SESSION 3A

PESTICIDE EFFICACY AS INFLUENCED BY FORMULATION AND ADJUVANTS

Chairman & Session Organiser	Dr P J Holloway *IACR-Long Ashton, Bristol, UK*
Papers	3A-1 to 3A-4

Maintaining uptake efficiency in product formulations of contact insecticides

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ABSTRACT

Bioassays used in the primary phases of insecticide discovery are intended to favour candidate compounds. The favourable weighting extends to their diluent and the published literature on insecticide penetration identifies that the simple solvent systems used at the screening stage are highly effective carriers and that potential antagonism from formulation is unlikely. Unfortunately, for many insecticides, it is all downhill from here and, on the path to product, researchers face a struggle to maintain the promising activity seen in the original assays. Whilst all can agree on the aims of keeping biological activity high, it is a difficult task for the formulation chemist. Faced with having to reconcile the demands of physicochemical properties, operator safety, costs, marketing desires, registration time-lines and environmental impact, considerations of biological performance often only reappear in the frame, when candidate products do not perform as well as expected in research farm trials. This issue has not diminished as the skills of the crop protection industry have increased. Indeed, recent improvements in empirical screening keep the emphasis on high throughputs of simple formulations. This paper reviews the factors affecting one aspect of biological performance, contact activity of insecticide formulations.

INTRODUCTION

One of the striking trends in the agrochemical industry over the last 20 years, has been a considerable increase in the laboratory potency observed for new insecticides. However, this trend has not been accurately reflected in the comparative reduction of field application rates for formulated products. Hartley & Graham-Bryce (1980) originally observed this incongruity, citing a comparison in the potency of DDT with deltamethrin. Averaged over four insect species tested in the laboratory, they calculated that the relative amount of DDT required for the same observed effect as deltamethrin was 1600 to 1. Nevertheless, in field use, the relative difference between the a.i. dose rates was only 50 to 1. Endeavouring to reconcile such disparity highlighted the extremely low utilisation of insecticides at the site of action, often < 0.1%, after placement in the target environment. Graham-Bryce (1984) also suggested that the processes which attenuate the applied dose have proportionately greater effects as rates of application are reduced.

Weaknesses in the dose-transfer efficiency of crop protection applications are not difficult to find; for example, Hall *et al.* (1993) highlight them in detail. Efficiency gains that might result in significant dose reductions of a.i. in an insect control programme may arise from three areas of research: understanding the biology of the pest and its natural control agents to optimise spray-timing, developing application techniques to maximise the amount of formulation contaminating the habitat of the pest, and addressing the factors which affect penetration of formulated compounds through the cuticles of insects and mites. The first two must not be ignored, because the behaviour of insects ensures that they are discrete targets in space and time; in this paper, only the third area is addressed. Information on the processes of insecticide interactions can be usefully brought together in a simulation (Day & Collins, 1992).

The possibilities for success are tantalising. Following the application of formulated pesticides, there is a complex interaction between the physical and chemical properties of the components of the formulation and the surface of the target. Consequently, Graham-Bryce (1979) considered that formulation offers considerable scope for manipulating the availability and efficacy of pesticides to harmful and beneficial organisms. It is a difficult subject for an industry worker to address because of constraints of confidentiality. Thus, in order to maximise use of published literature, this paper concentrates on the uptake of insecticides at the time of application and during droplet drying. Accordingly, it comes with a *caveat et emptor*, because this is just one aspect of the interaction of insects with insecticide formulations. With residual treatments, consideration should also be given to the nature of the target surface which plays a key role in treatment efficacy. Dose-transfer from plant surfaces has been reviewed by Ford & Salt (1987), whilst Chadwick (1985) has reviewed formulation interactions with surfaces in public hygiene.

PENETRATION OF INSECT CUTICLES

Given the complexity of insect cuticles, exhibiting hydrophobic layers overlaying non-living and living hydrophilic regions, it might be reasonable to expect it to be a formidable barrier to topically-applied insecticides. In reality, the data on commercially successful compounds applied in organic solvents, tends to suggest that it is an easily overcome barrier. Comparisons of ratios between dermal and intravenous LD_{50} values of many insecticides for insects and mammals by Hassal (1982), show that dose effects in insects are rarely reduced by the cuticle barrier. The usually small differences between toxicity of topical and injected insecticides has been interpreted (Soderlund, 1980) as evidence that penetration is not an important rate-limiting step in the intoxication process. In practice, this seems to hold true, because reduced insecticide uptake, for example, in housefly strains with the resistance gene *pen*, has little effect on toxicity, unless another resistance mechanism is present. If that was the whole story, the author would quit here. However, in the majority of original studies, the insecticide was formulated in an organic solvent which bypasses the lipophilic and water-repellent epicuticle (Lewis, 1980). It is illuminating that phosphoric acid applied in acetone penetrates quickly into *Periplaneta americana*, while phosphoric acid dissolved in water is not absorbed until all of the water has evaporated (Olsen & O'Brien, 1963). Because most product formulations are applied diluted in water, the insect cuticle is a valid barrier to address. Validity of challenge is not the real motivation though. The worth of bioavailability studies on formulations is simply that once a market is earned for a product, its price is set for the rate required on the label. If a third party adjuvant allows a lower rate of product per ha, the percent reduction in application costs for the a.i. is negatively correlated to profit for the a.i. manufacturer.

TARGETING EFFORT

The lipophilic compounds which perform well as contact insecticides easily access the first barrier, which is a lipid layer with epicuticular lipid filaments offering a hydrophobic pathway to the epidermal cells *via* pore canals. At the base of the cuticle, they are relatively less effective at partitioning into aqueous media, such as the haemolymph, which can effectively transport compounds around the insect body. Logically, if more polar insecticides could be formulated to penetrate into insect cuticle effectively, they would move away rapidly from the epidermal cells. Of course, physicochemical characteristics also have ramifications for absorption into insect tissues and this favours very lipophilic compounds. For example, for aliphatic alcohols, penetration from bathing solutions into cockroach nerve cords was negatively correlated with polarity (Eldefrawi & O'Brien 1967). Nevetheless, compounds with log $K_{ow} > 3$ did not display greater penetration, which is interesting, considering that many commercial contact insecticides have log K_{ow} values > 4.

Just as some a.i.s may be looked at more profitably, some formulation types will also be more amenable. There are many reasons why optimised one-pack formulations may not be possible and it is clear that tank mixes with adjuvants are the least restrictive solution. The exception is in ULV applications, where oil blends can be optimised if phase behaviour in the deposit is identified as exerting an effect on dose-transfer. The thermodynamic stability of microemulsions makes it possible to formulate the a.i. in the most suitable phase for the application role.

Once worth is seen in bioavailability studies on formulations for an insecticide, the first aim should be to understand its pharmacokinetics and identify scope for enhancement or antagonism. When commercial progress is likely, potential products may be modified at a regional level by specific-use formulations or use of tank-mix adjuvants.

GATHERING BASELINE DATA

Information on the pharmacokinetic profiles for compounds applied in a commercially relevant formulation are rare in the literature. However, useful information can be gleaned from studies of solvent-applied compounds and used to identify potential areas of interest and to design experiments. They are also reference points for the extrapolation of data to pharmacokinetic processes in other insect control situations. This is important because variation can be expected, for example, amongst pyrethroids, where species and strain-dependent differences affect cuticular penetration (Ruigt, 1985).

There are excellent reviews of the appropriate methodology (Lewis, 1980; Welling & Paterson, 1985), including interpretation of efficiency in absorption and partition processes. *In vivo* systems will be preferable to many workers, because insect activity influences contamination, for example, in relation to the movement of surface films across the cuticle. The alternative approach is *in vitro* techniques, such as isolated cuticle systems, that have the advantage of a potentially high degree of standardisation. Probably the best simulation of *in vivo* uptake occurs when retaining the epidermis of the integument. The outer plasma membrane of the epidermal cells controls movement of chemicals into the cuticle and the basement membrane limits transport between the haemolymph and epidermal cells (Richards, 1978); metabolism in these cells may also effect absorption rates of insecticides (Lewis, 1980).

The cuticular penetration of insecticides can be described mathematically (Lewis, 1980), as can measurements of internal distribution between tissues. By combining mathematical descriptions of experimentally derived pharmacokinetic data, a model of the processes can be created. This has been undertaken for insecticides of all the neuroactive chemical classes; Welling & Paterson (1985) have reviewed these models in detail. Why bother? Because mathematical models are representations of current understanding, they serve as a means of communication between workers of different disciplines. A useful consequence of designing models is that the areas where knowledge is inadequate become clear.

In a multidisciplined approach, potential exists for rational design of formulation vehicles. By modelling the effects of faster or slower uptake and greater or lesser quantities of toxicant absorbed, the scope for significant alteration of toxicant entering the target tissue will be known. However, increasing the rate of uptake will not always result in greater efficacy. In the case of cypermethrin in susceptible strains of insects, the active isomers are relatively stable to metabolism (Holden, 1979) and excretion rates are low, leading to accumulation of the toxicant, even at slow rates of penetration. This does not rule out the potential for antagonism by formulation, because poor presentation of the a.i. in a product can decrease biological effect. So much for the theory, notwithstanding that the needs of commercial research shield so much information; the next section reviews knowledge of formulation effects on contact insecticides.

EFFECTS OF FORMULATION

Solvents

Three processes characteristic of the formulating solvent influence penetration (Lewis, 1980): surface migration, interaction with epicuticular lipids and its concentration. Products containing organic solvents are unlikely to be in the year 2000 list of aims for formulation chemists; nevertheless, they work well but the properties of the carrier solvent can strongly affect the rate of penetration. DDT penetrates most rapidly into tsetse flies when its solvent is of low viscosity (< 1.14 mN/m^2, 25°C) and has a moderate (130 - 270°C, 760mm Hg) boiling point range (Hadaway *et al.*, 1976). Solvents of higher viscosity spread more slowly, contaminating a smaller area of the cuticle. Internal DDT recovery was lowest at each time point for carriers with low volatility (boiling point 300°C, 760mm Hg) and this correlated with low toxicity after 24h. Undoubtedly, oils of low volatility will reduce loss of volatile compounds but there is a balance to find with reductions in cuticular penetration.

Water-based formulations

Early work with aqueous-based applications (Treherne, 1957) found that penetration of insecticides was probably inversely related to polarity . This suggests that the hydrophobic wax layers of the epicuticle are the significant barrier. Supporting this conclusion, is the finding that for dimethoate, DDT, dieldrin, paraoxon, phosphoric acid and dipotassium hydrogen phosphate, speed of penetration was inversely related to polarity of the application solvent (Olsen &

O'Brien, 1963). In a later review of penetration studies, Welling & Paterson (1985) concluded that for a polar solvent, partitioning of insecticide into the epicuticular lipids can be the limiting process. However, a microemulsion formulation of cypermethrin (Lankford & Dawson, 1993) overcomes the incompatibility of water with the lipophilic epicuticle (Figure 1), which Olsen & O'Brien (1963) found to exert a rate-limiting effect on uptake of compounds into *P. americana*. This effect was more than simply increased surface contact with the target. Disruption of surface lipids has been found by Friberg (1990) for some microemulsions on human skin, with associated irritation caused by facilitated transdermal transport. The mechanism for this is believed to be that the microemulsions are in equilibrium with a liquid crystal, leading to solvation of the liquid crystal of the stratum corneum lipids into the liquid microemulsion, thus causing functional disruption. In insects, this may expose the more hydrophilic regions of the cuticle to aqueous formulations; rinsing studies suggest that the rapid movement of cypermethrin away from the surface is principally *via* the intact (o/w) microemulsion. Because there will be reduced diffusion of compounds solubilised in the disperse phase of the microemulsion (Lindman & Stilbs, 1987), it was proposed that penetration of the isotropic system explains the increased uptake of cypermethrin, in comparison with a solvent-borne application.

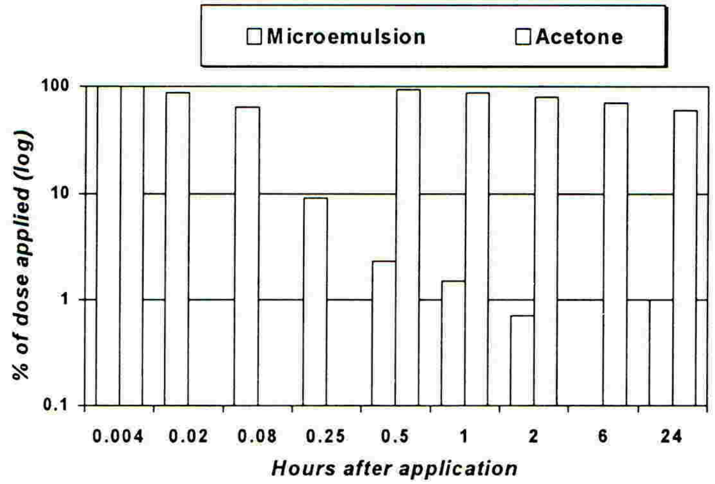

Figure 1. Surface recovery of cypermethrin from *Periplaneta americana* when applied in acetone or as a microemulsion.

Effect of adjuvants

Quantitative experiments analysing the effects of adjuvants on uptake are rare but one study of diflubenzuron (DFB) applied to *Spodoptera littoralis* (El Saidy *et al.*, 1990) indicates the potential in this area. All four of the commercial adjuvants tested at 0.3% increased absorption of topically-applied DFB significantly. In the two adjuvant combinations of paraffinic oil and surfactant, the foliar LC_{50} was halved. Although there was no relationship between effects on topical absorption and residual toxicity, alkoxylated alcohols and volatile silicones doubled uptake but increased the LC_{50}.

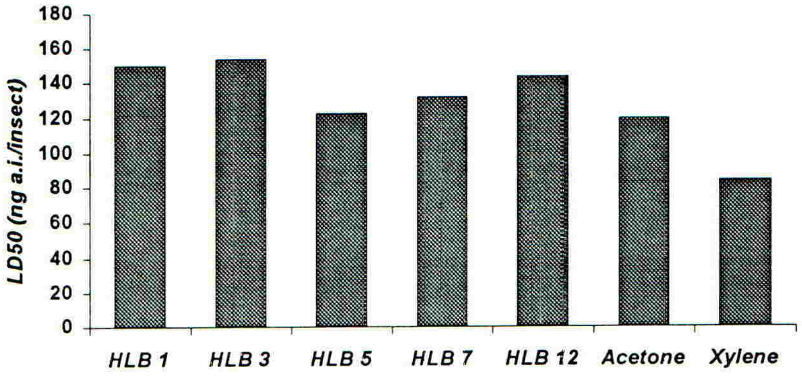

Figure 2. Effect of surfactant HLB and solvents on the contact performance of cypermethrin against *Blatella germanica*

Bioassays are the usual means of investigating surfactant effects. Some of the factors which may be important are concentration and composition of the surfactant, which includes the properties of Hydrophilic-Lipophilic Balance (HLB), solubility parameters, molar volume and electronic charge, as well as their effects on surface tension and contact angle. For contact action performance of cypermethrin microemulsions, these factors have been evaluated (Figure 2).

CONCLUSIONS

Remember that in the optimisation of contact insecticide formulations, increases in initial uptake might not manifest themselves into greater toxicity, if the toxicant is not rapidly distributed away from the cuticle and/or is highly resistant to metabolism. Whether formulating for one-pack products or addition of adjuvants, the rules of thumb for good contact activity of insecticide formulations are the same:

Avoid
- High concentrations of surfactants
- Surfactants with high molar volumes
- Surfactant blends with predominantly very low or very high HLB values
- Excess organic solvent

Endeavour to use
- A blend of surfactants
- An organic solvent which enhances uptake

In the application mixture, look for

- Good target retention
- Moderate rates of evaporation
- Low viscosity

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New formulation approaches to fluquinconazole for enhanced curativity and increased disease spectrum

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ABSTRACT

Conventional formulation approaches to fluquinconazole have produced several aqueous-based coformulations, which provide a high standard of long lasting protectant activity in cereal crops at recommended application timing. In common with the strobilurins, curative activity of such formulations is weak against cereal rusts and powdery mildews. In the case of fluquinconazole this is attributable to the high melting point characteristics of the molecule, which do not favour rapid penetration into upper leaf layers. Fluquinconazole is highly fungicidal *in vitro* compared with other DMIs, and it was therefore a challenge to transfer this known activity into technically advanced new generation products. A design programme was therefore undertaken to maximise the curative activity of fluquinconazole in a commercial formulation against key cereal pathogens, by modifying the penetration characteristics of the molecule.

INTRODUCTION

Physicochemical properties of fluquinconazole: a challenge to formulation design

The physicochemical properties of fluquinconazole (Fq) are extreme amongst the triazole class of fungicides (Wilde, 1994). The majority of azole fungicides have only two aromatic rings and at least four freely rotating bonds, which means that they are relatively low melting point solids or oils. Fluquinconazole has four aromatic rings and little rotational freedom, and is therefore a high melting point solid (193^{o}C). This property does not favour foliar penetration (Briggs & Bromilow, 1994). Solubility in both organic solvents and water is inversely proportional to the melting point, resulting in a typical organic solubility of *ca* 10g/litre and a water solubility of *ca* 1mg/litre. The exceptions are the highly polar, water miscible solvents NMP and DMSO, which have limited practical applications in foliar fungicide formulations. Particulate formulations are thus the only readily produced option. At 3.4, the log P value of fluquinconazole indicates the potential for xylem mobility, but conventional particulate formulations limit uptake (Stock & Davies, 1994; Stock, 1996). In the absence of vapour phase activity, redistribution on the crop is largely by mechanical means on a relatively long timescale. Therefore, there is a clear challenge to maximise the biological potential of this compound within the constraints of a commercially acceptable formulation-type.

An easy option to increase biological potential is to use tank-mix adjuvants. However, it is important that in order to maximise potential, an appropriate adjuvant is used. Too often adjuvants have been promoted as a general cure-all for deficiencies, such as lack of foliar penetration, without recognising the fact that there are specific requirements. Whilst the authors recognise that activity enhancement can be obtained for a.i.s with a variety of adjuvants, such improvements are generally obtained within the context of an inappropriate adjuvant being better than no adjuvant at all, due to the sub-optimal nature of a commercial formulation. As a counter to this, some commercial products have been launched with a specific partner adjuvant. However, the ideal standard is to have an optimised delivery system, which is robust enough to cope with a range of application challenges under commercial application conditions.

Identifying critical compound criteria for optimised biological activity

In order to design a delivery system to maximise compound potential, the limitations of conventional design relative to idealised model systems were identified. Screening formulations based upon aqueous acetone solutions containing surfactants generally allow maximal expression of biological activity in controlled laboratory conditions. Such systems, however, are clearly different from commercially acceptable formulations. However, they do provide an idealised target to aim for in a rational design process, the first step of which is to identify critical criteria where conventional formulation approaches under-perform.

(i) Foliar penetration investigations

Initial investigations using simplified formulation systems and tank-mixing approaches in pot trials and field studies indicated that systems which enhance foliar penetration of fluquinconazole induced a significant increase in biological activity. In particular, curative activity was enhanced (in the case of *Blumeria (Erysiphe) graminis* from poor to exceeding the best DMI standard) and the useful disease spectrum extended. A range of materials was therefore selected for systematic evaluation of uptake potential. Such materials included conventional surfactants, which are used in agrochemical formulations or as tank-mix adjuvants. However, beneficial surfactants were required at very high levels which were not compatible with one-pack formulation options. An alternative approach was to evaluate a range of oil-type carriers for their ability to enhance penetration. Within the tank-mix adjuvant field, a variety of oils are used including paraffinic, vegetable, methylated vegetable and acidified phospholipids. Clearly, such tank-mix additives must also contain emulsifiers to allow tank-mixing and, in some cases, the emulsifiers may provide greater benefit than the actual oils themselves (Grayson *et al*., 1993).

A range of oil-type carrier materials, most of which are not used in the agrochemical industry, was identified from a selection of commercial sources. When built into oil-based SC formulations the enhanced carrier of preference significantly improved the foliar delivery of fluquinconazole. Indeed, whilst foliar penetration of a conventional aqueous SC was less than 5% over a 14 day period, surface recovery of fluquinconazole decreased from 88% one day after application to wheat under glasshouse conditions to 42% at 7 days after application. This still resulted in a significant foliar reservoir for protectant action.

Within the oil-based system, the carrier acts as a transfer phase that facilitates uptake into the plant over an extended time period. In addition, there is a gradual redistribution from the site of penetration over a period of two weeks or more. It should be stressed that redistribution is not influenced *per se* by the formulation system, only the amount of penetrated fluquinconazole which becomes available for redistribution. The limited aqueous solubility of fluquinconazole and its marginal log P for xylem mobility clearly contribute to the extended distribution phase, providing continued protection within the extending leaf without the scorching effects associated with more mobile fungicides. Within this distribution regime, the metabolic stability of fluquinconazole is also beneficial in providing extended protectant activity, particularly against *Blumeria graminis*.

(ii) Microscopy studies

In addition to radiolabelled mechanistic investigations into the uptake potential of fluquinconazole, the biological impact of different delivery systems on key stages in fungal development was also evaluated in carefully controlled microscopy studies. Using optimised pathosystems grown under defined conditions, the dynamic responses of key infection structures to precisely timed applications of conventional and novel formulations of fluquinconazole were quantified. Spray timings and life cycle targets for the *Blumeria graminis* pathosystem are summarised in Figure 1.

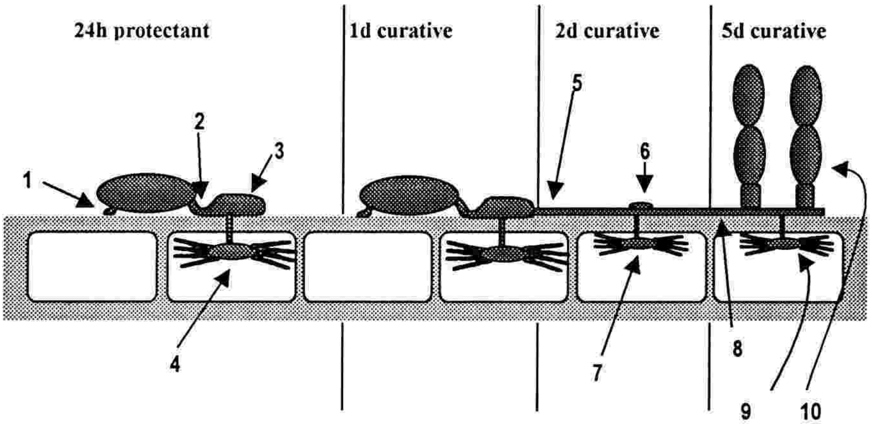

Figure 1. Spray timings and targets for *B. graminis* f. sp. *tritici* life cycle studies. **1.** Primary germ tube. **2.** Appressorial germ tube. **3.** Appressorium. **4.** Primary haustorium. **5.** Primary hypha. **6.** Hyphal appressorium. **7.** Secondary haustorium. **8.** Secondary hypha. **9.** Tertiary haustorium. **10.** Conidiophore and conidia.

A similar approach was used for *Mycosphaerella graminis* (anamorph *Septoria tritici*) and *Puccinia recondita* (data not shown). The protectant activity of key cereal fungicides on *B. graminis* was microscopically assessed 5d after inoculation (Table 1). The new formulation of fluquinconazole has exceptional spore germination inhibitory activity, matching that of kresoxim-methyl and exceeding that of epoxiconazole. Inhibition of spore germination is not typically associated with a DMI mode of action, since spore sterol reserves are generally utilised during this phase. It is however a known activity for respiration inhibitors, such as kresoxim-methyl and azoxystrobin (although the data in Table 1 indicates that the latter is weaker in this respect since significant numbers of mature appressoria are formed). It is possible that the new fluquinconazole formulation enhances uptake of the a.i. into the spore itself.

Comprehensive life cycle studies conducted according to the outline in Fig. 1 indicated that curative activity of the new fluquinconazole formulation was largely attributable to enhanced activity against the primary and subsequent haustoria, which support epiphytic hyphal colony expansion and sporulation. *B. graminis* haustoria are known to be sensitive targets for DMI activity, which is manifested by a reduction or inhibition of the growth of finger-like processes contributing to the surface area for nutrient uptake from the host. This is illustrated for a 3d curative spray timing in Figure 2 and confirms the biological effect of enhanced delivery of the a.i. identified in the previous section.

Table 1. Microscopic analysis of protectant activity of cereal fungicides vs *B. graminis* (monitored 5d after inoculation). Data relate to percentage distribution of infection structures.

Fungicide	Un-germinated spore	Primary germ tube	Appress-orium	Non-sporulating colony	Sporulating colony
Untreated	6	3	55	8	28
Fluquin. SC	31	13	31	4	21
Fluquin. SC + carrier	78	15	7	0	0
Epoxiconazole	59	19	20	2	0
Tebuconazole	7	6	87	0	0
Cyproconazole	6	4	82	8	0
Azoxystrobin	28	37	35	0	0
Kresoxim-methyl	76	24	0	0	0

(Fungicides used at field rate equivalent)

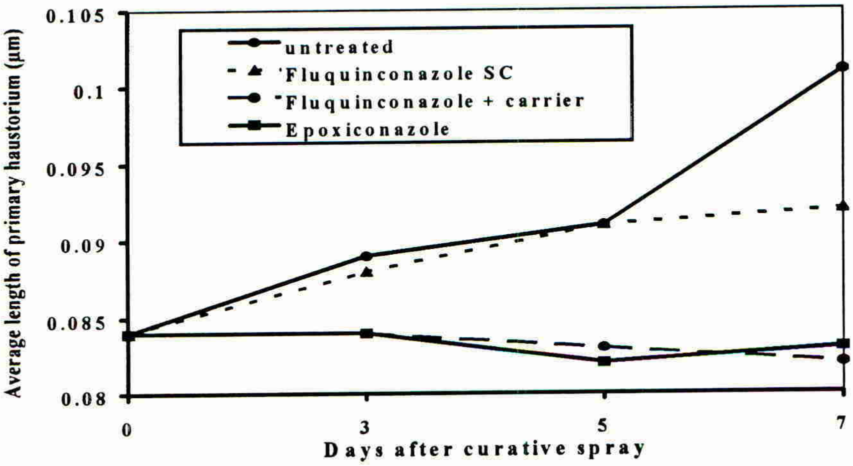

Figure 2. Microscopic analysis of the effect of a 3 day curative spray on subsequent haustorial elongation in *B. graminis*.

In the case of *M. graminicola*, enhanced curative activity of the new fluquinconazole formulation was identified for both pre- and post-penetration stages of the disease, specifically proliferation of 'latent' mycelium and pycnidium formation (data not shown). This activity exceeded the best DMI standards. Enhanced activity against *P. recondita* was also observed, both by a protectant mechanism involving perturbance of environmental stimulus recognition by germlings required for appressorium formation and by curative activity on early stages of colony growth prior to uredinium formation (data not shown). This protectant and early curative activity matched the strobilurins and moderately exceeded best DMI standards, but sprays timed to coincide with uredinium formation tended to have a suppressive, rather than an inhibitory effect on subsequent sporulation.

Biological investigations

(i) Glasshouse studies

Whilst it is known that existing fluquinconazole coformulations for cereal disease control provide long lasting activity (Wilde, 1994), the curative effects of such delivery systems are not exceptional. In order to investigate the various new oil-type carriers, biological support studies were conducted under glasshouse conditions using a tank-mix approach rather than attempting a full range of more complex formulations.

Table 2. Curative trial against *Blumeria graminis* var. *tritici* on wheat (Riband) using a range of carriers

Treatment	Rate a.i./ha)		(g Carrier	Rate (%v/v)	% Control
Fluquinconazole SC	50	50	-	-	0
Fluquinconazole SC	50	50	A	0.1	97.2
Fluquinconazole SC	50	50	B	0.1	100
Fluquinconazole SC	50	50	C	0.1	90.7

Addition of the new oil-type carriers dramatically enhanced the curative activity of a conventional fluquinconazole aqueous 50SC (Table 2). The carriers alone were biologically inert. Subsequently, a new oily flowable formulation, Flamenco®, was produced based on carrier B; initial glasshouse trial results are shown in Figure 3.

(ii) Field studies

Based upon mechanistic studies and associated biological support, field trials were conducted with the new oily flowable formulation of fluquinconazole. The new carrier technology

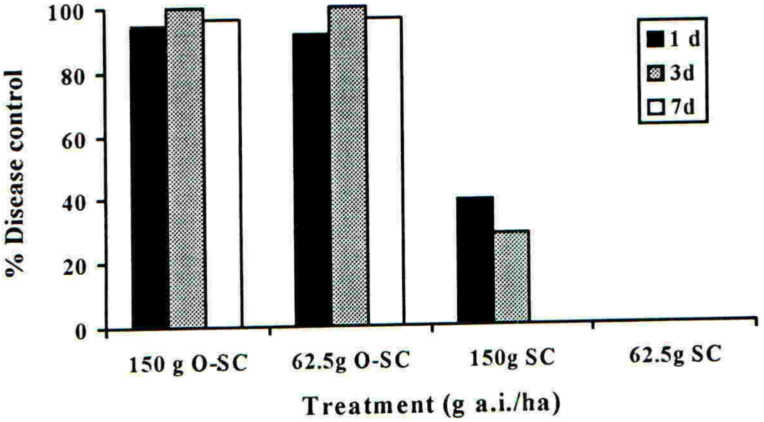

Figure 3. Protectant activity of new fluquinconazole oily-flowable formulation against *Blumeria graminis* (O-SC = New oily flowable formulation; SC= conventional aqueous SC).

greatly increased *Septoria* curative activity and extended the spectrum by providing commercially acceptable control of *Blumeria graminis* (Table 3). However, this is not seen as a direct substitute for existing commercial co-formulations, which provide very good disease control when applied at correct timing in appropriate disease conditions. Nevertheless the new formulation offers highly effective curative control and, thus, greater flexibility of timing.

Table 3. Per cent control of *B graminis* in wheat on F1-3 after application at GS31-32 (data represent mean of 13 trials in France in 1997).

Treatment (g a.i.)	20 d	30 d	40 d	50 d
Fluquinconazole Oil-SC (150 g)	86	85	95	77
Fenpropidin (188 g) + fenpropimorph (562 g)	52	78	84	46
Epoxiconazole (84 g) + fenpropimorph (250 g)	83	80	91	73
Kresoxim methyl (150 g) + fenpropimorph (300 g)	92	85	70	62

Impact of new carrier technology on other active ingredients

In exploiting new formulation opportunities for fluquinconazole, it was questioned whether the enhanced carrier system also offers any potential for other fungicides. It should be stressed that for any aspect of activity enhancement, it is simply a matter of matching the delivery system to the requirements of the a.i.. For example, if the foliar penetration of kresoxim-methyl is increased, this does not provide an activity benefit because it is rapidly metabolised in the plant to fungicidally ineffective components (Gold *et al.*, 1994). On the contrary, vapour phase activity in maximised by the use of a non-penetrating delivery system.

For most other fungicides, the physicochemical properties are not so "extreme", hence the formulation solution used for fluquinconazole is less beneficial for activity enhancement.

Nevertheless, the carrier technology used with fluquinconazole has shown activity benefits with other a.i.s, such as azoxystrobin. It is known that strobilurins have relatively poor curativity and that their strength lies with protectant activity, a physiological crop-greening effect and resulting yield enhancement. The latter parameter is apparently dependent upon dose-rate irrespective of disease control effects. In combination with our patented carrier technology, the curativity of azoxystrobin can also be increased.

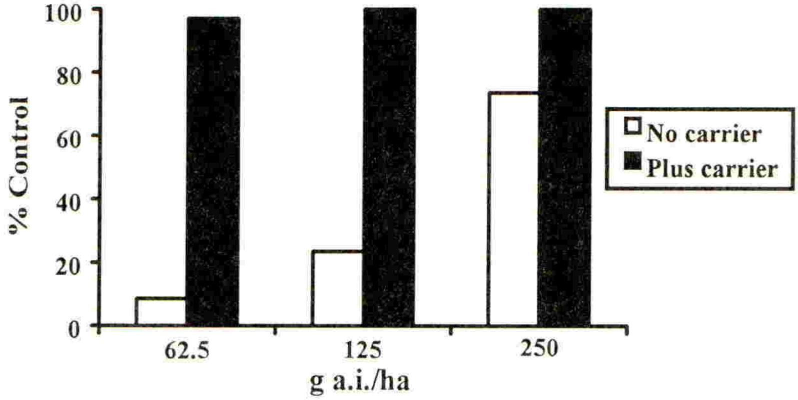

Figure 4. Influence of new carrier technology on the protectant activity of azoxystrobin against *Blumeria graminis*.

Data obtained under glasshouse conditions (Figure 4) show substantial increases in disease control. The effect on mildew activity is notable due to its perceived weakness against this pathogen. Whilst the carrier itself is fungicidally inert, it helps azoxstrobin to realise its fundamental and inherent activity. Improved targeting of the applied dose to the required site of action is likely to be the reason for this dramatic benefit.

In order to confirm this effect, glasshouse and field studies have been conducted mixing the new formulation of fluquinconazole with the commercially available azoxystrobin formulation. Percent disease control of *B. graminis* by azoxystrobin at 62.5g and 31.25g was 12% and 10% respectively. In the presence of the new oily-flowable formulation of fluquinconazole at 31.25g a.i., these values increased to 99% and 96% respectively, whilst disease control from 31.25g of fluquinconazole alone was 68%. This increased disease control under glasshouse conditions has been mirrored by enhanced yield figures from field trials (Table 4).

Table 4. Yield increases in wheat (t/ha) over untreated controls by mixtures of azoxystobin with new fluquinconazole oily-flowable formulation at two application timings. (Major crop pathogen: *Septoria tritici*)

Treatment	GS 37-39	GS 57-59
Fluquinconazole Oil-SC (1.5 l)	3.57	3.24
Azoxystrobin (1.0 l)	3.71	3.73
Fq. Oil-SC (0.75l) + Azoxystrobin (0.5l)	3.95	4.07

These data clearly show a positive interaction between the two products when both are used at reduced rates. Indeed, the yield responses attributed to the strobilurin, above that conventionally attributed to disease control, is still maintained at reduced rates. The enhanced targeting efficiency of the new formulation in the spray tank thus offers options both for dose reduction and, therefore, reduced environmental loading of a.i.s.

CONCLUSIONS

Systematic evaluation of new carrier technology has demonstrated that it is possible to dramatically increase the activity and spectrum of fluquinconazole within a one-pack scenario without the need for a partner adjuvant. This new technology also offers activity benefits with other fungicidal products when used in tank-mixes with the new fluquinconazole formulation. The extent of these combination-benefits is still under evaluation. Clearly as with any technology aimed at targeting pesticide delivery, not all a.i.s will benefit to the same extent. Benefits will depend upon a number of factors, principally the physicochemical properties of the active ingredient, and the degree of optimisation of the current commercial formulation.

ACKNOWLEDGMENTS

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The toxicity response from insecticides with an ethyl fatty ester-based adjuvant

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ABSTRACT

Vicchem EOP, a recently patented adjuvant based on ethyl fatty esters, was evaluated with several insecticides for the control of crickets and aphids. In laboratory studies, EOP at 2.0% v/v in the spray tank enhanced the efficacy of betacyfluthrin and deltamethrin three-fold against crickets, whereas dimethoate and carbaryl were not enhanced. In field studies, EOP at 1.2% v/v increased the efficacy of methomyl and endosulfan against aphids and worms on corn and imidacloprid against aphids on cotton. It is suggested that EOP slows the recrystallization of certain active ingredients in spray droplets maintaining a liquid state for increased contact. It may also soften the cuticle of insects, which would facilitate increased uptake of active ingredients.

INTRODUCTION

Adjuvants are well established for enhancing the efficacy of herbicides. The recently patented ethyl esterified seed-oils, for example, have been shown to provide efficacy superior to the methylated seed-oils with selective herbicides in the USA, Great Britain and Australia (Killick *et al.*, 1997).

In parallel with the use of herbicides, the grower also looks to eliminate or substantially reduce the damage that insects inflict on crops. The potential of using oil-based adjuvants to enhance insecticidal activity is now being broadly investigated (Ford, 1992; Ford & Salt, 1987). In the present work, the effects of an ethyl fatty acid ester adjuvant (EOP) on the efficacy of several classes of insecticides has been examined in the laboratory and field.

METHODS AND MATERIALS

Adjuvant

Vicchem EOP and Esterol 123 are proprietary products manufactured by the Victorian Chemical Company, of which Esterol 123 is substantially ethyl oleate. Vicchem EOP is Esterol 123 emulsified with nonionic surfactants, including esters of fatty acids.

Insecticides

The following insecticides were used with the adjuvant: *β-cyfluthrin* (∝-cyano-4-fluoro-3-phenoxybenzyl-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate, *deltamethrin* ((*S*)-∝-cyano-3-phenoxybenzyl (1R,3R)-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane-carboxylate; *carbaryl* (1-naphthyl methylcarbamate), *dimethoate* (*O,O*-dimethyl *S*-methylcarbamoylmethyl phosphorodithioate, *imidacloprid* (1-(6-chloro-3-pyridinyl) methyl)-*N*-nitro-2-imidaz-olinidin-2-ylideneamine, *methomyl* (*S*-methyl *N*-(methylcarbarnoyloxy) thioacetimidate), *endosulfan* (1,4,5,6,7,7-hexachloro-8,9,10-trinorborn-5-en-2,3-ylenebismethylene) sulphite. Formulations are listed in Table 1.

Table 1. Commercial formulations of insecticides used.

Insecticide	Type	Trade Name	g a.i./litre	Manufacturer
Betacyfluthrin	EC	Bulldock 25 EC	25.0	Bayer
Deltamethrin	EC	Decis Forte EC	27.5	AgrEvo
Carbaryl	EC	Bugmaster Flo	500.0	Rhone-Poulenc
Dimethoate	EC	Rogor	100.0	Hortico
Imidacloprid	EC	Provado	192.0	Bayer
Methomyl	WP	Lannate	90.0	DuPont
Endosulfan	EC	Thiodan	360.0	AgrEvo

Laboratory studies

The insecticides, betacyfluthrin, deltamethrin and carbaryl, are effective in controlling many chewing insects. The black field cricket (*Teleogryllus commodus*) was chosen as a chewing insect because it causes considerable damage to Australian pastures every year, mainly in the southern regions. The first instars (i.e. newly emerged crickets) from a laboratory culture were used for testing. The culture was maintained at 24°C in a controlled-temperature room. Adults were reared from nymphs in ventilated plastic containers (30 x 25 cm). The crickets were fed proprietary grain pellets throughout their life stages. Equal numbers of males and females were placed into containers with sand-trays (9cm diam.) for breeding. After copulation, the females oviposit their eggs into the sand-trays. The sand-trays were checked regularly for newly emerged crickets. First instars were removed daily for bioassays. Insecticides in all treatments were applied using a Potter tower (Burkard) to ensure consistent application rates. The tower was run at 40 kPa and delivered *ca* 50 µm VMD (volume mean diameter) droplets. Plain cabbage (supermarket grade) was used for both cricket and aphid bioassays.

Cabbage leaves were sectioned and placed onto the base of a glass Petri dish (9 cm diam.). One side of the leaf was sprayed and the leaf section was air-dried for 20 min in a fume hood. Controls were sprayed with water only. Five sections (replicates) were prepared for each dose. A sharpened steel cutter (18 mm diam.) was used to cut three discs from each sprayed section and placed into each dish using a camel hair brush, before replacing the lid. Each replicate contained ten crickets. Bioassays were conducted at 25°C and cricket mortality was assessed after 24 h. The dose-mortality data were interpreted with probit analysis (POLO-LeOra Software 1987).

Dimethoate, imidacloprid, methomyl and endosulfan are used against sucking insect, such as aphids. Green peach aphids (*Myzus persicae*) were reared and used to test dimethoate. The culture was maintained at 20°C in a controlled temperature cabinet. The culture was established from a single aphid collected in 1995 (Koo Wee Rup; Victoria). Petri dishes (Johns; 5cm diam.) were filled with nutrient agar (Oxoid; 1.0% agar) and when cooled, a capsicum leaf (Giant Bell) was placed onto the agar. Plates were inoculated with adult aphids which produced nymphs asexually. Only first instar nymphs were used for the bioassays. Cabbage leaf discs (35mm diam.) were cut with a sharpened brass cylinder as before. These discs were sprayed and air-dried for 20 min. Controls were sprayed with the adjuvant (EOP 2%) or water only. Five replicates were prepared for each dose. Discs were placed onto filter paper (Whatman) in the lid of a glass Petri dish (35 mm diam.) The filter paper absorbed any excess moisture from the cabbage disc and lessened the risk of aphids drowning. Aphids were added with a fine camel hair brush. Each replicate contained 10 first instar aphids. The base of the Petri dish was firmly pressed against the cabbage disc in the lid and held in place with rubber bands. Dishes were inverted and incubated at 25°C. Aphid mortality was assessed after 24 h.

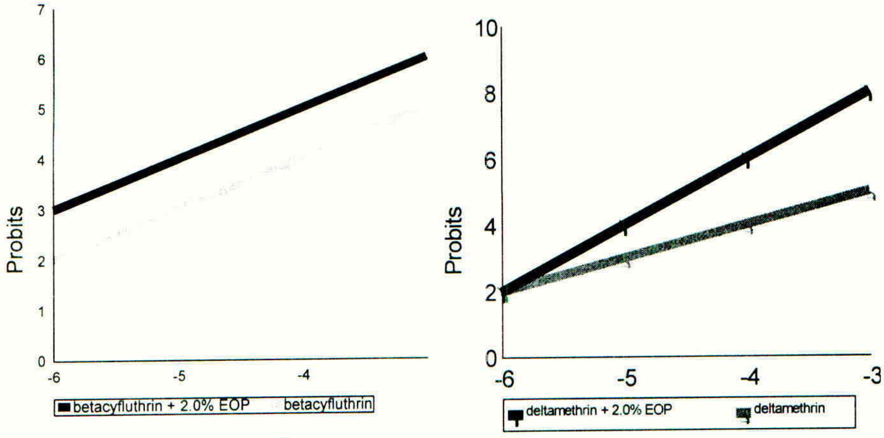
Field studies

In California, the typical total solution application rates for ground and air applications are 200 and 90 litres/ha, respectively. EOP is added at the rate of 1.2 liters/ha, which results in a spray concentration of 0.6% and 1.3% for ground and air, respectively. The insecticides applied with EOP in California were imidacloprid, methomyl and endosulfan. Application rates were in agreement with the standard label recommendations for the target insects on the listed crops. In Washington State, EOP was applied at 1.25% in combination with the label rate of dimethoate to control aphids in peas.

RESULTS

Betacyfluthrin and deltamethrin in the laboratory

EOP at 2% v/v of the spray solution shifted the position of the dose-response curve towards greater toxicity to crickets for the synthetic pyrethroids, betacyfluthrin and deltamethrin (Figures 1a and 1b). Probit analysis revealed that the LC_{50} for betacyfluthrin was reduced when applied with EOP at 2.0% v/v from 110 ppm to 50 ppm and increased the relative efficacy of deltamethrin three-fold (Table 2). EOP at 0.5% only tended to reduce the LC_{50} for crickets, but was not significantly reduced compared with using betacyfluthrin or deltamethrin.



a). Log dose (applied as 25 g a.i./litre EC)

b). Log dose (applied as 27 g a.i./litre EC)

Figure 1. Dose mortality relationship for crickets exposed to betacyfluthrin at different doses, with and without 2.0% EOP on cabbage leaf discs.

Table 2. Probit analysis of log dose-response for cricket bioassays with EOP.

Insecticide	EOP concentration %	LC_{50} ppm	LCL-UCL[a]	Slope[b]	S.E[c]
Betacyfluthrin	0	110	77.9-159.8	1.7	0.1
	2.0	50	33.3-77.6	1.3	0.1
	0.5	70	50.0-100.7	2.0	0.3
Deltamethrin	0	130	101.4-185.2	1.7	0.2
	2.0	40	22.8-70.0	2.1	0.2
	0.5	70	na[d]	1.8	0.2

[a] Lower (L) and upper (U) 95% confidence limits (CL).

[b] Slope of line of best fit.

[c] Standard error of slope.

[d] Unable to calculate 95% confidence limits: high heterogencity.

The increased toxicity for betacyfluthrin and deltamethrin when used with EOP supports the earlier research of Ford & Loveridge (1995) with the pyrethroids, cypermethrin and cyhalothrin.

Carbaryl in the laboratory

Carbaryl, like the pyrethroids, is active against chewing insects. Work with carbaryl was conducted in parallel with the pyrethroids but using crickets. Using EOP at 2.0% the carbaryl LC_{50} for crickets was slightly lower but not significantly different from carbaryl alone. In contrast to the synthetic pyrethroids, the LC_{50} for carbaryl was higher (3.51×10^{-3} g a.i./ml). This result is typical of the carbaryl group of insecticides, which are usually only effective at high rates.

Dimethoate in the laboratory

Aphid mortality was comparable to that of the synthetic pyrethroids when dimethoate was applied, showing an LC_{50} of 1.140 compared with 1.141 for betacyfluthrin. However, EOP at both 2.0% and 0.5% inhibited the insecticidal activity of dimethoate. The reasons for this ineffectiveness is being investigated further. The adjuvant may have chemically masked the insecticide or, alternatively, inhibited the penetration of the systemic insecticide into the leaf surface, leaving the aphids unaffected.

Imidacloprid, methomyl, endosulfan and dimethoate in the field

Aphids are becoming increasingly difficult to control with many insecticides while attempting to maintain high populations of beneficial insects in the cotton fields of California. Imidacloprid is a very effective product for aphid control and it has minimal effect on beneficials. However, it is slow acting, taking as much as 3 days for control. Under field usage conditions (Table 3), the addition of EOP at 1.2% to imidacloprid gave complete aphid control after 24h, compared with 72 h without adjuvant. It is postulated that EOP accelerates the uptake of imidacloprid, so that it is less susceptible to degradation by UV light.

The lack of activity of dimethoate when combined with EOP in the cabbage leaf laboratory test is in conflict with the results obtained in the field. In field trials, conducted by Washington State University in 1998, EOP was combined with dimethoate and sprayed on a pea field to control aphids. There was no significant difference in efficacy between EOP and dimethoate as compared with dimethoate applied alone (Table 3).

Methomyl and endosulfan are insecticides used on corn crops to control worms and aphids. In California field trials, the addition of EOP to spray solutions containing these products significantly increased the efficacy of both products against the target insects (Table 3), with no signs of phytotoxicity to the treated crop.

DISCUSSION

The spray adjuvant EOP enhanced the activity of the synthetic pyrethroids, betacyfluthrin and deltamethrin against black field crickets, when applied at 2.0%. The increase in activity may be attributed to the solvency power of EOP which significantly slows the recrystallization of the pyrethroid molecules in the aging droplet. Prolonging the liquid state of the pyrethroid would make it more available for transfer to the contacting insect. EOP may also facilitate the uptake of the pyrethroid into the insect by softening the cuticle.

The antagonism between EOP and dimethoate in the laboratory study was not evident in the field trials, where there was no difference in efficacy between the dimethoate applied singly or in combination with EOP.

EOP increased the activity of imidacloprid, methomyl and endosulfan in field studies but did not significantly increase the activity of carbaryl in laboratory studies. Adjuvancy of EOP is influenced by the type of insecticide used. The synthetic pyrethroids appear to exhibit the greatest increase in efficacy compared with other classes of insecticides.

Table 3. Assessment of aphid and worm control on various field crops with different insecticides applied singly and in combination with EOP.

Insecticide	Insect	Crop	EOP concentration %	Level of control (a)
Imidacloprid	Aphids	Cotton	0	3.5
Imidacloprid	Aphids	Cotton	1.2	5.0
Methomyl	Worms	Corn	0	4.0
Methomyl	Worms	Corn	1.2	5.0
Endosulfan	Aphids	Corn	0	4.0
Endosulfan	Aphids	Corn	1.2	4.5
Dimethoate	Aphids	Peas	0	4.5
Dimethoate	Aphids	Peas	1.2	4.5

(a) Control reported as: 0 – no control to 5.0 – complete control of target insect.

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Controls on the authorisation and use of adjuvants with agrochemicals in the UK

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ABSTRACT

Controls over the use of adjuvants with pesticides have been in force in the UK since 1989. Experience with the operation of the system has shown, over time, that there were differing understandings as to how the controls should be applied. Following a consultation exercise conducted in 1995/96, revisions were made to pesticide regulations, which have clarified the situation and established a more comprehensive system of control over the use of adjuvants *via* their publication in a revised official list.

INTRODUCTION

When the establishment of regulations for the control of pesticides under the Food and Environment Protection Act was debated in Parliament in 1986, there was concern about the status of adjuvants under the proposals. In particular, that over-regulation could stifle the adjuvants industry, which at that time was just establishing itself in the UK. The measures eventually introduced were limited, with control being exercised *via* the use of the adjuvant with the pesticide product. In addition, the evaluation process is confined to a risk assessment of that use; there is no evaluation of efficacy or crop safety. Unlike pesticides, there are no statutory controls over the advertisement, sale, supply or storage of adjuvants. The registration requirements for adjuvants have been described previously by Chapman & Mason (1993).

During recent years, it became clear that some improvements could usefully be made to the adjuvant authorisation system. The published list of adjuvants gave no details on the authorised uses, such as the crop/pesticide combinations, which led to confusion over the proper use of the products. In particular, the Pesticides Safety Directorate (PSD), authorisation holders, users and enforcement officers had developed differing views on the nature and extent of the controls.

As a result, it was decided to review the existing controls. Following a consultation exercise conducted in 1995/96, the relevant part (Consent) of the Control of Pesticides Regulations 1986 (COPR, 1996) was extensively re-drafted and now appears in the Control of Pesticides (Amendment) Regulations 1997 (COP(A)R, 1997). This paper explains important aspects of the amendment and how it affects the listing of adjuvants.

LEGISLATION

For the purposes of the regulations an adjuvant is defined as:

> 'A substance other than water, without significant pesticidal properties, which enhances or is intended to enhance, the effectiveness of a pesticide when it is added to that pesticide'.

In applying this definition in practice, it is PSD's established policy to consider only the following categories of spray additives as adjuvants (Pesticides Register, Issue 3, March 1989):

- extending agents
- wetting agents
- sticking agents
- fogging agents

All the amended controls on adjuvants appear in the Control of Pesticides Regulations 1986 Schedule 3, Paragraph 5, as amended by the Control of Pesticides (Amendment) Regulations 1997.

The Regulations specify that no person shall use a plant protection product in conjunction with an adjuvant in any manner, unless the adjuvant has been specified in the published list of adjuvants following an application by an applicant.

The use of a plant protection product with an adjuvant must be in accordance both with the conditions of the approval for the plant protection product and any additional requirements to which the use of that adjuvant with that plant protection product is subject. Those additional requirements form part of the published list entry for each adjuvant.

The Regulations enable Ministers to :

- Set data requirements which have to be met in order for an adjuvant to appear on the list, in order to ensure that the interests of human safety and environmental protection are addressed

- Determine the requirements to which the use of the adjuvant with a plant protection product are subject, i.e. specify the conditions of use on the published list of adjuvants

- Amend any requirement for reasons of safety, environmental protection or at the consent of the applicant

- Set further requirements which may be amended in the light of available information relating to the use of the adjuvant with approved plant protection products. This may be as a result of a review of an individual, or group, of adjuvants

- Remove an adjuvant from the published list for various reasons: if the applicant fails to comply with any data requirements set; if any relevant literature relating to the adjuvant is not in accordance either with the published conditions of use of the adjuvant or there is reference to a plant protection product and the use is not in accordance with the approved conditions of use of that plant protection product; for reasons of human safety or environmental protection; at the request of the applicant company

CLARIFICATION OF SPECIFIC POINTS

Experimental approvals

No application is required where the use of an adjuvant with an approved pesticide is for the purpose of research and development of the adjuvant, and is carried out under the direct control of the person intending to place the adjuvant on the market. This is subject to the pesticide being used within its approved conditions of use.

Applications

Applications are needed to create or amend a List entry and must comply with the data requirements set. The List entry refers to the 'applicant' company, whose role is described in COP(A)R 1997 as:

- the person making the application to include an adjuvant on the List
- the person responsible for meeting any data requirement
- the person responsible for any literature produced directly on their behalf
- the person who may request to have an adjuvant removed from the List

It is recognised that some 'applicants' may choose to make an application *via* a third party. In this case, the applicant should submit a signed declaration stating that the third party is acting on their behalf.

Marketing companies

There are no legal controls over companies marketing adjuvants (unless they are also 'applicants'). Applications are therefore not required for changes in marketing companies.

Containers and operator exposure

Controls under COPR operate only when the adjuvant is used with a pesticide. This is interpreted as being at the point when the adjuvant comes into physical contact with the pesticide. Consequently, the regulations do not extend to the control of the size, material and design of the container and, therefore, applications are not required to change the container type. Furthermore, there is no control on specifying personal protective equipment or other precautions for handling the adjuvant. These areas are controlled by other legislation, specifically the Health and Safety at Work Act, 1974, the Control of Substances Hazardous to Health Regulations, 1988 (COSHH, 1988) and the Chemicals (Hazard Information and Packaging for Supply) Regulations, 1994 (CHIP, 1944). It follows that personal protective equipment and other operator exposure requirements can only be specified with respect to use of the adjuvant and pesticide mixture.

Data requirements

When making an application a standard set of data requirements must be addressed to allow a risk assessment for the use of an adjuvant with a pesticide, as set out in 'The Registration Handbook':

- Complete application form, proposed draft label, compatibility assurance statement
- Full formulation details, including specification of the technical active material with any impurities, and health and safety data sheets for all co-formulants
- Basic physico-chemical properties, such as water solubility, octanol-water partition co-efficient, melting and boiling point
- Acute toxicology package (oral, dermal, skin and eye irritancy, skin sensitisation), proposed classification
- Acute toxicity to one fish and one aquatic invertebrate species
- Data on breakdown of adjuvant in water and evidence that the major components are prone to breakdown in the environment
- Residues data for crops destined for human or animal consumption

The residues requirements were reviewed as part of the consultation exercise, which resulted in a guidance document being issued - PSD CONSULTATION DOCUMENT 30 APRIL 1996 'CLARIFICATION OF ARRANGEMENTS FOR AUTHORISATION OF ADJUVANTS UNDER THE CONTROL OF PESTICIDES REGULATIONS 1986'. This provided general guidance on carrying out residues trials, permitted extrapolations between crops and the specific number of trials required to support various recommendations.

The document also provided guidance on those situations where residues data would not be required for the use of adjuvants on crops for human or animal consumption :

- When applied with up to half the recommended pesticide approved rate
- When applied up to certain listed crop growth stages (before a significant part of the consumable part of the crop has developed), at full pesticide approved rate
- Where it can be demonstrated that the physico-chemical properties of the adjuvant are sufficiently similar to an existing one

Evaluation process/Official List entry

Unlike the system for approval of pesticides, there is no facility for provisional listing of adjuvants. The arrangements require that an application must be complete and that the outcome of evaluation will result either in a published List entry or rejection. Where there are any doubts applications will be rejected.

Once the evaluation is complete, a List entry is published in the Pesticides Register for all new products or changes made to existing products. This is considered to be the legal document specifying all the conditions of use which must be complied with. As a result of COP(A)R 1997, a revised List entry was published for every existing product, after consultation with the relevant companies (Supplement to the April edition, Issue 4, of The Pesticides Register).

At any given time, there will only be a single List entry for each product. Where a product or an individual use, is due to be removed at some point in the future (e.g. following review or commercial withdrawal by the applicant), an amended List entry will be produced indicating when the product or individual use will be removed from the List. If it is only certain uses being withdrawn, then at the end of this specified period, usually two years, a revised List entry will be published with the withdrawn use deleted.

Labels and other literature

PSD does not have the power to specify the wording on adjuvant labels. It is the applicant's responsibility to ensure that their labels, product manuals, leaflets and other instructions for use are within the conditions of use set by their List entry. PSD will provide comments relating specifically to those areas of a draft label which relate to the conditions of use, but it must be emphasised that these are advisory only. However, under COP(A)R 1997, if any 'relevant literature' indicates uses that are outside those stipulated on the published List entries, PSD can remove the adjuvant from the List on safety grounds.

Reviews

Reviews of safety of adjuvants can be initiated by PSD in the same way as for pesticides, either on an individual product basis or by relevant classification. The regulations provide the means by which products can be removed from the List following evaluation of the review data. Unlike the situation which exists with pesticides, they cannot remain on the List while further data are generated.

Removal of adjuvant products from the List

Adjuvant products can be removed from the List under various circumstances, some of which have already been mentioned. These include, at the request of the applicant, when a product has an insufficient safety package (i.e. failure to meet Review data call-in), as a result of the outcome of a Review or if the applicant cannot be contacted by PSD (for instance, if the company has gone into liquidation or ceased trading).

FUTURE DEVELOPMENTS

The European Commission has indicated its intention to bring adjuvants within the scope of EC Directive 91/414. However, in the light of delays in progressing issues relating to the EC review programme for pesticides, any proposal to extend the scope in this way is likely to be some way off.

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SESSION 3B

FOOD SAFETY: IMPLICATIONS FOR MODERN AGRICULTURE

Chairman & Session Organiser	Dr R Burt *MAFF/DH Joint Food Safety and Standards Group, London, UK*
Papers	3B - 1 to 3B - 3

The role of the Food Standards Agency

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Food safety scares very frequently make the newspaper headlines emphasising political and public sensitivities on this issue. Food is a universal requirement and consumers have the right to expect it to be nourishing and wholesome. However several major incidents in recent years have shown that this is not always the case. The repercussions of the large outbreak of food poisoning in Scotland during 1996 caused by *E. coli* 0157 are still being felt while link between BSE and nv-CJD is of great and continuing concern. Against this background of major food safety problems are ranged a wide variety of other issues about potential and actual risks. Some of these issues such as those about the levels of pesticides residues in food are persistent while others are much more short lived such as, for example the problem with benzene contamination of carbonated soft drinks.

In response, the Government is committed to introducing major changes in the arrangements for handling food safety and standards in the UK. A White Paper was published in January 1998 which set out the detailed proposals for a Food Standards Agency which will have the responsibility of protecting public health by promoting a safer food supply and ensuring that consumers have the information they need to be able to choose a safe and healthy diet. The Agency will have a clear focus on protecting the public and a powerful statutory remit across the whole of the chain from "plough to plate". The Agency will operate in an open and transparent way consulting all those affected by its activities before it makes decisions except when it needs to take immediate action to protect public health. The new Agency will be autonomous in its daily operations but accountable to Parliament through Health Ministers. It will be governed by a college of independent commissioners who will be chosen for their skills and experience that they can bring to bear on its work. The commissioners will be free to publish their advice to Ministers providing a powerful guarantee of the body's independence.

The Agency will take on a broad range of functions. Its main purpose will be formulation and implementation of policy on food safety and standards involving the normal functions associated with Government Departments. This includes responsibility for drafting legislation, international negotiations both in Europe and elsewhere and the provision of advice to Ministers. The Agency will have a substantial budget for research and surveillance which will provide the scientific base for its policies. It will also set standards and monitor enforcement by local authorities to bring a new level of consistency to this area. The creation of the Agency will address one of the major criticisms of the current arrangements in that it will separate the responsibility for food safety from that of promoting the food and agricultural industries. This will send a clear message to consumers that their needs are being looked after properly while also allowing industry to operate in a market in which consumers have confidence.

Consumer concern about pesticide residues in food is a perennial issue which the Agency will address. The approvals system for pesticides in Great Britain is administered by the Pesticide Safety Directorate which is an executive agency of MAFF and covers most pesticides including horticultural, agricultural and amateur garden products while the Health and Safety Executive has responsibility for other non-agricultural pesticides. Responses to the White Paper recognised that the Food Standards Agency should have a locus in this area but it was recognised that the current arrangements were generally satisfactory although further safeguards were needed to ensure food safety concerns were given greater emphasis. The White Paper proposed a number of new measures to ensure that proper account is taken of food safety considerations in the authorisation of pesticides and their subsequent monitoring of residues in food. The main proposals are that the Agency should:

- provide assessors to the Advisory Committee on Pesticides (ACP) and its sub-committees to ensure food safety issues were given proper weight in the approvals process.
- nominate a member to the independent ACP and be consulted on membership of the ACP as a whole.
- provide a scientific liaison officer to the ACP who would have a scientific input to papers, help set the agenda for meetings and be involved in the briefing process.
- provide a membership of the ownership board for PSD to ensure that it is fully represented when advice for Ministers is prepared.
- work closely with PSD on drawing up their surveillance programmes including membership of the Working Party on Pesticide Residues.
- undertaken surveys of pesticide residues if it considers this necessary to supplement the programme run by PSD.

The practical implementation of these recommendations is currently under consideration but undoubtedly they should lead to even greater emphasis on food safety in the pesticide approval process with the consequent benefit of greater consumer confidence. A parallel exercise is also underway to consider the role the Agency will have in relation to veterinary medicines.

In the meantime, the Government has already a number of significant changes to the way it discharges its responsibilities for food safety and standards. The main emphasis has been to improve the openness and transparency of the decisions on food safety issues. Examples of these changes include:

- consumer or lay representatives are now included in all the major independent advisory committees — the minutes and papers discussed by these Committees are made available;
- results of MAFF-funded surveys and research are made more widely available including the publication of brand names of products tested;
- more information on Government activities on food safety are published. Examples include the hygiene assessment scares for individual abattoirs and a monthly Food Information Bulletin.

Food safety and the establishment of the Food Standards Agency remain a high priority for the Government.

The consumer's perspective: farm policies and our food – the need for change

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Consumers, particularly those on low incomes, want and need access to cheap food, but not at the expense of safety. Policy-makers must find delicate balance between the need for mass- produced cheap food and their responsibility to ensure production methods do not endanger public health and safety, and the environment.

Several issues will affect the development of food production over the next decade – negotiations in the World Trade Organisation (WTO) and Codex Alimentarius Commission (Codex) on agricultural trade and food standards, and talks on the expansion of the European Union (EU eastwards. It is crucial that the impact of farm policies on consumers informs these talks.

We have argued for many years that the Common Agricultural Policy (CAP) acts against consumers' interests and is in dire need of reform. This argument is supported by the considerable amount of research we have undertaken and published on this issue. As we said of the CAP in 1988: 'It overcharges consumers for food; it reduces consumer choice, it has an adverse effect on food quality; it disregards nutritional advice; and it harms consumers indirectly by contributing to environmental damage and the disruption of international trade' (1). While some reforms have been introduced in the 1990s, our criticisms of the policy are as valid now as they were in 1988.

NATIONAL CONSUMER COUNCIL'S REPORT

Our report examines the impact on consumers of national and European policies governing farm production processes in terms of the price, choice, safety and quality of food. It does not examine environmental and animal welfare impacts, not because we do not believe that these are important, but because other organisations are doing this. Nor does the report examine safety issues arising further down the food chain as this would require another volume.

The common agricultural policy (report Chapter 2)

In this chapter we outline the background of the CAP and its impact and cost implications for consumers and taxpayers, and the overall impact on the EU economy. We also look at choice and quality of food, and intensive farming.

Animal feed and the BSE crisis (report Chapter 3)

The BSE crisis is a clear example of the dangers of a policy which sidelines consumers' interests in favour of a supply-led approach to food production. The intensive farming encouraged by the CAP almost certainly gave rise to BSE. This chapter examines the spread of BSE and how the UK government and the Commission failed to act soon enough, or to appreciate fully the public health implications.

Hormones (report Chapter 4)

Consumers have been concerned about the implications of hormones in milk and meat production for some time. This chapter covers the different hormones and their uses in agriculture. It concludes that despite issues of public health the need to contain surpluses, caused by the CAP, was the driving force in introducing bans on hormone use.

Antibiotics (report Chapter 5)

In this chapter we look at the effects of antibiotic residues in food and the growing bacterial resistance to antibiotics used to treat humans. This is a particularly serious problem as consumers food choice cannot protect them against the risk. The high prices guaranteed by the CAP have encouraged farmers to intensify and as a result to use more antibiotics.

Pesticides (report Chapter 6)

The risk to human health from pesticide contamination is still significant. Chapter 6 considers the effects of residues on and inside food and the health issues associated with this. It is also looks at the contamination of drinking water and the huge clean-up costs which consumers have to bear. Regulation was slow to appear and it is inadequately monitored. And re-evaluating older pesticides has only recently been introduced in the EU.

Fertilisers and the nitrate problem (report Chapter 7)

The CAP's high support prices have encouraged the increased used of fertilisers. In this chapter we examine the problems of nitrate residues in food and water and the shortcomings of the Nitrate Directive.

The application of biotechnology (report Chapter 8)

Development of regulation has not kept pace with the technological advances in this field. The novelty of biotechnology is in itself a problem - as yet no adequate risk analysis exists. Using two examples chapter 8 considers the emergence of genetically modified products and the potential risks, and benefits, to consumers.

A new directive for agricultural policy (report Chapter 9)

In this chapter we look at the shortcomings of the European Commission's recent proposals for CAP reform - Agenda 2000 - and suggest a way forward. Using examples from Sweden, we show how effective better farming methods can be.

Reform of regulation (report Chapter 10)

The EU has developed rigorous testing procedures for agricultural inputs which form part of its regulations to protect the health and safety of consumers. In chapter 10, we consider the effectiveness of this regulation, and its monitoring and enforcement. We argue that the EU should promote the 'precautionary principle' - used where there is a potential serious threat to human health and the environment, even if certain cause and effect relationships are not established scientifically.

The international framework (report Chapter 11)

This chapter outlines the international framework in which UK and EU policy operates, considers its likely impact on consumers, and makes proposals for reform. It focuses on the Codex Alimentarius Commission (Codex), the World Trade Organisation (WTO), and the 1994 Uruguay Round Agreement.

SUMMARY OF RECOMMENDATIONS

The Council of Ministers should:

- change incentive systems by establishing a more market-oriented policy which brings prices more into line with consumer demand. Phase out quantity restrictions and export refunds, and reduce import levies. It should also phase out compensation payments and replace them with 'fully decoupled' direct payments;
- fund advisory programmes which encourage farmers to adopt production methods that enhance the quality of their produce and reduce the use of antibiotics, pesticides and nitrates. Such programmes should also form part of agricultural training courses;
- fund research and development of less intensive farming methods with a focus on improving both agricultural efficiency and quality of output;
- extend the EU ban on the use of mammalian meat- and bone-meat to all animal feed, and thoroughly evaluate the production processes using the precautionary principle;
- introduce a compulsory full ingredient labelling scheme for all animal feed;
- keep the current ban on the use of hormones in meat, and the moratorium on the use of BST in milk product in the EU in place;
- prohibit the use of antibiotics as growth promoters throughout the EU. Antibiotics should only be used when an infection is diagnosed and under veterinary direction;
- make sufficient resources available to DG XXIV (Consumer Policy) to enable it to monitor compliance with EU regulations in member states; and
- amend the Product Liability Directive to make the inclusion of primary agricultural products in national legislation compulsory.

The European Commission should:

- ensure that the programme for the systematic re-evaluation of old pesticides is quickly and strictly implemented;
- develop a system for ensuring that maximum residue levels (MRLs) are not exceeded for pesticides and nitrates in food and drinking water;
- bring forward proposals: for improved identification and registration of sheep and pigs along the lines of that for cattle; for compulsory treatment records for farm animals to ensure the hormone ban and tighter regulations on the use of antibiotics;
- ensure that monitoring of agricultural produce takes place in each member state to ensure compliance with EU regulations; and

- co-ordinate and make publicly available the findings of surveillance on residues of veterinary medicines, pesticides and nitrates in foodstuffs.

The international community should:

- include a consumer impact analysis in the forthcoming reviews of the WTO standards agreements and, if the agreements are found to operate in a way which discourages improvements in standards and consumer information, agree to reform them; and

agree to reform Codex by:

- adopting a full freedom of information policy;
- committing additional resources for better representation of consumer and developing country interests'
- opening up the expert committed to consumer participation; and
- reducing the dominance of food producers and requiring all experts who receive funding from industry to declare the details in a public register.

The retailer's response

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Retailing is about selling foods to as many customers as possible. Customers expect retailers to provide a wide range of products available at all times. It is a vital part of retailing to meet the needs of customers. Safety is an absolute requirement and to that end, the creation of a new Food Standards Agency should help to promote confidence in the safety of foods on sale in the United Kingdom. However, to achieve this objective the discussions of the Food Standards Agency must be open to discussion and challenge.

Retailers all have due diligence practices and procedures and this will cover the areas of New Product Development, assessment of new products for safety, and ongoing routine assessments of products once they have been launched into the business.

We have quality control stall in our depots covering most of our fresh food areas and our stores all operate to systems of control to ensure that we try and achieve consistency in all our stores irrespective of where the store may be located.

There are some important customer trends which we must consider. The important trends are the increase in importance of convenience foods, removal of many additives from foods, reduction in the amount of pesticides used, a willingness to experiment as a result of exotic holidays, and finally a tendency to shop less frequently. Many of these changes put pressure on the safety of foods and upon their shelf life.

Because we also use less pesticides on fruit and vegetables, there is a risk of increases in natural toxicants from moulds. It is important to balance the importance of natural toxicants against the use of pesticides.

The topic of genetically modified foods is one which is causing major concerns for everyone in the food business. Those working in the industry are probably able to see some of the benefits that genetic modification could bring. Customers tend to see more of the risks associated with genetically modified foods. These concerns have been heightened by some of the difficulties in ensuring traceability of gm soya as it goes through the supply chain to end up as trace ingredients in many foods. It has been interesting to see Monsanto starting to talk to the population at large through advertising and an internet site. The strategy of providing information balanced to be neither positive nor negative to their cause provides a model which those involved in the pesticide industry may well have to follow a similar strategy in the future.

Many of the trends that have been highlighted will continue into the future. Integrated crop management will be an important part of our requirements going forward. Perhaps with sensitive communication we may be able to build up customer confidence in genetically modified foods. Any business or organisation which fails to anticipate and respond to customer concerns will go out of business - the challenge to all of us in the retail sector is to anticipate these changes and respond to all customer concerns, to build a relationship with them so that we can build up trust, and thus sell more of the products that they require.

SESSION 3C

INTEGRATED CROP MANAGEMENT – EXPERIMENTAL STUDIES

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Session Organiser	J E B Young *ADAS Boxworth, Cambridge, UK*
Papers	3C-1 to 3C-4

But the overriding argument for the field scale came from the philosophy of the integrated systems which we were wanting to test. We wished to draw back from what some might see as over-reliance on pesticides and leachable nutrients. We wished to re-evaluate some of the older non-chemical pest, disease and weed control methods and examine again how to integrate them with modern chemistry. We wished to use more selective pesticides which would target our pest species with as little collateral damage to the ecology as possible. Our thinking was dominated by the experience of entomologists who knew that non-selective insecticides gave dramatic reduction in pest (particularly aphid) populations in the short term but by eliminating natural enemies could create some weeks later an even bigger pest population than would otherwise have occurred. Since three of our sites eventually turned out to have almost trivial insecticide use even in the conventional farming system (Fisher, 1998), this thinking can now be seen as unduly biased by the entomology. However, the large plots were also of interest in evaluating integrated use of resistant varieties and minimal fungicide use on a scale large enough for the disease epidemics not to be affected by the proximity of plots with very different disease status. As we tried to step back from over-reliance on chemistry, it made sense also to step back from the small plots in which current technology had been selected. As we sought to understand and exploit the crop ecology, we chose large plots because of the many mobile factors in our crops such as insect pests and their predators, vertebrate pests, and fungal spores.

THE SOLUTION ADOPTED

Out of this thinking came the IFS project which was part of a LINK programme on "Technology for Sustainable Farming Systems". Like all UK LINK Programmes, funding was shared between Government and the farming industry in its broadest sense. It was designed across six UK sites from Hampshire to Midlothian but it was accepted that both the integrated farming system (IFS) and the conventional farm practice (CFP) must be specific to the site. In fact the CFP comparisons were very close to current practice on the host farms. We now know that they compared very closely with current norms in both the amounts of nitrogen fertiliser and agrochemicals which were used and in the variable costs of operating the system. The major difference was between the sites which had potatoes and consequential higher pesticide use and variable costs, and those which did not. The integrated systems reflected the soil types and climatic expectations of the farm, the markets available locally (for instance for malting barley), and, it has to be admitted, the prejudices and interests of the site managers. Table 1 shows the management practices adopted for the integrated systems as a means of moving back from over-reliance on pesticides and leachable fertiliser at the various sites.

The two systems were compared in half-field plots or at some sites replicated twice to give four plots in each field. Each phase of the five-year rotation was present each year at each site and a proportion of the phases were replicated by a second split field. All plots were at least 2.5 ha in extent and a dedicated rectangular area of about 1 hectare in the midfield was used for the yield measurement. Full details of the rotations and practices will shortly become available in the final report but interim accounts have been published by Wall (1992), Prew (1993), Ogilvy *et al.* (1994), and Ogilvy *et al.* (1995).

Table 1. Importance of management practices in the Integrated Farming System at the various sites.

	South UK		>		North UK	
	Many-down	Box-worth	Sacre-well	Lower Hope	High Mow-thorpe	Path-head
Less demanding crops:		+		+	+	++
Later sowing of winter wheat	+	+	+	+		
Disease-resistant varieties	+	++	++	++		++
Non-inversion tillage		++	++	+	+	
Mechanical weed control		++	+	+	+	
Close crop monitoring	+	+	+	+	++	+
Headland management for predators	++			+	+	

PROBLEMS IN INTERPRETATION

The use of few large plots with little true replication was seen from the beginning as creating statistical problems. These expectations turned out to be entirely correct. Because of the lack of degrees of freedom, within-site analysis of most variables measured has been imprecise. Because of the large differences in ecology and, to some extent, of aims and objectives at the different sites, analyses combined over sites became difficult to interpret. Interpretation is further restricted by the problems of apparent non-homogeneity of variance between sites especially for integrative variables such as gross margins. There is some doubt as to whether variance has been adequately partitioned between error (i.e. differences between replicates) and the higher order interactions. The high and variable gross margins for potatoes compared with combinable crops and the low and uniform gross margins from set-aside further complicate interpretation. All analyses have been conducted on the assumption that results achieved over the same two paired plots, deliberately not randomised afresh each year, can be considered as replication of the system comparisons.

On the last point, the conventional soil analytical results for organic matter content and extractable phosphorus, potassium and magnesium are unlikely to have been affected by the previous or current crop and the annual samples can be considered as repeat samples of a variable changing slowly if at all. Three levels of error can then be distinguished with mean squares as in Table 2. Not surprisingly, the variance between fields within a site (Error A) far exceeds the within-field variance (Error B) by a factor of between 5 (for P) and 79 (for K). More importantly, however, the repeat samples within half fields for extractable P, though randomly located in each year of measurement, could not be considered to have the same variance (Error C) as that between systems (Error B) (variance ratio = 3.45). For the other variables, pooling the error between and within plots would be reasonable. In practice, such pooling has to be done for yields and gross margins because there are insufficient degrees of freedom for the important system comparison to regard the yields in subsequent years as a sub-plot treatment. In the absence of a suggestion for a better way of doing it, it is not intended to criticise the method of analysis that has been used but simply to point out that assumptions about error variance structure in output data from the IFS are difficult to test and therefore of uncertain influence on the statistical tests used. This is a disadvantage of the large plot design.

Table 2. A comparison of error variance in a cross site analysis of extractable phosphorus (P), potassium (K) and magnesium (Mg) and of organic matter (OM).

		P	K	Mg	OM
Error A	Fields within sites	1245	12282	4852	1.5376
Error B	Systems x fields within sites	233	1543	220	0.1785
Error C	Dates x systems x fields	67.5	1145	253	0.1281

Apart from the above, it is not the purpose of this paper to dwell on the rather predictable statistical problems which the design has generated but rather to ask the question as to whether the advantages of the large plot design do or do not validate the statistical sacrifices.

ADVANTAGES OF THE LARGE PLOTS: INVERTEBRATES

Holland (1998) has produced a preliminary summary of the pitfall-trap data from the IFS sites. His first conclusion is that both numbers and diversity of invertebrates differed between sites, years and crops and that differences between farming systems were small in comparison. This conclusion must be seen in the light of the very small use of insecticides, except on potatoes, in either CFP or IFS plots. The result, however, is very much in line with that of the similar large-plot "SCARAB" study. This important result has not surprised the agrochemical industry but has not been so readily accepted by those who criticise modern farming methods from an environmental standpoint. If, however, the results from the two comparisons with plots large enough to discount physical movement of invertebrates (LINK IFS and SCARAB) come to be seen as demonstrating that there are more important influences on invertebrate numbers than farming system, then the choice of large plot design will have been validated.

Since an important reason for the large plots was to measure the effects on invertebrates, a more detailed analysis is offered of the results from the Pathhead sites. The total numbers of each species trapped in the months of April to July were been summed for each factor: cropping system, year, field and phase of the rotation. A chi-squared value was calculated for each factor on each species. Because of the absence of true replication in this design, this cannot be used to test for statistical significance but is a useful device for ranking species by sensitivity to each factor. In Table 3, the species which were recorded each year at Pathhead have been listed in descending order of sensitivity to the cropping system. The method agrees with Holland (1998) in that for most species the effect of year exceeded the effect of phase in the rotation, which in turn exceeded the effect of field. The only real exception was *Lepthyphantes* spp. where the system effects exceeded those due to field and phase.

Table 3. Sensitivity to cropping system, year, field and phase of the rotation for species caught in pitfall-traps at Pathhead. (Ranked by sensitivity to cropping system).

Species		Sensitivity (i.e. Chi-squared value)			
		Cropping System	Year	Field	Rotational phase
Pterostichus melanarius	C	232	1556	294	684
Harpulus rufipes	C	108	879	129	280
Lepthyphantes spp.	L	49	147	17	12
Bembidion lampros	C	15	251	29	114
Amara spp.	C	15	232	39	282
Tachyporus hypnorum	S	14	70	47	198
Trechus quadristriatus	C	11	162	13	514
Other *Carabidae*	C	9	85	2	179
Nebria brevicollis	C	5	2348	647	3658
Tachyporus obtusus	S	5	50	22	43
Erigone spp.	L	4	1208	56	417
Philonthus cognatus	S	2	108	103	167
Loricera pilicornis	C	1	98	30	34
Pterostichus niger	C	1	108	53	78
Agonum dorsale	C	0	728	218	359
Carabus spp.	C	0	45	13	68
Asaphidion flavipes	C	0	17	5	36
Notiophilus biguttatus	C	0	18	8	9

C denotes Carabidae; S denotes Staphylinidae; L denotes Linyphiidae.

Pterostichus melanarius was the species most responsive to cropping system and had higher counts in the IFS than in CFP in all years, in all fields and in all phases of the rotation. It was the only species to exhibit such consistency. It was also strongly favoured by the IFS at Sacrewell and High Mowthorpe but little affected by cropping system at Boxworth, Lower Hope and Manydown. Holland (1998) describes it as "a large active predator of aphids and slugs and therefore important for bio-control". Of the eight species most sensitive to cropping system, six were Carabidae. Of the eight, five were favoured by the IFS but *Bembidion lampros*, *Tachyporus hypnorum* and *Trechus quadristriatus* were more frequently trapped in

CFP. Holland has pointed out that *B. lampros* and *T. quadristriatus* favour open ground and the reduced weeds in CFP wheat crops grown with autumn herbicide is a possible explanation of these effects.

Of the species most sensitive to phase in the rotation (Table 4), *Nebria brevicollis* was trapped particularly in the set-aside and in the wheat following set-aside. *P. melanarius* and *T. quadristriatus* were trapped particularly in the wheat after oilseed rape. *Erigone* spp. were favoured by set-aside but *Agonum dorsale* was mainly found in cereals, especially IFS wheat. Both wheat crops had 11 of the 18 recorded species more abundant in IFS than in CFP but the CFS winter rape and winter barley favoured more species than the IFS spring rape and spring barley.

Table 4. The effect of cropping system on the species most sensitive to phase of the rotation at Pathhead.

Phase:	WOR/SOR		WW		SAS		WW		WB/SB	
Cropping system:	CFP	IFS	CFP	IFS	CFP	IFS	CFP	IFS	CFP	IFS
Species	Total number of individuals trapped									
N. brevicollis	275	84	131	170	1055	1357	683	645	139	178
P. melanarius	98	326	428	494	354	724	196	298	109	209
T. quadristriatus	9	1	121	90	18	7	0	10	25	8
Erigone spp	156	82	105	160	345	424	172	251	255	206
A. dorsale	14	0	0	84	38	34	70	108	202	84
	Number of species									
IFS>CFP		7		11		10		11		5
CFP>IFS		11		5		6		6		12
No difference		0		2		2		1		1

WOR is winter oilseed rape; SOR is spring oilseed rape; WW is winter wheat; SAS is rotational set-aside; WB is winter barley; SB is spring barley.

OTHER ASPECTS

There is no doubt that, despite their search for a different integrated system, the managers of the IFS plots at each site were forced to be cautious by the large scale of the losses incurred if the integrated plot suffered a partial or total failure. This was most obvious for potatoes where, over the three sites that used them, the agrochemical use in IFS was 88% of CFP. In contrast, for first wheats, IFS managers succeeded in reducing their agrochemical use to only

65% of CFP (Fisher, 1998). Environmentalists might consider that the financial constraints made IFS site managers too cautious but farmers, who are the ultimate clients of this work, will certainly appreciate the fact that the scientists have been forced to consider the question of risk.

A major success of this project was in the reductions achieved in agrochemical inputs to wheat which was consistent across sites and ranged from £25/ha at Pathhead (whose CFP had the lowest input of £85/ha) to £50/ha saving on the relatively high input CFP at Sacrewell. Lower Hope achieved a saving of £50/ha on a CFP input of only £95/ha. Most of this has been achieved without loss of gross margin and most by substituting a disease resistant variety and/or a later sowing date and following up with low doses and/or reduced numbers of applications of agrochemicals. As far as the author is aware, this is the first time that this integrated approach to fungicide use has been rigorously tested on a field scale in the UK. All previous work has been done on small plots with some uncertainty as to whether good control over an area of about $40m^2$ would be sustained over large fields. The evidence is very clear that, on these large plots, integrated control of wheat diseases is profitable.

Another important aspect of the IFS experience has been the low incidence of damage due to birds and other vertebrate pests which are often disproportionate on small plots, especially of combinable break crops. Despite this, a number of non-cereal crops in the IFS, notably linseed at Boxworth, spring beans at High Mowthorpe and Lower Hope and spring rape at Pathhead have been among the less profitable and more variable crops in the IFS experiment. They have, however, allowed for the greatest reductions in inputs (Fisher, 1998). This is perhaps the first direct confirmation of the view widely held by farmers that spring-sown combinable break crops do carry real risks which are not just associated with disproportionate vertebrate pest damage on small plots.

CONCLUSIONS

1. Replicated small plot experiments have been an important and successful means of technology selection since 1935 but there are aspects of integrated farming which require a much larger plot.

2. There are considerable statistical problems in design and analysis of large-plot system comparisons which were predictable and are probably not amenable to solutions as neat as those available for small plots.

3. Despite this, the large plots approach in the IFS project was productive because it has demonstrated the following points that could not have been so credibly demonstrated in small plots:
    - Ground-active invertebrates, though very sensitive to year effects do reflect the choice of crop and the management to a lesser degree. However, there is no devastating effect of CFP and no consistent effect of system: some species have thrived under IFS, others have declined.
    - The carabid beetle *Pterostichus melanarius*, a predator of aphids and slugs is particularly sensitive to crop management and was strongly favoured by IFS at Pathhead and also at Sacrewell and High Mowthorpe.

- When large plots are put at risk, IFS experimenters behave like farmers and are far less inclined to risk input reduction on potatoes than on combinable crops.
- Integrated control of fungal disease on wheat was successful on the field scale.
- Spring-sown combinable break crops carry real risks even when grown on half-field scale to avoid disproportionate damage by vertebrate pests on small plots.

4. There is much in the above to indicate that farmers will appreciate the fact that the IFS concept has been tested on a scale which is similar to that on which they have to operate.

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Experimental design and methodologies in the LIFE Project: past, present and future

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ABSTRACT

The rationale behind the experimental design and methodologies used in the IACR-Long Ashton Research Station systems research "LIFE" project are described. These encompass the need for both large plots for farm-scale studies and ecological/environmental monitoring, together with within-system component studies to validate inputs and decision making processes. Attempts, using statistical methodologies, have been made in order to deal with both the problems of lack of replication and the changes made to the systems as they evolve in this dynamic study. Potential future developments in the LIFE project are discussed.

INTRODUCTION

The basis of almost all traditional field experiments is the small-scale replicated plot in a classical Fisher design, where main effects and interactions can be readily detected and quantified, and their statistical significance determined. However, these methods have certain disadvantages; in particular large-scale effects cannot be seen in small-scale experiments. For example, movement of pests or beneficial invertebrates between small plots may obscure differences that would otherwise build up over the longer term on a larger, field scale. Such long-term effects cannot be studied in factorial trials because of the practical constraints on the size of experiments with large field plots. Furthermore, long term effects such as crop rotation, will inevitably include ecological and environmental effects which cannot be distinguished from crop effects in traditional trials.

In arable cropping whole-systems experiments, such as the Less-Intensive Farming and Environment (LIFE) Project at IACR-Long Ashton, a different approach is required. There is a need to validate component decision-making processes using traditional small plot experiments within the whole system study. It is also essential to address the problem of investigating large scale effects over time which, of necessity, require relatively large plot sizes to reduce inter-plot interference and, hence, large land areas to give adequate replication. Such experiments have to be done with plots of field-scale size to compare a limited number of cropping systems. Prior to the LIFE project, such on-farm studies had been done elsewhere in Europe (Vereijken, 1989; El Titi *et al.,* 1990) usually without replication, to investigate long-term environmental effects (Zadoks, 1989).

Furthermore, there is a need for a dynamic system study on a scale which permits the realistic use of large farm machinery and in which "conventional" systems change each year to reflect current farming practice. The advanced integrated systems may also be annually modified on the basis of previous experience and new research developments.

ORIGINAL EXPERIMENTAL DESIGN - First 5-year Phase (Harvest 1990-1994)

The LIFE project, begun in 1989, was designed to provide scientifically sound and robust methodologies to underpin the development, testing, validation, optimisation and implementation of less-intensive, integrated arable production systems, which are economically, ecologically and environmentally sound and sustainable in the long term. As a consequence, it was decided that on-farm experimentation was needed at two levels of complexity. At the higher level, whole-systems were compared, including rotations, at realistic field sizes, and at the lower level, component experiments were done to investigate selected, key crop management and crop protection practices within each system. Systems research plots/field units were designed to be large enough to reveal the impact of ecological processes under normal conditions of crop management.

The LIFE project was initiated in a fully phased, long-term experiment, occupying *ca* 23 ha, with five large fields each divided into four, 1 ha, field units, with each field unit divided into synthesis and research analysis areas. An additional sixth field (Linterns) was included from 1993 onwards, as a replacement for one field because of a planning proposal that would have resulted in the loss of that field to a new road development. In the synthesis areas, the effects of the whole-system components and their interactions are studied and measured whereas in the analysis areas, selected components of the systems are studied in detail in "traditional" designed field experiments e.g. nitrogen dose response, disease control strategies and insecticide spray trials to test the validity of decisions for control of aphid vectors of BYDV. The 20 field units were used to compare four systems of production, which form a 2 x 2 factorial, in fully-phased 5-course rotations. This permitted comparisons to be made on a field scale of the environmental impact and effects of different management systems. The four comparisons comprised a conventional rotation (CON) and an integrated rotation (IFS) each managed by either standard farm practice (SFP), defined as that adopted by a technically competent farm manager and annually adjusted to reflect changes in conventional practice, or research-based lower input options (LI) generated from the dynamic study. An important goal of the project was to obtain conclusions which are valid under a wide range of environmental conditions, and are not unduly influenced by, for example, the combination of a "bad" year with a "valuable" crop. Thus, the five different fields were each started at a different year in the crop rotation. This effectively meant that each crop in the rotation would be grown somewhere on the study site each year and each field would be subject to a different set of crop x weather combinations. The crop rotations, husbandry practices and management decisions for the four systems of production are shown in Table 1.

Standard farm machinery was used throughout and a detailed diary of full husbandry records has been maintained. Crop yields were determined by taking 16 measured combine-cuts from pre-determined reference areas across the synthesis areas within each field unit and quality parameters were measured. Production costs (variable costs) were calculated on the basis of IACR-Long Ashton Farm purchase costs for seed, basal fertiliser, nitrogen and other nutrients, fungicides, insecticides, molluscicides, plant growth regulators and desiccants. The values for grain output are based upon HGCA average market price for the UK during the first week of October each year, for October delivery.

ANALYSIS OF FIRST FIVE YEARS' DATA

Many variables were measured repeatedly over time in each field unit, thus soils, crops, pests, diseases, weeds and bio-indicator flora and fauna were systematically monitored. In a rotation experiment of this type, the observed response in a field is a combination of environmental and crop effects. One possible design for such a system was for each field containing four field units to form a single replicate block, with the same rotation applied to all field units in a treatment, with the rotations starting at the same stage. This type of design was deliberately not used, as it is not possible to disentangle and quantify the environmental and crop effects in the experiment; a "bad" year with a "valuable" crop would have a major impact on predictions.

Table 1. Systems comparisons in the LIFE project (1990-94).

System Features	System Conventional (CON)	 Integrated (IFS)
Rotation	wheat:wheat:barley:rape	wheat:rape:wheat:oats:beans
Cultivar	High yielding	Disease resistant
Tillage	Plough	Non-inversion
Sowing date	September	October
Nutrition	Optimal supply	Soil/plant chemistry
Crop protection	Routine Prophylactic Programmes	Pests (forecast) Disease (threshold) Weeds (mechanical +/- low dose herbicide)

To enable the environmental and crop effects to be disentangled, the replicate rotations were each started at a different stage of the cycle so that in any one year, all crops were present, thus, were all subject to the same climatic variables. This enables the climate "effect" for a given year to be quantified. Indeed, the years behave as blocks in a "traditional" complete randomised block experiment, as the variability between fields within a single year would be expected to be considerably smaller than the differences between years, as would be assumed in a randomised block experiment with years as blocks. At the end of the rotation of five crops, each crop will have been subjected to five different climatic effects. Thus, comparisons between treatments will be more generally applicable than those based upon replicate rotations in phase. The year effects can be removed, thereby increasing the precision of the comparisons.

The original experiment was designed as a complete randomised block design, with years as blocks, in order that the results could have been analysed using analysis of variance. However, the rotation was modified to incorporate different crops, necessitating techniques such as Restricted Maximum Likelihood (implemented in Genstat) which would deal with the resulting unbalanced nature of the design.

CURRENT 7-YEAR PHASE (Harvest 1995-2001)

The first 5-year cycle of this farm-scale experiment was completed at harvest 1994, so that all crops in the rotation have been grown on each designated field unit. Whilst the data gained demonstrated that a less-intensive, integrated systems approach provided comparative economic viability to conventional systems, further improvements could be made. Thus, building upon the experience gained and using the technology and research data generated during the first five years, the project was re-appraised and modified in 1994. It now compares the following three production systems, using revised 7-course rotations (Table 2), with all field units maintaining their integrity, thus retaining continuity for environmental monitoring:

(i) Conventional/standard farm practice system;
(ii) Integrated system - growing crops for feed quality;
(iii) Integrated system - growing crops for milling/breadmaking quality.

Table 2. Crop rotations in systems comparisons in LIFE Phase II (1994 -2001).

	System	
Conventional (ICM)	*Integrated (Feed)*	*Integrated (Bread/Milling)*
Winter wheat	Winter wheat	Winter wheat
Winter oilseed rape	Winter oilseed rape	Spring oilseed rape
Winter wheat	Winter wheat	Winter wheat
Winter barley	Winter oats	Winter oats
Set-aside	Set-aside	Set-aside
Winter wheat	Winter wheat	Winter wheat
Winter beans	Spring beans	Spring beans

Results from the first three cropping years (1995, 1996, 1997) of LIFE Phase II have shown that whilst agrochemical input and cost reductions have been maintained in the less-intensive integrated systems, the large overall whole-system yield penalties previously experienced for cereal crops in Phase I have diminished (Jordan *et al.*, 1997). However, less-intensive integrated combinable break crops remain least profitable. Overall, yield reductions were attributed to a combination of inherently lower yielding disease-resistant wheats grown for breadmaking quality and spring crops grown in the rotation. Nevertheless, these small yield penalties in crops grown for breadmaking/milling quality have been compensated by yield improvements in crops grown for feed quality. This has resulted in improvements in Gross Margins and a 10% increase in overall profitability (Net Margin - after deductions in operational costs), over the 3-year period, compared with the conventional ICM production system (Table 3).

POTENTIAL FUTURE DEVELOPMENTS IN THE LIFE PROJECT

The LIFE project (1998-99) is now in its tenth cropping season and, thus, represents a valuable long-term resource for providing rational contributions to the continuing evolution of profitable arable farming systems that are environmentally sound and that meet the aims of policy makers.

Table 3. Yields and profitability of systems comparisons 1995-97.

	Conventional (ICM)	Integrated (Feed)	Integrated (Bread/Mill)
Yields (t/ha)	6.04	6.16	5.50
Income (£/ha)	941.48	875.61	838.79
Variable costs (£/ha)	235.90	152.67	154.51
Gross margin (£/ha)	705.58	722.94	684.28
Operational costs(£/ha)	253.00	197.06	200.72
Net margin (£/ha)	452.58	525.88	483.54

Our overall aim in considering possible future directions for research in the LIFE project has been, and must continue to be, the maintenance of the integrity of existing long-term systems comparisons of (i) a modern conventional system, based on ploughing as the primary method of cultivation, that reflects best current commercial practice, with (ii) an advanced integrated production system that is based on non-inversion tillage and which aims to rely more on natural regulatory processes and less on external inputs than the conventional system. Further development of both systems will rely increasingly on modelling studies to explore options and provide greater understanding of key aspects of the systems, with emphasis on profitable farming combined with optimisation of ecological interactions within the systems.

In addition, because the current second phase of the LIFE Project includes two systems of advanced integrated production, this provides us with an opportunity to replace one of the integrated systems with a third system, in order to explore a different option for profitable, environmentally favourable arable cropping systems. This system should show greater contrasts than the existing system comparisons, partly because two key components (soil conservation tillage and pesticide usage) in the advanced integrated crop production system of the LIFE project are known to influence pests and their natural enemies. However, to date, relatively small differences (usually not statistically significant), have been observed in the numbers of polyphagous predators that are active on the soil surface (mainly carabid and staphylinid beetles and linyphiid spiders), recorded in pitfall traps in the different systems (Winstone *et al.*, 1996). Differences between sites and between fields were found to be greater than differences between systems within fields. Similar results for carabid beetles have been reported from the related LINK IFS study (Holland *et al.*, 1996). It is possible that pitfall trapping is not sufficiently sensitive to pick up differences between systems, because numbers recorded in pitfall traps depend upon the activity of individuals as well as their numbers. Thus, greater activity of beetles in one system resulting from a shortage of prey items could mask lower densities of beetles. However, it is also possible that the conventional and integrated systems under study may not have been sufficiently contrasting to permit long-term differences to appear, even on the spatial scale of the 1 ha field units in the LIFE project, or the larger plots in the LINK IFS project.

In both the LIFE (Winstone *et al.*, 1996) and SCARAB (Hancock *et al.*, 1995) projects, broad-spectrum insecticides applied in the autumn have been shown to reduce numbers of certain groups of polyphagous predators active on the soil surface. Most species recover within a year, probably largely due to reinvasion of the treated area from surrounding areas. This suggests that systems which avoid the use of broad spectrum insecticides at these times of year could be especially valuable for conserving natural enemies.

Based upon these considerations, we have selected two possible options for a new system to be included in the LIFE project, as described below.

Organic crop production system

One of the advanced integrated systems within the LIFE project could be converted to a system grown under United Kingdom Register of Organic Farming Standards (UKROFS) regulations. Although this system would not be truly organic (because the `organic' field units would not be consolidated into a single unit, but interspersed with field units managed under conventional and integrated guidelines), the introduction of this system would permit us to make direct comparisons of many key components of organic systems, with integrated and conventional systems. The proposed seven-year crop rotation for the organic system would be: grass/clover; grass/clover; winter wheat; winter oats; vegetable crop (e.g. potatoes); winter wheat; spring wheat (undersown with grass/clover). As in the current system comparisons, this rotation would be phased so that each crop in the rotation is grown each year. This inclusion of an organic system would not only permit ecological, environmental and economic comparisons to be made between the systems, it would also provide valuable data on transitional effects during the initial period of conversion to an organic system. Furthermore, after the conversion phase, the organic field units would provide valuable sites for component studies on organic systems.

Given that organic systems are heavily dependent upon ploughing as the primary method of cultivation, which is considered essential for weed control, this would be expected to make the organic system behave in certain ways in a manner similar to the conventional ploughed system. However, the presence of a two-year grass/clover ley in the organic system is likely to have important effects, as is the restricted use of only those pesticides approved for use in organic systems. Alternatively, soil conservation tillage has been used for crop establishment in the integrated systems since 1989, and has provided improvements in soil structure, porosity, soil microbial activity, nutrient conservation, population densities of soil organisms (e.g. earthworms), reductions in agrochemical emissions, and integrated control of some pests and diseases, benefits that are highly appropriate for organic systems. Although weed control in non-plough systems remains a challenge, mechanical intervention combined with a multifunctional crop rotation, as practised in components of the LIFE project, provides an opportunity for effective weed management.

Zero tillage, direct-drilled system

Another potentially valuable option would be to convert one of the integrated systems, currently based on non-inversion tillage, to a zero-tillage integrated system, where crops are direct-drilled into the stubble of the previous crop. Although much previous research has been done on direct-drilled systems in the UK, the vast majority of these studies have involved direct drilling into fields where crop residues have previously been burnt *in situ*, providing a relatively clean soil surface for sowing the following crop. Long-term studies by IACR-Long Ashton (Donaldson *et al.*, 1996) have revealed that direct drilling into stubble can be a viable and potentially successful option. The main perceived benefits of a system based upon direct drilling into stubble would be minimisation of soil erosion and nutrient losses on erosion-prone soils; improved conservation of soil and water resources; enhanced degradation and adsorption of pesticides thereby decreasing their environmental impact; enhanced populations of polyphagous epigeal predators as a result of lack of soil disturbance, particularly in the period just before and after crop establishment (Kendall *et al.*, 1995; Symondson *et al.*, 1996; Tebrugge *et al.*, 1998). Potential problems with grass weeds in such a system could be overcome by an appropriate crop rotation combined with rotational weed control strategies, as already successfully used in the LIFE project (Jordan *et al.*, 1996). Slugs are potentially troublesome pests in zero-tillage systems and can cause severe reductions in yield of cereal crops (Christian *et al* ., in press) as well as break crops (Glen *et al.*, 1996). However, dramatic declines in slug numbers at both the Letcombe study site in Oxfordshire (Christian *et al* ., in press) and at the Long Ashton study site (Glen *et al.*, 1996) have been found after 3-4 years of high populations on non-ploughed plots, suggesting that natural enemies may, in time, build up to sufficient levels to cause declines in the numbers of these pests in zero tillage systems.

MODELLING STUDIES

Data produced from the LIFE project, will be used for detailed economic and energy analysis of conventional and advanced integrated production systems. The economic analysis will compare the competitiveness of both systems in the current economic situation. The structure of prices and subsidies is likely to change in the near future and, therefore, the results of such economic analysis have limitations. The energy analysis will compare both systems for efficiency in utilisation of energy flows within the system. Agriculture uses large amounts of energy, most of which is derived from fossil fuels. The reduction of current dependency of agriculture on non-renewable energy sources will be one of the keys to the sustainability of modern agriculture. The output of the energy analysis will consist of an energy balance for conventional production systems and a range of alternative integrated arable crop production strategies. The breakdown of energy usage in the system allows the identification of production systems with lower energy requirement.

CONCLUSIONS

- Systems research requires a different approach to experimental design compared to traditional trials.
- A key feature is that the need for large-scale experimental plots limits the amount of replication.
- Although the experimental design of the LIFE project was initially balanced, temporally, the need to remain dynamic to reflect market-driven and enforced political changes in rotation (e.g. inclusion of set-aside) led to an unbalanced design necessitating statistical techniques such as Restricted Maximum Likelihood (REML).
- Phase II of the LIFE project now addresses these limitations and the data from both Phases may be combined for pooled analysis.
- The Project, now in its tenth cropping year, has led to improvements in methodologies and decision-making for integrated production, and is an increasingly important long-term resource.
- Options for future developments and site exploitation have been identified.

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Methods for evaluating farm practice and attitudes to integrated crop management systems

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ABSTRACT

In this paper, results from surveys of winter wheat crops in north-east Scotland are used to illustrate methods for summarising variation in husbandry practice among farmers. The relevance of these methods to studying the uptake of integrated crop management (ICM) is discussed, with particular emphasis on the role of the farmer in determining the rate and nature of changes to husbandry practice during the implementation of ICM. Recently developed methods for determining the attitude of farmers to farming and the psychological factors underlying decision making are discussed and related to their possible impact on the future use of ICM.

INTRODUCTION

Large scale experimental studies of integrated crop management (ICM) systems have recently been conducted in the UK and other countries in north-western Europe (Glen *et al.*, 1995; Ogilvy *et al.*, 1995; Vereijken, 1992). The use of ICM is commonly justified by suggesting that its adoption will lead to a reduction in the use of external inputs by farming. This reduction (it is suggested) will increase ecological sustainability directly by reducing consumption of non-renewable inputs and by decreasing the harmful impact of farming on the wider environment. While it has been relatively easy to show that inputs can be reduced without significantly reducing profit margins, (Ogilvy *et al.*, 1995) almost inevitably it has been more difficult to establish the validity of claims that sustainability, or ecological friendliness, are enhanced by less intensive farming (Foster *et al.*, 1997; Foster *et al.*, 1998). There are two reasons why this is the case. First, the term "sustainability" is poorly defined (Hansen, 1996). Thus, attempts to demonstrate that sustainability is increased by a particular course of action are hindered by the difficulty in establishing how sustainable farming is now. Secondly, while economic comparisons between ICM systems and conventional systems can be based on objective measurements such as net profit, comparisons of the ecological value of different farming systems involve more subjective assessments. For example, should we give a higher ecological rating to a system which conserves a greater number of species, or to one which conserves a smaller number of rare species? Furthermore, while the economic benefits of ICM systems have been demonstrated in large field trials and at the farm scale, there has been relatively little analysis of the degree to which ICM methods are likely to be taken up by farmers, and hence of the impact which they are likely to have in practice at a national or regional level. In determining the value of any proposed ICM it will be important to have a bench-mark against which to assess its economic and ecological merits. In this paper we will illustrate methods for estimating such a figure from survey data from commercial crops, discuss variations observed in husbandry practice in relation to future adoption of ICM by farmers, and finally relate these observations to recent work on the development of methods for analysing farmers' decision making.

METHODS, RESULTS AND DISCUSSION

Characterizing the current production system

The COIRE (Crop Optimization by Integrated Risk Evaluation) project was established as a three year crop survey programme by SAC in 1993 (McRoberts *et al.*, 1994). In each of three consecutive growing seasons (starting in 1993/4) approximately 50 fields of autumn-sown oilseed rape and wheat were sampled at regular intervals to determine levels of pests, weeds and diseases (PWD). Farmers' actions were recorded on questionnaires, and a number of crop quality characteristics were also recorded. The survey sample was stratified into three major regional areas; the north-east, the south-east, and the south-west, corresponding roughly to the regional coverage of SAC's three centres at Aberdeen, Edinburgh and Auchincruive (Ayr) respectively. Initial analyses of these data suggested that both the farming landscape and the spectrum of PWD in the north-east region were more homogeneous than in the other two regions (McRoberts *et al.*, 1995; 1996). Despite this homogeneity, there was noticeable variation in husbandry practice. This variation may have a direct bearing on the future adoption of ICM by farmers in the region, which contains some of Scotland's most intensively managed arable land.

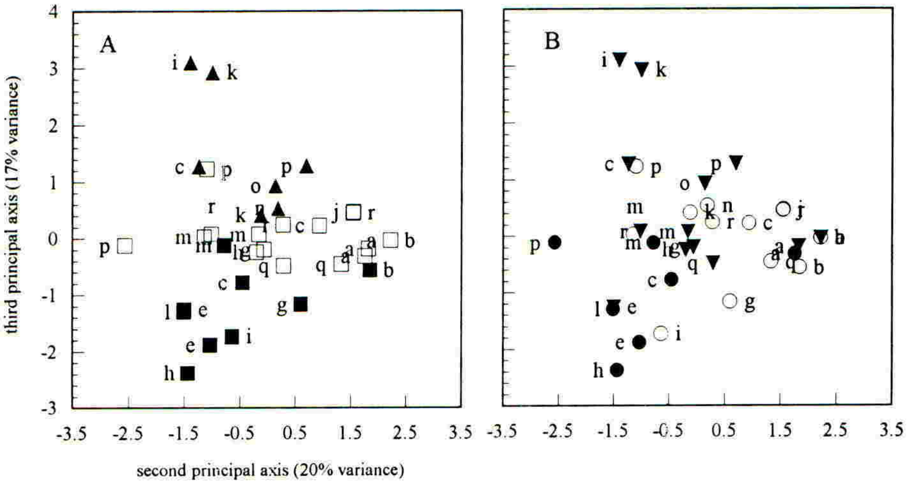

Figure 1. Ordinations of 33 fields of winter wheat on 18 farms in north-east Scotland. The ordinations are based on a principal components analysis of husbandry variables. Symbols in Fig. 1A (left) indicate three levels of inputs: ▲ = high; □ = medium; ■ = low. In Fig. 1B (right) symbols indicate growing seasons: ● = 1993/94; ○ = 1994/95; ▼ = 1995/96.

Data for a sample of 33 of the wheat crops from 18 different farms surveyed in the north-east are analysed here in further detail. A principal components analysis (PCP) of crop husbandry data, suggested that crop management varied varied more from year to year on some farms than others (Fig. 1). The third principal axis from the PCP accounted for 17% of the variation amongst the 33 crops and was significantly correlated (r = 0.91, P < 0.001; 31 d.f.) with the total number of inputs applied to the crop. An analysis of variance (ANOVA) suggested that the separation of the years along this axis was significant (F = 5.01, P = 0.013; 2,30 d.f.), but there was no consistent increase or decrease in the number of inputs across the three years. Farms which show marked changes in their vertical position in Figure 1B, are those with the biggest year to year variation in inputs. The second principal axis, which accounted for 20% of the variance, summarised the rotation in the sampled fields during the three years prior to sampling. Farms which show horizontal displacement between years in Figure 1B are those on which the rotation varied most. Data for the crop rotation and pesticide inputs to the crops for farms 'a', 'i', 'm', and 'p' are given in Table 1. Examination of the data in Table 1 and the corresponding positions of the points for the farms in Figure 1, indicates how the method of analysis can be used to compare the overall level of inputs on different farms, and also to track the changes in management practice associated with the implementation of ICM on farms over time. For example, farms 'a' and 'm' showed little variation, in inputs and had rotations which included at least two years of a particular crop (Table 1). Indeed, farm 'a' was one of two in the survey in which continuous (or near continuous) wheat was grown (the other being farm 'b'). Farm 'p' showed some variation between years in the number of inputs used, and had variable rotations. Similar results were obtained in an analysis of a set of farmers in south-west Scotland in relation to husbandry of oilseed rape crops (McRoberts *et al.*, 1996).

Modelling farmer decision making

The Edinburgh Study of Decision Making on Farms (ESDMF) is a recent attempt (Willock *et al.*, in press) to identify the factors which determine decision making by farmers. The study, which examined a large group of Scottish farmers, has allowed the development of psychometric scales which describe farmers' attitudes to farming, their objectives, and their implementation of farming practices. These scales were developed from questionnaires which were deliberately designed to allow a broad spectrum of farmers to answer all of the questions; i.e. there were no questions which related specifically to particular husbandry activities.

In the context of the future use of ICM by farmers, several results from this study are of interest. First, farmers who were in favour of the use of chemicals were also likely to have positive attitudes towards the ideas of sustainability, and the need for care of the environment. Secondly, a desire to obtain achievement in farming was associated both with production-oriented practices and with objectives related to sustainability and obtaining a good quality of life. Thirdly, when the psychometric scales relating to attitude, objectives and implementation were correlated with standard assessments of psychological variables, both farmers who were production-oriented and those who were more environmentally-oriented, were characterized by extroversion and openness. The personality characteristic of openness was found to be correlated (P < 0.1) with an attitudinal variable "openness in farming". This is of relevance to the uptake of ICM since this variable is associated with a willingness to take advice from a wide variety of sources and to experiment with new ideas.

Table 1. Husbandry variables for a sample of winter wheat crops on four farms showing different degrees of change in husbandry between cropping seasons.

Farm	Season	Cropping			Inputs to current crop			
		Previous year	2 years ago	3 years ago	Number of cultivations[1]	Number of fungicides[2]	Number of herbicides	Number of insecticides
a	1993/4	w[1]. wheat	w. wheat	potato	0	4	2	0
a	1994/5	w. wheat	w. wheat	w. wheat	1	3	1	0
a	1995/6	w. wheat	w. wheat	w. wheat	1	3	2	0
i	1993/4	s. oat	grass	grass	1	8	1	1
i	1994/5	w. OSR	w. barley	s. barley	0	2	2	0
m	1993/4	potato	grass	grass	1	3	0	0
m	1994/5	w. OSR	w. OSR	w. barley	1	3	1	1
m	1995/6	s.oat	s. oat	w. barley	0	3	2	0
p	1993/4	set-aside	s. barley	s. barley	2	3	1	0
p	1994/5	w. OSR	set-aside	w. wheat	1	7	0	0
p	1995/6	s. OSR	w. wheat	s. OSR	0	5	0	0

w. = winter s. = spring; [1] number of cultivations in addition to plough, harrow, drill, roll; [2] numbers in columns relating to pesticides are number of products used, not number of applications made.

It is clear from the results shown in Figure 1 that farming behaviour, even on a set of relatively similar farms in one area of Scotland, varied considerably. Therefore, we might expect the uptake of ICM to vary from farm to farm, with resulting consequences for the sustainability and profitability of arable farming in Scotland in the future.

The conceptual model of farming behaviour underlying the ESDMF is shown in Figure 2. Willock *et al.* (in press) concluded that their data largely supported this general model. The question then arises as to how to we can relate the findings of the COIRE project and the ESDMF, to produce quantitative models of the farming population which will be of value in predicting rates of uptake of new technology and practices.

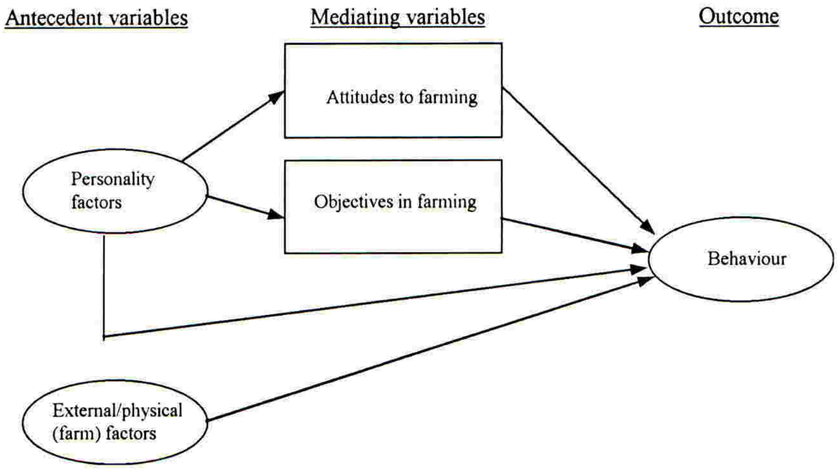

Figure 2. A conceptual model of the determinants of farming behaviour, based on Figure 1 in Willock *et al.* (in press).

The ESDMF and the COIRE project were initially established as independent pieces of research. However, we are currently applying the methods developed during the ESDMF in an analysis of the decision making process of the farmers and farm managers who collaborated in the COIRE project. This new project (SE-COIRE; Socio Economic aspects of COIRE), is an attempt to relate farm practice to socio-economic variables, which partly determine decision-making. It is a novel analysis of arable farmers which should allow policy makers to evaluate the consequences of the introduction of new technology into arable farming. Recent survey results reported in the farming press (Anon., 1998) suggest that ICM and other new technologies are viewed with some optimism by arable farmers, but less than 50% of respondents in the survey said that they planned to make increased use of ICM in the future. Since the antecedent variables in the decision making process are relatively fixed, any societal or political pressure to increase the adoption of ICM will have to act through changes in either or both of the mediating variables. One view of this issue (Vereijken, 1992) is that changes in the attitudes to and objectives of farming are required in society in general, if there is to be any substantial change to more sustainable production methods.

As ICM becomes more widely used in crop production, the methodology which we are developing can be applied to investigate farmers' perceptions of its value and limitations. Since, ultimately, it is farmers who decide which inputs are used, it is important that they are actively involved in any analysis of changes to the farming system as they occur.

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Global Integrated Crop Management success stories

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ABSTRACT

AgrEvo is committed to the production of reliable supplies of affordable food with the least impact on man and the environment, and sees ICM as the right way forward for farmers and growers to meet the requirements of long-term sustainable agricultural production. To this end, a global ICM network has been established. Some of the success stories arising from projects already carried out are described in this paper. They have shown that it is possible by careful product choice and timing, based on pest, disease and weed monitoring and the development of economic thresholds, to achieve levels of control and crop yield from IPM programmes that are often better than conventional ones. The need for fewer treatments has also resulted in IPM programmes being more cost-effective, and achieved with less environmental impact. Decision-support systems play an important role in ICM, as shown by the pest and disease control models from France and the Netherlands. Having well-trained staff working closely with farmers and growers in a practical field situation, often in conjunction with the public sector, were all important factors in the success stories.

INTRODUCTION

In his forthright Bawden Lecture at the 1997 Brighton Crop Protection Conference, Dennis Avery described the model farm of the future as one using still-more-powerful seeds, conservation tillage and integrated pest management, with precision farming applying exactly the right amount of seeds and chemicals for optimum yields (Avery, 1997). This is the concept of Integrated Crop Management, or ICM. It is achieving a balance between efficient, profitable crop production, but without damaging the environment or depleting natural resources for future generations. It has been developed to meet the requirements of long-term sustainability. There are many definitions of ICM. The one adopted here is that used in the UK by LEAF (Linking Environment and Farming): 'ICM is a whole farm policy aiming to provide the basis for efficient and profitable production which is economically viable and environmentally responsible' (Drummond & Purslow, 1997). It is not just about crop protection. There are other key activities, such as minimising pollution, reducing waste, conservation management and improving energy efficiency, all of which are essential components of ICM.

That part dealing with control of damaging weeds, pests and diseases is termed Integrated Pest Management, or IPM. The following definition is based on that for farmers given by the Global Crop Protection Federation (GCPF, 1997): 'IPM is the best combination of cultural, biological and chemical measures that yield the most cost-effective, environmentally-sound and socially-acceptable insect, weed, disease and other pest management for crops in a given situation'. There are many misconceptions about IPM. It is not organic farming, or only non-chemical control, nor is it the use of 'preferred pesticides'. It is also not reduced pesticide use *per se*, but 'as little as possible but as much as necessary'. IPM means using what is appropriate in a given situation, be it biological, cultural or chemical control, including biotechnology. Through the best mix of these methods of control, pest, disease and weed populations are kept below levels which will not cause economically unacceptable crop damage. IPM, like ICM, involves using the latest technology and professional advice.

As a member of GCPF, AgrEvo supports the integrated approach to farming and has established a global network to put this into practice. It is headed by a Global IPM/ICM Manager who steers and co-ordinates policy. Reporting to him are five Regional Managers covering Europe, North America, Latin America, Asia/Pacific and Africa/Middle East. These co-ordinate the activities of Country Representatives who are responsible for all of the AgrEvo IPM/ICM activities in each country. Two of their most important roles are to train staff in all aspects of ICM and to develop crop programmes with the Crop Managers. The activities of the group are monitored by a Steering Committee which has a membership drawn from all of the key business functions.

The implementation of ICM is achieved in all work activities from research, through development, to the introduction of crop management programmes. It includes new products and services combining traditional crop protection with biotechnology. Product stewardship is maintained in the areas of safe use, packaging, recycling, development of resistance management strategies and recommendation of dose rates that provide adequate pest control with the least harm to non-target organisms and the environment. This is achieved by applying products at the right time, according to economic thresholds, and by developing diagnostic techniques and decision-support systems to improve the timing of product application. The work of the above teams has produced many success stories, some of which are described below.

SUCCESS STORIES

Cotton in Brazil

Cotton is an important crop for Brazil with about 900,000 ha cultivated primarily by small and medium-size growers. It provides significant employment in both rural and urban areas. There are many insect pests affecting the crop, and insecticides make up the bulk of the cotton crop protection market. There is also an abundance of beneficial insects and knowledge of these throughout the growing period is a key element of IPM strategy. Over nearly twenty years AgrEvo Brazil has been promoting an IPM concept for this crop. The aim has been to make cotton growers aware of better ways to manage pest problems on a sound economic, social and environmental basis. It began with the need to solve the problem of increasing resistance of *Heliothis virescens* (cotton boll worm) to organophosphorus (OP) insecticides in the Santa Helena region of Goiás State. At that time, cotton crops received between fifteen and twenty-five insecticide applications. The introduction of IPM reduced the number to, on average, six per season, without adversely affecting yield. In 1983 a new pest, *Anthonomus grandis* (cotton boll weevil), became a serious problem and the number of insecticide treatments increased to between ten and twelve. However, by adapting the IPM strategy it was possible to reduce the number of spray applications to an average of eight per season. There were two distinct phases to the programme.

The first phase was to develop IPM in large plantations. AgrEvo formed its own technical teams, who between 1979 and 1991 advised plantation owners on the principles of the new technology and offered husbandry recommendations. As a result, the area under IPM increased rapidly from about 3,200 ha in 1979/80 to 32,000 ha in 1985/86, spread across several states. The number of insecticide treatments was reduced without loss of production, with less environmental impact, and a greater economic benefit to the farmers. Many growers then implemented basic IPM principles themselves. Following this successful introduction, phase two was established, and this involved working with extension services to spread the knowledge of IPM to small and medium farming communities more rapidly. Some examples are as follows.

In 1990/91 *A. grandis* was found to be attacking about half of the cotton in Paraná state, and there was a risk that growers might abandon the crop unless a solution could be found. With both financial and technical assistance from AgrEvo a promotional project was set up in 1990 in association with co-operatives and EMATER-PR, the official institute for rural extension services, to spread IPM philosophy and demonstrate how farmers could grow crops economically even where *A. grandis* was present. During the last eight years, over 700 demonstration plots, each of 2 to 5 ha, were set up in several regions to disseminate new husbandry technology to rural cotton communities. Regular field days were attended by a total of over 16,000 farmers. The agronomists involved had received extensive training in IPM techniques and worked in close contact with the cotton growers. Between 1990 and 1994, the average number of insecticide treatments on the IPM plots was 5.8 compared with 6.8 for the farmers' treatment. Seed cotton yields were 2.43 and 1.76 t/ha respectively. Following the success of the Paraná model, a similar programme was set up in the state of Mato Grosso do Sul in 1991, in conjunction with the University of Dourados, involving seventy demonstrations in the following three years. Here, an average of 4.9 applications were made to the IPM plots compared with 7.3 for the farmers' treatment. Cotton yields were 1.64 and 1.28 t/ha, respectively.

A further initiative has been the co-operation for the last fifteen years with the IPM programme in the State of São Paulo developed by CATI, the institute for rural extension services. Over 900 field demonstrations were carried out, and it was possible to reduce the numbers of treatments by at least 25% even where *A. grandis* was present. Key elements in the success of the IPM cotton programme were:

- Monitoring of pests and beneficials at 5 – 7 day intervals.
- Development of economic thresholds for all important pests.
- Timing of product use (endosulfan up to flowering and deltamethrin from full flowering onwards) to maintain high populations of beneficials for as long as possible.
- Collection and destruction of dropped infested buds for additional control of *A. grandis.*
- Chemical defoliation to control late pest attacks (in addition to facilitating harvesting and obtaining superior fibre quality).
- Cultural control by destruction of ratoon (remaining plants) after harvesting, and use of trap ratoon (adult *A.grandis* attracted onto regrowth), to control the pest later in the season and prevent high infestations the following year.

The main benefits to the cotton community were as follows:

- Awareness of the practicality of IPM techniques.
- Safer use of pesticides, with less risk for operators and the environment.
- Use of alternative low-cost technologies for supplementary pest control.
- Rational pesticide management for reducing pest resistance problems.
- Lower production costs and improved profitability.
- Encouragement for small to medium-scale farmers to continue their activities, thus preventing a rural exodus.

IPM in cotton can be considered a success story in Brazil. Both large and small growers have become aware of the benefits of IPM and over 60% of Brazilian cotton growers now adopt many of these concepts. Pest problems have been managed with reduced impact on the environment. Production costs have also been reduced, which has allowed the rural community to make a sufficient living from the crop. No significant problems with pest resistance have arisen during this period. The success of the cotton programme is also opening up new opportunities in a range of other crops, such as soya bean and vegetables.

Tomato in Brazil

Tomato is one of the most important vegetables in Brazil with 2.7 million tonnes per year grown on 61,200 ha, mainly in Rio de Janeiro State. AgrEvo, together with the ongoing DESUSMO Project (Development of Sustainable Farming Systems on Mountainous, low Fertility grazing land in South America), universities and other Brazilian institutions, initiated a project in September 1997 to demonstrate the viability of IPM tomato production. There were paired blocks, each of 3,000 plants, to compare IPM and conventional regimes. These received twelve and twenty-two insecticide, and sixteen and eighteen fungicide applications, respectively. The main pests were virus (spotted wilt) vectors and Lepidoptera (*Tuta absoluta and Neoleucinodes elegantalis*) and diseases *Phytophthora infestans* and *Alternaria solani.*

On the IPM area there were less effects on beneficial insects, improved fruit quality, a 12% higher yield and 13% higher gross turnover than on the conventional area. Factors in the success of the project were identified as training of technicians in scouting and other techniques, involvement of the local agricultural department and regional producer association, and promotion of IPM at field days, tomato grower meetings and local fairs. Several farmers encouraged by the success are now implementing the system in other vegetables, where the benefits are seen as improved quality, less risk of residues, better acceptance by consumers of IPM/ICM produced vegetables, and a secure food supply.

Wheat in France

Determination of pest thresholds and optimal times of application are important aspects of ICM. A model was developed following collaborative work between AgrEvo and INRA-ENSAR, the national research institute for agriculture, from 1991 to 1995. It enables farmers and advisers to forecast the development of populations of *Sitobion avenae* (grain aphid) on wheat, to predict an optimal date for insecticide application, and also to simulate grain yield based on aphid density, crop stage and date of application. A total of fifty-five model development trials was carried out in France in which deltamethrin was applied from GS 45 (Zadoks, 1974) at weekly intervals. Assessments were made of crop growth stage, aphids/ear, and presence of beneficials at each application, and yield at harvest. This was followed by validation trials in England, Germany and Belgium. It was found that predators could account for between 5 and 30% aphid mortality and so the impact of such beneficials is taken into account in the model. To use the model the following data must be provided:

- Crop drilling date.
- Assessment date and crop growth stage.
- Numbers of *S. avenae*/tiller based on examination of at least 100 tillers/field.
- Percentage of aphids parasitised by beneficials.
- Weather data.

The model, called COLIBRI, is available as a software package. It is an innovative tool for the integrated management of *S. avenae* on wheat. It is there to assist farmers' decisions and not replace direct field observations. It has been found to work well in practice, giving predicted optimal application dates close to those which occurred in practice. It has also provided useful information on *S. avenae* population dynamics.

Cotton and pigeon pea in India

IPM programmes were begun in 1996 based on a combination of agrochemicals:

- Endosulfan, which has good selectivity to beneficial insects.
- Triazophos, for an ovicidal effect against *Helicoverpa armigara* (cotton boll worm).
- Deltamethrin, which is highly effective at very low doses against Lepidopterous pests.
- Deltamethrin + triazophos, which controls mixed infestations of *H. armigara* with aphids, thrips and jassids, leading to a reduction in the number of insecticide sprays.

and products of natural origin:

- *Trichoderma viridae,* a bio-fungicide for control of seed and soil-borne fungi.
- A neem-based insecticide having antifeedent and insect growth regulator activity.

These programmes varied according to the geographical location and crop stage. AgrEvo staff were trained in identification of pests and beneficial arthropods, monitoring and scouting techniques and the determination of economic threshold levels (ETL's). They then passed on this knowledge to the farmers, together with information on the selection of the right agrochemical product, correct handling and timing of application. This was done by demonstrations on 0.4 ha plots, and the information from these plots was compared with the farmers' conventional practice for efficacy and cost. Following successful results at two locations in 1996, when in each case the IPM programme was the most profitable, the work was extended the following year to seven key cotton growing areas and one for pigeon pea (Table 1). In six out of the seven cotton trials, pest control and seed cotton yield were better on the IPM than on the farmers' treatment, but at all seven locations the IPM treatment was the most cost-effective.

Table 1. IPM control on cotton and pigeon pea in India in 1997.

	Cotton		Pigeon pea	
	IPM	Farmers	IPM	Farmers
No. of insecticide applications	9.7*	11.6	5*	7
% bud/pod pest damage	3.5	5.2	9.5	12.0
No. *H. armigera* larvae/25 plants	4.4	6.2	-	-
Relative plant protection cost/ha	100	115	100	140
Relative crop yield/ha	100	73	100	79
Relative cost:benefit ratio	100	71	100	71

*One seed treatment in addition to the number of sprays indicated.

Potato in the Netherlands

Control of potato blight *(Phytophthora infestans)* continues to be a major problem facing the potato grower. Spraying has traditionally been carried out on a routine calendar basis, commencing when the potato plants meet in the row or on receipt of disease warnings. There has been little flexibility to adjust the product dose or spray interval. AgrEvo has therefore developed the 'Flex concept' based on propamocarb-hydrochloride. The unique features of this chemical allow an innovative approach to designing a blight-protection programme consistent with ICM. This computerised warning system was developed over the past two seasons in conjunction with Dacom in the Netherlands. The concept is based on calculating a risk score. It takes account of:

- Varietal tolerance/sensitivity to *P. infestans*
- Recent weather or irrigation (i.e. recent disease conditions)
- Anticipated weather or irrigation (i.e. future disease conditions)
- Evidence of *P. infestans* infection in the area (including dumps and volunteers)
- Delay to the spray schedule

A total risk score is calculated by adding the individual risk scores from the above criteria. Scores of 2 or less constitute normal risk, and scores of 3 or more constitute high risk. From this, an appropriate dose (full, three-quarter or half) is derived depending on the spray interval (7, 10 or 14 days) and the level of risk. Such a concept eliminates unnecessary spraying or too high a dose being applied. Spraying at the right time against *P. infestans* is essential. Too early means a waste of chemical; too late will allow the disease to become established. Green leaf area assessed on a scale of 0 (leaf dead) to 10 for two trials in early September 1997 gave mean scores of 2.1 for the untreated, 5.7 for routine spraying at 7-day intervals (9 applications) and 5.8 for the Flex programme (7 applications). The concept has successfully been adopted by about five hundred farmers in the Netherlands. It has generally meant a saving of two applications, often with a reduced dose. A detailed knowledge of all the parameters involved (crop, climate, disease and its local presence, and the fungicide) was essential for the success of the project.

Rice in the Philippines

Large-scale IPM trials were carried out in lowland rice during 1995 and 1996 in conjunction with the Western Visyas Integrated Agricultural Research Center. These were designed not only to evaluate the level of pest control, but also to determine the impact on beneficial arthropods and the benefit to the farmer. On the IPM plots, one or two insecticide applications were made using deltamethrin to control *Nephotettix* spp. (green leaf hopper) and triazophos against *Scirpophaga incertulas* (yellow stem borer), compared with three or four by the farmer. Results have consistently shown that by regular monitoring of the population dynamics of these main insect pests and beneficials, such as *Lycosa pseudoannulata* (wolf spider) and *Cyrtorhinus lividipennis* (mirid bug), crop protection products can be used safely and effectively. For example, in one trial, deltamethrin was not applied because *Nephotettix spp.* and other foliar-feeding insects did not exceed the respective ETL's owing to the very high populations of *L. pseudoannulata* and *C. lividipennis*. However, the beneficial arthropods were not present in sufficient numbers to keep the population of *S. incertulas* below economically-damaging levels and triazophos was required to control this pest. Although an excellent level of control was obtained, there was a slight reduction in the population of beneficials. However, these recovered to normal levels a few days after spraying. The IPM treatment was the most effective in terms of *S. incertulas* control (deadhearts 50 days after planting and whiteheads 10 days before harvest), grain yield and cost effectiveness (Table 2).

The IPM programme has been well accepted by farmers and is now adopted on 100,000 ha of lowland rice. Key reasons for the success were:

- Acceptance of monitoring as a decision tool for applying the appropriate products.
- Reliability of level of pest control given by the crop protection products used.
- Selectivity to beneficial arthropods at the recommended doses of the products used.
- Co-operation of government extension workers, research organisations and the local crop protection association with training farmers in pest identification and monitoring.

This is just part of the ICM work on rice being undertaken in the Philippines. Other activities include use of resistant varieties, appropriate water management, crop nutrition and biological control agents.

Table 2. The effect of IPM programmes in lowland rice trials in the Philippines, 1995/96.

	IPM treatment	Farmers' practice	Untreated
% deadheart damage	2.2	2.6	5.7
% whitehead damage	1.7	2.4	5.6
No. *L. pseudoannulata*/ 100 hills/plot 21 DAT	270	140	270
Grain yield (t/ha)	5.2	4.0	3.7
Cost: benefit ratio	1: 1.5	1: 1.3	1:1.0

CONCLUSIONS

For ICM to be successful it must have the support of all the different sectors involved e.g. private industry, official research, extension service, government and farming communities. Farmers are often wary of implementing ICM into their daily activities, and the use of farm-scale demonstrations is therefore essential to give reassurance that ICM is necessary and that it does work in practice. Having overcome the initial apprehension it was encouraging that ICM techniques were then willingly taken up by farmers who realised the benefit. It enabled them to reduce the number of applications without loss of yield. Programmes were often more cost-effective and with less environmental impact. Effective implementation of ICM also requires training and education, the development of decision-support systems, and other new technology. Biotechnology will play an increasing role in ICM in the future.

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