SCARAB: THE ENVIRONMENTAL IMPLICATIONS OF REDUCING PESTICIDE INPUTS

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ABSTRACT

The SCARAB experiment is a major field-scale, long-term investigation of the ecological effects of two different pesticide regimes, Current Farm Practice (CFP) and Reduced Input Approach (RIA) on invertebrates, soil microbial biomass, earthworms, flora, crop pests and diseases. The pesticide regimes are compared on a total of 7 split fields, on three ADAS Research Centres, in six course rotations. Of the 139 pesticide units applied over 4 years, 55 herbicides, 55 fungicides and 29 insecticides were applied to CFP. RIA received only 32 herbicides, 29 fungicides and no insecticides. Adverse effects on some groups of invertebrates occurred following application of some broad-spectrum insecticides. Certain populations took longer than six months to recover. There has been a trend for soil biomass to increase in RIA. It has also been noted that total microbial biomass is closely linked to crop type and that, in general, levels are higher in cereal crops, compared with break crops. No overall treatment effects have yet been recorded on earthworm numbers under the two pesticide regimes, although earthworm populations vary widely between the sites according to soil type and organic matter content. In cereal crops, weed control has tended to be satisfactory when a reduced rate herbicide has been applied. Weed problems have occurred in RIA when lower rates of herbicide have been used in break or non-cereal crops. There have been no major problems from reduced pest and disease control.

INTRODUCTION

The SCARAB experiment, which is funded by MAFF, was specifically designed to pursue the results and hypotheses developed from the Boxworth Project (1981-1988) (Greig-Smith *et al.*,1992). It was considered that the generality of environmental effects seen at Boxworth, and particularly those on invertebrate populations associated with intensive cereals, should be evaluated at other sites and tested in other crops.

The overall objective of SCARAB is to establish the broad ecological consequences of applying two different pesticide regimes to six-course arable crop rotations, which include cereals and break crops (Cooper, 1990). The comparison of systems involving lower pesticide inputs with conventional crop production is designed to identify which particular pesticide regimes are harmful to non-target species. SCARAB is focused on the ecology of key invertebrate species, primarily those of economic importance such as predators and parasites of crop pests.

More specific objectives are to monitor the effects of the two pesticide regimes on the numbers, taxonomic composition and trophic structure of arthropod faunas. Also, the project examines the effects of the two pesticide regimes on floral diversity and distribution, non-target soil micro-organisms, soil microbial biomass and earthworms.

MATERIALS AND METHOD

SCARAB is sited on three ADAS research centres: Drayton in Warwickshire, Gleadthorpe in Nottinghamshire and High Mowthorpe in North Yorkshire. On all three sites, baseline monitoring started in June 1990, with the first differential treatments applied in autumn 1990. Rotations at each site are typical of the locality and are shown in Table 1.

TABLE 1. SCARAB rotations

SITE Drayton	Gleadthorpe	High Mowthorpe
Winter wheat	Potatoes	Winter oilseed rape
Winter wheat	Spring wheat	Winter wheat
Grass ley	Winter barley	Spring barley
Grass ley	Sugar beet	Spring beans
Grass ley	Spring wheat	Winter wheat
Grass ley	Winter barley	Winter barley

Two pesticide regimes are compared at each site. CFP represents the pesticide use by a technically competent, financially-aware farmer in a farming situation comparable to the site. All pesticides are applied at label recommended rates. RIA is intended to contrast with

CFP in its intensity of inputs. RIA consists of minimal use of fungicides and herbicides, which are applied at half-rate or less. No insecticides are used on RIA unless a severe threat of crop loss is evident.

Treatments are applied to conventionally drilled or planted farm crops on a split field basis. Treatment areas range from 4 to 17 ha. Crop monitoring and assessments are done on fixed plot areas marked out in each half of each field. Each pair of plots is located on a common field boundary and extends 150 m into the centre of the crop. Plots are 84 m wide with a 36 m buffer zone between plots.

Summarised data for total pesticide use in CFP and RIA is shown in Table 2. A pesticide unit is defined as one application of a pesticide product at the recommended rate for a particular task, dependent on its target and its intensity, crop timing and environmental conditions.

TABLE 2. Total Pesticide units applied 1990-1994

Pesticide regime	CFP	RIA
Herbicides	55	32.5
Fungicides	55	29
Insecticides	29	-
Total	139	61.5

In the first four years of SCARAB, a total of 139 pesticide units at full label recommended rate were applied to CFP. During this time , RIA received 44 percent of the pesticide units applied to CFP and no insecticides.

Monitoring of crop development, weed distribution, pest and disease levels and assessment of yield were done by ADAS Science staff.

Invertebrates were sampled using pitfall traps and Dietrick suction samplers (D-Vacs). Pitfall traps were left open for seven days in every 14 day period, except between harvest and drilling, or during autumn cultivations (spring-sown crops). The traps were arranged in four transects parallel with the field boundary, one in the boundary and the other three at 10 m, 75 m and 150 m into the field. D-Vac samples were taken on average on 18 occasions each year, every fortnight during April to October. Catches of invertebrates were identified and analysed by researchers at Southampton University.

Soil microbial biomass was sampled at High Mowthorpe and Gleadthorpe only. Soil samples were taken following each pesticide application, and since 1992, before the pesticide application as well. Six samples (about 1 kg weight from 2 to 10 cm depth) were taken in an oblong grid pattern at 10 m intervals in each plot. The following chemical and microbiological parameters were measured by researchers at University of Wales, Bangor (Hancock *et al.*, 1993): pH and soil moisture content; total soil fungal biomass, total soil microbial biomass, organic carbon, soil organic nitrogen, microbial biomass nitrogen; vital fungal biomass; indirect (agar plate) counting of bacteria and fungi and soil mineralisation rates in carbon amended and non-amended soil.

The long-term effects of the two pesticide regimes on earthworm populations were monitored by scientists from the Central Science Laboratory (CSL) twice a year, when earthworm activity is expected to be the highest. Three samples were collected in each treatment area, using a 50 cm x 50 cm quadrat, dropped at random at 10-20 m intervals. Earthworms were hand sorted from soil samples dug down to plough layer and assessed for total numbers, biomass, species composition and age composition (Tarrant *et al.*, 1994).

The occurrence of gross short-term mortality was monitored by searching four 1 m x 100 m transects of the field surface in both the CFP and RIA areas. Samples of worms were collected from the top 50 mm of soil using a corer of diameter 150 mm. At least 15 cores were taken at 2 m intervals to provide a pooled sample of at least 5 g of earthworms which were frozen for residue analysis. The core depth was chosen to be consistent with that used for estimating exposure of earthworms to pesticides in risk assessment (EPPO/CoE, 1993).

Data from all assessments were subjected to analysis of variance where appropriate and significance tests. The design of the experiment in not orthodox on that it lacks true replication of treatments, which is inevitable given the large-scale plots necessary for this type of study (Greig-Smith *et al.*, 1992).

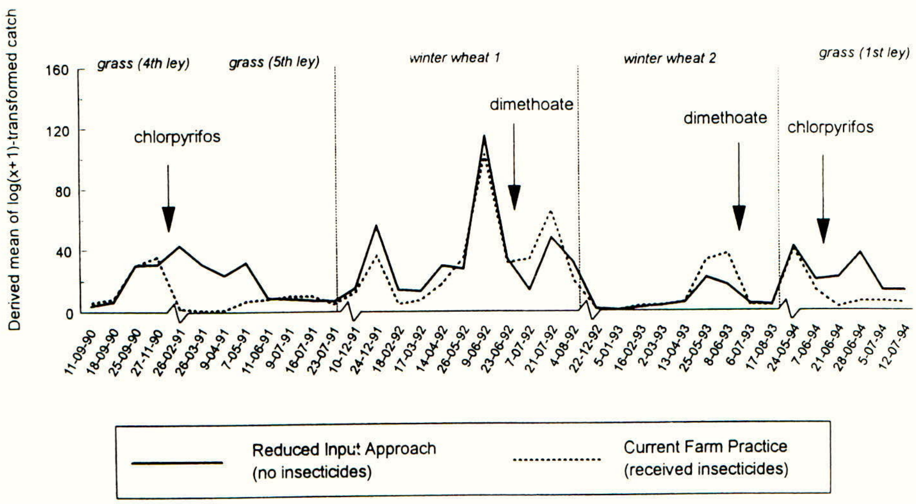
RESULTS

Arthropod monitoring

At the start of the SCARAB project, a baseline assessment was made of the taxonomic richness of arthropods at each site. A total of 258 taxonomic groups of arthropods was recorded in pitfall traps and 111 in D-vac samples. At all sites, pitfall trap samples were dominated by spiders (Araneae) and beetles (Coleoptera). The principle invertebrate families consisted of ground beetles (Carabidae), rove beetles (Staphylinidae), plaster beetles (Lathridiidae), blossom beetles (Nitidulidae) (Coleoptera) and money spiders (Linyphiidae) (Araneae). Invertebrates present in D-vac suction samples consisted mainly of Hemiptera, the lucerne-flea (*Sminthurus viridis*) (Colembola), thrips (Thysanoptera), flies (Diptera) and Coleoptera. The principle families of Coleoptera were Staphylinidae and Lathridiidae whilst the Hemiptera consisted mainly of aphids (Aphididae) and leafhoppers (Cicadellidae).

No irreversible and adverse long-term effects of full-rate pesticide use in CFP have been detected in pitfall trap catches of polyphagous predators (Çilgi & Frampton, 1994). However, winter use of chlorpyrifos did cause major reductions in several groups of Coleoptera which persisted for several months (Figure 1). Examination of the timing of two chlorpyrifos applications at Drayton indicate that they had similar effects on overall catches of Coleoptera (Figure 1), but differed markedly in their effects on individual species of Carabidae and Staphylinidae because different species were present at the time of each spray. Differences between CFP and RIA Collembola catches at Drayton persisted up to harvest 1994 in some taxa.

Figure 1. Pitfall trap catches of Coleoptera (all families grouped together) in SCARAB project Field 5 (Drayton)



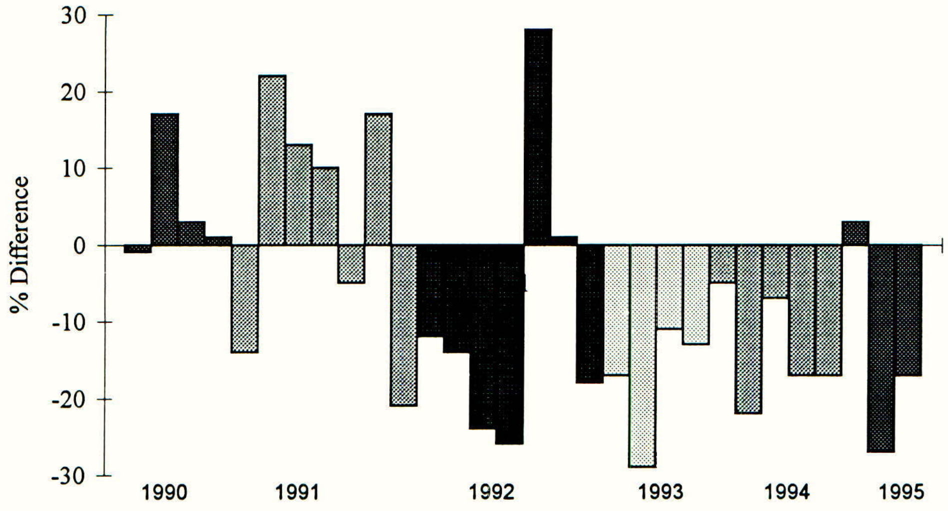
All pesticide effects detected so far have been attributed to insecticide use. No clear effects of fungicide or herbicide were apparent, but observed differences in arthropod populations between CFP and RIA not easily explained by pesticide use, could reflect subtle long-term indirect effects of herbicides and fungicides. Differences between the species composition of Collembola communities at High Mowthorpe in CFP and RIA could plausibly be explained by differences in weed communities which occurred between the CFP and RIA areas of fields because of reduced weed control in RIA.

Soil biomass dynamics

Although it represents a small fraction of soil organic matter (1-3% of soil organic carbon), soil microbial biomass is the major agent of chemical and biochemical transformations within soil ecosystems. Data from the first four years at two sites (High Mowthorpe and Gleadthorpe) have shown that the gross yearly biomass carbon levels appear to be strongly related to crop type and crop rotation. In three cereal crops at High Mowthorpe (winter barley and winter wheat), the pooled biomass data for Old Type field gave a value of 358 μg C g^{-1}. When break crops of spring beans and winter oilseed rape were grown in the same field, the pooled value was lower at 297 μg C g^{-1}. The same trend for lower biomass carbon levels in break crops was repeated at Gleadthorpe, despite the differences in soil type, microbial communities and crop rotation between the two sites. It is probable that the difference is due to increased root biomass in cereal crops. This increases the carbon flux via exudation from rootlets into the microbial soil component, which in turn, stimulates activity and resultant biomass size.

Periodic soil sampling around pesticide application events indicated that soil microbial biomass fluctuates more widely within the CFP management regime, than in RIA. Generally, the CFP regime has led to a reduction in microbial parameters, which has sometimes been statistically significantly different from RIA (data not presented). This trend can be seen in Old Type field North at High Mowthorpe from April 1990 to April 1995 (Figure 2).

Figure 2. % difference of CFP soil microbial biomass compared with RIA
Old Type, High Mowthorpe 1990-95

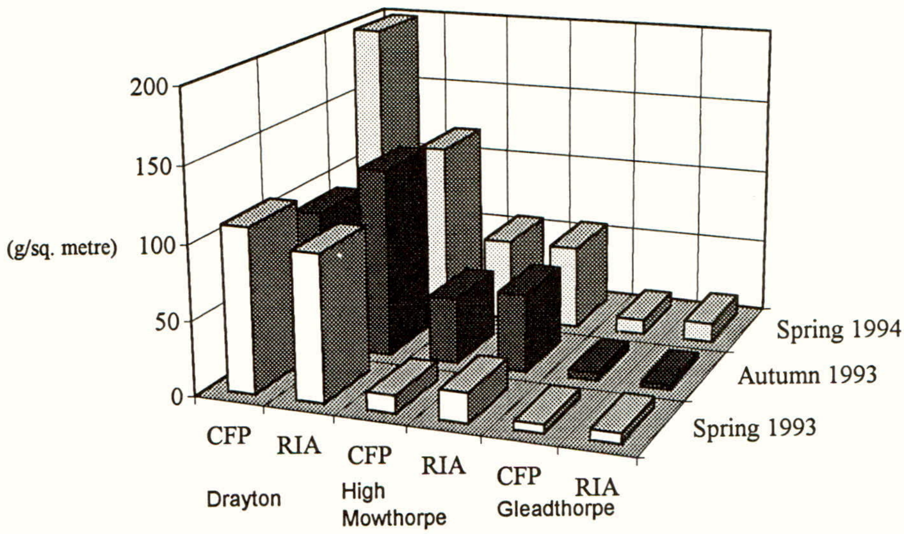


Earthworm populations

Earthworm monitoring did not start until spring 1993. Results since then have shown that there are large and statistically significant difference in earthworm biomass and numbers between the sites (Figure 3). However, there have been no consistent, ecologically significant differences between treatments at any of the sites. This is illustrated by the results at Drayton where biomass has been higher on different treatments in alternate seasons. At High Mowthorpe, although there have been large fluctuations in earthworm numbers and biomass over time, these changes have been similar on both treatment areas. At Gleadthorpe, earthworm numbers have continued to be very low.

Sampling after selected pesticide applications was done to determine any short-term effects on earthworms. No mortality was detected in earthworms, following applications of chlorpyrifos and propiconazole to grass. Residues of these pesticides in the soil were similar to the predicted values currently used in risk assessments. Residues of chlorpyrifos in earthworms were similar to predicted values, but propiconazole levels were higher than expected.

Figure 3. Changes in earthworm biomass at ADAS SCARAB sites 1993-1994



Pest, disease and flora monitoring

Pests

The major pests problems seen in SCARAB have been those normally associated with the range of crops grown at each site, and have followed normal cycles of development within years. Populations of grain aphids in winter wheat and winter barley crops at all three sites remained at low levels during autumn and spring, but rose above the threshold level of 66 % of tillers infested in late June/early July. Populations were well controlled by full-rate insecticides applied to CFP. Levels remained at threshold in RIA for periods of two to three weeks until natural decline through predation occurred . Pest levels in non-cereal break crops, oilseed rape and spring beans at High Mowthorpe and potatoes and sugar beet at Gleadthorpe, were in most cases below treatment thresholds, and did not contribute to significant reductions in yield and quality. High numbers of leatherjackets were found in the fifth year grass at Drayton. Generally, there has been no build up of pests through the rotations in the RIA treatment of any of the sites.

Diseases

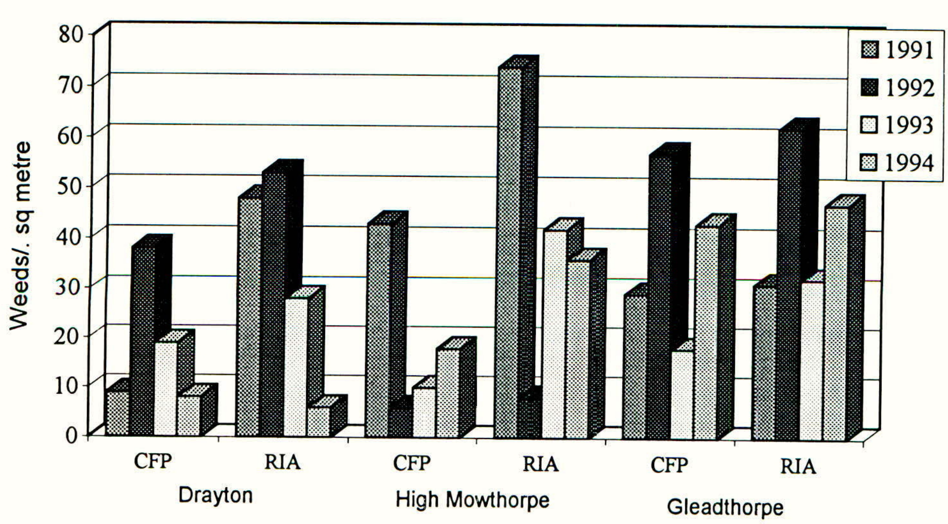
Disease in cereals was common at all sites. *Septoria tritici*, *Septoria nodorum* and powdery mildew all developed to levels requiring treatment in most years. Single or two spray programmes were effective in controlling the diseases present in CFP, and in RIA, when applied at half-rate or less. Fungicides were applied to spring beans at High Mowthorpe in 1991 and at Gleadthorpe in 1993 to control chocolate spot and downy mildew. The half rate treatment in RIA was as effective as full-rate at High Mowthorpe, but much less effective at Gleadthorpe, where disease levels in RIA were almost three times greater than in CFP. Threshold levels of disease were notably absent in oilseed rape, sugar beet and grass. As a result few fungicides were applied to these crops. Because of the high risk of potato blight in potatoes grown at Gleadthorpe in 1991 and 1994, both CFP and RIA received a similar comprehensive fungicide programme.

Weeds

Application of reduced rate herbicide over four years has significantly increased weed numbers and weed seed return in RIA at High Mowthorpe and Gleadthorpe. Poor control of weeds in RIA in the first year of SCARAB at High Mowthorpe led to an increase in weeds/m^2 of 112 percent compared with CFP. This difference in weed numbers persisted in winter wheat in 1992 and in winter barley in 1993, where the high numbers of weed contributed to major problems in harvesting and drying, and affected grain quality. In winter oilseed rape in 1994, weed numbers in RIA were still double those of CFP, following an application of full-rate herbicide to the whole field. At Gleadthorpe, weed control at half-rate in RIA in cereals was better than at High Mowthorpe, as the weed spectrum was broad-leaved weeds, with no problem weeds such as cleavers and blackgrass. The rates of the herbicides used in potatoes at Gleadthorpe are limited by soil type. Reduced rate herbicide in potatoes gave acceptable levels of weed control. Problems were seen in sugar beet with previous crop volunteers of potatoes and oilseed rape, but these were adequately controlled at full and half-rates of the standard industry repeat low-dose programme.

The trend of increasing weed numbers in RIA has not been seen at Drayton. In the two years when both fields were in winter wheat, half-rate herbicide gave effective weed control. Following wheat, both fields were planted with perennial ryegrass and managed as a silage crop, which has proved to be very competitive against established and newly germinating weeds. Data on total numbers of weeds at all sites during the four years of SCARAB are shown in Figure 4.

Figure 4. Changes in total weed numbers 1991 - 1994



DISCUSSION

The first four years of monitoring in SCARAB have shown that the effects of adopting a CFP pesticide regime on the arable ecosystem are not as severe as those found in the intensive regime demonstrated in the Boxworth Project (1981-1988) (Greig-Smith *et al.*, 1992). The most serious adverse effects of insecticide use on polyphagous predators have been caused by the use of chlorpyrifos. In contrast, none of the dimethoate sprays used in SCARAB fields have had comparable lasting effects. The importance of life-cycles and dispersal abilities of arthropods, which determine their vulnerability to pesticide use, was demonstrated in the Boxworth project and has been endorsed by the results so far from SCARAB. They also show that temporal and spatial distribution patterns of species could be as important in determining patterns of exposure and responses to pesticide use. The effects of the two regimes on soil microbial biomass and earthworm populations has not been consistent at any of the sites, but there are indications that, as SCARAB progresses, numbers of both are tending to increase in RIA.

For most crops at most sites, the effect of reduced fungicide use in RIA has not led to significant differences in disease levels between RIA and CFP. Greater differences in disease development and control have been seen in winter wheat than in spring barley, oilseed rape and grass. Insecticides used on CFP have been very effective in controlling the target pests. Levels remained high in RIA areas, which received no insecticide treatment. Some aspects of quality, such as specific weight in cereals, may have been reduced as a result of feeding by high pest levels in RIA.

The efficacy of half-rate herbicide treatments in SCARAB has varied from very effective to inadequate. Weed control was generally poorer in the broad-leaved break crops such as oilseed rape and beans, where broad-leaved weeds predominated, and were often out of the range of the herbicides applied. Weed control in cereal crops was generally better and differences in weed number and diversity between CFP and RIA were small. The residual levels of weeds left after treatment on RIA, and to some degree, CFP, have led to a measurable increase in weed seed return.

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LINK INTEGRATED FARMING SYSTEMS: A CONSIDERED APPROACH TO CROP PROTECTION

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ABSTRACT

Integrated farming requires a more considered approach to crop production and protection, and seeks to integrate cropping sequences, husbandry techniques, and disease resistant cultivars with more managed and efficient agrochemical use and natural biological control. The LINK Integrated Farming Systems project aims to develop practical and economically viable, integrated arable systems, which are environmentally more acceptable than conventional production systems. The first two years of the five year project on six sites in the UK have shown that generally inputs can be reduced and profitability maintained, but husbandry practices used to minimise leaching of nutrients and to replace agrochemical inputs may increase management time and result in higher operating costs. However, it will require three to five years of the study to be completed before a full evaluation of the economic and environmental effects can be made.

INTRODUCTION

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 have had to be addressed. However, in the last decade, there has been increased pressure on farmers to reduce costs per unit of output to maintain profitability. There has also been strong pressure from the EU, the national government and consumers for farmers to become more concerned over environmental protection and food quality. Many farmers have already moved 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. 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 leaching risk, pest, disease and weed problems.

Much previous and current agricultural research has been oriented towards single factors or problems, and short term studies. Alternative research methods are being 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 is being researched and encouraged in the UK and several other European countries (Vereijken & Royle, 1989; Jordan *et al.*, 1990; El Titi, 1992).

A large research project on integrated farming, 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). The project was set up on six sites to develop arable integrated farming systems which concentrate on practical feasibility and economic viability, but also take into account level of inputs and environmental impact. The integrated system is compared with local conventional practice at each site. This work is 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, The Game Conservancy Trust and Southampton University are collaborating in this project. Some of the results from the first two years of the project are presented in this paper.

METHODS

Sites and rotations

The project is being done at six sites with a wide range of soil types and geographical situations in the main arable areas of the UK. Four of the sites are on commercial farms, on the Manydown (MD) Estate near Basingstoke in Hampshire, on the Scott Abbott Arable Crop Station at Sacrewell (SW) in Cambridgeshire, on the Lower Hope (LH) Farms Estate near Hereford and on the Rosemains and Turniedykes farms at Pathhead (PH) in Midlothian. The other two are on ADAS Research Centres, at Boxworth (BW) in Cambridgeshire and High Mowthorpe (HM) in North Yorkshire. The integrated system is compared with a reference conventional system at each site on split or quartered fields, in five course rotations with all phases of the rotation present in each year (Table 1). Appropriate rotations were chosen for each site based on local practice. At least two fields are replicated at each site. Field-scale plots were chosen so that field operations could be carried out on a large enough scale to be commercially relevant and to minimise interference between treatments. Approximately 55 ha are devoted to this project at each site. Crop performance, environmental and economic impact assessments are recorded at each site.

TABLE 1. Crop rotations

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

System definitions

The integrated system is defined as a husbandry system which maximises profitability with a different balance of inputs to that used conventionally, and aims to achieve environmental benefits; whereas conventional practice is defined as crop husbandry which maximises profitability using external inputs applied within permitted limits to overcome constraints on production. Management controls have been built in so that treatment decisions are based on clear guidance to ensure a common approach wherever possible, and also to ensure a clear distinction between systems. However, the integrated approach does vary from site to site as a result of different soil and climatic conditions, different pest, disease and weed pressures and different environmental problems.

Integrated farming techniques

Crop protection

One of the main strategies in integrated farming is to increase the diversity of crop species in a rotation to prevent disease and pest carry-over from crop to crop. The aim is to have at least four different crops in a rotation and this has been achieved on five of the six LINK IFS sites. Disease resistant cultivars are used wherever possible, but yield and quality are also important considerations if crops are to remain financially viable. Alternative husbandry techniques such as mechanical weeding are used in conjunction with chemical control, and opportunities are taken in the integrated system to allow predators and parasites of pests to build up in sufficient numbers to help control crop pests. Time of establishment may be delayed to limit weed, pest and disease problems in the autumn. However, late establishment increases the risks of nutrients leaching from the soil profile between crops, so timing is chosen to address the most pressing environmental concern at an individual site. Pesticide use is optimised by basing decisions on thresholds, in-crop monitoring systems, crop mapping and patch treatments, trapping techniques and appropriate rates. The most specific pesticide is chosen where possible to minimise off-target effects so that species diversity is maintained.

Soil and nutrient management

Soil and nutrient management are key factors in an integrated farming system. Cultivations are planned on a rotational basis to minimise soil disturbance, retain soil structure and fertility, help minimise soil erosion, maximise crop performance and energy savings and encourage beneficial invertebrates such as earthworms and predatory beetles and spiders. However, it is recognised that cultivations are very soil specific and some soils do not respond well to repeated non-ploughing techniques, which can result in soil structure problems and increases in grass weeds. In addition, choice of crop can influence the degree of soil cultivation required, especially for crops like potatoes which require a deep tilth.

Nitrogen inputs are 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. Applications of other basal elements, such as phosphorus, potassium and magnesium, are calculated on a similar basis to nitrogen but dressings are usually applied on a rotational basis with the aim of maintaining soil fertility at an appropriate level rather than depleting soil reserves. Where practical, crop residues are returned to the soil to minimise loss of nutrients from the integrated system. Cover crops are used before all spring crops in the integrated system where weather conditions permit their establishment, and a green cover is maintained during the critical periods for leaching in the set-aside period, to retain soil nutrients in the top layer of the soil profile, to prevent soil erosion and the development of problem weeds.

RESULTS

The 1993 cropping year was the first treatment year following a baseline assessment year in 1992. The challenging weather conditions of this first year put the two farming systems to a rigorous test. A wet harvest in autumn 1992 resulted in delayed crop establishment, especially after potatoes, poor soil conditions, problems with slugs and difficulties in establishing effective autumn cover crops. Most crops eventually established quite well and gave acceptable yields. The wet summer and harvest of 1993 also caused numerous problems, notably very high blight risk conditions all season for the three potato crops and loss of quality in some milling wheat crops. The 1994 growing season was generally more favourable and most crops performed well. Individual problems with particular crops at some sites were apparant but these were not linked between sites.

Nitrogen use meaned across all crops in the rotation at each site is given in Figure 1. Overall, 15 and 16 percent less nitrogen was applied in the integrated system in 1993 and 1994 respectively compared with the conventional system. This was mainly a result of different nitrogen requirements for the crops on the two systems and differences in the residual levels of nitrogen in the soil.

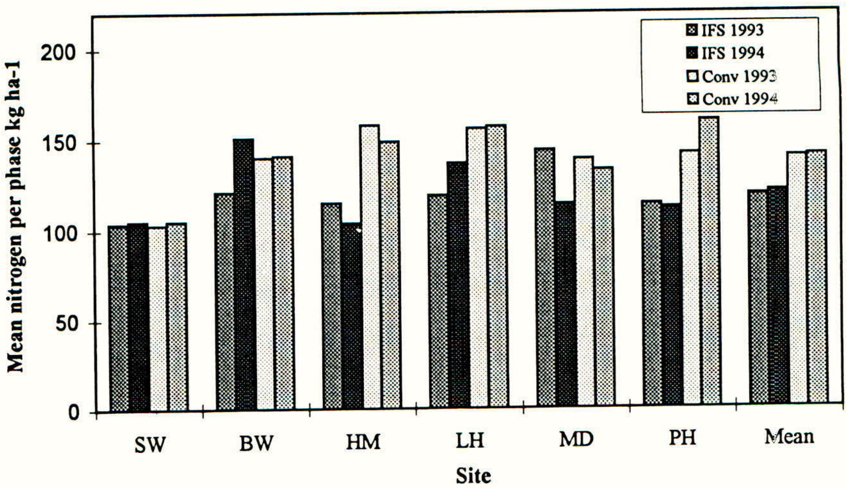

Fig. 1 - Mean nitrogen applied per phase kg ha -1

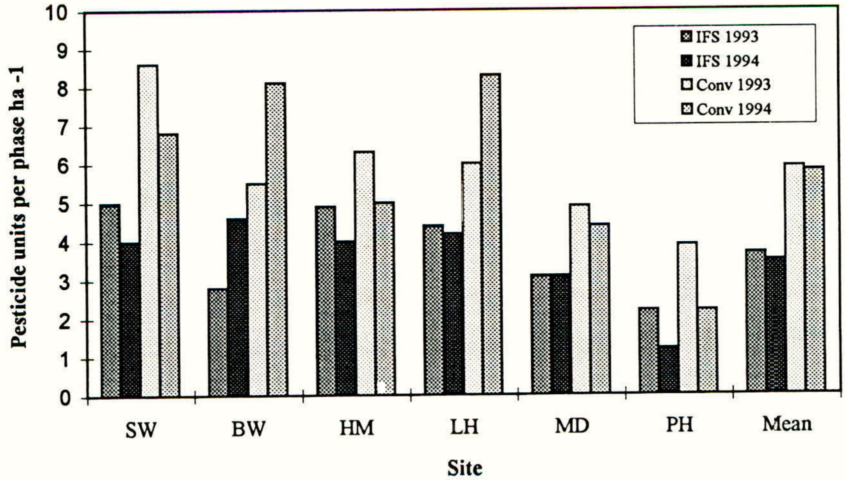

Fig. 2 - Mean pesticide units per phase ha-1

Pesticide use has been meaned on a similar basis to nitrogen. A pesticide unit in this situation is defined as one application of an active ingredient at the recommended rate for a particular task, dependent on the target and its intensity, crop, timing and environmental conditions. Overall, 37 and 39 percent fewer pesticide units were applied in the integrated system in 1993 and 1994 respectively (Figure 2). The lower inputs were achieved by growing a slightly different range of crops in the integrated system, including some spring-sown crops, altering cultivar choice for more disease-resistant cultivars, adopting delayed drilling in some cases to reduce the need for blackgrass control and autumn insecticide use, mechanical weeding especially in potatoes and some cereal crops, and using a more cautious, "wait and see" approach to treatment thresholds. There were fewer opportunities to replace pesticides with alternative techniques in the very high value, high risk, potato and vining pea crops in both cropping seasons. The more considered approach to crop protection in integrated systems does involve increased management time. This will be assessed as part of this project and will contribute to the full economic evaluation of integrated farming.

Over all the rotations, crop yields were not substantially affected by changing to an integrated system of production, when meaned over all sites in the first two treatment years (Figure 3). Wheat yields were generally lower on the integrated system compared with the conventional system because lower-yielding but higher-quality cultivars were chosen.

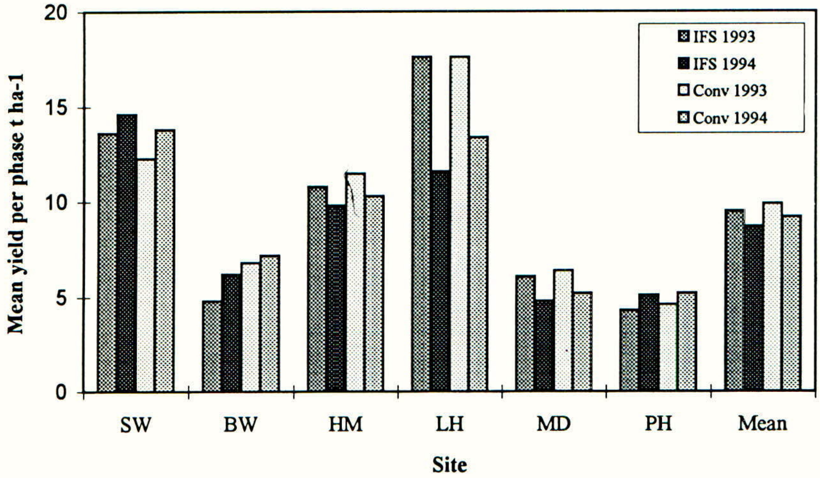

Fig. 3 - Mean yield per phase t ha -1

Financial returns for the two systems were meaned over each rotation for each site (Figure 4). Figures include the Arable Area Payments for eligible crops. It is recognised that the percentage of rotational set-aside to eligible crops is too high in these five-course rotations because of the design of the experiment. However, this will be taken into account when a full economic appraisal is undertaken at the end of the project. Gross output was generally lower on the integrated system, compared with the conventional system, but overall, the differences between the two systems were small. The three sites which grow potatoes, Sacrewell, High Mowthorpe and Lower Hope, had the highest mean gross outputs but also the highest costs. Variable costs were generally lower on the integrated system which reflected the reduced nitrogen and pesticide use. Overall, the two systems gave very similar gross margins, although there were individual site differences (Figure 4). In 1993, the integrated system was more profitable than conventional practice at Sacrewell, Lower Hope and Manydown and in 1994 was more profitable at Sacrewell, Boxworth and Pathhead. However, it will be three to five years before it is possible to make a reliable comparison of the profitability of the two systems.

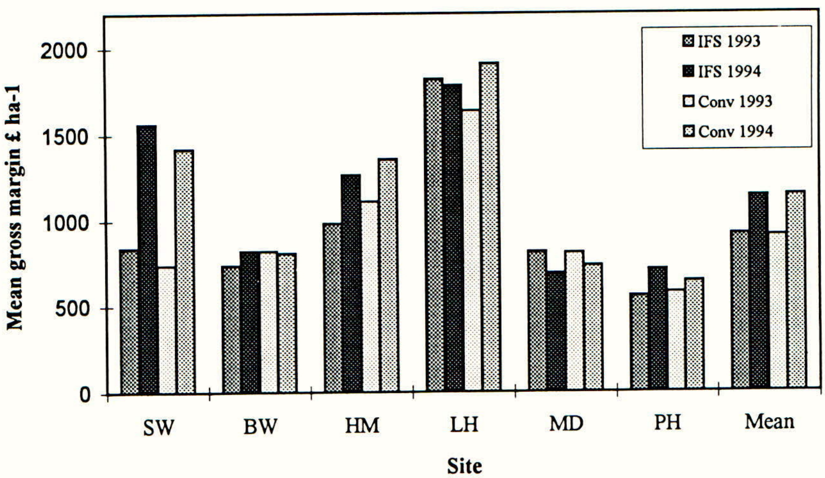

Fig. 4 - Mean gross margin per phase £ ha -1

Operating costs for all field operations and crop drying and handling were estimated to provide a measure of the efficiency of the integrated system when compared with conventional practice, but the data are not presented here. The initial estimate of operating costs reflected the higher costs on the potato sites and also the slightly higher overall costs of operating the integrated system. The implications of adopting an integrated system on labour and machinery requirements and work patterns are being investigated as part of this study and will be reported at the end of the project.

DISCUSSION

Research in Europe has shown that the more managed integrated approach to crop production, which combines natural regulatory components and husbandry practices into farming activities, with the aim of replacing purchased off-farm inputs, is feasible on a large scale and is a logical development for current agricultural practice (El Titi, 1992; Jordan & Hutcheon, 1994). Many successful integrated farming pilot schemes have put research into practice in Europe (Wijnands, 1992; Jordan *et al.*, 1993). The main objectives of an integrated system of production are to address environmental concerns, to ensure inputs are managed efficiently and effectively, and to maintain or increase quality of produce and profitability. If successful, an integrated system will meet the most pressing concerns of industry, consumers and governments alike. The LINK IFS project seeks to develop the integrated system across a wide range of crops, soil types and locations in the UK, covering many environmental and cropping issues. Initial results from the first two years are encouraging, and the successful components will be built into future practice as the system continues to evolve. However, it is already apparent that there are many conflicts to be addressed in the development of an integrated system; for example techniques adopted to solve one environmental problem may exacerbate other problems. Further work is planned within the project to investigate in more depth the economic and environmental implications of altering farming practice, to ensure that practical, relevant and viable systems are available for the industry.

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