SESSION 3B

PEST AND DISEASE MANAGEMENT IN ORGANIC PRODUCTION SYSTEMS

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Papers:	3B-1 to 3B-5

The research needs of organic farming: distinct or just the same as other agricultural research?

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ABSTRACT

The increasing importance of organic agriculture requires a critical assessment of its research needs. Different philosophical roots result in its research needs being distinct from other systems of production. Successful organic farming depends upon the functioning of a whole integrated system. The development of quantitative models incorporating these features and information on key processes is fundamental. Other major needs are an increased understanding of soil biology and of key species, e.g. arbuscular mycorrhizal fungi. Comparisons of organic and conventional systems are seen as having limited value in the development of organic farming methods.

INTRODUCTION

Interest in organic farming is currently at an unparalleled level. From a base of less than 0.1% of the total EU agricultural area in 1985, it has increased to over 2%. Extrapolating this rate of growth would lead to 30% of Western European Agriculture being organic by 2010. In the UK, land registered and managed organically was 1.3% of the total agricultural area in April 1999, with the highest number of producers being in the Northwest and South of England, Scotland and Wales (Soil Association 1999).

Growth in activity seems to be related to both current financial pressures and a changing view of public expectation of agricultural industries. In a review of farm incomes in Scotland, using data from the Scottish Executive Rural Affairs Department, Cook and Ramsay (1999) found that for mixed farms, net farm income for the 1998 crop year was just £416. This was augmented by direct subsidy receipts of £26,284. For cereal farms the comparable figures were £5.9k and £28.0k. The difficult financial climate in agriculture is a significant driver for the increased interest in organic production. In parallel with economic changes, the 1997/8 surveys of farmland birds, have indicated decreases for a number of species of Conservation Concern (Red List Birds) such as the song thrush, linnet and corn bunting (Noble *et al*, 1999). Links between bird populations and farming systems are complex, but decreases in the numbers of common birds have increased public interest in how the countryside is used and hence their interest in methods of farming.

The future growth of organic farming is thus likely to depend both upon the economics of this system of production and upon its ability to meet public expectations as to environmental benefits. The research needs of organic farming must relate to these key objectives. Critical issues for research planning thus include the extent to which the needs of organic farming can be met through the use of data from other systems of farming, and how data can be presented to the organic industry in a way appropriate to their needs. Both of these issues require an analysis of the key features of farming systems and a comparative diagnosis of critical research needs.

The characteristics of different farming systems

Farming systems can be characterised in a range of ways. A characterisation based on the use of externally derived resources is shown in Table 1. This also indicates the key needs for the further development of the systems. There is a gradation between intensive arable cropping systems and mixed organic systems, although they differ in more ways than they share future needs.

Table 1. A suggested gradation of farming systems based on external resource use and their most important development needs.

Development Type			
Intensive Arable →	Environmentally aware cropping (IPM/ICM) →	Mixed Farming →	Organic
Development Needs			
•Cost reduction	•Optimisation of element use and biological control	•Additionality between enterprises	•Management of biological cycles
•Externalisation of costs	•Cost reduction	•Rotations	•Ecology of production systems
•Simplification of management	•Optimisation of yields	•Scale/links	•Use of biodiversity
•Maximisation of yields	•Product quality	•Flexible management	•Product health and quality

For intensive arable systems the highest priority is the reduction of costs to allow them to compete at world market prices. This requires maximisation of unit size, the externalisation of costs and a narrow focus on production. The philosophical tenets underpinning this type of system are:

- The enterprise conforms to an industrial model with the efficiency of crop production and maximising economics as the primary goal.
- Efficient production needs a relatively simple management model, hence a reliance on linear systems so the identification of a disease problem, is followed by the application of the chemical most likely to give control.

- The system depends upon maximising externalities. The costs of diffuse pollution are thus funded by the water industry, and those of farm enlargement, e.g. job and facility losses by government.
- Environmental features are viewed as entities to be funded by grants.

For organic production systems the dominant characteristics are different, but not always the opposite of the features of intensive systems. The features of organic systems were defined by Woodward and Lampkin (1990). They noted that the complexity of organic systems had resulted in attempts to define them in terms of what they were not. This has resulted in misconceptions, especially in relation to the non-use of chemicals, the substitution of organic materials for chemicals, and emphasis on traditional values. The standards expressed by the International Federation of Organic Agriculture Movements make clear the importance of food quality, natural systems and cycles, minimal environmental impact, high animal welfare and the need to consider social impacts. Key features of organic systems can thus be summarised as:

- Although the production of high yields of crops and animals are of major importance, they must be achieved by the management of nature not domination.
- Pest or disease problems at an unacceptable level within the system are seen as a failure to manage the ecological processes and cycles which normally control them. The integrated nature of the system aims to avoid problems by balancing crop demand, e.g. for nutrients, with availability.
- The integrated nature of the system is designed to deliver quality food, animal welfare, and biodiversity throughout the system and social structures e.g. rural communities, rather than just saleable products. Farmers, and their families, are important components of the system.
- Through the management of natural cycles, and recycling, the system internalises costs externalised by intensive crop production. Local food production with nutrient cycling is important, and food miles are a source of concern.

"Conventional" arable and organic systems thus differ fundamentally in many ways which influence their research priorities. Although, not without importance in conventional systems, the key needs of organic systems relate to an understanding of ecological processes such as soil biological activity, vegetation dynamics and insect population ecology, the long-term monitoring of their effects on production, and an understanding of the links between land, production and food quality. The information needs of organic systems are summarised in Table 2 which identifies the pivotal role of studies at the systems level, on soil processes, and on the key crop/symbiont and pest/pathogen organisms within organic systems. These research needs of organic agriculture are now examined in greater detail.

The Agricultural System

Research on organic farming as a holistic integrated entity is key to its development as a means of producing of quality food. Organic systems depend on rotations where the enterprise on a specific land area will change, perhaps annually. An aim of a rotation is to optimise the match of cropping to land, soil and climate. This means that it is not possible to compare organic with non-organic systems in the same way as crop production on fields or small plots can be compared for response to different chemical treatments. For most of the UK soil variability and previous cropping history precludes the easy matching of replicated systems and hence simple organic versus non-organic comparisons. Although organic farming depends upon rotations for the control of nutrient supply and soil-borne diseases, it depends upon the scale of the system and its inherent biodiversity for effects on pests and air-borne diseases. A key element of organic farming research is thus to identify those elements which need to be assessed at a whole systems level, i.e. are dominated by interactions or large scale ecological processes and those which can be assessed and quantified at a plot scale. For this latter case, factors which affect the scaling of data from plot to field to system, need to be identified (Atkinson & McKinlay, 1995).

Our inability to replicate agricultural systems makes it difficult to apply the procedures of the scientific method at this scale. They can be applied for more detailed aspects. This also precludes the use of standard parametric tests e.g. ANOVA at this level. There is thus a need to identify rigorous quantitative methods of analysis for systems level data. The lack of acceptance of systems studies by conventional scientific journals means that much important literature on organic farming has been published outwith mainstream journals, so much information is inaccessible to the scientific community.

For the systems levels the key issues are the identification of factors influencing the scaling of process data to this scale, and the identification and description of internal transfers, organisms, resources and energy within the system. At the current time, knowledge of the metapopulation ecology of the key pests and natural predators of common field crops e.g. spring cereals, are poorly understood, but important to pest management. A typical crop rotation, some of the major nutrient flows into and from the rotation, and possible crop health, are shown in Figure 1. Husbandry practices aimed at optimising nutrient supply have significant effects on crop health and influence the risk of damage from pests and diseases.

If holistic research is to be carried out on farming systems then the human element must be included. Organic farming is commonly described as a low input system, but it is high input with respect to management inputs. This complicates systems comparisons. The impact of the human operator on crop yield and animal performance is difficult to quantify. While assessing the importance of human/farm animal contact on animal welfare may be critical it is not non-measurable in normal terms.

Comparisons of Agricultural Systems

The relative performance of organic and conventional systems is a critical issue (MacKerron *et al*, 1999). The types of comparisons which can be made are summarised in Table 3. The commonest, but least useful are small plot studies comparing "organic" and conventional crop protection regimes. These use varieties optimised for conventional treatment and planted in pure stands. The key element here is clarity in identifying the focus of the comparison.

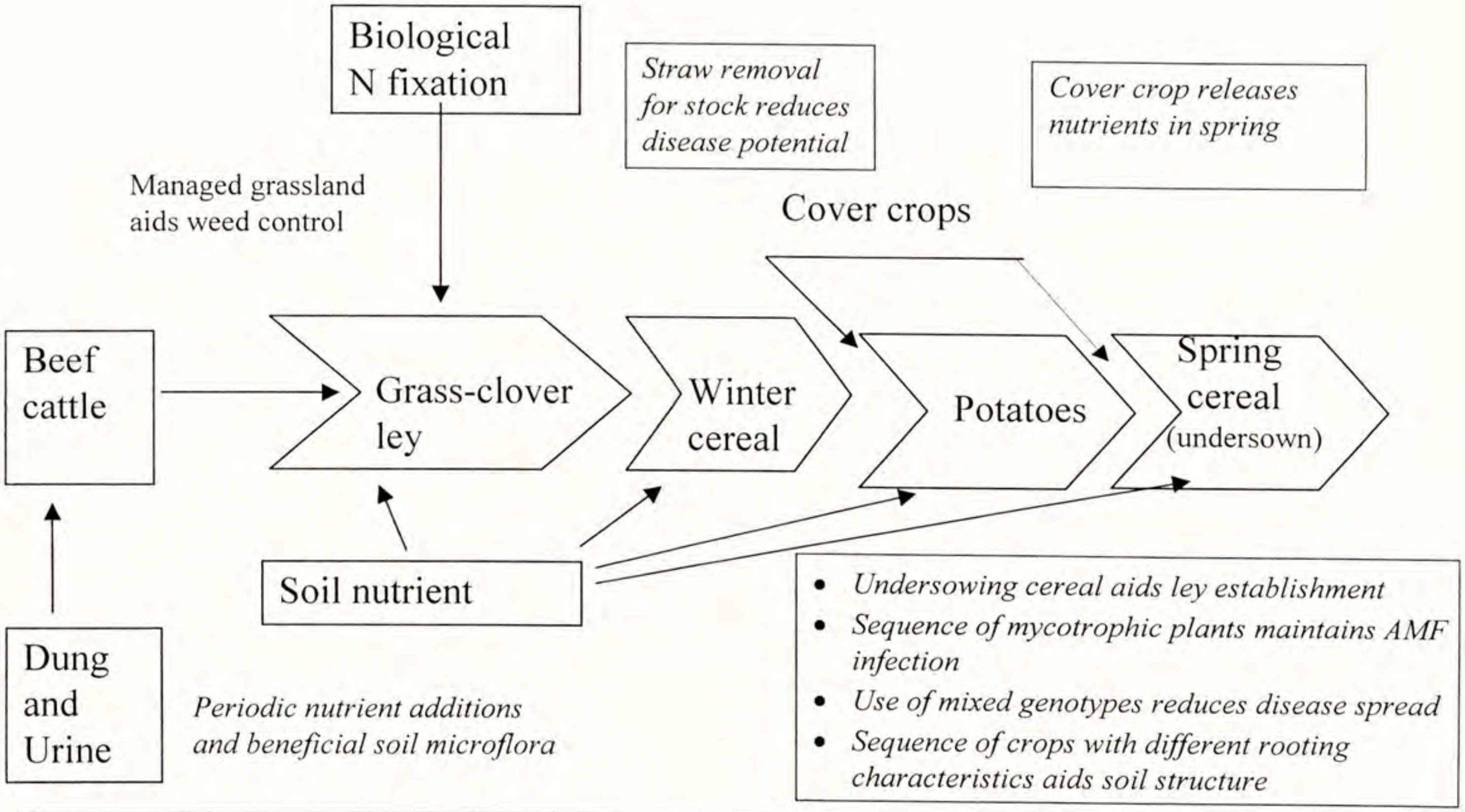

Figure1. A typical mixed stock/crop rotation and some of its influences on crop health

Table 2. The knowledge needs of organic farming systems

Scale:	Type of information:
Role and place within agriculture and rural economies	• Philosophical basis of system • Implications for the sustainability of rural communities and options for diversification • Definition of societal vision of agricultural practice
Individual farmed system	• Methods for synthesising results from the testing of scientific hypotheses with these obtained otherwise • Identification of criteria governing the use of data from non-organic systems in organic models • Links between land use features and farming options • Rotation and recycling implications of management decisions • Ecology of key organisms • Statistical methods for analysing whole farm data
Individual Crop	• Linking studies of processes to the field crop scale • Assessing the impact of prior years' actions • Acquisition of major and trace nutrients from soil and the assessment of its implications for crop health • The conservation of nutrients within the soil system • Interactions between key nutrients in potentially nutrient limited situations • The role of genotype diversity in the crop and the spatial arrangement of the crop and other species for crop health
Soil systems	• Nutrient transformations within soil and the role of symbiotic, beneficial and pathogenic organisms in this and in nutrient speciation
Individual species	• The biology, genetics and ecology of key organisms

Table 3. Options for comparisons of organic and conventional agricultural systems

Scale of comparison	Comparison possible
Farm Systems	• Gross and net margins relative to size or enterprise value • Yields for similar crop types • Disease/pest incidence • Systems assessment via models • Biodiversity
Crop	• If, within appropriate systems, detailed crop development, soil processes etc.

Soil Health

The founders of the organic movement saw the maintenance of soil biological activity as critical to the health of the system. An era of meeting nutrient needs through fertilisers and soil "disease" protection through sterilants resulted in an inadequate knowledge base for soil biology. Much research has measured total soil biomass or the presence of specific organisms. The functional activity of these organisms is, however, key to the management of soil health. Although the products of soil biological processes are important to all systems of agriculture, they are vital to the functioning of organic systems and thus a higher priority for organic research. The roles of both the consortia of organisms in soils and individual organisms need clarification. Developments in this area have the greatest scope to increase both crop yield and food quality. At the field scale, managing existing microbes adapted to specific soil conditions is more likely to help than the addition of "exotic" microbes.

Studies on target organisms

The biology of organisms involved in the maintenance of crop health was unimportant when protection was achieved via chemicals. Recent research has indicated the extent of the co-evolution of land plants, and their associated micro-organisms. It is now clear that susceptibility to diseases is increased when plants which would naturally rely on a symbiont such as Arbuscular Mycorrhizal Fungi (AMF), for much of their resistance to soil borne pathogens, are deprived of this support (Figure 2).

AMF influence resistance to disease through changes in nitrogen status, changes in morphology (growth regulation), modification of root longevity (reduced exposure to disease), minimisation of pathogen induced stress, and a reduction in the severity of pathogen attack (Hooker *et al*, 1994).

The importance of AMF in inducing disease resistance identifies a need for better understanding of their biology and genetics. Molecular genetic techniques have allowed the differentation of the morphologically similar AMF on different species, and demonstrated that genetically distinct types of the same "species" of AMF can be found on different species. AMF are obligate symbionts so understanding their functioning must involve the separation of their activity from that of root cells. In AMF infected plants it is now possible to separately identify plant and fungal genes which are both up, and down regulated, during symbiosis. Molecular studies, of this type, are needed if the functioning of the symbiosis is to be optimised to benefit of crop health and production.

Conclusions

The philosophical basis of organic farming has been shown to be distinct from other systems of agriculture. Organic agriculture depends upon ecological processes and cycles rather than on the more targeted approaches of other systems. These differences mean that the research to develop organic agriculture will differ from that needed for other systems. For the future, the needs of organic production will remain focussed on understanding systems, the development of quantitative models and increased understanding of soil biological processes and key organisms.

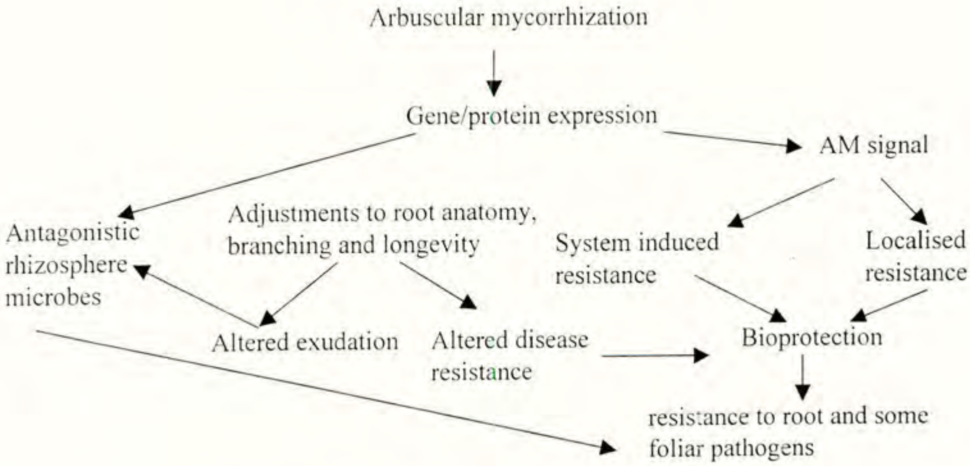

Figure 2. The impact of Arbuscular Mycorrhizas on plant health (after Gianinazzi 1995)

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The impact of pests and diseases in organic agriculture

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ABSTRACT

In organic agriculture, the importance of noxious organisms will tend to increase in the future. Reasons for this development include the general trend to lower crop diversity on individual farms, the demand for constant market supply and excellent quality, as well as new regulations on organic agriculture such as limitations of copper use. Approaches to meet the new challenges include improvement of yield security (e.g. resistant or tolerant varieties, crop protection agents) as well as economic strategies which counterbalance local and regional impacts of climate. One of the major bottlenecks for the introduction of new crop protection techniques into practice is the trend for increasingly restrictive registration procedures in Europe.

INTRODUCTION

Organic farmers have suffered serious losses due to pests and diseases since the very beginning of organic farming. In particular, perennial crops such as top fruit or grapevine were prone to heavy losses due to noxious organisms, often virtually prohibiting organic production of such crops. Although many pests and diseases have similar importance in organic farming as in conventional production systems, there are important differences as well. In Switzerland, conventional farmers use pesticides (43 M Euro worth) on arable crops which represent approximately 60% of the total pesticide use (Anonymous, 1997). In contrast, organic farmers use virtually no pesticides on arable crops as only Late Blight (*Phytophthora infestans*) makes farmers use a fungicide (Tamm *et al.*, 1999).

However, recent developments indicate that several noxious organisms cause more yield losses and that farmers are becoming more dependent on efficient crop protection strategies. This paper aims to (i) identify some of the most important organisms at present and those which are likely to become important, (ii) to elucidate some of the reasons that may contribute to this development, and (iii) to discuss the potential of some approaches to mediate the impact of pests and diseases.

THE IMPACT OF PESTS AND DISEASES ON ECONOMY

The consequences of losses due to pests and diseases differ considerably, depending on region, crop, farm structure or market demands. Noxious organisms may be classified by the type of impact they cause. A very simple classification can be made by differentiating noxious organisms which (i) cause more or less regular losses which seldom exceed 20% or cause increased sanitation costs (e.g. weeds) on a regular base, and (ii) such organisms which may cause total loss of the yield and/or hamper the survival of perennial crops. Noxious organisms of the first category do not cause incalculable losses. From the farmers point of view, lower yields per hectare may easily be compensated by higher prices and increased production areas. In contrast, noxious organisms that cause incalculable losses do influence organic production on several levels:

- A crop can be lost in one year if weather conditions are conducive for the development of an epidemic. The farmer can compensate for the yield loss, provided that he is able to diversify within his farm. High risk crops include potato and tomato (*P. infestans*) (Erwin and Ribeiro, 1996), cherry (*Monilinia laxa* (Tamm *et al.*, 1995), *Rhagoletis cerasi* (Boller *et al.*, 1987)), strawberry (*Botrytis cinerea* (Bulger, 1987)), or grapevine (*Uncinula necator*, *Plasmopara viticola* (Pearson and Goheen, 1988)).

- Due to macroclimatic effects, heavy yield losses occur not only on individual farms but also within a whole region. In consequence, the market demand can not be met with sufficient quantities. The fact that yields fluctuate much more in organic agriculture than in conventional systems has become one of the single most important factors that limit the growth of the organic market share.

- In regions where a high risk crop is cultivated traditionally, conversion of farms to organic agriculture may be seriously hindered. In the region of Basel (Switzerland), for instance, sweet cherry has been cultivated by almost every farmer. Although sweet cherry contribute only 2-5 % to the income, farmers are very reluctant to convert to organic agriculture since they fear the risks that come with organic sweet cherry production.

- There is a high demand for crops such as wheat. However, wheat production cannot be sufficiently increased if there is a lack of appropriate partner crops to be used in crop rotations. In Switzerland, for instance, rape seed production is limited due to unsolved problems with *Sclerotinia sclerotiorum* and *Meligethes aeneus* (Koechlin *et al.*, 1999). As a result, wheat production cannot be extended as desired.

- Noxious organisms may prevent the production of a crop within a region. In consequence, the possibilities for diversification into new crops of high demand (e.g. hops, ornamental plants) may be limited.

PRESENT AND FUTURE THREATS TO PLANT HEALTH

Many pests and diseases have threatened agriculture for a long time (Agrios, 1988). Apple scab (*Venturia inaequalis*), for instance, causes economic losses world-wide, regardless of the production scheme either by damage to the crop or by costs due to fungicide use (MacHardy, 1996). Furthermore, organic as well as conventional agriculture is likely to experience the introduction and spread of "new" noxious organisms such as Fire Blight *(Erwinia amylovora)* on Apple and Pears (Germany, Switzerland) (Hasler and Kellerhals, 1995), Flavenscence dorée on grapevine (France) (Rousseau, 1997), or more aggressive strains of Late Blight (*P. infestans*) on tomato and potato (world-wide) (Andrivon *et al.*, 1998; Lebreton *et al.*, 1999).

Many potentially noxious organisms that have not been considered as very important to organic agriculture in the past are likely to cause much more serious problems in the future. The reasons are man-made altogether as many of the "new" problems are due to (i) higher specialisation on farm level, (ii) higher market demands on quality standards on appearance of the produce, (iii) demand for constant market supply, and (iv) changes in regulations on international as well as national level.

(i) In continental Europe, farms tend to shift from highly diverse production and income structures towards highly specialised structures where the income depends on very few or even one single crop. Viticulture is one example where the farmers income depend on one single crop which is prone to two most important fungal diseases (*U. necator, P. viticola*). So far, viticulture has been an exception in its extreme dependency to one single crop. However, there is a very clear trend that farms which had animal husbandry, arable crops, vegetable production and even top fruit at the same time are now focussing on fewer crops and sources of income. As the quality demands as well as pressure on prices increase continuously, only very professional and knowledgeable farmers are able to meet these demands. In consequence, farmers with high diversity of crops find it difficult to maintain high standards of production in several crops.

(ii) Lately, the industry quality requirements have become stricter. There is a general agreement between organic farmers that organic produce has to meet the highest standards of "internal" quality. The requirements on "external quality" have been considered as less important so far. However, stricter thresholds have a tremendous impact on efficacy requirements of crop protection techniques. For instance, organic apple production becomes virtually impossible if quality requirements include factors such as zero tolerance for scab, or sooty blotch as well as equal fruit size. A similar example is leek, where complete suppression of thrips is extremely difficult and impractical altogether in some regions.

(iii) The organic farmers are not yet able to provide the market with constant and predictable quantities of a given product. Extreme fluctuations of produce cause very unstable prizes. Moreover, organic production will not be able to obtain and keep market shares above 5% if market supply fluctuates from year to year. Therefore, the lack of constancy of yields of products such as potato has become a major bottleneck for the expansion of the market share of organic products.

(iv) Changes in regulations have a serious impact on demand for crop protection strategies. Most important, the pending ban of copper use in organic agriculture (EU, 1991; EU, 1997) may cripple the organic production of crops such as grapevine, top fruit, or potato. Alternative strategies for the control of the respective diseases have to be developed as fast as possible. The second important change in regulations is the requirement for use of organically produced plant material. So far, most organic farmers used seed that was free from seed-borne diseases as it was usually conventionally treated against soil-borne diseases. As disease and pest-free planting material is a prerequisite for prevention of noxious organisms, the production of first-rate organic planting material will be of paramount importance.

PROSPECTS OF CROP PROTECTION STRATEGIES AND MAJOR BOTTLENECKS

Organic agriculture always dreamed of agro-ecosystems with very high self-regulatory capacity (Lampkin, 1990; Schmid and Henggeler, 2000). The strategies that finally lead to improved plant health are diverse and have to be adapted depending on a particular crop as well as the region. In an ideal organic system, all possible measures that lead to improved stability of the system have to be implemented, finally resulting in a system that does not suffer from noxious organisms. In this context, pesticide-based crop protection strategies are considered as undesirable.

A set of strategies that contributes to improved plant health is described schematically in Figure1.

Sanitation.

Sanitation includes strategies such as use of high-quality seeds (e.g. wheat, *Tilletia caries* (Ruegger *et al*., 1998)), removal of overwintering sources of inoculum (sweet cherry, *M. laxa* (Byrde and Willetts, 1977)), or removal of infected volunteer plants (potato, *P. infestans*) (Hooker, 1990).

Avoidance techniques.

Avoidance techniques are usually achieved by exposing a crop at later physiological stages to a noxious organism (e.g. chitting of seed potato).

Variety.

The use of tolerant or resistant varieties still remains the backbone of organic agriculture, provided that resistant varieties with acceptable agronomic and consumption properties are available (e.g. apple, *V. inaequalis* (Kellerhals *et al*., 1997)).

Variety mixtures.

Variety mixtures have become a very efficient technique to stabilise yields and quality of certain crops (Zhu *et al*., 2000). In Switzerland, for instance, more than 90 % of the organic wheat is grown in variety mixtures.

Intercropping.

Intercropping is a technique which has not yet been applied widely. Whereas the control of fungal diseases may be difficult by this strategy, entomologists have achieved spectacular successes in suppression of pests (apple, *Dysaphis plantigena*) (Altieri, 1994).

Soil management and plant nutrition.

Although the impact of soil management and plant nutrition is well known in its principles, there is still a huge potential to be exploited (tomato, *P. infestans*) (Koechlin *et al*., 1999).

Crop protection.

Finally, the use of crop protection agents such as fungicides/insecticides, antagonists, or inducers of resistance remains the single solution if none of the strategies mentioned above leads to acceptable control of noxious organisms. For instance, the development of a biocontrol agent against *Cydia pomonella* and the introduction of a neem-based product against *D. pomonella* have facilitated the reliable organic production of apple (Wyss and Tamm, 1996).

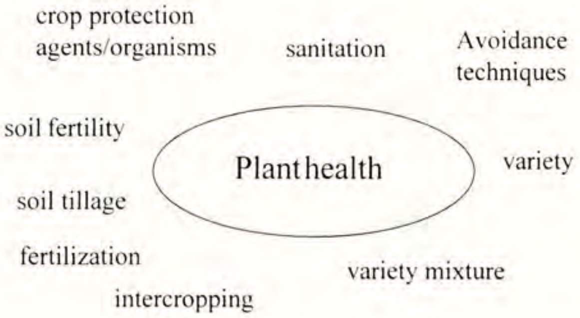

Figure1.: Strategies that may contribute to improved plant health. See text for details.

The future development of organic agriculture will be influenced by at least four distinct concepts which will be described below. Certainly, the developments will differ between crops, regions, traditions, and market demands.

The stabilised agro-ecosystem.

There is a huge potential to improve general stability of the organic agro-ecosystems. This can be achieved by use of resistant varieties, variety mixtures, appropriate habitat management, or soil management strategies (fertiliser, crop rotation etc.). One of the major draw-backs is the fact that there are no universal rules for a given crop that work in all environments. Therefore, every single farmer has to adapt a general concept to his individual situation. As a result, there is a huge demand for advisory services.

The silver bullet approach.

Several problems have been solved by the availability of pesticides such as copper, or more recently, neem-based insecticides. The universal applicability of such products and the relatively easy use make them very attractive to many farmers. However, there are two major disadvantages of this concept: First, pesticides with high efficacy tend to supersede more costly system-stabilising techniques such as wildflower-strips or resistant varieties. Second, there is a clear tendency that registration of new crop protection products becomes more difficult and costly due to extended registration requirements. As a result, the development and introduction of new crop protection products in the relatively small organic market may be hindered in the future.

The risk diversification scheme.

On farm level, the diversification of crops is an attractive method to avoid high risks due to noxious organisms. At present, large farms that previously relied on conventional monoculture diversify when they convert to organic production. However, the professional management of several commodities requires very knowledgeable farmers and usually causes higher costs on machinery. Furthermore, the regional fluctuations of yield that restrict the expansion of organic agriculture will persist.

The trade approach.

Yield losses are usually limited to a certain region. Quite often, the overall production on a larger scale (e.g. Europe) is quite constant. For example, potato production in Switzerland and some parts of France was low in 1999 due to severe attacks by *P. infestans*. In Bavaria and Austria, however, yields were quite high and satisfactory. As the constant supply of the European markets is a prerequisite for the extension of the organic market share, trade may represent a suitable approach to overcome shortcomings of supply as it is independent of progress in crop protection techniques. However, efficient and fair trade structures that help farmers to keep prices as well as market supply constant on a multi-region scale are yet to be developed.

CONCLUSIONS

Pests and diseases of plants are still a threat to farmers and hinder the expansion of organic agriculture. Strategies to improve the situation require the collaboration of farmers, governmental authorities, scientists, advisory services, and farmers associations.

- Scientists and, wherever appropriate, industrial partners have to develop more reliable production systems, based on the principles described above.

- The development and introduction of improved crop protection products has to be facilitated by registration procedures which are adapted to the particular requirements of organic agriculture. Therefore, collaboration of registration authorities is required to ensure the development of organic crop protection.

- Improvment of production technology is not the only answer to shortcomings in market supply and stability of the farmers income. Improved market structures may contribute even more to the development of organic agriculture than science can do. Therefore, there is a huge potential for farmers organisations to develop and introduce innovative marketing structures.

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Use of living ground covers for managing the whitefly *Bemisia tabaci* as a geminivirus vector in tomatoes

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ABSTRACT

The impact of whitefly-transmitted geminiviruses on tomato yields depends on plant age at time of infection, and is greatest during the first eight weeks after germination (critical period). Thus, a preventative scheme (based upon minimizing contact between the vector and the tomato plant during the critical period) is being pursued for resource-poor Central American farmers who plant tomatoes on small plots (< 0.5 ha). This scheme includes the use of living mulches after transplanting, to mask the crop from immigrating viruliferous whiteflies. Research conducted over six years shows that living covers reduce whitefly adult numbers, delay geminivirus dissemination, reduce disease severity, and provide higher yields in tomatoes. These covers include perennial peanuts (*Arachis pintoi*, Leguminosae), cinquillo (*Drymaria cordata*, Caryophyllaceae) and coriander (*Coriandrum sativum*, Umbelliferae). In some cases, perennial peanuts have provided both the highest yield and net profit (40 t/ha and US $ 38,000/ha), followed by "cinquillo" (36 t/ha, US $ 32,000 /ha) and coriander (30 t/ha, US $ 31,000/ha); normal yields in Costa Rica range from 21-35 t/ha. Since coriander provides additional economic returns when sold (US $ 5,000/ha), and is much easier to establish and remove than the other living covers, it is being recommended for commercial use.

INTRODUCTION

The Tomato Yellow Mottle Virus (ToYMoV), so far reported only for Costa Rica, is one of the many geminiviruses affecting tomatoes in the Americas, and is vectored by *Bemsia tabaci* (Homoptera: Aleyrodidae). The impact of diseases caused by this virus on crop yield depends on plant age at time of infection, and is greatest during the first eight weeks after germination (critical period).

In the search for management approaches to deal with both whiteflies and geminiviruses, a preventative scheme suited for resource-poor growers who normally plant staked tomatoes on small plots (< 0.5 ha), is under development. This scheme focuses on minimizing contact between the vector and the tomato plant during the critical period, and includes protection of seedbeds with tunnels of fine netting, as well as the use of mulches after transplanting, appearing to mask the crop from immigrating viruliferous whiteflies. The objective of this paper is to summarize recent research findings (Cubillo *et al.* 1999; Hilje & Stansly, 1998, 1999) that substantiate the role of living ground covers in reducing incoming whiteflies, slow down virus spread and reduce disease severity, as well as providing high tomato yields and decrease production costs.

METHODS AND MATERIALS

Research results encompass data from eight experiments, carried out for six years. Living ground covers were tested in large plots, so as to minimize interference between treatments. Some experiments involved a conventional statistical design (a randomized complete block design), with large experimental units (230-240 m^2). In the others no design was used, so that large plots (900-1200 m^2) were split into two equivalent subplots, each one receiving either a ground cover or the absolute control treatment (bare ground).

Living covers included perennial peanuts (*Arachis pintoi*, Leguminosae), the low-growing weed "cinquillo" (*Drymaria cordata*, Caryophyllaceae) and coriander (*Coriandrum sativum*, Umbelliferae). They were compared to the absolute control and a silver plastic cover (commercial standard); the latter corresponded to a silver/black, coextruded plastic (56" x 1.25 Mls) (Olefinas S.A., Guatemala). Living covers were established well before tomatoes were transplanted, whereas silver plastic was put in place over the 30 cm-wide bed two weeks before transplanting. All covers remained in the field throughout the season, except for coriander, which was removed at 35 days after trasplanting (DAT).

Tomato seedlings (var. Hayslip, Asgrow Seed Co., Michigan) were produced according to standard procedures under field tunnels covered with Tildenet IN50. Seedlings (22 days-old) were transplanted at 1.2 m between rows and 0.4 m between plants. Soil was prepared before transplanting and fertilized according to local practices. No insecticides were used in any plot during the experiments, but fungicides and bactericides were used as needed.

The variables measured included whitefly adult numbers, ToYMoV incidence and severity, and yields. *Adult whitefly abundance* was monitored weekly by randomly inspecting the underside of the highest, fully expanded leaf, in 30 tomato plants per plot. For assessing *disease incidence*, at the beginning of the crop season 100 tomato plants were selected in a systematic way and marked with a colored ribbon, and they were inspected weekly for geminivirus symptoms, to quantify the proportion of diseased plants. The same plants were used to appraise *disease severity*, for which they were evaluated weekly according to a standard visual scale. They were also harvested to determine *yields*, according to local quality standards or categories. ANOVA was performed to all variables, whereas economic data were analyzed by partial budgeting.

RESULTS

Adult numbers were always higher in the bare soil treatment, in all the experiments. They were lowest in the silver plastic treatment, which also gave rise to a substantial delay in ToYMoV dissemination and a strong reduction of disease severity, while providing high yields and net profits; they were as high as 50 t/ha and US$ 30,350/ha, respectively.

The silver plastic treatment was followed by living covers, which were also able to noticeably reduce whitefly adult numbers (Figure 1A), delay ToYMoV dissemination (Figure 1B), decrease disease severity (Figure 1C), and provide high yields and net profits. Even though their ranking varied according to each experiment, on the average perennial peanuts provided both the highest yield and net profit (22 t/ha, US $ 16,000 /ha), followed by coriander (19 t/ha, US$ 10,000 /ha) and Drymaria (17 t/ha, US$ 8,000 /ha). Nonetheless, yields in one of the replicates were as high as 30 t/ha (coriander), 36 t/ha (Drymaria) and 40 t/ha (perennial peanuts), with net profits of US$ 31,000, US$ 32,000 and US$ 38,000/ha, respectively.

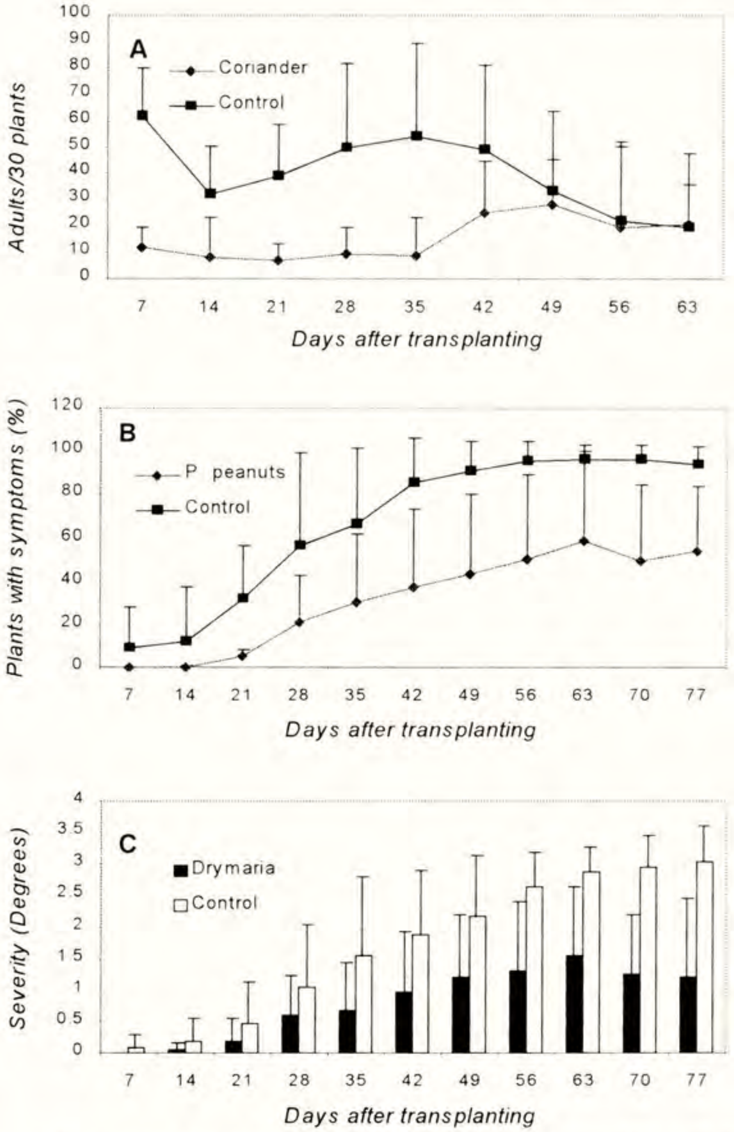

Figure 1. Contrasts between tomato plots with bare soil versus plots with different types of ground covers. Data correspond to weekly averages of whitefly adult numbers (**A**), ToYMoV incidence (**B**) and disease severity (**C**), plus 95% confidence intervals. Data taken from different experiments, Costa Rica, 1994-1999.

DISCUSSION

Whitefly numbers were always lower in treatments with either inert (silver plastic) or living ground covers. The only exceptions occurred late in the crop season, when adults moved to adjacent plots. In the case of silver plastic, perennial peanuts and Drymaria, this was probably due to the abundant growth of the tomato plant canopy, which probably hid the cover. For the coriander plot, the latter was removed at 35 DAT, so that the respective plot resembled a control treatment (bare soil). In all these cases, tomato plants in these plots were more succulent and thus possibly more attractive to whiteflies.

Vector pressure (adult numbers) during the critical period clearly influenced the rate of spread of the ToYMoV. In all cases, disease incidence reached 100% in the absolute control treatments, by the end of the season. This occurred with an average vector density as low as 0.3 adults/plant.

In all experiments, silver plastic was the best treatment in terms of reduction of incoming whitefly adults, delay of ToYMoV dissemination, reduction of disease severity, and highest tomato yields. It was followed by living ground covers, but their degree of effectiveness varied with each experiment; this can probably be attributed to the specific position of each living cover within the experimental plot. At any rate, living ground covers are a good alternative for managing whiteflies as geminivirus vectors, providing yields equal or superior to standard yields in Costa Rica, which range from 21-35 t/ha. Also, it has been shown that they do not harbor either whiteflies or geminiviruses, so that their use does not pose a risk for tomato production. In the case of coriander, since it can provide additional economic returns when sold ($ 5,000 /ha, on the average), and is much easier to establish and remove than the other living covers, it can be recommended for commercial use.

In summary, living ground covers can be a sustainable alternative to produce tomatoes, as they can be profitable and do not represent any environmental liability. Likewise, they are locally available and may provide additional income through sale of seed, forage or other products, and return extra organic matter and even nutrients to the soil.

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Control of seed borne diseases in production of organic cereals

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ABSTRACT

In production of organic seed it is important to have some control measures on seed borne diseases to avoid propagation and spread of serious diseases. Due to lack of acceptable treatment methods the only way for the moment is to discard seed lots with unacceptable infections. Experiments have been started to find new and alternative methods for controlling seed borne diseases. In spring barley the results show good effect with 5% acetic acid on leaf stripe (*Pyrenophora graminea*) but problems with unacceptable effects on seed germination have to be solved. The old method with hot water treatment can be used and the results indicate good results against leaf stripe using water at 55°C. The effect of hot water was enhanced by first soaking the seeds in water at 20°C. Controlling loose smut (*Ustilago nuda*) is more complicated and here pre treatment with soaking seeds in water at 45°C succeeded by short treatment in water at 50°C gave good results.

INTRODUCTION

In organic barley production, seed borne diseases like leaf stripe (*Pyrenophora graminea*) and loose smut (*Ustilago nuda*) can relatively quickly give rise to serious problems with reduction in yield. Chemical seed treatment is not possible in the last generations of organic seed production and the current strategy in production of healthy organic seed in Denmark is to discard seed lots with infections above defined threshold values (Nielsen *et al.*, 1998). In this way large amounts of seeds can be discarded. At present increasing the area for production is the only way to ensure adequate quantities and qualities of seed of different varieties.

Today, the number of acceptable control measures in organic seed production is rather limited. Use of resistant varieties is an obvious possibility, but we know only little about the distribution of resistance against seed borne diseases in modern varieties. Other methods could be to reintroduce old techniques like hot water treatment or to use chemicals different from the conventional seed treatments that are acceptable to the organic production.

The heat treatment in water to control seed pathogens in cereals were invented by J.L. Jensen in the 1870-80's (Jensen 1888). Heat treatment in water is usually divided into hot-water (high temperatures, >50°C) and short duration (<10 minutes) and warm-water (low temperatures, <50°C) and long duration (1-3 hours)). From about the 1890's to about 1930 several papers were published on the effect of these treatments, especially the warm-water method which was recommended for a wide range of pathogens, including leaf stripe and loose smut (Lind & Ravn, 1918). More recently studies were carried out on hot-water treatment aiming at control of leaf stripe and warm-water treatments to control loose smut of barley (Winter *et al.*, 1996, 1998).

Treatments based on pH-effects, i.e. manipulation the pH-value on the seed surface have been known for a long time (Buttress & Dennis 1947). These methods have primarily been used to control common bunt in wheat, and they have been based on increasing pH with alkaline treatments, using chalk and wood-ash. More recently Spiess & Dutschke (1991) tested different alkaline treatments showing good effects against common bunt (*Tilletia caries*). Treatments based on decreasing pH by the use of acids, to control barley leaf stripe and loose smut have to our knowledge not been tried before.

The objective of the present study was to investigate combinations of hot- and warm-water treatments on control efficacy and side effects on germination properties on barley leaf stripe and loose smut. Further, the objective was to study the effect of treatments based on pH-effects, using acetic acid as an example.

MATERIALS AND METHODS

All experiments were carried out at Research Centre Flakkebjerg, Slagelse, Denmark

The seeds used in the experiments were natural infected with either leaf stripe (*Pyrenophora graminea*) or loose smut (*Ustilago nuda*). Field emergence was counted at the 1-leaf stages and later on, the number of plants with leaf stripe or loose smut was counted. Plot size in all experiments was 9 m rows with 200 plants in 4 replicates.

Chemical seed treatment was included as standard in the trials with leaf stripe (Fungazil A or Fungazil bejdse, *imazalil*, 50g/l) or loose smut (Fungazil C, *imazalil*, 25g/l + *carboxin* 400 g/l)

Acetic acid against leaf stripe

Seeds of spring barley were treated with 5% acetic acid, pH 2,5 (same as vinegar) and then dried on filter paper for 24 hours. The seed was sown in a field trial with complete randomised blocks and 4 replicates.

Hot water against leaf stripe and loose smut

The first experiment with hot water was performed as a three factorial trial in spring barley. At first, the seeds were soaked in water at 20°C for 10, 20 and 30 minutes (factor 1) and then treated with hot water at 45°C, 50°C and 55°C (factor 2) for 2, 4 or 6 minutes (factor 3).

The second experiment with hot water was performed with randomised, complete blocks (4 rep.) in spring barley. The seeds were first, as a pre treatment, soaked in water (20°C or 45°C for 60 or 120 minutes) and then treated with hot water at 50°C or 55°C for 2 or 4 minutes.

RESULTS

Acetic acid

There was a clear dose response effect of acetic acid on leaf stripe (Table 1) but at the same time there is also reduction in seed germination at the high dose. Increasing the dose to 50 ml/kg gave full control in 1999 but only 81% control in 2000. The disease pressure was very high in 2000 but the number of plants was low. At the dose level 50 ml/kg a significant reduction in plants to 77-83% compared to untreated were observed.

Table 1. Control of leaf stripe (*Pyrenophora graminea*) in spring barley by seed treatment with 5% acetic acid. 1999 and 2000.

		1999		2000	
	Dose rate per kg seed	Rel. plant emergence	% leaf stripe	Rel. plant emergence	% leaf stripe
Control		100*a*	7.8*a*	100*a*	15.0*a*
imazalil	0.05g/kg	99*a*	0*c*	126*a*	0.2*c*
5% Acetic acid	10 ml/kg	102*a*	8.3*a*	117*a*	9.8*b*
5% Acetic acid	20 ml/kg	101*a*	6.5*a*	104*a*	10.1*b*
5% Acetic acid	30 ml/kg	97*a*	4.5*b*	120*a*	5.7*bc*
5% Acetic acid	40 ml/kg	94*a*	3.4*b*	128*a*	4.8*bc*
5% Acetic acid	50 ml/kg	83*a*	0*c*	77*a*	3.1*c*

Number of plants in untreated: 17.3 (1999) and 9.5 (2000) per m row.
Figures with the same letter are not significantly different

Hot water

1. Pre-treatment (soaking) at 20 C and then hot-water treatment at 45°C - 55°C.

Soaking the seeds first at 20°C as a pre-treatment and then treating them with hot water at 45°C - 55 C had no effect on loose smut (results not shown).

There was a considerable reduction in leaf stripe after hot water treatment at 50°C and especially at 55°C (Table 2). The effect of hot water was increased if a pre-treatment for 10, 20 or 30 minutes was included. There seems to be no difference between the duration of the pre-treatment.

Table 2 Relative plant emergence and attack of leaf stripe (*Pyrenophora graminea*) in spring barley after pre-treatment in water (20°C) and then hot water at 45°C, 50°C and 55°C for 2, 4 or 6 minutes.

Hot water		Pre-treatment in minutes							
		0	10	20	30	0	10	20	30
temp.	min.	%. leaf stripe				Relative plant emergence			
45°C	0	9.0*abc*	9.9*a*	7.8*b-g*	7.1*b-h*	100*a-g*	105*abc*	105*a-d*	104*a-f*
	2	8.5*a-e*	6.9*c-h*	7.8*a-g*	6.2*fgh*	98*e-i*	103*a-f*	101*a-f*	104*a-f*
	4	9.1*ab*	7.4*b-h*	6.5*e-h*	7.1*b-h*	100*a-g*	99*b-h*	98*c-i*	102*a-f*
	6	6.5*e-h*	8.1*a-f*	6.9*d-h*	7.3*b-h*	103*a-f*	101*a-f*	100*a-h*	102*a-f*
50°C	0	6.7*d-h*	7.6*b-g*	6.2*fgh*	5.4*hi*	102*a-f*	104*a-e*	100*a-h*	100*a-h*
	2	6.0*fgh*	5.9*gh*	3.3*ij*	2.8*jkl*	103*a-f*	99*b-h*	102*a-f*	107*a*
	4	3.0*jk*	1.8*j-n*	2.2*j-n*	1.0*k-n*	103*a-f*	103*a-f*	102*a-f*	106*ab*
	6	2.6*jm*	0.2*n*	0.7*lmn*	0.5*lmn*	99*b-h*	100*a-h*	104*af*	93*g-j*
55°C	0	5.3*hi*	8.8*ad*	6.8*d-h*	6.1*fgh*	98*d-i*	100*a-g*	105*a-e*	100*a-h*
	2	2.2*jn*	0.4*lmn*	0.2*n*	0.3*n*	100*a-g*	98*b-n*	103*a-f*	98*b-n*
	4	1.5*jn*	0.6*mn*	1.0*k-n*	0.6*nm*	101*a-g*	91*ij*	100*a-h*	97*f-j*
	6	0.3*n*	1.5*j-n*	0,3*n*	0.6*nm*	93*hij*	72*k*	61*l*	47*m*
imazalil *(0.05/kg seed)*		0.2*n*				90*j*			

Number of plants in untreated: 18.6 per m row

Only the high water temperature (55°C) for 6 minutes had a negative effect on the emergence of plants in the field. Combination of pre-treatment and high water temperature decreased the emergence significantly (Table 2).

2. Pre-treatment at 20°C (soaking) or 45°C (warm water) and then hot-water treatment with 50°C or 55°C.

Loose smut could only be controlled by first soaking the kernels at 45°C and then the hot water treatment at 50°C or 55°C (Table 3). However, only hot-water at 50°C for 2 minutes showed a high treatment efficacy without side effects on germination.

Table 3 Relative plant emergence and attack of loose smut (*Ustilago nuda*) in spring barley after pre-treatment in water (20°C or 45°C for 60 or 120 minutes) and then treatment with hot water at 50°C or 55°C for 2 or 4 minutes.

Pre-treatment		Hot water treatment									
		0	50°C		55°C		0	50°C		55°C	
			2 min.	4 min.	2 min.	4 min.		2 min.	4 min.	2 min.	4 min.
T[2]	min.	% plants with loose smut					Relative plant emergence (untreated = 100)				
20	60	16.4*a-d*	15.5*a-e*	16.0*a-d*	16.5*a-d*	15.5*a-e*	106*a-g*	118*a*	109*a-d*	111*abc*	105*a-g*
	120	14.3*a-f*	16.8*ab*	17.4*a*	12.5*ef*	15.6*a-e*	109*a-d*	114*ab*	110*a-d*	104*b-g*	105*a-g*
45	60	14.2*a-f*	13.3*c-f*	11.1*fg*	0.6*h*	0*h*	109*a-d*	108*a-e*	109*a-d*	80*j*	56*k*
	120	3.4*h*	0.2*h*	0.3*h*	0*h*	0*h*	106*a-g*	97*d-i*	94*f-i*	88*ij*	56*k*
Untreated		14.7					**100**				
carb.+imaz.[1]		8.4 *g*					98*d-i*				

Number of plants in untreated: 15.2 per m row [1] *carboxin + imazalil 0.8 g/kg seed + 0.05 g/kg seed.*
[2] *T= Temp. °C*

DISCUSSION

Seed treatment in conventional agriculture normally gives a control level of 99-100% of seed borne diseases like common bunt, leaf stripe and loose smut. This high and consistent level is difficult to achieve with alternative methods but the results with acetic acid and hot water are promising.

Acetic acid in the same concentration as vinegar had a good effect on leaf stripe but the volume used was high (50 ml/kg) and had a negative effect on the number of emerging plants in the field. New trials where concentration and volume is changed will show if acetic acid can be used in practice for controlling leaf stripe.

Our results show that pre-treatment (soaking) in water at 20°C could enhance the effect of hot-water treatment on leaf stripe. Water temperature at 50°C for 6 minutes and 55°C for 2, 4 or 6 minutes had a high effect on leaf stripe comparable to chemical standard. However, combination of pre-treatment and then water temperature at 55°C seems to be harmful to the seeds. Winter *et al.* (1996, 1998) also found that leaf stripe could be controlled at levels comparable to chemical standards by both hot-water (52°C, 10 min.) and warm-water (45°C, 2 h), but hot-water had negative effects on germination. Our results indicate that effects comparable to chemical standard can be obtained without negative side effects on germination.

The infection of loose smut is deep in the seed and long pre-treatment in water is necessary for controlling the disease. Combination of high water temperature for pre-treatment and high temperature in the succeeding hot water treatment can, however, be harmful to the seeds. Our results indicate that the best combination was pre-treatment at 45°C for 120 minutes succeeded by hot water treatment at 50°C for 2 minutes. This combination seems to control loose smut (98-99% control) without side effects on germination. Winter *et al.* (1996, 1998) used 3 hours for 45°C treatment to obtain same efficacy. Based on our results, durations longer than 2 hours should not be necessary. Compared to the chemical standard in the trial the effect was very high. Seed treatment with the chemical standard gave, in our trial, an unexpected low control level. Normally a control level at 95-98% would be expected using this product.

Generally, to minimise problems of re-drying and to avoid side effects on germination, treatments with shortest duration and lowest possible temperatures should be chosen. Optimisation, however, is necessary if these methods are going to be implemented on a larger scale.

To avoid losses of large quantities of seeds in organic agriculture due to infections of seed borne diseases, it is necessary to have some kind of control measures. The results presented here indicate that there are alternatives to the conventional seed treatments, but the methods have to be optimised further. Also the practical feasibility and the economy have to be considered carefully, especially concerning re-drying procedures and costs.

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What is the scope for using organic acceptable biocides in organic plant production?

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ABSTRACT

In organic production systems, rotation, variety choice and other husbandary approaches form the basis of pest and disease management. Control of fungal diseases and insect pests throughout the production cycle of organic fruit and vegetables (and specifically in organic vegetable transplant and top-fruit production) is considered a technical barrier The use of biocides in organic production is reviewed from the point of view of current organic standards. Recent research evaluating some AIs for activity against mildew (*Peronospora* spp.) in several species of vegetable must be considered in the context of UK and EU wide organic production standards, and regulatory procedures.

INTRODUCTION

In organic production systems pest and disease management is based upon rotation, crop species/variety and other husbandry practices controlled through organic standards regulated by national certifying bodies and the EU (EU, 1991). At an international level the standards operated by IFOAM (IFOAM, 2000) are near agreement and are gaining widespread acceptance. This paper considers biocide use in organic plant production, however, crop storage also represents a very important part of the supply chain where crop loss and/or deterioration can be more or less controlled through the use of a wide range of 'chemical' and 'non-chemical' methods.

The extent of pest and disease pressure in organic production systems varies widely, depending primarily on the climate, topography, crop type and crop husbandry practices employed by the organic producer, thus, the scope and necessity for the use of organic acceptable biocides will vary. Control of fungal diseases and insect pests throughout the production cycle of organic fruit and vegetables is considered a technical barrier. In the case of combinable and other agricultural crops, pest and disease pressure tends to be less significant, partly due to lower crop value, thus biocidal products tend to be used to a limited extent or not at all. In general there is a presumption that the use of biocidal active ingredients (AIs) is restricted to those situations where there are no alternative approaches.

EU and national legislation controlling organic standards operate alongside legislation controlling the use of biocidal products in agriculture generally and although there is a move towards harmonisation (in Europe and also internationally), there are differences in the organically acceptable biocides between countries that will persist for some time.

This has important implications for the operation of organic production systems in different countries, indeed national differences may affect the viability of certain crops and enterprises. Furthermore, due to these various differences it is inevitable that, during their production, organic foods will have been exposed to different types and amounts of biocidal active ingredients that may also have implications for trade in organic food between countries operating under different conditions and national legislation.

EU REGULATION ON ORGANIC PRODUCTION

The EU Regulation on organic production (2092/91), (EU, 1991) states in Annex I that "*pests, diseases and weeds shall be controlled by a combination of the following methods:*

- *Choice of appropriate species and varieties*
- *Appropriate rotation programme*
- *Mechanical cultivation procedures*
- *Protection of natural enemies of pests through provisions favourable to them (eg hedges, nesting sites, release of predators)*
- *Flame weeding*

Only in cases of immediate threat to the crop may recourse be had to products referred to in Annex II."

Implementation of the final clause is left to the discretion of the member state inspection body or authority and refers to a specified list of substances in Annex II(B), presented in Table 1. The specified conditions of use are binding and restrict the use of products, for example, to certain species, pests or methods of use. Furthermore, products listed in Annex II(B) can only be used in accordance with the provisions of Annex I and the specific provisions of the plant protection legislation applicable within the Member State where the product is used. Four of the substances listed are identified in the Regulation as not considered to be plant protection products (marked *) in some member states and are not subject to the provisions of the plant protection legislation. In the UK specifically, products that operate through physical means only ('physical barriers') are also considered to fall outside of the control of pesticide regulations. The list of substances on the EU Annex II(B) list which may fall into this category has not yet been determined.

The list in Annex II(B) of the Regulation is limiting, thus only those specified products may be used; additional products can only be included following consideration under the procedure described in Articles 13 and 14 of the Regulation. EU Regulation 2092/91 was substantially revised in 1997 by Regulation 1488/97 (EU, 1997). This introduced four categories of product and also excluded any product that was not registered as a plant protection product in at least one member state. Thus, certain products diatomaceous earth, ryania, stone meal are not currently included in the Regulation.

Table 1. Pesticides - Products for plant protection (EU Reg. 2092/91, amended by 1488/97 - Annex II(B))

Name	Description, conditions
I. Substances of crop or animal origin	
Azadirachtin (extract from *Azadirachta indica* - Neem tree)	Insecticide. Only for production of seeds & vegetative material
Beeswax*	Pruning agent
Gelatine	Insecticide
Hydrolised proteins*	Attractant, in combination with other products of Annex II(B)
Lecithin	Fungicide
Nicotine (aqueous extract from *Nicotiana tabacum*)	Insecticide. Aphids in subtropical fruit trees, tropical crops, only at start of vegetative period. ***Need recognised.*** **Expire 31/3/2002**
Plant oils (e.g. mint, pine, caraway)	Insecticide, acaricide, fungicide, sprout inhibitor
Pyrethrins (extract from *Chryanthemum cinerariaefolium*)	Insecticide
Quassia (extracted from *Quassia amara*)	Insecticide, repellent
Rotenone (extracted from *Derris spp.* & *Lonchocarpus spp.* & *Terphrosia spp.*)	Insecticide. ***Need recognised.***
II. Microorganisms used for biological control	
Microorganisms (bacteria, viruses & fungi) eg *Bacillus thuringensis, Granulosis* virus, etc	Only products not genetically modified in the meaning of EU Directive 90/220/EEC

Name	Description, conditions
III. Substances in traps and/or dispensers	
Diammonium phosphate*	Attrractant, only in traps
Metaldehyde	Molluscicide, only in traps with repellant to higher animals. **Expire 31/3/2002**
Pheromones	Insecticde, attractant; in traps & dispensers
Pyrethroids (only deltamethrin or lambdacyhalothrin)	Insecticide, in traps with attractants. Only against *Batrocera oleae* & *Ceratitis capitata wied.* ***Need recognised.*** **Expire 31/3/2002**
IV. Other substances from traditional use in Organic farming	
Copper (copper hydroxide, copper oxychloride, (tribasic) copper sulphate, cuprous oxide	Fungicide. ***Need recognised.*** **Expire 31/3/2002**
Fatty acid potassium salt (soft soap)	Insecticide
Lime sulphur (Calcium polysulphide)	Fungicide, insectide, acaricide; only for winter treatments in fruit & olive trees and vines
Paraffin oil	Insecticide, acaricide
Mineral oils	Insecticide, fungicide. Only in fruit & olive trees, vines and tropical crops (eg bananas). ***Need recognised.*** **Expire 31/3/2002**
Potassium permanganate	Fungicide, bactericide. Only in fruit & olive trees and vines
Quartz sand*	Repellant
Sulphur	Fungicide, acaricide, repellant

* In certain member states these products are not considered as plant protection products and are not subject to the provisions of the plant protection legislation.

Source: EU, 1991, as amended.

Certain products allowed for use in the EU Regulation and included in Table 1 are included with specific conditions of use which considerably limit their (possibly justified) more widespread use within organic systems. Five products are only permitted for use until 31

March 20002 (aqueous extract from *Nicotiana tabacum* for control of aphids in subtropical fruit trees and tropical crops, only at the start of the vegetative period; Metaldehyde as a molluscicide in traps with higher animal repellant; Copper salts; mineral oils in fruit and olive trees, vines and tropical crops).

IFOAM BASIC STANDARDS

The IFOAM Basic Standards (IFOAM, 2000) have the same basic framework as the EU Regulation, including a limiting list of products in Appendix 2 which does not include specific descriptions or conditions for use, but which identifies certain products as 'Restricted'. In these cases, the certifying body is required to set conditions and procedures for use. Factors such as contamination, risk of nutritional imbalances, importation of inputs from outside the farm and depletion of natural resources shall be taken into consideration.

The IFOAM Standards also include a more specific and detailed description of the range of husbandry practices recommended to manage pests and diseases (in common with the standards of many certifying bodies in Europe). Criteria are also specified for evaluation of additional inputs to organic agriculture presented in Appendix 3. In Europe (and as regards other countries recognised as third countries for the purposes of import of organic food into the EU), national certifying bodies can only operate standards which conform to the EU Regulation.

Table 2. Products for plant pest and disease control (IFOAM Basic Standards (IFOAM, 2000) - Appendix 2

Name	**Restricted**	**Name**	**Restricted**
Algal preparations	NO	Plant oils	NO
Animal preparations & oils	YES	Plant preparations	YES
Bacterial preparations (eg *BT*)	NO	Plant based repellents	YES
Beeswax	YES	Potassium bicarbonate	NO
Biodynamic preparations	NO	Potassium permangenate	YES
Calcium hydroxide	NO	Propolis	NO
Chitin nematicides (natural origin)	NO	Pyrethrum (*C. cinerariaefolium*)	NO
Chloride of lime	YES	Quassia (*Quassia amara*)	YES
Clay (eg bentonite, perlite, vermiculite, zeolite)		Quicklime	YES
Copper salts (eg sulphate, hydroxide, oxychloride, octanoate)	YES	Release of parasites, predators and sterilised insects	YES
Dairy products (eg milk, casein)	NO	Rotenone (*Derris elliptica, Lonchocarpus spp., Thephrosia spp.*)	YES
Diatomaceous earth	YES	Ryania (*Ryania speciosa*)	YES
Fungal preparations	YES	Sabadilla	NO
Gelatin	NO	Seasalt and salty water	NO
Lecithin	NO	Silicates (eg sodium silicate, quartz)	NO
Light mineral oils (eg paraffin)	YES	Soda	NO
Lime sulphur (calcium polysulphide)	NO	Sodium bicarbonate	YES
Natural acids (eg vinegar)	NO	Soft soap	NO
Neem (*Azadirachta indica*)	NO	Sulphur	YES
Pheromones - in traps or dispensers only	YES	Tobacco tea (pure nicotine is forbidden)	YES
Physical methods (eg chromatic traps, mechanical traps)	NO	Viral preparations (eg granulosis virus)	YES

PRIORITIES FOR ACTION

It is clear that there are important inconsistencies between the EU Organic Regulation, national organic standards; as well as EU and national rules concerning pesticide approval. Recent UK research has evaluated the efficacy of some organically acceptable AIs for activity against mildew (*Peronospora* spp.) in several species of vegetable in glasshouse trials (Clarkson *et al*, 1999; Lawson *et al*, 1999). These have shown that several plant oils and extracts can be effective in the control of fungal diseases. Figure 1 shows the results of an experiment testing several application rates of a range of AIs (including the tri-basic copper/sulphur based 'Top Cop').

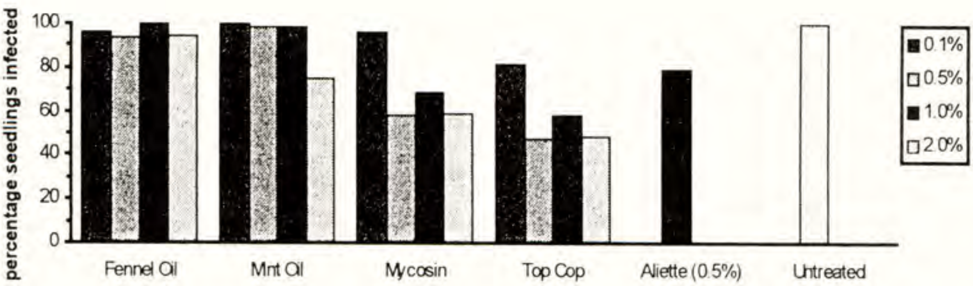

Figure 1. Effect of Fennel oil, Mint oil, Mycosin and Top Cop compared to a conventional fungicide and an untreated control on infection rate (%) of brassica seedlings with downy mildew

Clearly, these 'botanicals' represent a potentially valuable source of AIs that may be effective and safe from both an environmental and a human health point of view, however, their approval for use under national pesticide rules requires urgent attention. In reviewing pesticidal products from plant oils, Price (1999) reports that the plant oils from several species have been shown to have insecticidal activity and reports the extensive level of interest in this topic visible in internet based ethnobotanical and phytochemical databases (for example http:/www.ars-grin.gov.duke/). A review of botanicals (Pinniger 1996) highlights that only 20 substances are approved in the EU, and of these, only two (including the most dangerous and undesirable) are approved for use in the UK. Many apparently benign substances with fungicidal as well as insecticidal activity are not approved for use in the UK.

In some EU member states, such substances are permitted for use, highlighting the necessity to achieve a common standard throughout Europe where uneven access to products is inevitably leading to distortions in the relative production potential of certain vegetable and fruit crops.

CONCLUSIONS

Many products considered acceptable under the EU Regulation have proven efficacy against key plant pests and diseases - in some cases where alternative cultural or biological control is not possible, however, there are clearly several important legislative barriers to the use of such substances, and these vary throughout the EU.

It is proposed that an appropriate pan-European response relevant to the organic sector be developed to overcome some of the barriers to the use of effective and organically acceptable AIs. This could assist in the development of more economically viable and environmentally benign production systems to the benefit of both organic and conventional producers in the EU.

ACKNOWLEDGEMENTS

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SESSION 3C

ICM IN COTTON: A SUCCESS STORY?

Chairman:	Professor G A Matthews *Imperial College, Ascot, UK*
Session Organiser:	Dr D J Wright *Imperial College, Ascot, UK*
Papers:	3C-1 to 3C-4

The FAO/EU Cotton IPM Programme in Asia; problems and prospects

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ABSTRACT

The new FAO Programme for Cotton IPM in Asia, funded by the European Union, became operational late 1999. It covers six countries, including the three large cotton producers in Asia: China, India and Pakistan. Cotton crop protection in the region for the most part is still very much chemically dependent, although technologically a reduction of such dependency appears feasible.

The problem is that often new IPM methodologies remain stuck in academia or on drawing boards, while farmers continue as before, i.e., spray frequently and according to the calendar. The FAO Programme focuses on season-long participatory field training according to the so-called farmer field school model as the best strategy to turn farmers into IPM practitioners. The methodology has been pioneered and brought to fruition in IPM training of rice farmers in Asia.

Although there are substantial differences between cotton and rice agro-ecosystems, indications are that this approach is equally suitable to bring cotton farmers' crop protection practices more in line with the tenets of IPM.

Problems and prospects in achieving this general objective are reviewed in the light of first experiences and observations in the Programme's inception phase.

PROGRAMME RATIONALE

In October 1999 a new regional IPM Programme was launched by FAO in Asia, addressing itself to cotton and funded by the European Union. Participating countries are China, India, Pakistan, Bangladesh, Vietnam and the Philippines, in which the former three are major cotton producers (together accounting for half of the world's production area and about 40% of the global output; see Table 1). The latter three are relatively minor producers.

Table 1. Cotton Production Statistics for China, India and Pakistan and the Whole World (1998)*

Country	Production (Metric Tons x 1,000 seed cotton)	Area Harvested (1,000 hectares)	Yield (kg/hectare)
China	10,665	4,501	2,369
India	5,177	9,290	557
Pakistan	4,686	2,930	1,599
Total of 3 Countries	20,528	16,721	4,525
Total World	*51,793*	*33,180*	

* compiled from: FAO Selected Indicators of Food and Agriculture Development in Asia - Pacific Region, 1988 – 1998. RAP Publication 1999/34, October 1999.

The Programme's development objective was defined as:

"Sustainable, profitable and environmentally sound production of cotton in the participating countries through the development, promotion, and practice of IPM by farmers and extension staff".

Main factor prompting initiation of this effort was excessive dependency of cotton crop protection on chemical pesticides, particularly insecticides. As a result, actual practices not only fall substantially short of whatever criteria of sustainability and environmental soundness one may apply, but also jeopardize human health and the environment as well as the crop's profitability.

Table 2, based on data from Ahmad (1999), illustrates such increasing dependency for Pakistan (the figures on total insecticide imports very closely reflect use on cotton, being by far the most important target crop for insecticidal spraying). Trends elsewhere are similar.

Table 2. Import of Pesticides in Pakistan

Year	Metric Tons Active Ingredient	% Growth since 1981
1981	*905*	-
1985	*3,489*	*285*
1989	*4,706*	*420*
1993	*4,919*	*443*
1997	*11,209*	*1,139*

Such crisis situations by themselves, however urgent, don't lead to development co-operation projects, unless there is some real potential for remedial action. In the particular case of cotton crop protection, a history of almost half a century has repeatedly shown that, technologically speaking, a way out can be found whenever cotton-growing is trapped in a so-called 'pesticide treadmill'. Starting with the pioneering cotton IPM work of J.E. Wille in Peru in the 1950s, resulting in a reduction of seasonal spraying frequency from about sixteen to approximately two and a half (Ordish, 1969), the technical feasibility of moving away from over-reliance on chemicals in cotton crop protection has been documented in various parts of the world.

But getting this technology down to the farmers' level appeared another matter. In a recent review article with the provocative title "The illusion of Integrated Pest Management", Ehler and Bottrell (2000) argue that, in the United States, "in some ways, the chief beneficiaries of the IPM movement have been research scientists, extension agents, and government bureaucrats instead of the farmers."

If this is true for the US, which its relatively tightly structured university/extension/farmers – triad, the problem is far more acute in other countries, like the ones in the Programme region, with its less integrated and more hierarchically structured research/extension/farmers – relations. In other words, there is a real risk that all our efforts to promote IPM in the developing world through technical assistance flounder at the level where it really counts, that is, with the farmers.

All this points to the need to address the discrepancy between potentialities of IPM and continuing realities of chemical dependency by focussing on the farmers. Based on earlier experiences in parallel regional FAO IPM programmes in rice and vegetables, farmers' capacitation to self-reliance as cotton IPM practitioners is served best by implementation of season-long, participatory training according to the "Training of Trainers/Farmers Field School" (TOT/FFS) method. Key differences between the TOT/FFS and more conventional, non- or less-interactive methods of farmers training are discussed in the following section.

TOT/FFS VERSUS CONVENTIONAL EXTENSION

Table 3 summarizes the main differences between FFS-type and conventional extension systems.

Does this participatory extension approach work? Comparative assessments of FFS versus conventional strategies in Asia are few and, so far, limited to rice only (van de Fliert (1993) in Indonesia and Mangan and Mangan (1998) in China). Both suggest that the FFS approach is superior in making farmers self-reliant in IPM decision making.

Table 3. Difference between participatory (FFS) and conventional extension systems

Parameter	Extension	System
	FFS	Conventional
Criteria for Decision Making	Set of principles: • Grow a healthy crop • Conserve natural enemies • Regular field observations as basis for management decisions by farmers	Based on prescribed Economic Threshold Levels (ETL). Mechanical instructions: • Count • Refer to ETL • Spray when pest nrs. exceed ETL
Technology Packages	Fixed technology packages not working. Human resource development prerequisite for sustainable agriculture	Technology packages essential as substitutes for heavy investment in human resource development.
Role of Pesticides	May cause problems. Must be used as a last resort and on the basis of farmers' analysis of the ecosystem	Use of pesticides unquestioned. Part of essential package, just like chemical fertilizers
Consideration of Natural Enemies	Essential for proper decision making and within farmers' capability	Too difficult for farmers. Pests – natural enemies interactions too complex for effective decision making
Research	Carried out at all levels. Local studies with full farmers' participation and all stakeholders interact in setting agendas	Technology developed in research institutions and passed on via extension to farmers as passive recipients of technology packages

PROSPECTS

A full assessment of prospects for the FAO Cotton IPM Programme involves not only technical feasibility but also methodological suitability and the presence of a conducive socio-political environment. An illustrative example of the interacting nature of these different determinants of success or failure in IPM is provided by a comprehensive analysis of the cotton growing crisis in Thailand (Castella *et al.*, 1999). In the following part, the aforementioned three categories are discussed separately.

Technical feasibility

As mentioned earlier, re-orientation of crop protection away from overdependance on the chemical approach towards integrated strategies has proved possible in a variety of situations over the last fifty years. This is the case for the Asian region, but unfortunately publications are few and mostly in the grey area of project progress reports, training manuals and the like (for example, a compilation of results of project-funded cotton IPM field demonstration-study areas in the CABI-Bioscience "Farmer participatory Cotton IPM source book", 2000; mimeographed).

Methodology

Results of comparative assessment of the TOT/FFS approach as an alternative to conventional models are only available for rice (see above). Although there is no published specific information on this issue for cotton, the TOT/FFS method as developed for crop protection on rice in Asia has proved sufficiently robust to find applications in disciplines other than crop protection, crops other than rice, and parts of the world other than Asia. Viewed in that perspective, one may assume its usefulness in cotton as well. A case in point is provided by the successful conduction of a season-long cotton TOT/FFS in Vietnam in 1996, on initiative of the national Vietnam Cotton Company and well before the start of the FAO Cotton IPM Programme in Asia (personal communication Prof. Nguyen Tho).

Socio-political aspects: new roles of farmers

In recent years, there have been major changes in the socio-political sphere, profoundly affecting the functioning of the farmers. In the past they often were at the receiving end of general technology packages, delivered from some central authority, but now find themselves more in the role of entrepreneurs in need of capability for independent decision making. This is perhaps clearest in China, in the wake of the transition during the 1980s from agricultural communes to "household responsibility systems". As stressed by Gallagher (1995), farmers need complete training – not simple messages – to meet the new challenges and the FFS - approach appears to fit this bill better than conventional extension models. Moreover, an important, albeit somewhat intangible, alleged benefit of the FFS is in its fostering of community-level commitments to the cause of sustainable agriculture in general (Pretty, 1995).

Socio-political aspects: more organically grown cotton

Movements towards production of organic cotton gain momentum by a combination of market-driven demand, farmers' preferences and increasing awareness of failure of conventional, chemically dependant production schemes (Myers and Stolton, 1999). Although organic cropping and IPM are not identical, there is synergistic interaction and commonality in progress.

PROBLEMS

The FAO Cotton IPM Programme in Asia is still very much in the initial phase, in which progress is largely by trial and error. In the absence of a substantial experience in implementation, the following enumeration of principal problem areas is indicative and will probably need to be changed in the light of experiences to come from field execution

Field training programme: qualitative aspects

The Programme was initiated as an offshoot of the FAO Rice IPM Programme (presently called Community IPM Programme), which fulfilled a 'model' function with respect to curricular contents, targeting to farmers, season-long nature of the field training, participatory methodology, and promotion of further spread of the IPM message at the community level.

On curricular contents , the rice agro-ecosystem has some unique features to set it apart from other target crops of Asian FAO IPM programmes, i.e. vegetables and cotton. Complexes of pest and disease antagonists in rice are rich and diverse, guaranteeing a balanced system which usually remains free from injurious outbreaks if not disturbed by pesticides. Such internal homeostatic mechanisms are usually not developed to that extent in vegetables, particulary the non-indigenous species such as crucifers grown in, for example, highland situations. This has consequences for curricular contents of training programmes. In the words of Max Whitten, former manager of the FAO Regional Vegetable IPM Programme, the emphasis in the Rice IPM training is on "informed non-intervention", in Vegetable IPM on "informed intervention". The Cotton TOT/FFS curriculum in this respect assumes a somewhat intermediate position, but there is still considerable need of technological strengthening of criteria for "informed intervention".

On the targeting to farmers, it was indicated above, in citing Ehler and Bottrell's (2000) recent paper, that a main problem in all IPM-related training and development activities is that the efforts get stuck at the level of researchers, extensionists and bureaucrats without effectively reaching the farmers. The participatory TOT/FFS model is specifically designed to overcome this important drawback, but first experiences in the practice of Cotton IPM training implementation indicate that this vital aspect remains the Achilles heel of the system. After TOTs, however enthusiastically undertaken, follow-up FFSs often fizzle out because of reversal to familiar top down extension practices and inability of TOT alumni to conduct subsequent FFSs because of unavailability of budget or assignment to other duties.

Field training programme: quantitative aspects

On the fostering of multiplier mechanisms at the farmer community level, this aspect is essential to success or failure on the longer term. Programme planning entails that at the end of the five-year period of its implementation about 90,000 farmers will have received FFS training. This is only a fraction of the millions of cotton farmers in the region, which poses the need for mechanisms of post-FFS spread of the IPM message at the community level. Indications are that there is only a limited extent of 'spontaneous' transfer of IPM knowledge from trained to untrained farmers. The aspect of promoting IPM at the grassroot level is very much central to the present FAO IPM Community Programme (formerly Rice IPM

Programme) and lessons learned in the course of its implementation are to be incorporated in the design of further strategies for the Cotton IPM Programme.

The political conundrum: IPM vs pesticide industry

There are strong national pesticide industries in the region, particularly in the larger countries, with active engagement of agricultural extension service centers in the sale of their products. These same countries have a long tradition in IPM-related research and development activities and governments actively promote the IPM-approach in letter and spirit. Altogether, the IPM movement sometimes appears to proceed as in a vehicle where accelerator and brake pedals are being pressed at the same time and with equal vigour. But there are encouraging signs that meetings of the minds are possible. For example in China there was a recent (June 2000) announcement of the phasing out of five insecticides (parathion, methyl-parathion, monocrotophos, methamidophos and phosphamidon), considered incompatible with IPM from the viewpoints of toxicity to humans and/or deleterious broad-spectrum action on natural biological control agents.

CONCLUSION

Starting point for the FAO Cotton IPM Programme is a crisis situation brought about by excessive use of chemicals and a sense of urgency to do something about this. This is not the first or only endeavour to this purpose, but what the FAO Programme perhaps sets apart from other efforts is its focus on farmers as the most direct victims of the malady. As the old saying goes, the best surgeon is he that has been hacked himself, and this applies also to remedial action for the present cotton crop protection predicament.

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Global implementation of ICM in cotton

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ABSTRACT

Through the development of new crop protection products, seeds, biotechnology and agronomic services, such as diagnostic systems and resistance management strategies, Aventis CropScience is providing the farmer with valuable integrated crop management (ICM) tools for sustainable, safe and economic agricultural production. ICM is seen as the successful way forward for farming, and is an integral part of the Company policy of helping the farmer produce reliable supplies of affordable food and fibre with the least impact on the environment. A global network has been established with experienced staff carrying out research work, training farmers and advisors and liaising with the key contacts in each country. Some of the success stories arising out of projects carried out in cotton in the Republic of Uzbekistan, Greece, India, Colombia and South Africa are described in this paper. They have shown that it is possible by careful choice of the product, dose and timing, based on pest monitoring and the development of economic thresholds, and other ICM tools, to use pest management strategies and achieve crop yields from ICM programmes that are often better than conventional ones. The need for fewer treatments has also resulted in the integrated programmes being more cost effective and achieved with less effect on beneficial arthropods. Reasons for the success of the projects are discussed.

INTRODUCTION

As a leading company in plant protection and crop production, Aventis Cropscience is committed to the principles of sustainable agriculture and sustainable development. The aim is to provide reliable supplies of affordable food and fibre with the least impact on the environment. This is the concept of integrated crop management (ICM), which is seen as the successful way forward for farming, and is an integral part of Company policy. Through the development of new crop protection products, seeds, biotechnology and agronomic services, such as diagnostic systems and resistance management strategies, the farmer is provided with valuable ICM tools for sustainable, safe and economic agricultural production. A global network has been established by the Company with trained staff carrying out research work, educating farmers and advisors and liaising with the key contacts in each country. Some of the success stories arising out of the work on cotton in Brazil and India were reported at The 1998 Brighton Conference (Hewson *et al.*, 1998). Further projects undertaken in the cotton crop are described in this paper.

Numerous insects and mites attack cotton throughout its growth period, causing damage both in terms of yield and quality. It is important to use a wide range of natural and chemical resources not only to prevent this loss but also by combining or alternating different classes of active ingredients as part of a resistance management strategy. It is also important that application is made only when the economic threshold level for a particular pest has been reached. The awareness that predators and parasitoids can be used to advantage is further important. ICM involves using the latest technology and a good example is transgenic cotton containing the Bt (*Bacillus thuringiensis)* toxin to control boll worms. However, transgenic cotton does not prevent damage from other important insect or mite pests, and strategies also need to be devised to prevent resistance developing to the Bt toxin (MacIntosh, 1999).

SUCCESS STORIES

Republic of Uzbekistan

Cotton is a very important crop for Uzbekistan, with 1.5 million ha grown. This accounts for 40% of the agricultural land use. The integrated pest management (IPM) project 'Integrated Cotton Production' was carried out in 1999 by Aventis CropScience (as AgrEvo) in co-operation with the Department of Integrated Cotton Protection (ICP) of the Uzbekistan Scientific Research Institute of Plant Protection. The object of the work was to develop scientific-based approaches to plant protection, especially thresholds, in order to prevent yield loss. It was undertaken on the Ahunbabaev Farm in the Urta-Chirchik district of Tashkent. The total plot size was 4.2 ha and there were three treatments; the IPM programme, the existing farm (kolkhoz) method and an untreated control.

A seed treatment was applied to control *Xanthomonas*. On the IPM plot this was bronopol, which gave the highest germination (72.4%) and lowest infection (5.1%), compared with guazatin for the farm treatment (70.1% germination, 10.2% infection) and the untreated control (65.5% germination, 27.8% infection). The cost of the bronopol treatment was 20.1% less than the guazatin.

A single application was made, according to economic thresholds using pheromone traps, to control the red spider mite, *Tetranychus urticae*. A combination of triazophos plus deltamethrin was used on the IPM plot, and this reduced treatment costs by 46.5% compared with the sulphur and dimethoate applied to the farm plot. The percentage control (14 DAT) was 91.4 for the IPM plot and 89.6 for the farmer's application. No additional treatments were needed for the management of other insect pests, diseases or weeds.

For defoliation, the farm treatment was sodium corbamid chlorate, which was 11.7% more expensive than the thidiazuron plus diuron used in the IPM programme. Assessed 14 DAT, the mean number of leaves per plant was 4.9 for the IPM treatment, 6.8 for the farm treatment and 30.4 for the untreated control. Corresponding figures for the number of opened bolls per plant were 10.0, 8.5 and 10.9.

The overall reduction in costs for the IPM programme was 17.1%. Despite this, improved efficacy was obtained and this led to an increase in yield over the farm treatment of 0.33 t/ha, which equates to $US 14.2/ha. The IPM programme was clearly cost effective and this approach provides a similar opportunity for reducing costs, whilst maintaining yields, in other crops. Good co-operation between the Company and ICP was an important factor in the success of the project.

Greece

Greece is the leading producer of cotton in Europe, with about 420,000 ha grown mainly in the central-southern and northern parts of the country. On 1 ha plots on each of seventeen farms an integrated programme was compared with the farmers' (conventional) programme, which varied according to the locality, and a control, which received no insecticide application. The object of the study was to introduce a complete pest management programme, and to improve the farmers' knowledge and understanding of ICM. Co-operators in the project were the Hellenic Cotton Board, the Benakio Institute, cotton consultant Mr Claude le Rumeur, distributors and farmers. There were six or seven insecticide applications on the integrated plots, compared with eight to ten on the conventional (Table 1).

Table 1. Comparison of integrated and conventional pest control treatments.

Pest	Timing	Integrated	Conventional
Pectinophora gossypiella	1. 3 weeks after first flower	deltamethrin	cypermethrin
(Pink boll worm)	2. 2 weeks later	triazophos	lambda-cyhalothrin
*Heliothis armigera**	1. First generation	endosulfan	monocrotophos
(American boll worm)	2. Second generation	deltamethrin	lambda-cyhalothrin
Aphis gossypi (cotton aphid)	Threshold of 10 mobile stages/leaf	endosulfan	carbofuran
Tetranychus urticae	Threshold of 3-5 mobile stages/leaf	propargite	dicofol-tetradifon
Lygus and *Thrips* spp.	First signs of damage	endosulfan	monocrotophos

* Threshold of one larvae per ten plants for each generation.

Prevention of *Verticillium* was achieved in both treatments by using resistant varieties. Weed control was also the same (prometryne + trifluralin) on both treatments. Although mepiqut chloride was used for plant growth regulation in both programmes, timing of application for the integrated approach was made according to the 'Pix indicator', which was developed by Aventis CropScience as a tool which is easy to use by farmers. It is placed against the last five nodes of the plant and the colour of the indicator at the position of the youngest leaf denotes whether or not an application is necessary, and, if so, the dose to be used. It resulted in a lower amount of chemical being used for the integrated (1.25 – 5.0 g a.i./ha) compared with the conventional programme (5.0 – 7.5 g a.i./ha).

Irrigation of the cotton plant is very important, especially during the early stages of growth when the productive potential of the plant is being formed. The needs of the plant for water reach a maximum during the blossom period and decrease when fruiting of the bolls is complete. It is farmers' practice to reduce the amount of water in the early stages in order not to have to apply plant growth regulators. However, this is the opposite of what the plant requires. Lack of water results in stress, adversely affects root development and decreases fruit set and retention of the bolls. In the integrated approach, irrigation was applied in order to achieve optimum growth of the plant. Farmers' practice, described above, was used for the conventional programme.

In the ICM programme, application of fertiliser was based on soil analysis and leaf diagnosis, rather than the single base application in the conventional programme.

The range of control (%) for some of the key pests is given in Table 2.

Table 2. Efficacy of integrated and conventional programmes for the main cotton pests.

Species	Integrated	Conventional
H. armigera	83 - 94	78
P. gossypiella	74 – 96	56 – 61
A. gossypi	50	91

No differences were found between the two programmes in terms of lint quality, but harvest was achieved 5 – 7 days earlier from the integrated plots.

The generally higher level of pest management achieved by the integrated treatment was reflected by a 22% increase in seed cotton yield. Taking into account the number and cost of applications (85,000 to 95,000 drh/ha for the integrated and 120,000 to 130,000 drh/ha for the conventional) the gross margin was 227,500 drh/ha.

A key factor in the success of the programme was the involvement of all the interested parties, who shared their knowledge and experience. The farmers benefited from not only the new agronomic and environmental information they received but also improved profitability from growing this important crop. This successful approach is being extended to other crops such as peaches, apples and potatoes.

India

Managing insect pests and diseases poses the greatest challenge to cotton farmers throughout India, and is one of the major constraints to increasing productivity. Farmers largely depend on the use of chemical products, but inadequate knowledge of the pest, together with improper selection and use of plant protection measures, often results in poor pest management leading to economic yield loss. The objective of this work was to develop region-specific ICM/IPM packages for cotton. Agronomic guidelines cover all aspects of growing the crop, and include seed rates, plant spacing, fertilisers, weed management and the use of border crops of jowar or maize to encourage beneficial insects to migrate into the crop. Insecticide and fungicide applications combine agrochemical and biorational products (Hewson, *et al.*, 1998; Tanweer *et al.*, 1999) in three window-based packages. The time periods or 'windows' are from sowing to 70 days later, from 70 to 110 days after sowing and from 110 to 150 days after sowing. Economic threshold levels have been devised for all the key pests. Farmers are educated in pest scouting techniques, economic threshold levels, identification of beneficial insects and the selection of best pest management options. In addition, IPM Clubs have been established in each cotton region where farmers and advisors attend field days and receive IPM newsletters during the season. The range of results obtained in eight trials is shown in Table 3.

Table 3. Comparison of IPM with farmer's practice, Punjab, 1999.

	IPM programme	Farmer's treatment
Number of sprays	9 – 12	10 - 18
Yield (kg/ha)	625 - 2,125	500 – 1,825

In all eight trials, the IPM programme resulted in the highest yields, and the increase over the farmer's treatment ranged from 175 to 1,050 kg/ha. With fewer pesticide applications and higher yields the IPM programme provided the better cost-benefit ratio. These results confirm the findings of similar trials carried out in earlier years (Hewson, *et al.*, 1998; Tanweer *et al.*, 1999).

Colombia

In Colombia, management of the American boll weevil, *Anthonomus grandis*, was formerly carried out using enormous quantities of organophosphate (OP) insecticides applied between four and twelve times per season. Integrated pest management schemes have now been initiated to reduce this very high dependence on chemical products. In Cerete, the use of endosulfan at 525 g a.i./ha has made it possible to reduce the number of treatments per season to five compared with a programme of seven OP's at 960 g a.i./ha. In Valle del Cauca, endosulfan not only effectively reduced *A. grandis* and the cotton leaf worm, *Alabama argillacea*, as effectively as the OP programme, but, as found in Cerete, it had much less effect on beneficial arthropods of the genera *Hippodamia*, *Supputius* and *Polistes*. IPM programmes now use more selective products (endodsulfan, insect growth regulators and biological products) during the growth period of the cotton. Synthetic pyrethroids are only used if populations of the tobacco bud worm, *Heliothis virescens*, increase to unacceptable levels, and even then for not longer than one month. In a similar way, OP's are only applied at the end of the season in the event of aphid build up.

South Africa

In the area of irrigated cotton, boll worms (mainly *H. armigera)* are the main pest problem. In trials carried out in 1996, large unreplicated plots of 0.5 ha were used, and applications based on local boll worm thresholds. A strategy based on two sprays of endosulfan at either 350 or 525 g a.i./ha followed by two of deltamethrin at either 6.25 or 12.5 g a.i./ha was compared with an alternative programme of three thiodicarb sprays at 375 g a.i./ha followed by three of profenophos at 750 g a.i./ha. Efficacy, assessed by counting the numbers of larvae on 40 plants, was generally better throughout the season with the endosulfan/deltamethrin programme, despite fewer sprays being applied. This also resulted in higher yields of seed cotton. The lower rates of endosulfan/deltamethrin gave 2,830 kg/ha, the higher rates 3,420 kg/ha, the thiodicarb/profenophos 2,670 kg/ha and the untreated 2,170 kg/ha. There were no significant differences between the three programmes in relation to the numbers of the beneficial *Coccinelidae*, and no resurgance of secondary pests (*Aphis* and *Tetranychus* spp.)

CONCLUSIONS

The case studies described in this paper confirm the results for cotton reported in an earlier paper (Hewson, *et al.*, 1998). The integrated programmes tended to give improved efficacy and higher crop yields. Since they were often obtained with lower application rates, or fewer treatments, they were more cost effective. There were often considerably higher beneficial insect populations in the integrated programmes compared to the conventional pest control approaches. Maintaining the populations of beneficial insects during the early stages of cotton growth may help not only with managing the main pests but also secondary pests, further reducing the number of treatments required. Many of the programmes have concentrated on IPM because effective management of insect pests is the main problem facing the cotton grower. However, there is a need to extend these programmes to cover all the aspects of ICM, such as seed rates, fertilisers and irrigation, and this is beginning to happen as illustrated by the work in Greece and India. Key factors in the success of these projects have been: a) the involvement of all interested parties; b) development of local programmes involving thresholds and 'windows' tailored to suit local needs; c) use of farm-scale demonstrations; d) training and educating farmers in scouting techniques and identification of beneficial arthropods; e) use of economic thresholds to determine optimum timing; and f) development of simple ICM tools for the farmer such as the 'Pix indicator' in Greece. Results obtained in cotton show that similar opportunities for reducing costs, whilst maintaining yields, are possible in other crops.

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Prospects for integration of non-chemical and chemical pest management in cotton

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ABSTRACT

A large body of work on ICM-compatible technologies, such as the use of baculoviruses, pheromones and augmentative releases of natural enemies, has been carried out in major cotton producing nations. However, little of this work has included research to maximise integration of these technologies as part of an ICM system. We consider some of the biorational work undertaken in Egypt and Thailand and then consider in greater detail a current project in Uzbekistan. Side effects of pesticides on beneficials are a key concern in Uzbekistan, the fourth largest cotton producer in the world. After two decades of successfully replacing intensive insecticide and acaricide use with mass releases of natural enemies, chemical control is now resuming increased importance as the output from the countries' several hundred "Bio-labs" is facing decline due to inadequate funds for operational and maintenance costs. We outline the training and research initiatives in Uzbekistan that form part of a current World Bank-funded project that aims, amongst other things, to improve compatibility between insecticide use and existing augmentation programmes for biological control agents. The applicability of such initiatives to other major cotton growing regions is also considered.

INTRODUCTION

In a number of countries there has been substantial progress in development of technologies that have potential for inclusion in an ICM system. Technologies developed include the use of baculoviruses, pheromones and augmentative releases of predators and parasitoids. However, in many cases these have simply been tested or adopted as alternatives to chemical pesticides, rather than as components of an ICM system, which may or may not include chemical use. This paper describes firstly examples of these technologies in Egypt and Thailand, then in more detail current developments in Uzbekistan, where large-scale trials are being implemented to study the integration of different methods of pest management and their impact on crop quality and yield.

DEVELOPMENT OF ICM TECHNOLOGIES

Baculoviruses and Pheromones (Egypt and Thailand)

Campion and Jones (1991) reviewed use of baculoviruses and pheromones in cotton pest control; research in Egypt and Thailand are presented here as examples.

In Egypt, cotton pest management is dominated by early season control of *Spodoptera littoralis* and late season control of *Pectinophora gossypiella*. *Spodoptera littoralis* nuclear polyhedrosis virus (NPV) was extensively tested in the field and was shown to be as effective as use of chemical insecticides, or the hand collection of egg masses, and equivalent in price or cheaper than other pest control measures (Jones, 1994). The compatibility of virus use with IPM regimes, and the conservation of naturally occurring natural enemies has also been demonstrated through monitoring of field populations (Jones, 1998). Despite this, the use of virus has not been widely adopted for cotton pest management in Egypt, mainly due to reluctance of government or private enterprise to invest in large-scale production facilities for the virus.

Greater success has been obtained with mating disruption of *P. gossypiella* with sex pheromones. This technique has been used on a large scale in the United States, and on a smaller scale elsewhere. In Egypt, mating disruption was shown to be at least as effective as insecticide application, and also was shown to give additional benefits to farmers, such as increased honey production (Campion, 1994). The technique was adopted by the Ministry of Agriculture (which has responsibility for control of the cotton pest complex in Egypt) and applied to almost 400,000 ha (1997-98) (D. Russell, pers. comm.). However, adoption of the method has declined recently due to changes in political and economic circumstances.

In Thailand the cotton acreage has declined dramatically in recent years, due to the increasing cost of chemical control of insect pests. In response the Department of Agriculture has also been developing NPV to control *H. armigera* and *Spodoptera exigua* on cotton. The main pest is *H. armigera* and Ketunuti & Prathomrut (1989) demonstrated that effective control could be achieved through application of NPV at a rate of $1.3\text{-}1.95 \times 10^{12}$ polyhedral inclusion bodies/ha. In field trials, the same authors demonstrated that the use of NPV, applied mid-season, could replace up to six of the 15 or more insecticide applications used normally. This led to a local cotton production company establishing a small factory for production of NPV for use in IPM regimes (Jones, 1994). Unfortunately, production problems led to the company ceasing to produce *H. armigera* NPV. However, its potential for use in an IPM system was clearly demonstrated.

Mass Releases of Parasitoids and Predators (Uzbekistan)

Uzbekistan, as the primary cotton producer of the former Soviet Union, presently stands as the fourth largest cotton producer in the world, after China, USA and India. Uzbekistan's total cotton yield in 1999 was 3.64 million tonnes (with an average yield of 2.4 tonnes seed cotton/ha) (Ministry of Agriculture data, Tashkent). Under the Soviet regime, Uzbekistan accomplished a unique technological achievement by shifting from a predominantly insecticide-based pest management system on cotton, to one based on mass release of natural enemies. The shift occurred in 1973 following the issue of a decree by the then Soviet government to develop and implement a biological control system to replace more than two decades of intensive use of synthetic, broad-spectrum insecticides on cotton. This had contributed to serious declines in cotton yields primarily as a result of pesticide-induced destruction of natural enemies.

By 1990, at the time of the break-up of the Soviet Union, more than 700 "Bio-labs" (including 550 mechanised lines) had been established in Uzbekistan mainly for the rearing of the parasitoids *Trichogramma pintoi* (targeting eggs of the bollworm, *Helicoverpa armigera*) and *Bracon hebetor* (against larvae of *H. armigera*). In addition, a few lines were producing relatively smaller numbers of the green lacewing, *Chrysoperla carnea*. However, since independence the funds available for the operational and maintenance costs of the "Bio-labs" have fallen sharply and at present less than half of the mechanised lines are thought to be fully operational.

The deterioration of the biocontrol capacity of Uzbekistan, coupled with the increased availability of pesticides, is a cause for considerable concern, particularly since insecticides used against aphids and *H. armigera* are now dominated by non-selective pyrethroids (S. Macan, Aventis, pers. comm.). The main thrust of the effort against *H. armigera* is still through mass releases of *T. pintoi* and *B. hebetor*, although bollworm outbreaks in both 1998 and 2000 might suggest that existing methods are not always adequate.

A World Bank funded project (1996-2000) has aimed to redress these problems through an applied research programme that aims in particular to:

- develop new automated entomophage production lines for *T. pintoi*, *B. hebetor* and *C. carnea*
- develop methods of mechanical entomophage dispersal
- promote the selective and appropriate use of pesticides
- encourage integration of biological, chemical and cultural means of pest control

The work considered here is part of this project, and is centred on minimising pesticide side effects and assessing the potential of integration of biological and chemical pest management in Uzbekistan.

TRAINING AND RESEARCH INITIATIVES IN UZBEKISTAN

The cotton pest management in Uzbekistan is characterised by:

- relatively lower pest diversity and incidence than most other key cotton growing areas, partially a result of generally hard winters and a short, hot cropping season
- mass releases of three species of natural enemies
- a complement of wild natural enemies (whose effect has yet to be adequately elucidated under present regimes)
- relatively low frequencies of insecticide and acaricide application

However, since key cotton pests such as *H. armigera*, *Bemisia tabaci* and *Tetranychus* spp. have shown an ability to severely reduce yields under pre-1973 intensive insecticide regimes (M. Rashidov, pers. comm.), it is critical that integration between biological, chemical and cultural controls is optimised under the present conditions of increasing insecticide and acaricide availability. This need has been addressed by the World Bank-funded, NRInternational project in Uzbekistan in two main ways:

- holding a workshop with researchers and trainers considering the theoretical and practical aspects of side effects of pesticides on beneficial organisms (Nov. 1999)
- running one season of field studies (in three locations) assessing compatibility and interactions between existing mass release approaches, selective pesticides (seed treatment and foliar applications) as well as threshold spraying of two insecticides available commercially (April – October 2000).

Side effects workshop

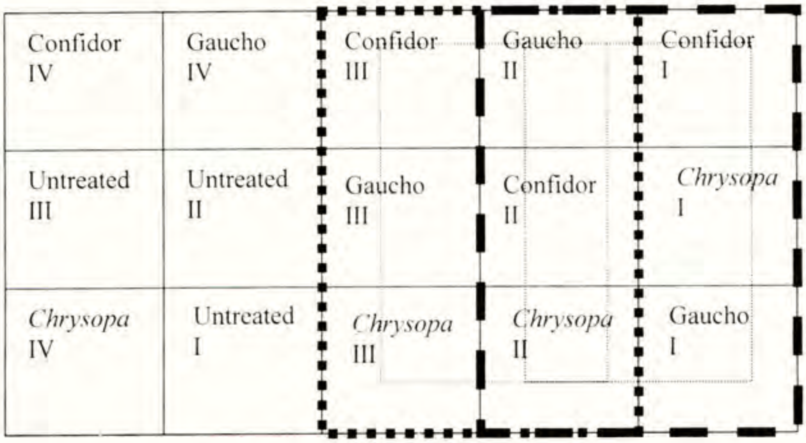
Prior to the workshop, a comprehensive training manual was produced and translated into the Russian language. The production of such a resource in Russian was considered an essential pre-requisite given the comparative isolation of the former Soviet republics from the international scientific community and the consequent lack of familiarity with the harmonised protocols for side effects testing of the International Organisation for Biological Control (IOBC). The major themes of the manual are:

- toxicity, action and physico-chemical properties of pesticides
- background and rationale of the sequential testing system
- ecotoxicological principles and field testing protocols
- standard protocols for initial and extended laboratory tests, and semi-field tests
- integration of chemical and biological control
- resistance to insecticides and ICM
- resources

Approximately 30 participants attended the workshop, these being from a wide range of organisations within Uzbekistan including the National Plant Protection Centre, Plant Protection Institute, Component Implementation Unit (Integrated Cotton Pest Management), regional plant protection centres, Tashkent State Agricultural University and chemical companies (local representatives of transnational companies). The workshop ran over six days and included five half-day practical sessions using *T. pintoi*, *B. hebetor* and *C. carnea* as test organisms.

Field studies

These were established in three regions of Uzbekistan: Tashkent, Syrdarya and Surkhandarya. Incomplete block designs were used because some treatment combinations were necessarily missing. This was to allow nesting of optional treatments with biocontrol agents (*T. pintoi* and/or *B. hebetor*) on those blocks where standardised thresholds for *H. armigera* were exceeded. In addition, limitations in available field space allowed only three control and four treatment plots per block, with four blocks per trial. Given the need to assess the impact of augmented natural enemies (all with the capacity for aerial dispersal as adults) relatively large plot sizes were selected (*ca* 1 ha). The layout of the Surkhandarya site is shown as an example in Figure 1.



Confidor IV	Gaucho IV	Confidor III	Gaucho II	Confidor I
Untreated III	Untreated II	Gaucho III	Confidor II	*Chrysopa* I
Chrysopa IV	Untreated I	*Chrysopa* III	*Chrysopa* II	Gaucho I

Fig. 1. Plot design for an integrated study on cotton in Surkhandarya, Uzbekistan (May – November 2000). *Chrysopa* plots: three sequential releases of 3000 eggs/ha; Gaucho plots: imidacloprid seed treatment; Confidor plots: early-season foliar applications with imidacloprid; ▪▪▪▪▪▪ : *Trichogramma* release plots (three sequential releases of 60-70,000 *T. pintoi* pupae/adults/ha following presence of *H. armigera* in pheromone traps); — — : *Bracon* release plots (three sequential releases of 1000 *B. hebetor* adults/ha on 3 occasions following thresholds of 5 larvae/100 plants); .... : parasitoid release areas (within 20 m of release area perimeter). Pyrethroid and/or organophosphates applied to any plots (except controls) where *H. armigera* threshold >10 larvae/100 plants.

Although at the time of writing the experiments are still in progress, several significant findings have emerged already. These are:

- early season attack by aphids and thrips does not appear to have been reduced significantly by imidacloprid seed treatments (possibly partly due to poor irrigation at the time of germination), although foliar application of the same chemical had some effect on reducing aphid populations
- water- and weed-stressed cotton plants appeared to suffer far more from early-season pest attack than healthy plants
- *Trichogramma pintoi* releases in Surkandarya were not able to suppress heavy *H. armigera* outbreaks in the region; possible reasons for this are being investigated at present, but quality of biological stock is considered a likely culprit
- wild natural enemies, including *C. carnea* and Coccinelidae (notably *Coccinella septempunctata*) are very abundant and appear to provide important regulation of early season sucking pests

DISCUSSION AND CONCLUSION

It is apparent that, even if a technology has been demonstrated to be scientifically and practically effective, it is not necessarily adopted by farmers and incorporated as part of an IPM or ICM system. Moreover, ICM strategies need to be flexible and continuously reviewed owing to the dynamics within and outside of the cropping system (Verkerk &

Wright, 1998). Changes in the market availability of pesticides or the deterioration of entomophage production capacity, as experienced recently in Uzbekistan as a result of political and economic flux, can have major effects on the viability of particular approaches. The work and examples reported here demonstrate that relying on any one technology, either chemical or biological, is ultimately not sustainable. In systems with relatively low insecticide and acaricide inputs (e.g., Uzbekistan and many smallholder cotton farming systems in Sub-Saharan Africa) biological control by wild natural enemy populations should not be underestimated. Hence, it is essential both that the impact of pest management practices on these is well studied and understood, and conservation strategies are developed.

Although, as shown above, adoption of ICM can be limited due to technical, political or economic difficulties, it is ultimately dependent on the willingness of farmers and other stakeholders to adopt less familiar or new technologies which may be perceived as risky, and ICM strategies more generally. It has been shown with rice and other crops that promotion of ICM through Farmer Field Schools is an effective route to adoption (e.g., Jones, 1996). Similar programmes are presently being promoted in organic cotton in Zimbabwe and other African countries (S. Page, pers. comm.) and conventional cotton in Asia (Eveleens, 2000). Adaptations of these approaches, backed up by detailed research on technology development and impact is likely to be the key to future adoption of ICM programmes.

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Developing and implementing insecticide resistance management practices in cotton ICM programmes in India

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ABSTRACT

Pyrethroid, organophosphate, carbamate and cyclodiene resistance levels for the cotton bollworm (*Helicoverpa armigera*) have been monitored routinely at sites throughout India since 1993 using discriminating dose assays. Resistance by *H. armigera* and other pests to commonly used insecticides is a severe constraint to cotton production in India. An integrated crop management strategy was developed aimed at maximising profit while minimising insecticide use and the impact of insecticide resistance. Appropriate varieties and agronomy, plus seed treatment where necessary, allow the first foliar insecticides to be delayed until at least 70 days from planting. Insecticides for fruit and leaf feeders are then rotated, taking account of seasonal shifts in their efficacy and the pest spectrum faced; with endosulfan first, followed by particular organophosphates, leaving one to two pyrethroid sprays until the late season when pink bollworm is also present. This system (customised for the different regions of India) was demonstrated in village participatory trials, reaching 24 villages across four states in 1998-9. In all areas the quantity of insecticide a.i. used was reduced by >29%; yields increased substantially and net profit rose $40 to $226/ha when compared with farmers not in the schemes.

INTRODUCTION

Insecticide use on cotton in India consumes 50% of the total agricultural insecticide on 5% of the agricultural land and is increasing at c.7% per year. Insecticides account for c. 44% of cotton growing costs nationally and c.19% of total production costs (ICAC 1998).

The American bollworm (*Helicoverpa armigera* Hübner) is recorded from over 20 crops and 180 wild hosts in India. Heavy spraying, particularly on cotton, resulted in resistance to cypermethrin in *H.armigera* (Dhingra *et al.* 1988). More limited recent survey work is also identifying difficulties with resistance in the whitefly *Bemisia tabaci*, pink bollworm (*Pectinophora gossypiella*), the leafworm (*Spodoptera litura*) and the spotted bollworm (*Earias vitella*).

Resistance measurement and mechanisms

Detailed results from the long term monitoring operations for resistance in *H. armigera* (1993-1998) are analysed by Armes *et al.* (1996) and by Russell *et al.* (1998) who draw conclusions based on these data. The number of sites from which pyrethroid resistance was recorded rose dramatically from two in 1987 to 98 in 1993 (Armes *et al.* 1995 and 1996, Jadhav & Armes, 1996).

Pyrethroid (cypermethrin and fenvalerate) resistance is ubiquitous in *H. armigera* and is stable at 50-80% (close to 100% in coastal Andhra Pradesh). Synergist studies show both mono-oxygenase and esterase mediated metabolic mechanisms to be important. Nerve insensitivity has also been demonstrated from Andhra Pradesh and Maharashtra and declines in cuticular permeability have been demonstrated in a New Delhi strain. Organophosphate (quinalphos) and cyclodiene (endosulfan) resistance is stable at around 20-50%, and probably mainly mediated by enhanced levels of mixed function oxidases. Resistance to carbamates (methomyl) is present in the Punjab and Andhra Pradesh but is currently at low to moderate levels. A preliminary baseline study showed no resistance to diet incorporated *Bacillus thuringiensis* (LD_{50}s from 63-110 ng/larvae compared to the susceptible baseline of 54-60 ng/larvae). More restricted work with other lepidopterous pests of cotton has shown significant resistance to organophosphates in *S. litura* and to quinalphos and methomyl in *P. gossypiella*. *Earias vitella* is showing significant resistance to organophosphatesand carbamates in N. India. *Bemisia tabaci* resistance studies since 1997 in the Punjab and Andhra Pradesh show significant resistance to cypermethrin, acephate and monocrotophos but continued susceptibility to chlorpyrifos, profenofos, triazophos, endosulfan, and the neonicotinyl, imidacloprid. Of the considerable range of 'new' chemistries, effective in other parts of the world for bollworm and whitefly control, only imidocloprid and spinosad have been registered for use on cotton in India (in 1999 and 2000).

Table 1 summarises the currently available information for cotton pests. There is, however, a great deal of variation between areas, between seasons and within seasons at individual sites.

Resistance stability

In the only species so far tested, *H.armigera*, resistance to endosulfan and quinalphos declines rapidly in both the laboratory and the field in the absence of selective pressure. Pyrethroid resistance appears to be much more stable. The mechanisms underlying these relationships are discussed in Armes *et al.* (1996), McCaffery (1999) and by Kranthi *et al.* (1997 and in press).

Table 1. Generalised scheme of insecticide resistance levels in cotton pests in India using example insecticides (pyrethroids - cypermethrin and fenvalerate; organophosphates – monocrotophos, quinalphos, chlorpyrifos, profenofos, acephate, triazophos; carbamates – methomyl; cyclodienes – endosulfan; neonicotinyl - imidocloprid). *North* – mainly Punjab, *Central* – mainly Maharashtra and Andhra Pradesh, *South* – Tamil Nadu

Pest Species	Insecticide	North	Central	South
American bollworm	Pyrethroids	Very high	Very high	High
(H. armigera)	Quinalphos	Low	Low (high in Guntur)	Low
	Monocrotophos	Mod.	High	High
	Methomyl	Low/Mod.	Low/Mod.	Low/Mod.
	Endosulfan	Mod.	Mod.	Mod.
Pink bollworm	Pyrethroids	None	None	None
(P. gossypiella)	Quinalphos	Mod.	Mod.	Mod.
	Monocrotophos	Low	Low	Low
	Methomyl	Low	Mod.	Low
Spotted bollworm	Pyrethroids	None	None	None
(E. vitella)	Quinalphos	Mod.	None	-
	Monocrotophos	High	None	-
	Methomyl	High	None	-
Leafworm	Pyrethroids	Mod.	High	-
(S. litura)	Quinalphos	Mod./High	Mod./High	Mod.
	Monocrotophos	Mod.	High	Mod.
	Methomyl	None	Low	None
Whitefly	Cypermethrin	Mod./High.	Mod./High	-
(B. tabaci)	Fenvalerate	High	High	
	Quinalphos	-	None	-
	Acephate	Mod./High.	-	-
	Monocrotophos	Mod.	Mod.	-
	Profenofos	None	None	-
	Chlorpyrifos	None	None	-
	Triazophos	None	-	-
	Metasystox	-	Low	-
	Methomyl	Mod.	Mod.	-
	Endosulfan	None	None	
	Imidocloprid	-	None	-

* Low - detectable resistance but not sufficient to give rise to field control problems
Mod. - moderate resistance, insecticide still useful but compromised
High - resistance sufficiently severe to significantly impair usefulness

Development of practical management of resistant insects

IRM strategies in India, as elsewhere, have included strong recommendations for the alternation of chemicals groups in successive spray rounds. The IPM strategy for southern India being recommended by the current research grouping, involves the use of profenofos when eggs only are present early in the season followed by the cyclodiene, endosulfan, an organophosphate (quinalphos or chlorpyrifos), a carbamate (carbaryl or thiodicarb) and finally pyrethroids (cypermethrin, fenvalerate, deltamethrin or lambda cyhalothrin). The complex patterns of cross-resistance between chemical groups and within groups such as the pyrethroids and organophosphates complicate the use of this strategy, even under ideal management conditions.

Potential components of IPM strategies

The Indian cotton system has been severely altered by the intensive use of pesticides in recent decades. Even where pesticides are not sprayed at all, as on a 250 acre block in the Indian Punjab in 1997, numbers of beneficials can often be almost vanishingly low (J. Singh unpublished data). The short-term need is to reduce the insecticide pressure, especially in the early season and from broad-spectrum materials, in order to allow the beneficial fauna to recover its role, in addition to reducing the resistance selection pressure.

National trials have been underway for some years now to test the efficacy of various treatments ranging from 'fully non-chemical' to 'fully chemical'. The importance of neem based products, NPV, *Bt* and the use of *Trichogramma* spp. as egg parasitoids, marigold and other plants as trap crops for *H. armigera* eggs has been explored. A great diversity of results and recommendations has arisen from these trials and considerable success is being achieved on an experimental basis. The use of neem in particular, especially where egg numbers are low, seems to be beneficial. Sundaramurthy and Uthamasamy (1996) provide a comprehensive review of integrated management of pest insects in Indian cotton and highlight a number of non-chemical successes. However, the overall analysis to date of the national trials in the ICAR programme for the development of IPM packages under selective crop conditions, shows conventional insecticide-based cotton pest control, judiciously applied, to be still the most reliable and cost effective way of maintaining yields in most areas and years. Many organisations are exploring the use of trap crops, inter-cropping, oviposition deterrents and NPV. However, the availability of reliable products of proven efficacy is not such as to make it currently advisable to recommend them for wider farmer use and over 95% of farmers still rely on sprayed insecticides.

ICM/IPM/IRM DEMONSTRATIONS

Picking up on the results of work at ICRISAT in 1992-5 (Armes 1996), an expanding series of demonstrations of IPM within an integrated crop management context, which focused on minimising the impact of insecticide resistance, was undertaken in farmers fields in the 1996-7 to 1998-9 seasons. The scale of operations increased from 20 farmers in one state in 1995 to 1,650 farmers in 24 villages in 4 states in 1998. The details of the recommendations varied to take account of the agronomic appropriateness of particular varieties, the availability of irrigation, the local pest complex etc. Each component was intended to provide a stand-alone benefit even if not used in conjunction with all components of the package:

The trials were undertaken by the village community in which the farms were based. Project staff were based in the area to ensure continuity of advice to the farmer, who was to make the pest control decisions based on his own scouting, supplemented by advice from project staff, especially in the first year. Practical advice and decision making support was provided to the farmers on two models. Young village residents were trained as IPM support staff (three per village) and employed throughout the cotton season in the Punjab, Andhra Pradesh and Tamil Nadu. Each group of villages was supported with one IPM qualified field research assistant from the parent research organisation. This model was moderately successful. In Maharashtra support was provided during the cotton season by final year BSc Agriculture undergraduates from Akola University (two resident in each village) as part of their 'village placement' training for the degree. This model was extremely successful with both farmers and students and is recommended where the academic system allows it. The field liaison was supported evening village meetings and with cotton IPM booklets and brochures in local languages, sold to the farmers. These were extremely popular and have run through several editions.

The components of the IRM methodology for central and southern India are summarised below. The advice provided took into account existing University and state recommendations for IPM and local knowledge of the efficacy of particular materials within an IRM context (modifications of detail were necessary for the predominantly irrigated Punjab where the pest sequence is different):

Seed: use of certified varieties or hybrids that are tolerant to sucking pests;
Spacing: wide spacing (specified)
Assisting beneficial organisms: delay in spraying toxic material as long as possible; use of seed treatment to remove the need for early sucking pest sprays;
Fertiliser: Need based after soil analysis (details provided); avoid excessive nitrogen.
Spray decisions: following intervention thresholds below which application have been shown to be uneconomic; rotation of chemical groups; not re-treating control failures with members of the same chemical group;
Manual control of large bollworm larvae (difficult to kill with chemicals)*:* hand-pick before spraying and again 3 days later; squeezing *Earias* larvae in the shoot tips;
Sampling: weekly sampling of 50 plants (method and objectives provided);
Chemical control: use only materials from the list provided (a.i. and manufacturers) and in the order suggested for particular pest problems;
Chemical control thresholds:
Sucking pests: spray action thresholds provides for jassids, thrips, whitefly;
Bollworms: Helicoverpa egg action threshold of 1 per plant. For larvae, recommendations differ with stages in the crop phenology;
Before squaring: *Earias vitella* is the main problem and a threshold of 5 damaged tips per 50 plants is provided for mechanical control;
Main squaring period: plant examinations; spray at one live larva per plant or 10% of fruit showing damage;
Green and open boll period: all bolls on 50 plants examined for fresh bollworm damage. Spray at 5% *H. armigera* or 10% bollworm damage overall.

Table 2. Chemical Control Schedule (simplified) for the central and southern Indian 'best-bet' trials 1987-8 (need-based; alternatives for a given spray round are in order of preference)

Spray round	Pest	Common name	Total dose per acre
Pre-planting	Sucking pests	Imidocloprid	5.25g
1	Jassids/aphids	Methyl demeton 25 EC	400ml
		Dimethoate 30 EC	550ml
		Acephate 75 SP	250-300g
2	Low bollworm egg or larval numbers	Neem	as recommended
	High egg numbers	Profenofos 50EC	500ml
3	1st bollworms	Endosulfan 35 EC	600ml
4	2nd bollworms	Quinalphos 25 EC	800ml
		Chlorpyrifos 20EC	800ml
5	3rd bollworms	Carbaryl 50 WP	800g
		Thiodicarb 75 WP	300g
6	Last bollworms	Cypermethrin 25 EC	210ml
		Fenvalerate 20 EC	220ml
		Deltamethrin 2.8 EC	220ml
		Lambda cyhalothrin	180ml
If present and over threshold at any time			
	Whitefly	Triazophos 40 EC	450ml
		Neem	as recommended
	Mites	Ethion 50 EC	400ml

RESULTS

Demonstrations were undertaken with 1,650 farmers in 1 village in Tamil Nadu, 3 in Andhra Pradesh, 9 in Maharashtra and 11 in the Punjab in 1998-9. A summary of the results is presented in table 3.

Helicoverpa armigera and *B. tabaci* numbers were devastatingly high across the Punjab in 1998 with numbers above the intervention thresholds for 107 days out of the 140-day 'season'. The number of applications was not reduced but the use of mixtures and of the more toxic materials declined dramatically.

Although they comprised less than 50% of the spray rounds in any given state, organophosphates were responsible for 96% of the human dermal toxicity hazard in the non-project villages. Pyrethroids, which have other problems in IPM programmes, accounted for less than 1% of the overall risk. The estimated total impact on beneficial arthropods (using the published LD_{50}s) was reduced by 85% for egg parasitoids, 62% for larval ectoparasitoids, 78% for ladybird predators and 63% for lacewing predators (Iyengar and Russell in press).

Table 3. Outcome for IRM crop management scheme: participating farmers compared with matched control farmers from nearby villages.

	Punjab	Tamil Nadu	Andhra Pradesh	Maharashtra
Reduction in pesticide use % (no. spra	-2	46	44	95
Reduction in pesticide use % (a.i./ha)	29	42	69	92
Reduction in plant protection cost %	21	39	55	88
Yield increase (%)	49	17	31	70
Net increase in profitability ($/ha)	40#	93	125	226#
Reduction in health hazard* (%)	48	77	89	92

* Calculated on the basis of human LD_{50} dose reductions from the WHO tables for the particular chemicals involved

\# Non-participating farmers were operating at a loss.

Uptake of results

The Indian Council for Agricultural Research is supporting a suite of village demonstrations of the project outputs in the four states. The Common Fund for Commodities (of the UN) is providing support for a US$4 million project to extend and implement the results of this work in China, Pakistan, India and Africa from 2000 – 2004.The knowledge gained is being fed into the six country, EU-funded, Asian Cotton IPM Farmer Field School project (2000-2004).

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