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).

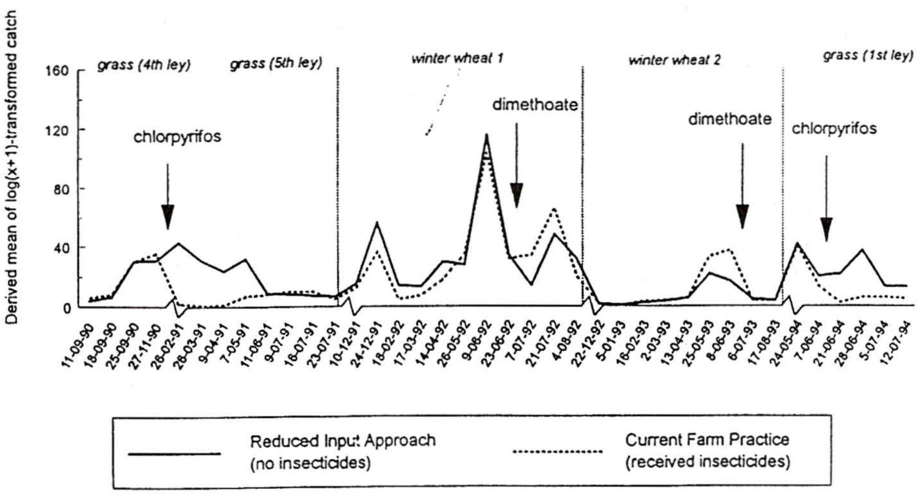
RESULTS

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)



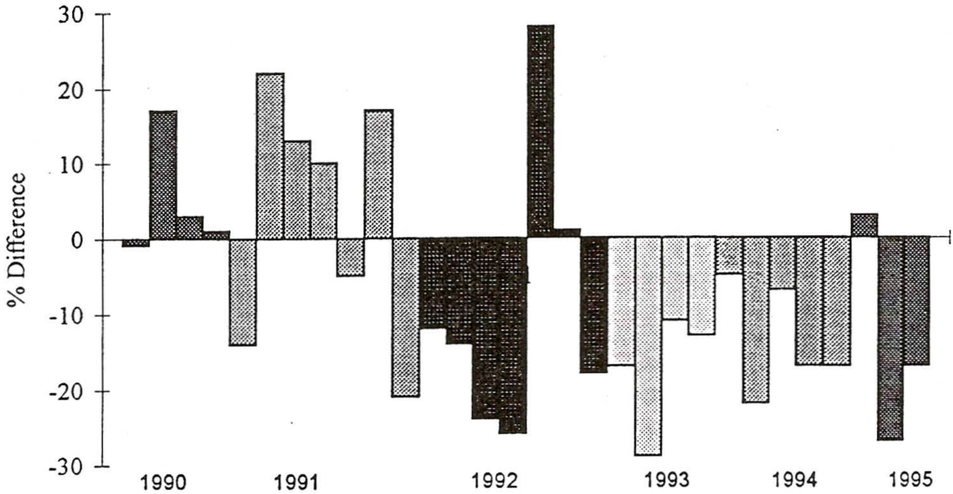
All pesticide effects detected so far have been attributed to insecticide use. No clear effects of fungicide or herbicide were apparent, but observed differences in arthropod populations between CFP and RIA not easily explained by pesticide use, could reflect subtle long-term indirect effects of herbicides 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 $\mu g\ C\ g^{-1}$. When break crops of spring beans and winter oilseed rape were grown in the same field, the pooled value was lower at 297 $\mu g\ C\ g^{-1}$. 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

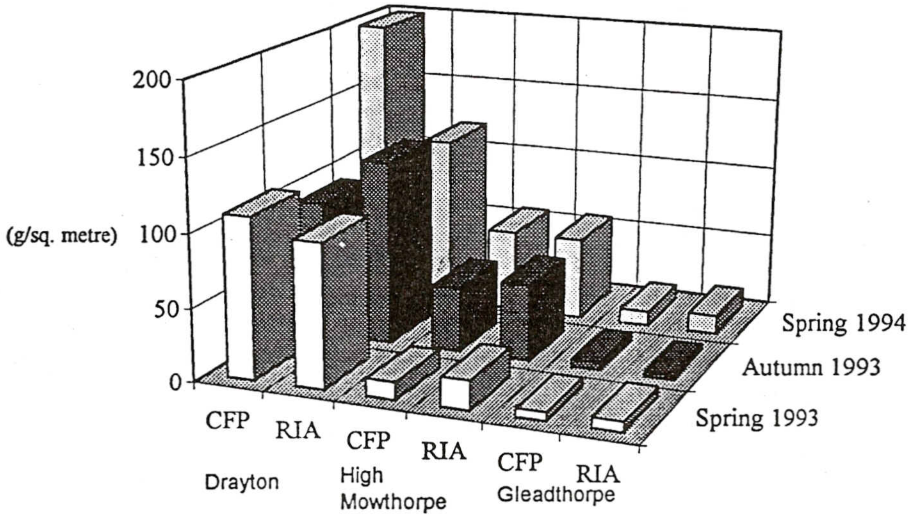


Earthworm populations

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

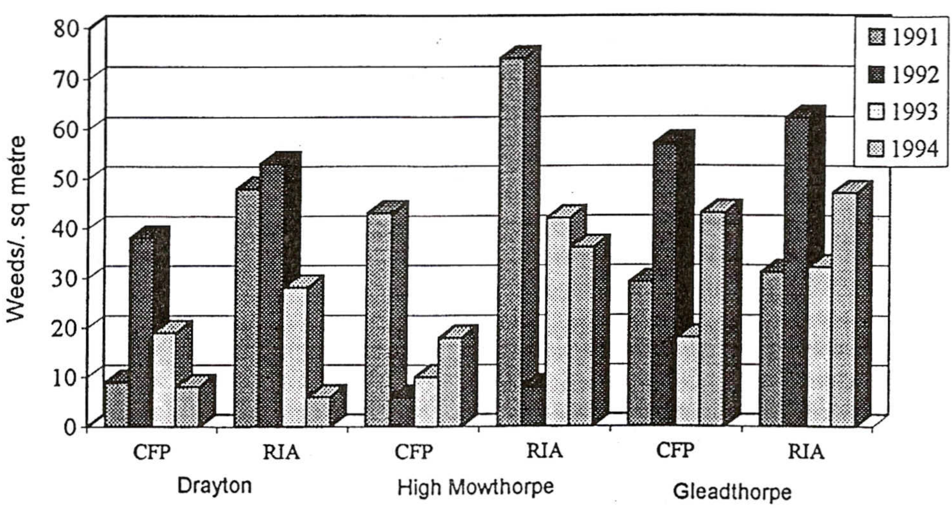
Disease in cereals was common at all sites. *Septoria tritici*, *Septoria nodorum* and powdery mildew all developed to levels requiring treatment in most years. Single or two spray programmes were effective in controlling the diseases present in CFP, and in RIA, when applied at half-rate or less. Fungicides 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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REFERENCES

Çilgi, T & Frampton, G.K. (1994). Arthropod populations under current and reduced-input pesticide regimes: Results from the first four treatment years of the MAFF SCARAB project. *Brighton Crop Protection Conference - Pests and Diseases*, **6B-4**, 653-60.

Cooper, D.A. (1990). Development of an experimental programme to pursue the results of the Boxworth Project. *Brighton Crop Protection Conference-Pests and Diseases*, **1**, 153-62.

EPPO/CoE (1993) Decision-making scheme for the environmental risk assessment of plant protection products. Chapter 8. Earthworms. *EPPO Bulletin* **23**, 131-149.

Greig-Smith, P.W.; Frampton, G.K.; Hardy, A.R. (Eds) (1992). *Pesticides, cereal farming and the environment,* HMSO, London.

Hancock, M., Frampton, G.K., Çilgi, T., Jones, S.E and Johnson, D. B. (1993). Ecological Aspects of SCARAB and TALISMAN Studies. *Ecology and Integrated Farming Systems - Proceedings of the 13th Long Ashton International Symposium* **17**, 289-306.

Tarrant., S.A. Field., A. Jones., C. McCoy. (1994). Effects on earthworm populations of reducing pesticide use: Part of the Scarab Project. *Brighton Crop Protection Conference - Pests and Diseases*, **9C-2**, 1289-1294.