consumer awareness of food safety issues has increased, leading to higher demands for safe healthy food produced by environmentally friendly methods. This is likely to influence the uptake of integrated farming systems, alongside or in preference to organic production in the future. Farmer uptake would be greatly assisted by the provision of sound technical and practical advice, which may need presentation in a suitable form, because currently, few crop advisors have the necessary training or first-hand experience of integrated farming.

The continuing change in the economic situation in farming, especially in relation to reduced prices for crop produce, changes to the CAP under Agenda 2000, proposed pesticide and fertiliser taxes, combined with environmental and consumer demands, increase the need for further evaluation of this data and sound research on integrated approaches, to underpin the development of sustainable agricultural systems.

Relevance to government policy

The LINK IFS project, along with the other research projects in IACPA, has shown that it is possible to reduce agrochemical inputs and combine profitability with environmental sensitivity - without the need for statutory controls or financial inducements. Provision of underpinning research, effective technology transfer and training for farmers, potentially via networks of associated pilot farms, as demonstrated successfully in the Netherlands and Germany (Wijnands *et al.*, 1998; El Titi, 1998) could help the UK meet many of its environmental objectives in relation to arable production systems, without the need for regulation.

Future research needs

These are being considered by the IACPA group outside of this project, as well as by the new LINK SAPPIO programme. Underpinning research into integrated crop management is still needed to continue to develop and evolve these integrated systems to meet future needs, and incorporate the results from current research, especially on the physiological management of crops and the utilisation of decision support systems, that also featured in the LINK TSFS programme. Soil types and crops not covered by the existing studies should be incorporated to widen the applicability, and the inclusion of mixed farming systems should be considered on some sites. In parallel, comparisons of intensive, integrated and organic systems of production could provide sound information on the economic, agronomic, environmental and sustainability consequences of a range of systems to meet farmers' and policy needs for the future.

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APPENDIX A - Publication list

Papers and articles

1992

1. WALL C
   A LINK collaborative research programme on Technologies for Sustainable Farming Systems. Proc of the Brighton Crop Protection Conference - Pests and Diseases 1992, III: 1107-1114.

1993

2. HOLLAND J M
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Promotional information

Timing	Title	Produced by:
June 1996	**LINK IFS: Update** *News and information about the LINK Integrated Farming Systems Project*	The British Agrochemical Association, Peterborough
June 1997	**LINK IFS: Update 2**	The BAA, Peterborough
May 1998	**LINK IFS: Update 3**	The BAA, Peterborough
Autumn 1998	**Project Progress No. 1** *Optimising the benefits from integrated farming*	Home-Grown Cereals Authority, London
October 1998	**Integrated Farming: Agricultural research into practice** *A report from the Integrated Arable Crop Production Alliance for Farmers, Agronomists and Advisors*	MAFF, London

APPENDIX B - Organisations and staff involved

Sponsors	Role	Location
LINK		
Dr Clive Wall	LINK Programme Co-ordinator	MAFF, 1A Page Street, London, SW1P 4PQ
Dr Alex Bainbridge	*Former co-ordinator*	
Ministry of Agriculture, Fisheries and Food		
Roy Hathaway	Former Head of Arable Crops Policy Div.	Nobel House, 17 Smith Square, London, SW1P 3JR
Chris Barnes	*Former Head of ACP Div.*	
Dr David Cooper	Chief Scientist Group, Project Officer	Page Street, London
Ingrid Meakin	Chief Scientist Group, Assistant Project Officer	Page Street, London
Jonathan Alltimes	*Former Assistant Project Officer*	
Scottish Executive Rural Affairs Department (SERAD - formerly SOAEFD)		
Dr Rosi Waterhouse	Sponsor representative	Pentland House, 47 Robb's Loan, Edinburgh, EH14 1TY
Dr Toby Willison	Sponsor representative	Pentland House, Edinburgh
Home-Grown Cereals Authority		
Dr Clive Edwards	R&D Dept. Project Officer	Caledonia House, 223 Pentonville Rd, London, N1 9RG
Dr Chris Rawlinson	*Former Head of Cereals R&D*	
Dr Frank Ellis	*Former Head of Oilseeds R&D*	
Zeneca		
John Coutts	Sponsor representative	20 Burnt Hill Way, Wrecclesham, Farnham, Surrey, GU10 4RP
Dr David Riley	*Former sponsor representative*	
John Finney	*Former sponsor representative*	
Dr Peter Chapman	Statistical input	Jealott's Hill Research Station, Bracknell, Berks, RG42 6EY
Eddie McIndoe	Statistical input	Jealott's Hill Research Station
Mark Lennon	*PhD student, statistical support*	
Mike Coulson	Earthworm input	Jealott's Hill Research Station
John Bembridge	Earthworm input	Jealott's Hill Research Station
The British Agrochemicals Association		
Patrick Goldsworthy	Sponsor representative	4 Lincoln Court, Lincoln Road, Peterborough, PE1 2RP
John Page	*Former sponsor representative*	

Site input	Role	Location
Sacrewell		
Prof Bob Prew	Site Manager	Formerly IACR. 203 Sharpenhoe Road, Streatley, Luton, LU3 3PR
Mike Hewitt	Scientific input	IACR Rothamsted, Harpenden, Herts, AL5 2JQ
Liz Stockdale	Scientific input	IACR Rothamsted
Dr John North	William Scott Abbott Trust representative	Univ. of Cambridge, Dept. of Land Economy, 19 Silver Street, Cambridge, CB3 9ET
John Ward	Farm Consultant	Sacrewell
Boxworth		
Dr Sarah Cook	Site Manager	ADAS Boxworth, Boxworth, Cambs, CB3 8NN
Jim Orson	*Research and technical input*	*Now at Morley Research*
James Clarke	Research input & weed control advice	ADAS Boxworth
Philip Jones	Scientific input	ADAS Boxworth
Neil Cross	*Former Farm Manager*	
High Mowthorpe		
Sue Ogilvy	Project Leader	ADAS High Mowthorpe, Duggleby, Malton, N Yks, YO17 8BP
David Turley	Site Manager	ADAS High Mowthorpe
Katharine Winter	*Scientific input*	
Dale Welburn	Scientific input	ADAS High Mowthorpe
Lesley Baker	Scientific input	ADAS High Mowthorpe
Stephen Newell	Farm Manager	ADAS High Mowthorpe
Lower Hope		
John Spink	Site Manager	ADAS Rosemaund, Preston Wynne, Hereford, HR1 3PG
Richard Laverick	Research input	ADAS Rosemaund
Sally Leighton	*Scientific input*	
John Llewellin	Farm Manager	Lower Hope Estate
Manydown		
Dr John Holland	Site Manager	The Game Conservancy Trust, Fordingbridge, Hampshire, SP6 1EF
Dr Nick Sotherton	Research input	The Game Conservancy Trust
Sue Thomas	Scientific input	The Game Conservancy Trust
Richard Stirling	Farm Director	The Manydown Estate
Hugh Oliver-Bellasis	Managing Director	The Manydown Estate
Andrew Wayne	Agronomy input	Faulkner and Partners
Pathhead		
Dr Neil Fisher	Site Manager	Formerly SAC. 37 Buckstone Terrace, Edinburgh, EH10 6QH
Martin Richards	Research input	SAC, Kings Buildings, West Mains Rd, Edinburgh, EH9 3JG
Alistair Drysdale	Scientific input	SAC, Bush Estate, Penicuik, Edinburgh, EH26 0PH
Bill Gray	Farm Manager	Rosemains & Turniedykes Farms, Pathhead, Edinburgh,

Other participants	Role	Location
Statisticians (in addition to Zeneca input)		
Prof. Clifford Pearce	ASRU report	Applied Statistics Research Unit, University of Kent
George Dyke	ASRU report and original randomisation of treatments	IACR Rothamsted
Prof. Roger Mead	Support of PhD student	University of Reading, Dept of Applied Statistics, Harry Pitt Building, Whiteknights Rd, PO Box 240, Reading, RG6 6FN
Dr Hans Spechter	Initial statistical support	formerly ADAS High Mowthorpe
Prof. Joe Perry	Initial statistical input	IACR Rothamsted
Nicholas Aebischer	Initial statistical input	The Game Conservancy Trust
Dr Tony Hunter	Initial statistical input	BIOSS
Steering Group Members (in addition to those already named)		
David Jack	Farmer representative	HGCA, Jackstown, Rothienorman, Inverurie, Aberdeenshire, AB51 8UR
Tony Pexton	Farmer representative	NFU, Watton Grange, Watton, Driffield, E Yorks
Rob Clare	Research input	ADAS Rosemaund
David Perks	Research input	Formerly ADAS High Mowthorpe
Technical Support		
David Harris	Business Management	ADAS Boxworth
Bill Basford	Machinery advice and energy use	ADAS Gleadthorpe Grange, Meden Vale, Mansfield, Notts, NG20 9PD
Nigel Penlington	Energy use	ADAS Gleadthorpe Grange
Dr Bill Parker	Pest control advice	ADAS Wolverhampton, Woodthorne, Wergs Road, Wolverhampton, WV6 8TQ
Dr Gillian Goodlass	Soil science advice	ADAS High Mowthorpe
Bill Clark	Disease control advice	ADAS Boxworth
Administration Support		
Dorothy Doel	Financial adminstration	ADAS Boxworth
Jill Gosling	Report adminstration	ADAS Rosemaund
Promotional support		
Dick Whitehead	IFS Updates editor	Pelch Cottage, 60 Seend Clieve, Melksham, Wilts, SN12 6PZ
Economics bolt-on project		
Prof. Dyno Keatinge	Economic input	Formerly University of Reading,
Dr Julian Park	Economic input	University of Reading, Dept of Agriculture, Earley Gate, PO Box 236, Reading, RG6 2AT
Dr Alison Bailey	*Economic input*	*Now at Cranfield University.*

Nitrogen utilisation and loss bolt-on project

Dr Gillian Goodlass	Soil science input	ADAS High Mowthorpe
Dr Jo Smith	Soil science input	IACR Rothamsted

Weed seedbank bolt-on project

Dr Naomi Jones	Weed biology input	ADAS Boxworth
Dr Bob Froud-Williams	Weed biology input	University of Reading
Rebecca Macey	Seedbank input	University of Reading

Weed studies PhD

Gillian Champion	Weed biology input	University of Reading

APPENDIX C - Associated projects

Project title:	**LINK Integrated Farming Systems** (Main study)
Sponsors:	(LINK) MAFF, SOAFED, HGCA, Zeneca, BAA
Project Leader:	Sue Ogilvy, ADAS High Mowthorpe
Collaborators:	ADAS, IACR Rothamsted, William Scott Abbott Trust, The Game Conservancy Trust, SAC
Objectives:	1. To validate the latest research results into a production system which will optimise inputs compatible with profitability and environmental concerns. 2. To make valid comparisons between the integrated system of production and conventional practice for profitability, energy balance and environmental effect. 3. To investigate scientifically the interactions between component parts of the system.
Sites:	Sacrewell, Boxworth, High Mowthorpe, Lower Hope, Manydown, Pathhead
Funding:	£1543k
Duration:	1992 - 1997

Project title:	**Integrated Farming Systems: the economic evaluation of input decisions** (Validation experiments)
Sponsors:	MAFF, HGCA
Project Leader:	Dr Sarah Cook, ADAS Boxworth
Collaborators:	ADAS, SAC
Objectives:	1. To validate the crucial decisions e.g. nitrogen and pesticide inputs, of the IFS rotation to complement the field investigation. 2. To measure the effect of these decisions on yield and profitability, and strengthen the interpretation of the systems study.
Sites:	Boxworth, High Mowthorpe, Lower Hope, Pathhead
Funding:	£450k
Duration:	1993-1997

Project title:	**Weed management in integrated farming systems** (Seedbank studies)
Sponsors:	MAFF
Project Leader:	Dr Naomi Jones, ADAS Boxworth
Collaborators:	ADAS, University of Reading
Objectives:	1. To assess the long term changes in the seedbank as a result of integrated as opposed to conventional farming practices at a range of sites and rotations, and analyse management and weed data to determine their effects and reasons for grass weed problems. 2. To review the literature to collate what is already known about the effects of individual and combined field operations on the soil seedbank and weed flora. 3. To gain a greater understanding of seedbank dynamics and the relationship with the weed flora as a result of a variety of farming practices combined and in isolation at a range of sites.
Sites:	All the LINK IFS sites.
Funding:	£269k
Duration:	1997 - 2000

Project title:	**Assessment of the financial and economic impacts demonstrated by low-input, Integrated Farming Systems LINK funded experiments** (Economics bolt-on project)
Sponsors:	MAFF
Project Leader:	Prof. Dyno Keatinge and Dr Julian Park, University of Reading
Collaborators:	University of Reading and ADAS, all LINK IFS collaborators plus IACR Long Ashton (LIFE project) and CWS (FOFP project)
Objectives:	1. To examine the results of the current low input experimental strategies and their consequent financial and environment implications at a farm level. 2. To provide financial guidance to LINK IFS researchers so that integrated systems can be further developed in both a cost-effective and environmentally benign manner. 3. To further understand the constraints and likelihood of a widespread adoption of low input strategies and of their associated economic consequences which would lay the foundations for a subsequent macro-level analysis for national policy development.
Funding:	£207k
Duration:	1995 - 1998

Project title:	**The effect of farming systems on nitrogen utilisation and loss** (nitrogen bolt-on project)
Sponsors:	MAFF
Project Leader:	Dr Gillian Goodlass, ADAS High Mowthorpe
Collaborators:	ADAS and IACR Rothamsted, and other LINK IFS collaborators
Objectives:	1. To develop an integrated arable farming system which addresses the need to optimise the use of inorganic nitrogen by the efficient management of inputs and the use of husbandry procedures to minimise nitrogen losses, to ensure an adequate level of crop production to sustain profitability. 2. To determine the impact of an integrated system of crop management compared with a conventional system, on N losses over three years of a five course cropping rotation. 3. To determine the efficiency of cover crops in capturing soil mineral nitrogen overwinter prior to spring cropping, and during the set-aside phase, and to investigate whether an integrated system, involving cover cropping, has an effect on mineralisable N levels available to following crops. 4. To evaluate the N balance and computer modelling techniques as methods for predicting N losses from farming systems, and to use the information produced to reduce the losses from the integrated system.
Sites:	All the LINK IFS sites.
Funding:	£134k
Duration:	1995 - 1997

Project title:	**The incidence and control of volunteer potatoes in conventional and integrated farming systems**
Sponsors:	(LINK) MAFF, PMB
Project Leader:	David Turley, ADAS Mowthorpe
Collaborators:	ADAS and IACR Rothamsted
Objectives:	1. To quantify the scope of the vounteer potato problem in an arable rotation growing potatoes, one year in five. In particular, to look at the rate of increase or decline of volunteer plants in successive crops after potatoes, when subjected to two contrasting farming systems with different approaches to soil management and pesticide use. 2. To determine to what extent potato volunteers are reservoirs of pests and diseases, and to estimate the degree of risk they pose to adjacent potato crops. 3. To determine the timescale over which potato volunteer plants emerge in a range of crops, and to map the distribution of plants. 4. To compare a number of herbicide programmes within the two systems on small fixed plots. 5. To devise cultural and chemical control strategies in conventional and integrated arable farming systems over a five course cropping rotation.
Sites:	Sacrewell, High Mowthorpe, Lower Hope
Funding:	£140k
Duration:	1994 - 1997

Project title:	**Multi-site crop rotation experiments: recommendations for design and analysis, based on the LINK IFS project**
Sponsors:	MAFF, Zeneca - CASE PhD studentship
Project Leader:	Mark Lennon
Collaborators:	University of Reading (Prof R Mead), Zeneca (Dr P Chapman)
Objectives:	1. What is a sensible set of objectives for an experiment of this type? Is it practical to try to achieve a large number of objectives with a single experiment or should we tackle different objectives with separate experiments. 2. How big should plots be? Is it necessary to use plots of 2 ha plus, and how can we assess plot variability. Is it permissable to have treatments which are flexible, as in this experiment, or must we define the treatments more precisely? 3. How much true replication and within plot sampling is required to enable us to achieve the objectives with desired levels of precision? Conversely, what levels of precision should we expect given realistic levels of resource/replication? What are the optimum within plot sampling strategies? What scope is there for improving the precision of this type of experiment by making use of pre-treatment information? What novel, modern techniques of experimental design are available to enable us to improve precision? 4. How should profitability be measured and what are the statistical implications?
Funding:	£30k
Duration:	1994 - 1997

Project title:	**Effects of polyphagous predators on cereal pests**
Sponsors:	HGCA
Project Leader:	Dr John Holland, The Game Conservancy Trust
Collaborators:	None
Objectives:	1. To evaluate the impact of polyphagous predators on cereal aphids and to determine the subsequent influence on cereal yield and quality. 2. To compare the quantitative and qualitative role of polyphagous predators within the IFS and CFP systems of the LINK IFS project. 3. To examine the extent to which polyphagous predators contribute to orange wheat blossom midge control.
Sites:	Manydown
Funding:	£35k
Duration:	1996 - 1997

Project title:	**Impact of IFS on arable weeds**
Sponsors:	MAFF, CASE PhD studentship
Project Leader:	Gill Champion
Collaborators:	University of Reading (Dr R Froud-Williams), The Game Conservancy Trust
Objectives:	1. To investigate the agronomic, environmental and economic consequences of reduced agrochemical inputs with particular emphasis on weeds.
Sites:	Manydown
Funding:	£30k
Duration:	1994 - 1997

APPENDIX D - Chapter 1 - Introduction

Definitions

Europe - International Organisation for Biological Control (IOBC)

Integrated production is a farming system that produces high quality food and other products by using natural resources and regulating mechanisms to replace polluting inputs and to secure sustainable farming. Emphasis is placed on a holistic systems approach involving the entire farm as the basic unit, on the central role of agro-ecosystems, on balanced nutrient cycles and on the welfare of all species in animal husbandry. The preservation and improvement of soil fertility and of a diversified environment are essential components. Biological, technical and chemical methods are balanced carefully taking into account the protection of the environment, profitability and social requirements.

UK - Integrated Arable Crop Production Alliance

A whole farm policy aiming to provide the basis for efficient and profitable production which is economically viable and environmentally responsible. It integrates beneficial natural processes into modern farming practices using advanced technology and aims to minimise the environmental risks while conserving, enhancing and recreating that which is of environmental importance.

UK - Sustainable Development White Paper

To provide an adequate supply of good quality food and other products in an efficient manner. To minimise consumption of non-renewable and other resources, including by recycling. To safeguard the quality of soil, water and the air, and to preserve where feasible and enhance biodiversity in the importance of the landscape.

UK - British Agrochemical Association in conjunction with the ATB, LEAF and Sainsburys.

ICM is a method of farming that balances the requirements of running a profitable business with responsibility and sensitivity to the environment. It includes practices that avoid waste, enhance energy efficiency and minimise pollution. ICM combines the best of modern technology with some basic principles of good farming practice and is a whole farm, long term strategy.

USA - US Dept of Agriculture

An integrated system of plant and animal production practices having a site-specific application that will, over the long term: satisfy human food and fibre needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of non-renewable resources and on-farm resources and integrate where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole.

Table 1.2 - Research and demonstration projects in the Integrated Arable Crop Production Alliance

Project title and coordinator	Background
LIFE (Less Intensive Farming and the Environment) **Vic Jordan, IACR Long Ashton**	Based at IACR Long Ashton Research Station on 25 ha and also previously on two pilot farms in the South-west of England. This project started in 1990 and is now in its second rotational phase. Funded by MAFF, and previously the EU.
LINK IFS (Integrated Farming Systems) **Sue Ogilvy, ADAS High Mowthorpe**	Based on six sites in Hampshire, Cambridgeshire (2), Herefordshire, Yorkshire and Midlothian, on approximately 50 ha on each farm. This project started in 1992 and has now completed its first rotational phase. Four of the sites were maintained in 1998 to assist with technology transfer and the development of a new research programme. Funded by MAFF, SOAEFD, HGCA, BAA and Zeneca. Details in this report.
FOFP (Focus on Farming Practice) **Alistair Leake, CWS Agriculture**	A seven-year evaluation of integrated v conventional farming on 60 ha of a commercial CWS farm at Stoughton in Leicestershire, funded by CWS Agriculture, Profarma and Hydro Agri. This project started in 1993.
RPMS (Rhône Poulenc Farm Management Study) **Steve Higginbotham, Aventis**	A long term study which started in 1994 on the 57 ha Rhône Poulenc farm in Essex, comparing integrated and conventional farming, alongside organic farming.
BEAM (Balancing Environment and Agriculture in the Marches) **Richard Laverick, ADAS Rosemaund**	This is a five year Objective 5b project funded by MAFF and the EU which commenced in 1996 on a 285 ha mixed farm in North Herefordshire. The management of the three major enterprises, arable, sheep and beef are integrated alongwith the management of the landscape and environment. Business performance is monitored in conjunction with environment and biodiversity improvements. The major partners are ADAS, AgrEvo, Countrywide Farmers, Dupont, Environment Agency, Kemira and Titley Farms.
LEAF (Linking Environment And Farming) **Caroline Drummond, LEAF**	Launched in 1991 and funded by over 100 industry bodies, and with over 1500 farmer members, LEAF is at the forefront in promoting Integrated Crop Management. There is a network of LEAF Demonstration Farms throughout the UK showing ICM in practice and encouraging farmers to take up ICM through the LEAF audit.
TIBRE (Targeted Inputs for a Better Rural Environment) **Antje Branding, Scottish Natural Heritage**	An initiative developed by SNH which concentrates on promoting and encouraging the uptake of technologies that will reduce the environmental impact of farming practices, whilst at least maintaining profitability and without significantly increasing management input.
FWAG (Farming and Wildlife Advisory Group) **Richard Knight, FWAG**	FWAG promotes wildlife and landscape conservation on commercial farms throughout the UK. Practical advice on conservation issues is delivered through the Landwise whole farm reporting system.

APPENDIX E - Chapter 2 - Method

Table 2.2 - Aims, environmental issues and perceived problems at each site

Site	Desired site aims	Environmental issues	Perceived problems
Sacrewell	To demonstrate IFS is economically viable. To show feasibility of combining cultural and husbandry methods with lower chemical inputs. To determine if there were environmental benefits.	N leaching to groundwater. Autumn and summer pesticide use. Beneficial insects. Ecological infrastructure Biodiversity	Pests Broad-leaved weeds Grass weeds
Boxworth	To increase or maintain profitability. To reduce environmental impact. To contain or reduce grass weeds.	Pesticides leaching Beneficial insects. Energy use	Grass weeds Weed seedbanks Pesticide resistance
High Mowthorpe	To develop a profitable integrated system. To lower fertiliser and pesticide requirements. To minimise nitrate leaching.	Nitrogen and pesticides leaching to groundwater Pesticide persistance Biodiversity	Broad-leaved weeds Grass weeds Volunteer crop weeds Diseases Pests
Lower Hope	To maintain profitability on the integrated system. To improve soil stability. To reduce agrochemical inputs.	Soil erosion to surface water. Soil structure compaction. Autumn and summer pesticide use.	Diseases Soil erosion
Manydown	To maintain profitability and quality. To decrease agro-chemical inputs. To increase biodiversity. To reduce the risk of nitrate leaching.	Ecological infrastructure Summer pesticide use Pesticide toxicity	Grass weeds Broad-leaved weeds Diseases
Pathhead	To retain or improve profitability. To reduce environmental impact of N fertilisers and pesticides. To improve biodiversity.	Biodiversity Ecological infrastructure Beneficial invertebrates Nitrogen and pesticide leaching to surface water and ground water. Energy use	Weeds Diseases

Table 2.3 - Integrated practices adopted at each site

Practice	Sites						Comments
	SW	BW	HM	LH	MD	PH	
Crop choice							
• Diverse crop rotation	+	+	+	+	+	+	At least 3 or more different species in a rotation to break disease, pest and weed problems, to utilise nutrient residues and improve soil structure.
• Disease or pest resistant cultivars	+	+	+	+	+	+	High priority as well as yield and quality to reduce need for treatments.
• Spring cropping	+	(+)	+	+	+	++	Chosen for crop quality and inherent need for lower inputs.
• Legumes	+	+	+	+	+	-	Chosen for lower need for inputs and nitrogen fixation.
• Rotational set-aside	+	-	+	+	-	+	Good for biodiversity and increases options for nitrogen uptake and weed control.
• Headland set-aside	-	+	-	-	-	-	Good for biodiversity and headland management.
Cultivations							
• Minimum tillage	+	++	+	-	-	-	Used where appropriate for soil type and crops, reduces erosion, energy use, and effects on invertebrates.
• Rotational ploughing	+	++	+	+	+	+	Used to control weeds, especially with minimum tillage.
• Stale seedbeds	+	+	-	-	+	-	Used to create and control weed flushes, especially blackgrass.
• Delayed drilling	+	+	-	+	+	+	Used to control blackgrass, reduce BYDV infection, reduce lodging risk and disease incidence.
• One pass cult/drill operation	-	+	-	-	-	-	Energy saving operation of minimum tillage.
• Mechanical weeding	+	+	+	+	+	-	Interrow cultivations in potatoes, comb weeding in cereals and other crops.
Nutrient management							
• Routine soil sampling	+	+	+	+	+	+	Annual sampling to assess nutrient status.
• Rotational P, K, Mg inputs	+	+	+	+	+	+	Basal fertiliser applied according to soil status and crop demand, usually only 1 in 5 yrs.
• Spring SMN sampling	+	+	+	+	+	+	Used to adjust spring nitrogen fertiliser dressing.
• Incubated spring SMN	+	+	+	+	+	+	Indicates potential mineralisable N, to refine N top dressing adjustment.
• No autumn N	+	+	+	+	+	+	Reduce risk of autumn leaching.
• Split N dressings	+	+	+	+	+	+	Reduce risk of spring leaching, apply when crop can utilise.
• Crop residue incorporation	+	+	+	-	-	-	Straw incorporated to improve soil condition and reduce removal of nutrients.
• Cover cropping	+	+	+	+	-	-	Used overwinter to reduce nitrate leaching and soil erosion.
• Early crop establishment	-	-	+	-	-	+	Used to reduce autumn nitrate leaching on high risk sites.
• Grass/clover ley	-	-	-	+	-	-	Established on rotational set-aside to improve fertility and soil stability.
• Legumes	+	+	+	+	+	-	Used to reduce N fertiliser inputs and increase fertility.
• Foliar P application	+	-	-	-	-	-	Used in potato crop to improve uptake.

Practice	Sites						Comments
	SW	BW	HM	LH	MD	PH	
Crop protection							
• Resistant varieties	+	+	+	+	+	+	Main method to reduce need for inputs.
• Increased crop monitoring	+	+	+	+	+	+	Essential to determine crop problems. Treatment timing adjusted in response to monitoring.
• Use of thresholds	+	+	+	+	+	+	Essential to ensure treatments applied when needed. Most appropriate for pest problems.
• In crop monitors	+	-	+	+	-	-	Used where available eg blight monitors in field for potatoes.
• Pest trapping/sampling	+	+	+	+	+	+	Used to determine thresholds eg slug traps, pheromone traps for pea moth, weevils
• Careful pesticide selection	+	+	+	+	+	+	Appropriate pesticide for the job, selective treatment, low leaching risk, minimal environmental impact.
• Appropriate doses	+	+	+	+	+	+	Rates to match problem, crop and environmental conditions.
• Stale seedbeds	+	+	-	-	+	+	Weed control option to flush weeds and remove by cultivation.
• Mechanical weeding	+	+	+	+	+	-	Weed control option used in conjunction with herbicides.
• Higher seedrates	+	+	+	+	-	-	Used to provide extra competition for weed control and to cope with mechanical weeding damage.
• Mechanical haulm removal	-	-	-	+	-	-	Used in potatoes instead of a chemical desiccant.
• Forecasting	+	-	+	+	+	+	Prediction schemes for pest or disease attack eg aphids, blight, BYDV.
• Pesticide placement	+	-	-	-	+	-	Incorporation of pesticide rather than broadcasting eg for slug pellets, and patch spraying of herbicides and insecticides.
Field margins/beneficials							
• Sown/managed margins	+	+	+	+	+	+	Improved field margins, sown wildflower or target strips for habitat & food provision.
• Beetle banks	-	-	-	-	+	-	Margins within fields for overwintering habitats for invertebrates.
• Conservation headlands	-	-	-	-	+	+	Used to improve biodiversity and provide food sources for farmland birds.
• Headland set-aside	-	+	-	-	-	-	Larger field margin areas, very good for biodiversity.
• Rotational set-aside	+	-	+	+	-	+	Provides overwinter stubbles, feeding and nesting sites for birds & general invertebrates.
• Sterile strip	-	-	-	-	+	-	Run alongside field margins to provide dry areas for birds.
• Overwintered stubbles	+	+	+	+	-	+	Stubbles left as long as possible before cultivation for spring crops. Good for birds.
• Residual broad-leaved weeds	-	-	-	-	+	+	Some non-agressive weeds left in crop as food sources for invertebrates and birds.

- = not adopted, + = adopted, ++ = adopted to a high degree

APPENDIX F - Statistical considerations

Experimental design, data management and statistical analysis: lessons learnt from the LINK IFS project

Peter Chapman and Eddie McIndoe, Zeneca

Introduction

This Appendix takes a rather more in depth look at some of the issues in the LINK IFS project which relate to experimental design, data management and trial conduct. Its content is therefore rather more technical than the earlier Chapter 3. A great deal was learned during the course of this experiment which could lead to significant improvements if a similar study were to be carried out in the future. These lessons are discussed and synthesised in a set of recommendations.

Experimental design

Within-site replication

As was explained in Chapter 3, additional plots were introduced at each site in order to provide replication. Some sites introduced additional split fields, some quartered existing fields, and some did both. Either way, the additional plots required a significant amount of additional resource in order to carry out the experiment. Two questions therefore need to be addressed:

- With hindsight and taking account of the results of the experiment, were the additional plots of value and was the additional work justified?
- If the additional plots were beneficial, was it better to use additional fields, or additional plots within a field?

<u>Was replication justified?</u>
Had the original design of five split fields been implemented, the system*phase*year interaction would have been used as a substitute for the experimental error. The answer to this question therefore hangs on whether this interaction exists, which we can determine by testing for statistical significance. Table F.1 shows, from the analysis of yield at each of the six sites, the mean square for the system*phase* year interaction and the error mean square which was used as the estimate of experimental error variance. The F-test based on the ratio of these two values tells us whether the interaction is statistically significant. At two of the sites, Boxworth and Lower Hope, the interaction is highly significant and at a third site, High Mowthorpe, significance is around the 10% mark suggesting that an interaction may exist. For the other three sites, there is no interaction. Thus, for some assessments at some sites the interaction is real, so it would be very unwise to rely on the system*phase*year interaction as a substitute for the error mean square. Had the interaction mean square been used as a substitute for true error mean square it would have been too large in some analyses, thereby reducing the power of the experiment and preventing the detection of some treatment differences. The conclusion must therefore be that the additional plots were needed.

Table F.1 - Statistical analysis of yield (t/ha). Comparison of the mean square for the phase* year*system interaction with the within-field error mean square across all phases of the rotation at each site separately.

Site	Within-field Mean square	DF	Phase*year*system Mean square	DF	Probability of F stat. for phase*year*system interaction
Sacrewell*	0.0008	4	0.0019	16	0.1945
Boxworth	0.3232	24	1.1818	16	0.0021
H Mowthorpe*	0.0020	26	0.0055	16	0.0106
Lower Hope*	0.0007	11	0.0149	16	<0.0001
Manydown	0.3561	28	0.4712	16	0.2509
Pathhead	0.6754	8	0.4746	16	0.7396

* Results from the analysis of yield on the log scale. DF = degrees of freedom.

Split or quartered fields: which is better?
The ANOVA structures in Chapter 3, Table 3.2 show clearly that the different replication strategies yield quite different benefits. Sacrewell and High Mowthorpe opted exclusively for quartered fields, with the result all of their degrees of freedom for error are within-field. Since the between field error degrees of freedom do not influence the precision of system effects, this would appear to be the superior strategy. In contrast, at the Pathhead site, which relied exclusively on additional fields for replication, ten of the additional degrees of freedom were between field and ten were within-field. Had pathhead had the same number of plots but only five fields - i.e. had Pathhead relied exclusively on quartered fields to provide replication - all 20 additional degrees of freedomm would have been within-field, thereby maximising precision for estimating system effects. The largest number of plots at any one site was 18 at Manydown. This site opted for a mixed strategy with seven fields in total, two of which were quartered. This strategy results in ten degrees of freedom for between field error and 30 for within-field error.

On the surface, therefore, it appears that the better strategy was to opt exclusively for quartered fields. However, further investigation reveals this conclusion to be less than clear cut:

- For the three sites that used a combination of additional fields and quartered fields, it is possible to partition the within-field error sums of squares and degrees of freedom, and hence the error variance, into two components, one deriving from additional fields and one deriving from additional plots within a field. Since these are both estimates of the within-field experimental error variance they should be similar. Tables F.2 and F.3 show the estimates for the three sites for two of the more important output variables, yield and production margin. The estimate based on replicate fields is significantly larger than that based on quartered fields in the analysis of yield at Lower Hope and in the analysis of production margin at Boxworth. The estimate based on replicate fields is significantly smaller in the analysis of production margin at Manydown. Interpretation of these results is not easy, but they suggest some form of bias. For example, when the error variance based on quartered fields is much less than that based on replicate fields it suggests that the two integrated plots within a quartered field are much more alike than we would expect.

Table F.2 - Statistical analysis of yield. Estimates of error mean square variance derived from additional fields compared with estimates derived from additional plots within a field

Site	With-in field error mean square estimated from replicated fields	Degrees of freedom	Within-field error mean square estimated from quartered fields	Degrees of freedom
Sacrewell*	-	-	0.3048	4
Boxworth	0.3941	5	0.3045	19
H Mowthorpe*	-	-	0.2493	20
Lower Hope*	0.1913	3	0.0206	5
Manydown	0.1946	10	0.4459	18
Pathhead	0.6754	8	-	-

* Results from analysis of yield with potatoes removed

Table F.3 - Statistical analysis of production margin. Estimates of error mean square variance derived from additional fields compared with estimates derived from additional plots within a field

Site	With-in field error mean square estimated from replicated fields	Degrees of freedom	Within-field error mean square estimated from quartered fields	Degrees of freedom
Sacrewell*	-	-	1569.17	4
Boxworth	10559.64	5	3139.55	19
H Mowthorpe*	-	-	2863.60	18
Lower Hope*	2215.01	3	1162.16	7
Manydown	3257.11	10	15905.55	18
Pathhead	7401.58	8	-	-

* Results from analysis of yield with potatoes removed

- For very many measurements, for example pesticide applications, the two conventional values within a field are identical, as are the two integrated values. The reason for this is not clear: it could be that the within-plot measurements that triggered the application were identical in each plot, or it could be that a single trigger was used for both plots. Either way the net result is that, for some measurements, the quartered fields were really split fields because the third and fourth plots contribute nothing. To prevent these plots seriously biasing the results, they were set to missing values prior to analysis. As a result Sacrewell and High Mowthorpe, which relied exclusively on quartered fields, in effect had no replication for estimating within-field experimental error variance for a large number of measurements.

In conclusion, therefore, although in theory quartered fields should have been a more effective method of introducing additional replication, in practice it turns out to have been a dubious method for some assessments, and a totally ineffective method for many of the other assessments. If similar experiments are to be carried out in future, this is an issue that needs to be thoroughly reviewed at the design stage.

Design of sampling schemes

If it is to achieve its objectives, any experiment must have its objectives specified as precisely as possible. The treatments, number of replicates and measurements can then be selected so as to maximise the probability of achieving these objectives.

A difficulty with the LINK IFS project is that some of the objectives were not specified sufficiently precisely, particularly so in the case of environmental objectives. Specific difficulties are listed below:

- A large number of measurements were taken during the course of the experiment which have not been used. pre-treatment measurements were taken at some sites, although not so comprehensively, nor to the same standard as the post-treatment measurements. Also a large number of post-treatment measurements have been made and not used. For example, the crop morphology data sheet includes 66 columns of data, only five of which have been analysed. These measurements must have cost something, and this money could have been used elsewhere where there was a shortage of funds. So, with hindsight, it can be concluded that if more thought had been put in at the outset, the funds available for the study could have been used more efficiently.
- Given that an important objective of the experiment was to demonstrate environmental benefits, the environmental measurements were rather patchy and there was a lack of consistency between sites. The main environmental measurement was of beneficial insects via pitfall traps, and the original plan was to sample once a month. Although no site succeeded in sampling once per month, some sites managed more than one sample per month in some months. Furthermore, there was a lack of consistency on the level of detail in organism identification - for example, some sites identified individual species, whilst others were content to group species. Extracting useful information from these beneficial data has proved difficult so again the lesson is clear: had a detailed analysis plan for the beneficial data been determined at the outset, the data would have been collected in a consistent way to a pre-determined format, would have generated some useful results, and possibly at less expense.
- Farm practices are known to have large effects on beneficial populations and any analysis should seek to quantify the relationship between the two. However, farm practices were not included in the database, making the investigation of any relationships difficult. Farm practices do appear in the trial diaries, but often without precise dates which, again, makes it difficult to make use of the information.

Conduct of the experiment

With a multi-centre experiment such as this, there are bound to be mistakes although generally the experiment was carried out to a very high standard. In some instances, there was a failure to follow the detail of the protocol which has made interpretation of the results more difficult. In particular, some environmental samples were not taken at the right time - for example, pre-treatment counts being made after the experiment had started.

An issue which does need to be considered for future experiments is the possibility of making all procedures blind. In both medical and pharmaceutical experiments, it is usual for neither experimenters nor patients to know which treatment has been applied to which patient (Senn, 1997). Furthermore, it is known that non-blind trials can lead to biased results, although the participants in the study may be completely unaware that they are introducing bias. Although it is difficult to see how blind procedures could have been introduced into the LINK IFS project, it is also clear that the opportunities for introducing bias were considerable. This is a topic that deserves to be researched.

Data management

In any large-scale experiment such as this, data management is a major issue. Although no provision was made at the outset for data management, nor was any resource allocated, this was recognised as a major deficiency and the situation quickly corrected. To date over two man years worth of effort have been allocated to the project under the following headings:

- Discussions at the outset that led to changes in the design.
- Research into the design and analysis of the validation trials which led to significant improvements in their power and precision.
- Design of the data recording sheets.
- QC audits of the completed recording forms and actions leading to an improvement in the quality of the data recorded.
- Site visits in order to aid data entry.
- Statistical analysis and tabulation of results on completion of the study.
- Contributions to the interpretation and reporting of the study.

Once the resource issue had been sorted data management presented few difficulties, but with hindsight, there are two ways in which data handling could have been improved.

- The data recording sheet was not finalised until the beginning of the second harvest year. Furthermore, no prototype was tested prior to introduction of the final data recording sheet, nor were site personnel given training on its use. At the time, this was not perceived to be a source of possible difficulties. However, site personnel clearly had some difficulties with some of the finer points of data entry and, as a result, the quality of data entered, particularly in the early years, was lower than was desirable. In the event, a considerable amount of resource was needed to clean up the data prior to statistical analysis.
- A considerable amount of effort, such as species identification, was often needed prior to entering data at both the sites themselves and at the ADAS Wolverhampton laboratory. Again, with hindsight, it appears that the amount of effort involved in this pre-work appears, in some instances, to have delayed the completion of data entry forms, particularly so for some of the environmental variables.

Conclusions and recommendations

This section includes a number of recommendations that, if adopted, would lead to superior results if a similar experiment were to be conducted in the future. Adoption of many of these recommendations would be difficult and could clearly be seen as 'over the top'. However, they should at least be considered and only discarded if it is felt that they are too expensive or too impractical.

- Experimental objectives should be stated precisely at the outset. This in turn would determine what kinds of data summaries and data analyses were required and would enable the right data to be collected. This would require significant amounts of discussion and conferring between interested parties.

- The level of precision desired in the final results should also be specified. For example, do we wish to be able to detect a 5 % difference in profit or will a 20 % detection limit be acceptable. The answer to these questions determines how big an experiment is required.
- The trial design, including treatments, number of replicates and measurements should all be selected so as to enable the objectives to be achieved. In particular, measurements that are not relevant to the objectives should not be made.
- The resource required to carry out the experiment should be assessed as accurately as possible and funds made available to meet the resource needs. This should include a significant amount of resource for data management.
- Research aimed at eliminating bias from large-scale field experiments should be initiated. In particular, practical methods of introducing blind procedures should be explored.
- Ideally, a protoype experiment should be run at one site for one year. During this period every aspect of the study should be put to the test, including design, resource levels, data recording and so forth. The following year should be a review year before the trial proper commences.

References

Senn, S. (1997) Statistical Issues in Drug Development. Wiley: Chichester.

APPENDIX G - CHAPTER 6 - Economics

Additional data

* Indicates a significant difference at the 5 % level.

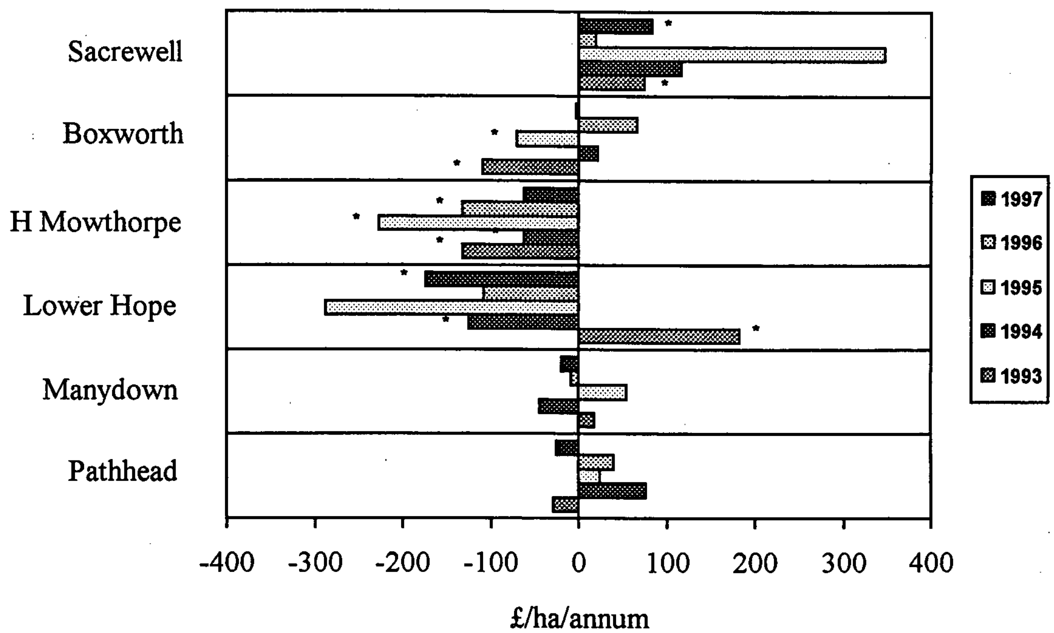

Figure 6.11 - Difference in production margin (IFS-CFP), all sites/all crops

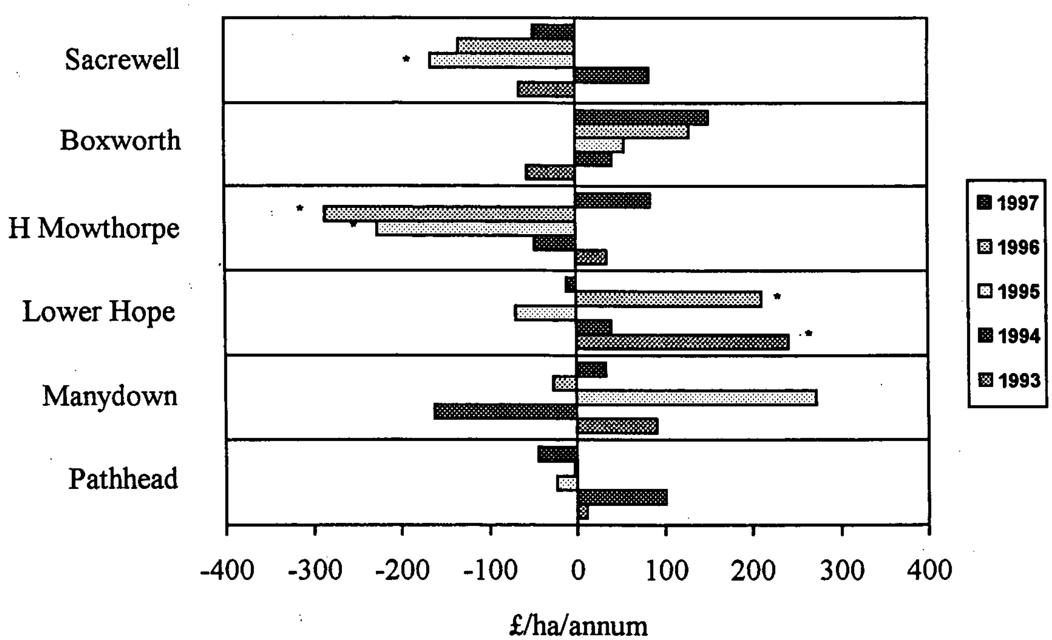

Figure 6.12 - Difference in production margin (IFS-CFP), first wheats

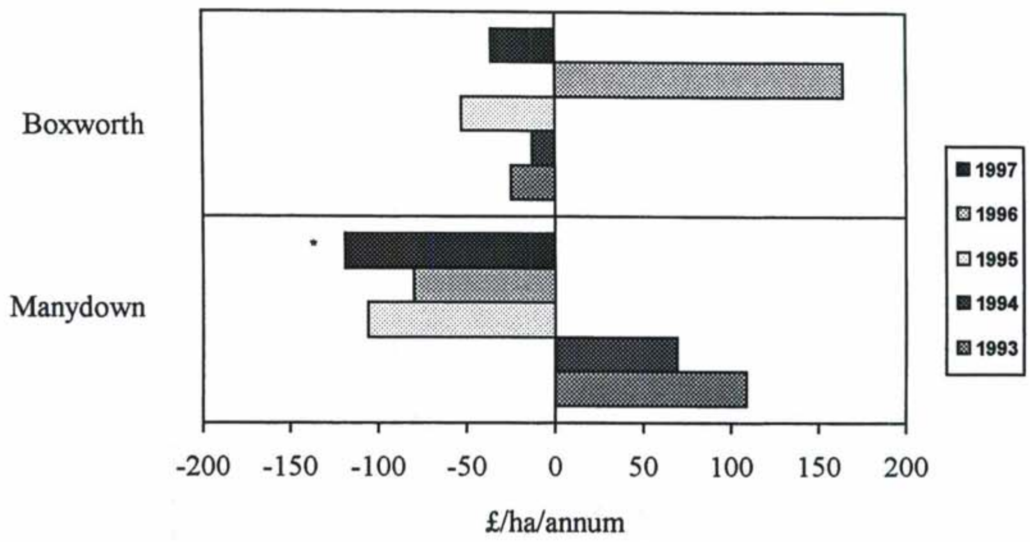

Figure 6.13 - Difference in production margin (IFS-CFP), second wheats

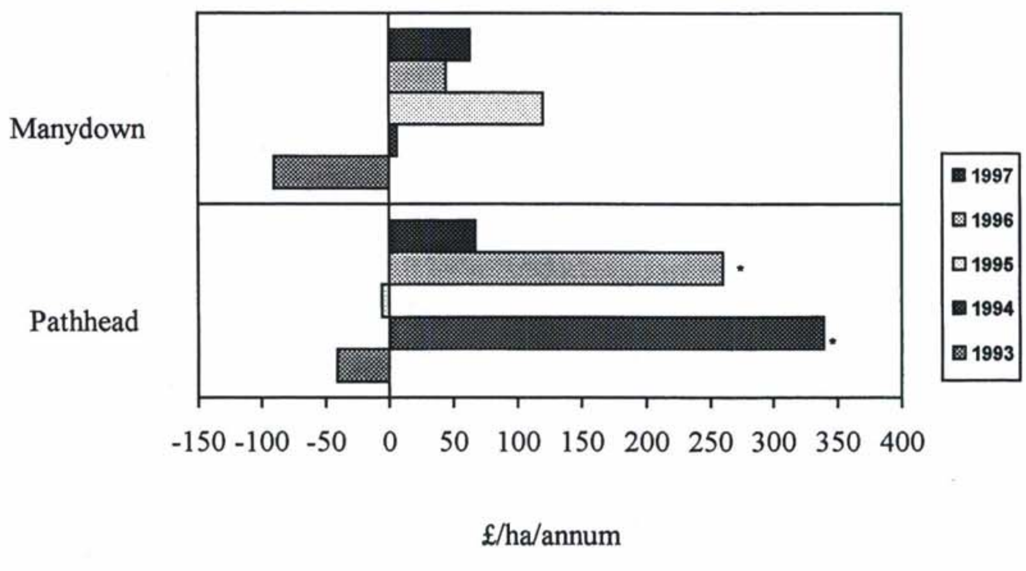

Figure 6.14 - Difference in production margin (IFS-CFP), barley

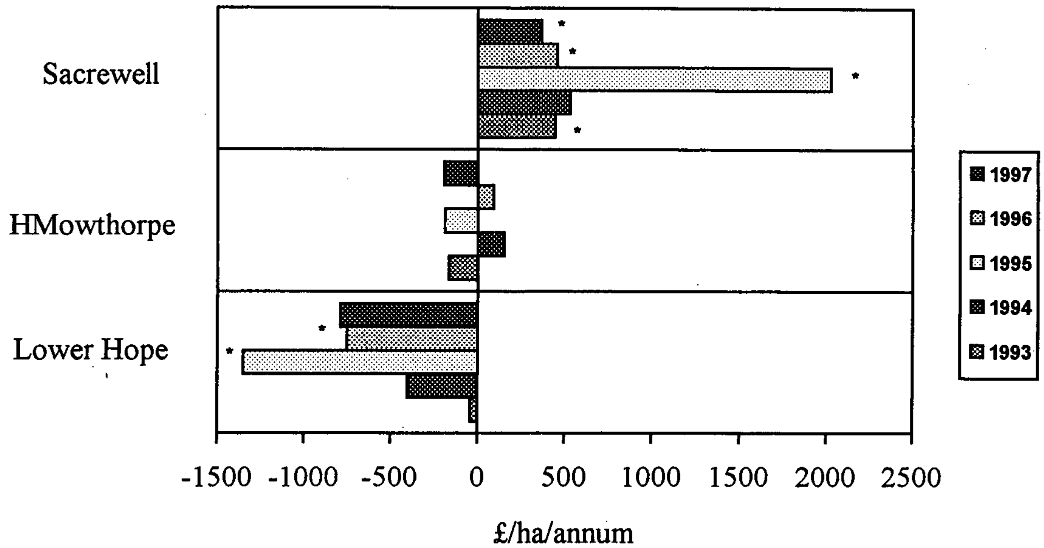

Figure 6.15 - Difference in production margin (IFS-CFP), potatoes

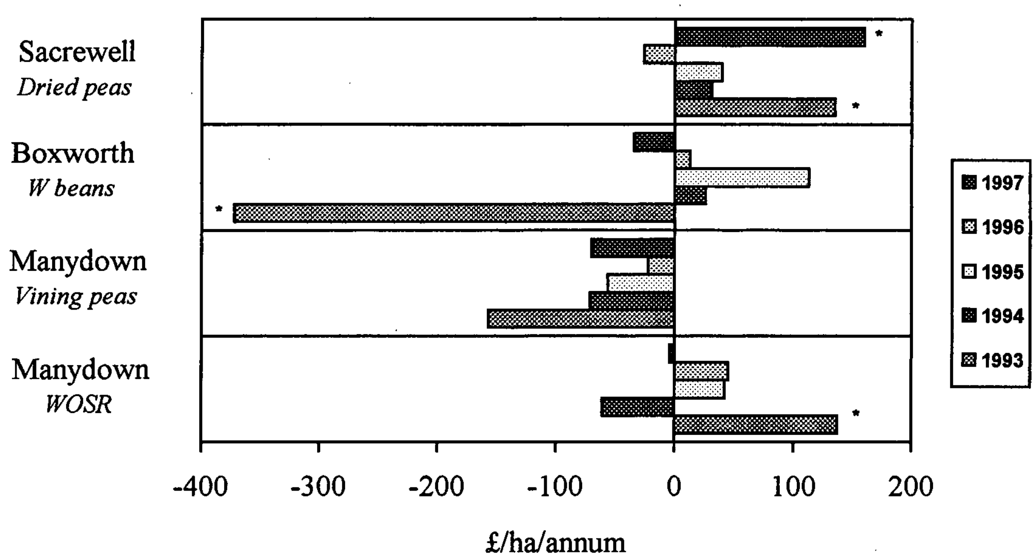

Figure 6.16 - Difference in production margin (IFS-CFP), break crops with same crops on IFS and CFP

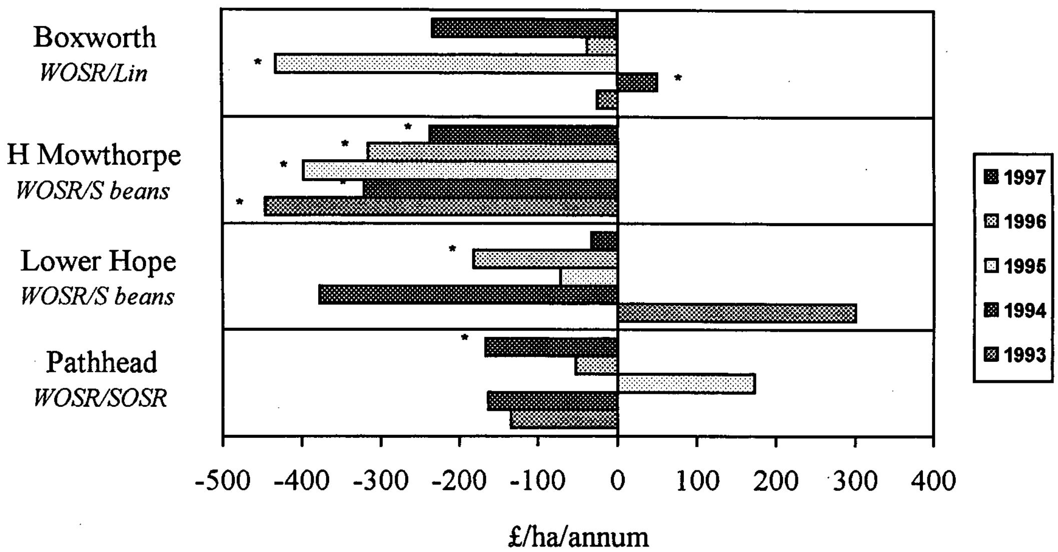

Figure 6.17 - Difference in production margin (IFS-CFP), break crops with different crops on IFS and CFP

APPENDIX H - CHAPTER 7 - Invertebrates (beetles and spiders)

Table 7.2 - Results of analysis examining effect of farming system (S), phase by system (P*S), year by system (Y*S) and phase by year by system (P*Y*S) on invertebrate abundance and diversity during April-July. Only results for the highest order interaction are presented.

Taxa	Sacrewell	Boxworth	High Mowthorpe	Lower Hope	Manydown
Abundance					
Ground beetles	-	P*S	P*Y*S	-	-
Rove beetles	P*Y*S	S, P*S,	P*Y*S	P*S,Y*S	S
Money spiders	-	P*S	P*Y*S	P*Y*S	-
Number of taxa					
Ground beetles	-	P*S	P*Y*S	Y*S	-
Rove beetles	S, P*S, P*Y*S	P*Y*S	P*S	P*S, Y*S	-
Money spiders	-	P*Y*S	P*Y*S	Y*S	-

Table 7.3 - Results of analysis examining effect of farming system (S), phase by system (P*S), year by system (Y*S) and phase by year by system (P*Y*S) on abundance of individual taxa. Only results for the highest order interaction are presented.

Family	Genus	Month	Result	Cause
Sacrewell				
Carabidae	*Pterostichus melanarius*	June	-	
Carabidae	*Pterostichus melanarius*	July	P*Y*S	No trend
Boxworth				
Carabidae	*Amara* spp.	April	P*Y*S	No trend
		May	P*Y*S	Fewer in the integrated linseed
Carabidae	*Notiophilus biguttatus*	April	P*Y*S	No trend
	Agonum dorsale	June	-	
	Pterostichus melanarius	June	-	
	Pterostichus melanarius	July	P*Y*S	No trend
Staphylinidae	*Tachyporus hypnorum*	May	-	
Linyphiidae	*Erigone* spp.	April	P*S, Y*S	Fewer in the integrated linseed and second wheat and in 1997
		May	P*Y*S	Fewer in integrated linseed and winter wheat each for two crop/years
		June	-	
		July	P*S, Y*S	Fewer in the integrated plots of linseed, winter beans and second wheat, and in 1995 and 1997.
	Oedothorax spp.	May	P*Y*S	More in integrated plots in three crop/years
		June	-	
		July	P*Y*S	Fewer in the integrated linseed, fluctuations between the systems in other crops

High Mowthorpe				
Carabidae	*Amara* spp.	April	Y*S	Higher in integrated system in 1994
Carabidae	*Notiophilus biguttatus*	April	P*Y*S	No trend
	Bembidion lampros	April	P*Y*S	Higher in integrated wheat in four years
		May	-	
		June	P*S	Higher in integrated spring beans
	Agonum dorsale	June	P*Y*S	Lower in integrated spring beans in four years, fluctuations in other crops
	Nebria brevicollis	June	-	
	Pterostichus melanarius	July	S	Higher in integrated system
Linyphiidae	*Erigone* spp.	April	-	
		May	-	
		June	Y*S	No trend
		July	P*S	Higher in integrated wheat and set-aside
	Leptyphantes spp.	July	-	
Lower Hope				
Carabidae	*Trechus quadristriatus*	Nov	-	
	Amara spp.	May	P*S	Lower in integrated spring beans and set-aside
	Bembidion lampros	April	P*S	Higher in integrated spring beans
		May	P*S	Higher in integrated spring beans, lower in wheat after potatoes
		June	S	Higher in integrated system
	Pterostichus melanarius	July	P*Y*S	Higher in integrated spring beans and both wheat crops
Staphylinidae	*Tachyporus hypnorum*	May	P*S	Lower in integrated spring beans
		June	P*Y*S	Fewer in integrated spring beans and winter wheat each for two crop/years
Linyphiidae	*Erigone* spp.	April	P*Y*S	No trend
		May	P*S, Y*S	Fewer in integrated wheat and set-aside and for two years
		June	P*S	No trend
		July	-	
	Oedothorax spp.	May	P*Y*S	No trend
		June	Y*S	Higher in integrated system in 1997
Manydown				
Carabidae	*Trechus quadristriatus*	Nov	P*Y*S	No trend
	Nebria brevicollis	Nov	-	
		June	-	
	Notiophilus biguttatus	April	-	
	Amara spp.	May	-	
	Bembidion lampros	April	-	
		May	P*Y*S	No trend
		June	-	
	Pterostichus melanarius	July	-	
Staphylinidae	*Tachyporus hypnorum*	May	-	
		June	-	
Linyphiidae	*Erigone* spp.	April	-	
		May	P*Y*S	No trend
		June	-	
		July	-	
	Oedothorax spp.	May	-	
		June	-	
		July	-	
	Leptyphantes spp.	July	-	

APPENDIX I - CHAPTER 8 - Earthworms

Table 8.1- Table of the average total number of worms/m^2 and the average total weight (g/m^2) for each year in both systems and the difference (IFS - CFP) between systems in each year.

Site	Year	Mean number of worms/m^2			Mean weight of worms/m^2		
		CFP	IFS	Diff.	CFP	IFS	Diff.
Sacrewell	1992	4.94	9.63	4.69	1.67	3.87	2.20
	1995	4.55	30.35	25.80	2.38	10.48	8.10
	1997	2.32	5.44	3.13	0.98	2.46	1.48
	Mean of 1995 & 1997	3.56	19.28	15.72	1.76	6.92	5.16
Boxworth	1992	70.25	56.75	-13.50	16.52	12.76	-3..77
	1995	84.45	72.60	-11.85	19.03	17.31	-1.73
	1997	68.10	57.65	-10.45	18.87	16.18	-2.69
	Mean of 1995 & 1997	76.28	65.13	-11.15	18.95	16.75	-2.21
High Mowthorpe	1992	12.15	12.45	0.30	9.00	9.93	0.93
	1995	16.88	7.94	-8.94*	6.18	5.33	-0.85
	1997	8.90	13.35	4.45*	3.41	5.73	2.33*
	Mean of 1995 & 1997	12.45	10.95	-1.50	4.64	5.55	0.92
Lower Hope	1992	7.38	6.69	-0.69	3.13	2.07	-1.07
	1995	9.65	18.30	8.65	2.18	5.24	3.07
	1997	2.35	4.35	2.00	1.53	3.23	1.70
	Mean of 1995 & 1997	6.00	11.33	5.33	1.85	4.24	2.39
Manydown	1992	42.37	30.54	-11.84	10.27	10.84	0.58
	1995	22.77	26.44	3.67	10.21	13.17	2.96
	1997	7.44	19.07	11.64	1.78	9.12	7.34*
	Mean of 1995 & 1997	15.10	22.75	7.65	6.00	11.15	5.15
Pathhead	1992	42.96	60.04	17.09	10.79	15.29	4.50
	1995	75.35	68.15	-7.20	14.53	13.13	-1.40
	1997	63.20	60.40	-2.80	14.80	14.67	-0.14
	Mean of 1995 & 1997	69.28	64.28	-5.00	14.67	13.90	-0.77
Overall Mean of 1995 & 1997		31.22	32.88	1.66	8.14	9.87	1.73

(* Statistically significant result, $P<0.05$)

APPENDIX J - CHAPTER 10 - Crop protection

Table 10.6 - System differences in weight of active ingredient used (kg/ha ai)

	Herbicides	Fungicides	Insecticides	PGRs
CFP	2.18	2.13	1.11	0.51
IFS	1.95	0.92	1.77	0.22
CFP-IFS	0.23	1.21*	-0.66*	0.29*

Table 10.7 - System differences in pesticide active ingredient units used (units/ha)

	Herbicides	Fungicides	Insecticides	PGRs
CFP	1.39	2.85	0.69	0.51
IFS	1.11	1.62	0.36	0.22
CFP-IFS	0.27^{NS}	1.23*	0.33*	0.29*

Table 10.8 - Site differences in weight of active ingredient used (kg/ha ai)

	SW	BW	HM	LH	MD	PH
CFP	17.93	3.63	4.03	4.33	3.02	2.65
IFS	15.91	2.07	2.88	4.85	2.27	1.22
CFP-IFS	2.03*	1.56*	1.15*	-0.53*	0.75*	1.43*

Table 10.9 - Site differences in pesticide active ingredient units used (units/ha)

	SW	BW	HM	LH	MD	PH	Overall Mean
CFP	7.62	4.42	6.22	5.72	4.13	3.66	5.29
IFS	3.91	2.55	4.90	3.25	3.38	1.61	3.27
CFP-IFS	3.71*	1.86*	1.32*	2.47*	0.75*	2.04*	2.03*

Table 10.10 - Year differences in weight of active ingredient used (kg/ha ai)

	1993	1994	1995	1996	1997	Overall Mean
CFP	5.44	5.36	6.22	6.18	6.45	5.93
IFS	6.12	4.00	4.37	4.70	5.15	4.87
CFP-IFS	-0.68*	1.37*	1.85*	1.49*	1.31*	1.07*

Table 10.11 - Year differences in pesticide active ingredient units used (units/ha)

	1993	1994	1995	1996	1997	Overall Mean
CFP	5.49	5.27	5.78	4.96	4.98	5.29
IFS	3.82	2.89	3.14	3.07	3.42	3.27
CFP-IFS	1.67*	2.39*	2.63*	1.89*	1.56*	2.03*

(* Statistically significant result, $P<0.01$)

Table 10.12 - Cost of pesticide used by crop on CFP and IFS and the difference (CFP-IFS) (£/ha)

CFP/IFS crops	Herbicides			Fungicides			Insecticides			PGRs		
	CFP	IFS	Diff	CFP	IFS	Dif	CFP	IFS	Dif	CFP	IFS	Dif
1st W Wheat/1st W Wheats	37.7	32.9	4.8*	52.4	25.2	27.2*	8.0	2.5	5.5*	3.3	1.8	1.5*
2nd W Wheats/2nd W Wheats	56.4	48.5	7.9	45.0	22.3	22.7*	2.7	1.5	1.2	3.0	1.4	1.6*
S Barley/S Barley	27.2	29.2	2.0	30.2	27.8	5.4	0	0	0	0	0	0
W Barley/S Barley	17.9	9.7	8.3	32.4	3.1	29.3*	2.2	0	2.2	8.5	0	8.5*
Potatoes/Potatoes	76.9	45.3	31.7*	113.6	108.1	5.5	125.3	122.6	2.7	0	0	0
Peas/Peas	46.3	34.2	12.1*	9.5	6.0	3.5	6.3	8.8	-2.5	0	0	0
W Beans/W Beans	15.2	32.0	-16.8*	23.8	0	23.8*	0	0	0	0	0	0
Set-Aside/Set-Aside	23.2	18.7	4.5	0	0	0	0	0	0	0	0	0
W Oilseed Rape/W Oilseed Rape	30.4	25.6	4.8	44.5	32.7	11.8*	3.4	1.4	2.0	0	0	0
W Oilseed Rape/Linseed	48.6	48.3	0.3	17.9	0	17.9*	12.4	2.5	9.9*	0	0	0
W Oilseed Rape/S Beans	57.9	27.7	30.2*	22.0	6.4	15.6*	9.3	0.6	8.7*	0	0	0
W Oilseed Rape/S Oilseed Rape	43.8	12.0	31.8*	39.2	0	39.2*	10.3	2.5	7.8*	0	0	0
Mean	41.4	31.6	9.8*	42.0	24.4	17.6*	17.6	14.1	3.5*	1.7	0.8	0.9*

(* Statistically significant result, P<0.05)

Table 10.13 - Weight of active ingredient used by crop on CFP and IFS and the difference (CFP-IFS) (kg/ha ai)

CFP/IFS crops	Herbicides			Fungicides			Insecticides			PGRs		
	CFP	IFS	Diff	CFP	IFS	Dif	CFP	IFS	Dif	CFP	IFS	Dif
1st W Wheat/1st W Wheats	2.35	1.81	0.54*	1.84	0.74	1.10*	0.33	0.09	0.24*	1.10	0.53	0.57*
2nd W Wheats/2nd W Wheats	2.32	1.83	0.49	1.09	0.51	0.58*	0.15	0.04	0.11	0.97	0.43	0.54*
S Barley/S Barley	1.18	1.05	-0.13	0.50	0.31	0.19	0	0	0	0	0	0
W Barley/S Barley	1.07	0.05	1.02*	0.72	0.03	0.68*	0.06	0	0.06	1.17	0	1.17*
Potatoes/Potatoes	3.54	5.63	2.09*	11.35	5.09	6.26*	9.41	17.21	-7.80*	0	0	0
Peas/Peas	4.87	3.10	1.77*	0.83	0.75	0.08	0.26	0.23	0.04	0	0	0
W Beans/W Beans	0.92	0.45	0.47	1.03	0	1.03*	0	0	0	0	0	0
Set-Aside/Set-Aside	1.65	1.53	0.11	0	0	0	0	0	0	0	0	0
W Oilseed Rape/W Oilseed Rape	1.30	1.11	0.19	0.94	0.72	0.22	0.02	0.01	0.01	0	0	0
W Oilseed Rape/Linseed	0.39	0.41	-0.02	0.75	0	0.75*	0.09	0.07	0.02	0	0	0
W Oilseed Rape/S Beans	1.18	1.18	0.00	0.50	0.36	0.14	0.20	0	0.20*	0	0	0
W Oilseed Rape/S Oilseed Rape	0.68	0.25	0.43	1.11	0.00	1.11*	0.14	0	0.14	0.20	0	0.20
Mean	2.18	1.95	0.23	2.13	0.92	1.21	1.11	1.77	-0.66	0.51	0.22	0.29

(* Statistically significant result, $P<0.05$)

Table 10.14 - Pesticide active ingredient units used by crop on CFP and IFS and the difference (CFP-IFS) (units/ha)

CFP/IFS crops	Herbicides			Fungicides			Insecticides			PGRs		
	CFP	IFS	Diff	CFP	IFS	Dif	CFP	IFS	Dif	CFP	IFS	Dif
1st W Wheat/1st W Wheats	1.69	1.49	0.21*	2.73	1.24	1.50*	0.73	0.15	0.58*	0.77	0.41	0.35*
2nd W Wheats/2nd W Wheats	1.99	1.84	0.15	2.31	1.15	1.16*	0.30	0.08	0.22	0.78	0.34	0.44*
S Barley/S Barley	1.53	1.61	-0.07	1.42	1.05	0.37	0	0	0	0	0	0
W Barley/S Barley	0.87	0.82	0.05	1.72	0.13	1.58*	0.38	0	0.38	0.96	0	0.96*
Potatoes/Potatoes	1.45	0.61	0.84*	12.84	9.59	3.25*	2.04	1.68	0.36*	0	0	0
Peas/Peas	1.95	1.34	0.61*	0.35	0.34	0.01	0.89	1.25	-0.36*	0	0	0
W Beans/W Beans	0.97	0.54	0.43	1.26	0	1.26*	0	0	0	0	0	0
Set-Aside/Set-Aside	0.60	0.45	0.15	0	0	0	0	0	0	0	0	0
W Oilseed Rape/W Oilseed Rape	1.22	0.97	0.25	1.92	1.36	0.55*	0.92	0.74	0.18	0	0	0
W Oilseed Rape/Linseed	0.85	1.16	-0.31	1.36	0	1.36*	0.42	0.37	0.05	0	0	0
W Oilseed Rape/S Beans	1.09	0.86	0.22	1.00	0.38	0.62*	0.79	0.16	0.63*	0	0	0
W Oilseed Rape/S Oilseed Rape	0.77	0.20	0.57	1.93	0	1.93*	0.85	0.03	0.82*	0.22	0	0.22
Mean	1.39	1.11	0.27	2.85	1.62	1.23	0.69	0.36	0.33	0.37	0.17	0.20

(* Statistically significant result, P<0.05)

APPENDIX K - The effect of farming systems on nitrogen utilisation and loss (Nitrogen bolt-on project).

Gillian Goodlass, ADAS High Mowthorpe and Jo Smith, IACR Rothamsted

Introduction

This study, funded by MAFF, was a bolt-on project to the main LINK IFS project and covered additional sampling of soil and plant material and interpretation of nitrogen data. The bolt-on project began in spring 1995, not at the start of the main project in 1992.

Method

For the main project, crop nitrogen requirement was determined by means of ADAS Fertiplan (based on soil type and previous cropping/N use) for the conventional crop and measurement of soil mineral nitrogen for the integrated crop. In this study, additional soil mineral nitrogen (SMN) and crop N measurements were carried out in the final three years to enable N losses (in terms of soil N balance) to be calculated. Detailed site and crop husbandry information was collected and entered into the SUNDIAL model, developed by researchers at IACR Rothamsted, for prediction of changes in various aspects of soil N supply throughout the course of the rotation (Smith & Glendining, 1996).

N balance

Three different N Balance components were calculated as follows:

- Overwinter N loss = Spring SMN+plantN - Autumn SMN+plant N (cover crops only)
- SMN change = Spring SMN - autumn SMN
- Unused N = Spring SMN + Fertiliser N - N offtake

Although called 'N loss' throughout this report, the over winter changes in SMN may represent crop uptake as well as several different soil processes such as leaching, denitrification and mineralisation. The SUNDIAL model was used to identify these.

SUNDIAL

The Rothamsted nitrogen (N) turnover model is known by the acronym SUNDIAL (Simulation of nitrogen dynamics in arable land) and simulates N turnover in the soil/crop system.

The SUNDIAL model is driven by weekly inputs of total rainfall, total evapotranspiration over grass, and average air temperature. Any missing data values were replaced with the averaged values for that week. Where these data were not recorded data from nearby meteorological stations were used.

For each experimental plot, separate SUNDIAL setup files were produced containing soil type, cropping history and management practices. Each plot was simulated for six years from the harvest of the preceding crop in 1991 to harvest in 1997, using common weather data for all plots. The simulation included the 1992 baseline crop, but these data were not included in the analysis of the five year rotation.

Comparison of N losses from IFS and CFP

In general, predicted N losses over the whole rotation have been reduced with IFS. However, at individual sites, there is considerable variation in the effect of CFP compared with IFS due to factors such as soil, crop, season and management.

Season

The six sites of the LINK-IFS project were distributed throughout the UK and so covered a range of climates. The timing of the drainage period and the volume of drainage which occurred thus varied greatly between seasons and sites. Calculated drainage (the excess of rainfall over evapotranspiration) can vary between seasons by up to 100%. The largest amounts of N lost by leaching are usually associated with seasons when there are large volumes of drainage in the early winter.

Soil

For four sites, it was possible to find a comparable two season sequence of cropping to look at the effect of site separately to any influence of cropping. These are sequences from the CFP and look at the leaching loss under a winter wheat crop which followed a winter oilseed rape crop. The total estimated losses were low at this point in the rotation but there were still clear differences between sites (Table K.1). Leaching losses were higher in the shallow soil, but at this point in the rotation it was not possible to see any clear textural effect in the deeper soils.

Table K.1 - Simulated losses of N under winter wheat following winter oilseed rape at 4 sites during the winter of 1993-1994.

Site	Soil	Rotation phases	Total simulated loss (kg/ha N)	Simulated leaching loss (kg/ha N)
Pathhead	Deep loamy	V - I	66	12
Boxworth	Deep clay loam	I - II	51	15
Lower Hope	Deep loamy	III - IV	71	18
High Mowthorpe	Shallow clay loam over chalk	III - IV	89	25

Management

Where crops were the same in both IFS and CFP, there may have been differences in N losses due to changes in management. For example, mechanical weeding may have affected mineralisation rates, whilst sowing date and cultivar changes could have affected crop uptake. However, predicted changes were small and consistent differences in soil mineral N measurements were not identified.

Crop

The effect of different crops in the IFS and CFP rotations can be clearly seen at Sacrewell and Boxworth in the autumn SMN measurements (Table K.2) where levels were higher following spring crops preceeded by cover crops. These high levels were lost by the following spring.

Table K.2 - Effect of previous cropping on autumn SMN measurements and overwinter change in SMN

Site	Crop		Autumn SMN (kg/ha)		SMN Change (kg/ha)	
	CFP	IFS	CFP	IFS	CFP	IFS
Sacrewell (0-60 cm)	Peas	Peas+cover	70	89	-40	-48
Boxworth (0-90 cm)	WOSR	Linseed+cover	135	176	1	-49

The higher levels of SMN at Boxworth in this table compared with data presented in Chapter 11, Fig. 11.4 are because data from the deeper sampling depth are used here.

Efficiency of cover crops

Leaching during cover cropping

Simulated leaching data show that cover cropping significantly reduces N leaching overwinter (Fig. K.1 shows data for High Mowthorpe). At all sites where cover crops were used in the IFS before spring crops, leaching losses were reduced compared to comparable conventional plots. On average, the use of cover crops before potatoes at Sacrewell (Phase 5) reduced amounts of N leached by 19 kg/ha N. Cover crop management was not uniform across seasons at all sites. At High Mowthorpe in 1997, natural regeneration took place overwinter in the CFP rotations, replacing the previous overwinter fallow. The use of natural regeneration had a similar effect to the use of cover crops and differences between the systems were reduced.

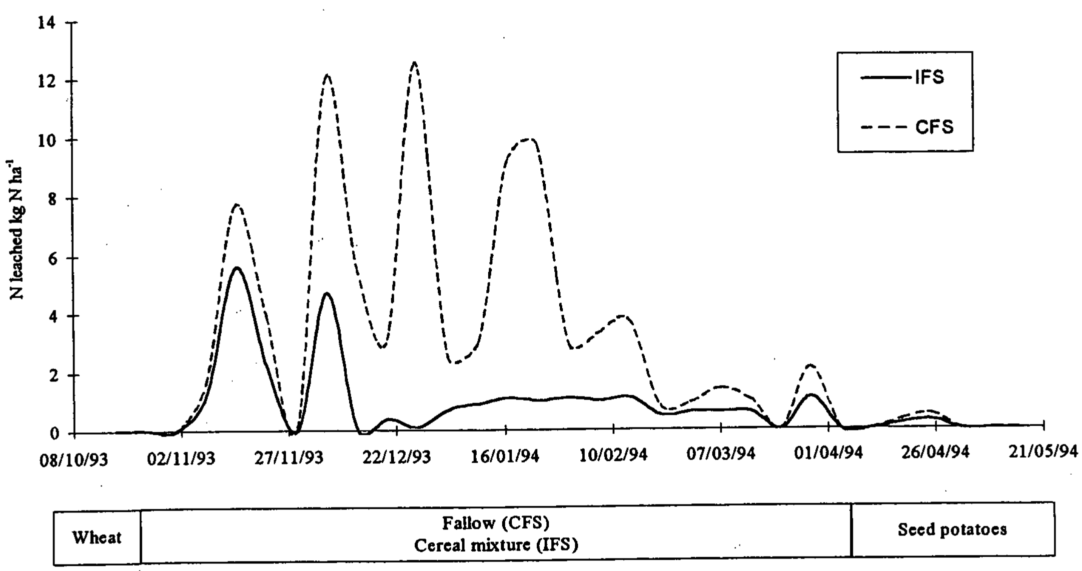

Figure K.1 - N leached overwinter 1993-1994 for Phase V at High Mowthorpe. (Total amounts leached were 25 kg/ha N and 68 kg/ha N for the IFS and CFP respectively.)

Effect on mineralisable N

The simulated data show that where cover crops were included in the rotation and other cropping was identical, there was an increase in soil organic N (Fig. K.2). Within the CFP rotation at Sacrewell, a stable but fluctuating HUM-BIO pool was simulated, while the IFS rotation seemed to be accumulating organic N. However, the differences between the pools of organic N in the soil at the end of the simulated period corresponded to only a 6.25% increase in the pool size, and it is perhaps not surprising that such a small increase has not been detected as an increase in the measured soil mineral N levels.

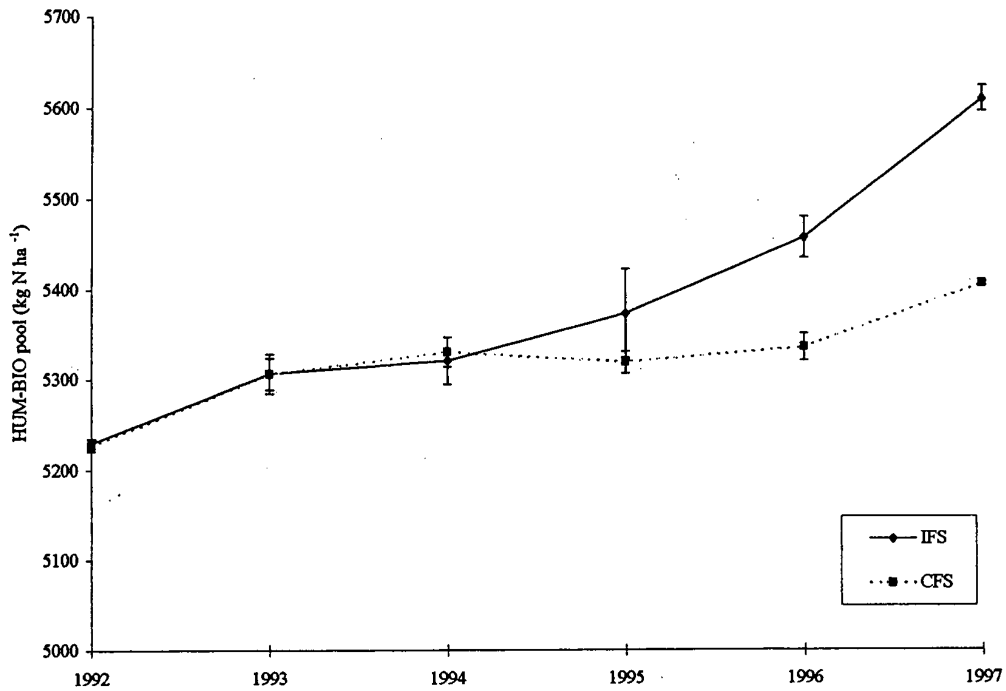

Figure K.2 - Change in simulated HUM-BIO pool (soil organic N) during the rotation at Sacrewell. (Points are averaged across all phases for each year, with the standard error of the mean given.)

Evaluation of N balance and computer modelling techniques

Measurements of mineral N were made (0-30, 30-60 and 60-90 cm) in winter and spring at most sites, and these can be used to give some indication of the validity of the simulations of N cycling. A graphical comparison of the simulated and measured values was made but only limited statistical analyses were possible using the measurements provided. For example at Pathhead, the mean difference (**M**) between simulated and measured data was 3.7 kg/ha N for the conventional system and -0.44 kg/ha N for the integrated system. The Student's-**t** values of **M** were within the critical 5% **t**-value for the two tailed test, and so the bias in the prediction was not statistically significant in either system. Maximum errors observed in these simulations were 28 and 17 kg/ha N, with a root mean square error of 13 and 9 kg/ha N for the conventional and integrated systems respectively. Similar results were seen when the results for other sites were compared, allowing reasonable confidence in the simulation of N cycling using the SUNDIAL model. However, for a full evaluation of the simulations further data would be needed. Other long term studies (Bhogal *et al.*, 1997) have shown that reducing fertiliser N inputs can lead to reduced soil organic matter levels.

Conclusions

1. Although the soil mineral nitrogen residues were not reduced to below 60 kg/ha pre-winter, the integrated system had a degree of success with overall fertiliser nitrogen inputs being reduced at five of the six sites.

2. Autumn sown cover crops were successfully used to reduce loss of nitrate through over-winter leaching. However, where unused residues from the cover crop occur (seen as high soil mineral N in the following autumn at Boxworth and Sacrewell), these may be at risk of leaching over the following winter.

3. Comparisons of other long term studies with the simulation models and actual measurements indicates that the role of nitrogen in integrated farming systems is not yet resolved. A further rotational sequence would be needed to determine whether some of the long term effects on soil N supply can be realised.

4. Improvements in the precision of N fertiliser decision making may help in the more effective use of fertilisers, but evidence from the classical experimental work at Rothamsted suggests that it is not desirable to reduce overall soil fertility too far. Indeed the simulations of soil biomass pools suggest that a reduction in soil mineral nitrogen may not be a realistic goal. A better target may be to improve the efficiency of crop uptake from both soil and fertiliser sources.

References

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APPENDIX L - Workshop discussions

John Coutts, Zeneca

A meeting was held on 25 November 1997 to capture the knowledge, skills, experience and thoughts about key integrated practices which had been applied successfully in the LINK IFS project, and information about how they had been implemented. The meeting involved all the site managers and the farm manager from the Pathhead site. The agreed conclusions from the workshop were to be included in the final report and used in communications about the outcome from the project.

Process

Each participant was required to think as an 'Integrated Farmer', and undertook the following tasks:

1. Brainstorm the practices the individual as a farmer would adopt and those that would be discarded, in order to be fully integrated.
2. Group similar practices and prioritise the top five.
3. Identify the benefits to be obtained from the top five practices, and assign a level of significance, i.e. are the benefits likely to motivate 'real' farmers to adopt the practice.
4. Take each of the top three practices in turn and brainstorm how to ensure successful implementation.
5. Take the whole scenario developed so far and identify the implications for the farmer, his staff and his advisor.

Priority integrated practices

Top five practices

- Targetted and selective pesticide use) combined
- Monitoring)
- Nutrient balancing
- Crop diversity
- Field margins

Other priority practices

- Flexible cultivation
- Risk management
- Resistant varieties
- Mechanical weeding
- Utilisation of cultivations and delayed drilling to control pests, weeds and diseases

Benefits and implementation

1. Targetting and monitoring - in part to enable selective agrochemical use

Benefits
- Lower costs

- Survival of beneficial insects = lower agrochemical costs, greater biodiversity and an enhanced environment.
- Less pollution from improved farm practices = less risk of litigation, character stains and restriction of freedom = improved image.
- Reduced operator risks = happier employees.
- Less risk of resistance = retained product choice = maintained efficacy/response and achievement of target yields, quality and profit.
- Satisfying the 'spirit' as well as the 'letter' of Quality Assurance Schemes = improved public, consumer and public acceptability of farming(ers).
- Successful management = minimised risk and optimised cost: Benefit.
- Knowledge and experience acquired (including from mistakes = increased probability of future success).
- Applications timed accurately = greater cost effectiveness and less waste/pollution.

Benefits highly significant - well worth having

Implementation
(Concerned with the crop, its potential, pests, weeds and diseases, inputs, soil location etc.)
- Define the target market, yield, quality and profit.
- Gather information about the field:
  - Soil: wheat bulb fly risk, PCN risk, P & K status, pH, soil N, soil structure.
  - Plants: trace elements, canopy, pests, weeds and diseases.
- Gather information about products, dose and environmental properties.
- Walk fields regularly, focus monitoring by variety, anticipate problems.
- Have a working knowledge of pests, weeds and diseases, damage symptoms, thresholds and treatment benefits.
- Install a farm meteorological station and utilise both short and long term weather forecasts.
- Tap into seasonal sources of information (e.g. crop action notes).
- Consider in-field blight risk monitors.
- Record inputs applied, responses, yields and quality achieved and costs. Ensure information recorded complies with Quality Assurance needs.
- Calibrate equipment regularly.
- Ensure operators are trained to required levels of competance.

2. *Crop diversity (and variety resistance)*

Benefits
- Biodiversity and countryside mosaic = public satisfaction = improved farmer image.
- Less pest pressure = lower agrochemical costs.
- Less risk of resistance = retention of product choice and management options = maintain levels of efficacy, yield and profit preservation.
- Rotation and location of different crops in adjacent = reduced pest and disease pressure = lower control costs.
- Allows more first wheats = opportunity to grow for yield and quality = greater rotational profit.
- Reduced risk = consistent rotational profit.
- Lower fixed costs.

- Workload spread = easier management and operational logistics/investment = relaxed sleep and holidays.
- Allows greater flexibility with soil management/cultivations = improved soil structure = better crops = maximisation and consistency of profit.
- Longer intervals between crops allows a greater opportunity for pest, weed and disease control = less risk of crop loss.
- Less nitrate leaching from balancing crops which release nutrients with those that uptake nutrients in the rotation.

Benefits highly significant - well worth having

Implementation
(Concerned with soil, location and target markets)
- Care with volunteers - need to design the rotation and keep good records.
- Need a good knowledge of 'area payments' and crop costs prior to designing the rotation.
- Varieties need to be chosen carefully - prioritise target market, disease resistance, field position, likely drilling date, growing costs etc.
- Disperse crops and varieties.
- Optimise/limit choices to simplify management.
- Workload needs thought and careful management.

3. *Field margins*

Benefits
- Improved public relations = less hassle = continued freedom to operate and less risk of mandatory schemes or legislation.
- Income from incentive schemes.
- Improved environment = personal satisfaction.
- Barrier to pollution = reduced risk of contamination and consequent legislation/litigation.
- Lower pest pressure = reduced input costs.
- Opportunity to encourage game = income and pleasure.
- Opportunity to improve field access and design traffic management system = simplified operations = timeliness.

Becoming increasingly significant

Implementation
- Have, keep and position them.
- Design as a management tool e.g. buffer zones to reduce water contamination, field access.
- Locate on poorer ground.
- Mix/diversify margins.
- Opportunity to regularise fields.

4. Nutrient balancing

Benefits

- Fertiliser inputs optimised = lower costs.
- Less pollution = less risk of litigation.
- Fertiliser applied efficiently = reduced operational costs and more precise timing = costs minimised.
- Quality, yield and market targets achieved = increased potential to achieve target price and financial budget = consistent profit.
- Input matched to targets = optimisation = risk minimisation = improved sleep, less worry/stress.
- Job security.

Potential benefits highly significant

Implementation

- Understanding crop requirements.
- Soil sampling to establish reserves and leaching risk.
- Rotational aplication of P, K and Mg.
- Maintenance of soil indices at appropriate levels.
- Incorporation of crop residues to minimise offtakes and pollution.
- Equipment calibration.

Implications

1. For the farmer

- Personal satisfaction having achieved the needs of the market, the consumer, the local community and the law, as well as having contributed to the attractiveness of the UK landscape.
- Need for discipline, expertise and knowledge within the business (self and/or others).
- Need to plan, conduct audits (e.g. LEAF) and join Quality Assurance Schemes.
- Need to communicate farm policy, personal philosophy and values to staff and others involved closely on the farm.
- Need to ensure staff are involved, have the required skills and necessary training/certificates of competence.
- Continued personal professional development.

2. For the staff

- Need to agree and support farm policy/philosophy.
- Willingness to acquire knowledge, skills and 'change'.
- Acceptance of need for training and to acquire the necessary certificates of competance.
- Positive approach. Use of initiative in day-to-day operations, e.g. crop inspection/awareness and cultivation needs.

3. For the advisor

- Awareness of farm policy and philosophy.
- Involvement at the 'planning' as well as 'implementation' stage.
- Knowledge and experience of Integrated Farming principles, practices and benefits.

Summary of benefits

- Improved farming/farmer image - public, politicians, consumers.
- Lower costs.
- Reduced risk of yield, quality and profit loss.
- Personal satisfaction and less stressful lifestyle.
- Reduced risk of further legislation/mandatory schemes and litigation.
- Less contamination of the environment.
- A more attractive countryside.

APPENDIX M - Financial and economic impacts - Economics bolt-on study

J Keatinge, J Park, A Bailey, T Rehman, R Tranter and C Yates, University of Reading

EXECUTIVE SUMMARY

Background

This report presents the results and conclusions from the LINK-IFS trial conducted at six geographically different sites across England and Scotland. The trial, lasting five years (1993 to 1997), was designed to contrast and compare the financial, environmental, management and energy use of Conventional and Integrated Farming Systems (CFS and IAFS respectively). Additional information, where appropriate, is included from similar projects, i.e. LA-LIFE, CWS Focus on Farming Practice and the Rhone Poulenc Management Study. In the first instance IAFS are defined and other recent integrated farming experiments are described. Detailed information is provided on the exact rotations used at each site and sources of data are discussed.

The LINK-IFS project was set up in 1992 "*to compare, on a farm scale, conventional and integrated systems in terms of economics, and agronomic and environmental impact*". The research undertaken in this 'bolt-on' MAFF funded project undertaken at The University of Reading had the following specific objectives: to advise on the appropriateness of the data being collected; to investigate the decision-making processes of the site leaders; to evaluate the experiment undertaking environmental and energy analysis as well as more traditional economic and financial analysis; to develop a quantitative financial model to allow trade-offs between financial and environmental impacts to be assessed; and, to suggest areas of further research including a macro-level study.

Data collection

The authors had no role in the drawing up of specifications for the original experiments as they were designed in 1992. However, as with the design of all experiments, trade-offs had to be made in terms of what was achievable in terms of data collection and the time and constraints of funding. As such the size of the project, the geographic dispersion of sites and the large number of variables being recorded meant that there were some problems in the data gathering exercise. This led to several "updates" of data which added to interpretation problems. Several specific problems existed in the initial stages of the project which were eventually resolved by the project management team. Against this background guidelines for improving data collection logistics and suggestions for potential additional data collection are made.

Investigation of decision making

An initial pilot questionnaire was circulated to site leaders and farm managers in the second month of the bolt-on project. A second more comprehensive study was undertaken during 1997, and consisted of interviews with the site leaders, farm managers and representative local farmers for each of the six LINK-IFS sites, as well as the three other main IAFS projects. Finally, site leaders were questioned about their post-experimental thoughts and opinions. The results show that each group of decision makers were technically up-to-date, had a good knowledge of financial matters and were aware of the various challenges facing farming. However, there are indications that the site leaders were more environmentally "concerned" than the site farm managers who, in turn, were more "concerned" than the "control" farmers and managers. As one might expect, the site leaders were clearly enthusiasts for IAFS and very knowledgeable about the concepts behind, and the practical operation of, such systems. Site leaders generally felt that knowledge gained during the rotations made them increasingly confident about the integrated decisions they made. This, combined with the fact that most site leaders believed the level of skill required to manage in an integrated fashion was higher when compared with conventional systems may suggest that conversion to integrated systems is not simply a matter of demonstrating economic viability.

Financial, climatic and technical results

A comparison of conventional and integrated farming systems is made via an examination of data from the integrated arable farming systems projects. This is achieved utilising data mainly from the LINK-IFS project but supported by data from the three other integrated systems projects. Data was collected and analysed on four aspects: Financial (gross margins, equipment use and management time); Environmental (invertebrate numbers, earthworm biomass, nitrogen balances and organic matter levels); Climatic/Technical (rainfall, temperature, management time and technical feasibility); and, Agronomic (crop morphology, weed levels, pest levels, disease levels and soil nutrient status). Analysis and interpretation of agronomic data is confined mainly to the report emanating from the main project and is therefore not included here (the executive summary of the main project report is included as an appendix of this report for reference purposes).

Net margins varied across sites with those sites growing potatoes showing the highest level of output. The overall difference in net margins between the two systems across all sites was less than 2% with the conventional system achieving the highest net margins. Both variable and operating costs showed considerable variation across sites. In general, variable costs were lower for the integrated system, although, operating costs were similar for both systems. A substantial degree of variation in the results can be attributed to crop prices. These results were very similar to those from the three other IAFS projects and showed in terms of gross margins no significant difference between the two systems (although IAFS margins were slightly lower).

Several economic scenarios were also analysed. On sites where potatoes were grown these were removed from the rotation for purposes of analysis. The results showed the very large effect of this crop on the financial performance of the whole rotation. In one case, the IAFS performed better than the CFS, the opposite was true of the other two sites. As part of EU policies to reduce prices to the world market level, a scenario of world prices without AAP was tested. As might be expected, net margins were considerably reduced on both systems (an average of £1200 over the rotation). However, calculations suggest that overall the CFS would still be 4% more profitable than IAFS. With an increase in chemical prices of 50%, three of the sites showed that the IAFS could achieve higher net margins, although net margins were reduced on every site. Finally, an Agenda 2000 (cap reform) scenario (as of March 1998) was tested. The results showed a small detrimental effect on the integrated system. In short, the results suggest that the financial difference between CFS and IAFS under a wide range of scenarios is minimal (within +/- 5% in many cases).

Data has been recorded on monthly temperatures and rainfall over the past 32 years at five of the sites. The results showed that rainfall has been similar, although variable, for the five years of the experiment in comparison with the historical records. There was some evidence to suggest that temperatures have been slightly hotter over the last five years. However, no correlation between financial performance and climatic data could be found for any of the sites.

Workability is a function of climate and soil and is expressed as the number of Available Working Days (AWD's) from 1st September until the soil becomes too wet to work for a given site. At Boxworth, for example, in a normal year, there are 84 AWD's whereas at High Mowthorpe there are 60 and Lower Hope, 50 AWD's. This means that in drier areas, they could take longer over autumn cultivations and consider more use of integrated techniques such as delayed drilling or stale seedbeds, although this would probably reduce yield potential. Additionally, a given season may be exceptionally wet and therefore the AWD's would be considerably curtailed. Clearly, one option would be to drill a proportion of spring crops. However, the fall in potential output may be too great to consider such an option.

Environmental results

Despite sites achieving reductions in nearly all instances with respect to inputs in the IAFS compared to the CFS, the results of the environmental indicators do not reflect these reductions. No clear differences were observed for nitrogen balances, organic matter content, invertebrate numbers and earthworm biomass. In all cases there exists a complex balance affected by many exogenous variables, such as soil type, rainfall, soil disturbance, localised variations in soil type and topography, crop rotation and sequence to name but a few. Therefore, any effects of the two systems will be masked. Although "validation plots" were set up to look at the impacts of agronomic procedures, it is unlikely that such small plots would provide a useful base for exploring environmental impacts. Clearly, research to suggest the type and design of experiments/monitoring that could more effectively measure environmental impact may help to identify robust monitoring protocols for use in future systems experiments.

In terms of energy use, savings of up to 15% were made at some sites. The potential exists for greater savings in energy to be made if cultivation systems could be manipulated to include less ploughing. Cultivation changes within the IAFS experiment were not that radical, mainly because many of the sites had to work with existing equipment. In terms of financial savings to the individual farmer this is fairly insignificant (especially if the tax exemption on red diesel is considered). However, a 10% saving in energy at the national level (given a 100% uptake of IAFS) may be viewed as a large and significant benefit.

Financial and environmental trade-off modelling

To facilitate the analysis of trade-offs between financial returns from farming and its environmental impact, combined environmental economic models are used. These models utilise a framework that allows for conventional agricultural production as well as the production of externalities. These results illustrate the degree to which both conventional and integrated margins are reduced as a result of imputing an economic value for environmental impact.

Environmental and natural resource accounting has the potential to provide a format for exploring the trade-off between financial and environmental impacts, and between the differing environmental impacts themselves. The examples given illustrate the application of the accounting framework to the comparison of different farming systems, achieved through the definition of the costs and benefits of agri-environmental measures, both positive and negative. Although, only a limited number of environmental data have been used in the model, the information provided can be said to loosely cover the three aspects of the environment, as a source of raw materials, as an assimilator of waste, and as a provider of environmental services. The proposed framework is flexible enough to incorporate data regarding other environmental impacts as they become available and, even without complete valuation, presents the data in a format which can aid the understanding of agricultural and environmental trade-offs.

Further research

In this section the report summarises the work on integrated farming systems to date and proposes the framework of a macro-level study. The objectives of this proposed research would be:

- to assess the complex attitude of farmers towards IAFS, according to farm and farmer characteristics (farm size - according to economic size, farm type - according to enterprise mix as defined by the FBS, geographical location, owner/tenant, level of awareness of IAFS, education, age, etc) under different levels of assumed profitability and economic risk;

- to predict the uptake of IAFS in England and Wales by farm type and region using the FBS data to aggregate the results from a farmers' attitude study;

- to examine the potential of different policy and market scenarios on the uptake of IAFS (including pesticide taxes, changes to the subsidy schemes, changing market prices, modulation or proposed policy scenarios such as Agenda 2000); and,

- to provide a tool for effective policy generation for the further promulgation of pro-environment agricultural practices.

Synthesis and summary

The adoption of an IAFS approach can complicate what has become a formalised crop growth procedure, particularly as many farmers are, at present, uncertain about some aspects of IAFS. This general increase in complexity associated with an IAFS approach may mean that some individual farmers and managers will have to rely more on the support of specialists and advisors trained in IAFS to aid their decision making. At present, however, the availability of suitably qualified advisors is limited.

Another important impact of adopting IAFS is associated with the concept of risk and uncertainty. Utilising certain techniques such as later drilling or threshold spraying will expose the enterprise to greater overall risk. This increased risk may be dependent upon the regional location of the farm or the markets into which products are sold.

The overall balance of crops in the rotation is important. For instance, rotations with more wheat and barley have, in the past, produced a high rotational margin. Including spring sown combinable crops may reduce margins but will also provide more opportunity for weed control. Legumes in the rotation may reduce the required inputs, leave residual nitrogen in the soil and provide a break from cereal cropping. Additionally, financial accounts will give little indication of the riskiness of changing an established rotation to include crops with which the individual farmer or manager is not familiar.

It not easy to estimate the value that farmers put on possible environmental benefits that may accrue from the adoption of integrated systems. Despite the environmental accounts presented in this report, the perceived financial return to the farmer from increased numbers of beetles or earthworms is likely to be small in comparison to the changes made, and the constraints imposed on, their farming system. The real tangible benefits occurring from the wider adoption of the IAFS approach may lie at a national level in terms of habitat preservation, reduced nutrient and carbon dioxide emissions and a preservation of biodiversity. However, environmental benefit will be related to the degree to which farmers adopt the whole integrated approach as opposed to *ad hoc* individual techniques. Clearly a distinction needs to be made between farmers adopting a few integrated techniques which fit in well with their existing farming system and those who are more aggressive in adopting a comprehensive integrated approach along the lines of that being demonstrated on some of the experimental farms. Organisations such as LEAF have a key role in demonstrating that individual integrated techniques can be relatively easily adopted on some farms, although, few farms in the UK are currently following the integrated guidelines as laid out in the IOBC/WPRS Bulletin.

Some IAFS techniques are being adopted due to market forces, e.g. the rising cost of fertilisers and pesticides, combined with lower product prices means that farmers are looking more closely at their use. However, allowing the market to drive the adoption of methods using lower inputs accounts for only part of an IAFS approach and may mean that the overall rate of change is likely to be slow. This suggests that if Government is keen to encourage the wider adoption of the IAFS approach, then some financial encouragement for farmers to change may be required as well as a package of extension and education. Such measures could include penalties for non-use of IAFS, direct area payments or some form of cross-compliance (for instance relating the adoption of an integrated farming approach to area aid payments). Alternatively, quality labels (similar to the RSPCA's Freedom Foods) could be introduced to indicate a range of products grown in an environmentally friendly manner. This would fit in with the increasing demands for audit trails or Identified Product Sourcing by retailers, processors and consumer groups.

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