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INVITED PAPER

IMPLEMENTING COTTON INTEGRATED PEST MANAGEMENT

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SUMMARY

Strategies for the implementation of integrated pest management (IPM) of cotton differ significantly depending on the agroecosystem and incidence of pests. Examples of successful IPM programmes from different countries, including those which involve insecticide treatments, are given in contrast to cases of inappropriate use of insecticides leading to pest resistance and crop failure. Inter-disciplinary research and farmer participation on a regional basis is necessary if IPM is to be implemented successfully.

INTRODUCTION

Cotton is grown in over 70 countries, ranging from the most northerly areas in north-west China through tropical areas to southern production areas in Argentina and Australia. Annual global production is approximately 19×10^6 t lint (Gillham *et al.*, 1995; Table 1), but has declined in some major producing areas such as Pakistan and China due to serious insect control problems. The yields of seed cotton per hectare and agricultural practices vary very significantly, but in all areas insect pests continue to be an important factor. Following the availability of insecticides, growers have unfortunately relied on chemical control but, with increasing concern about pests becoming resistant to insecticides, health hazards associated with the more toxic chemicals and adverse effects on the environment, increasing emphasis is being given to integrated pest management (IPM).

The principles of IPM involving the harmonious integration of different control tactics to minimize or eliminate the use of insecticides (Smith and Reynolds, 1966) have been advocated for several decades, but implementation of IPM has been slow (Wearing, 1988). Scientific studies to develop alternative strategies require long-term sustained commitment, which has become more difficult to achieve with inadequate funds being available and emphasis on short-term contracts. However, apart from difficulties in obtaining appropriate scientific data, implementation has required a positive policy to provide a framework in which the many organizations and disciplines involved can operate with farmers. In the absence of such a policy farmers, unaware of the problems associated with unregulated use of pesticides, have generally increased the number of insecticide products used and applications per season until insecticide resistance has resulted

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Table 1. *Production of cotton lint (10^3 t) and lint yield (kg ha^{-1}) in 1991–95, based on International Cotton Advisory Committee world statistics October 1994*

	Lint		
Country	Production		Yield
China	4719.4		787.2
USA	3670.2		747.6
Central Asia	2320.0		784.6
India	2192.8		290.1
Pakistan	1859.8		652.7
Brazil	580.2		369.9
Egypt	328.2		866.0
Mexico	86.4		729.7
Other	3361.2		516.3
Total	19 118.2	Average	582.1

Source: Gillham *et al.*, 1995.

in crop failures. Notable examples of excessive insecticide use have led to disasters in Nicaragua, Mexico and more recently in India and eastern China. The occurrence of these disasters is often the catalyst to promote IPM, but this requires organizational and disciplinary co-operation to achieve practical implementation. In the USA, where cotton is grown in a range of different agroecosystems and IPM has been studied by computer modelling (Frisbie *et al.*, 1989), regional programmes have been advocated as more cost-effective for individual farmers than confining action to farm-level IPM (Frisbie *et al.*, 1994). Some farmers, especially in the USA and Australia, are now employing independent consultants using computer models involving plant growth data as well as pest scouting information to assist in pest management decision making.

SUCCESSFUL IPM PROGRAMMES

An IPM programme will vary depending on the agro-ecological environment and pest complex. In some circumstances relatively few tactics have been successfully integrated, but in most situations, the diversity of pests and cropping practices requires a more complex strategy. This diversity is illustrated by a few examples.

In Uzbekistan, with large-scale farms, the adverse effects on human health of pesticides, including defoliants such as the organophosphate Butifos sprayed on up to 2×10^6 ha annually, led to the emphasis on biological control (Filippov, 1992; Gillham and Matthews, 1994). In consequence there are now over 700 bio-factories producing the parasitoids *Trichogramma pintoi* and to a lesser extent *Bracon herbetor*. The egg parasitoid is released early in the season as soon as pheromone traps detect *Helicoverpa armigera* or *Agrotis* moths. *B. herbetor* is released if larvae are

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subsequently found by crop scouting. The same techniques are used in neighbouring countries (Kovalenkov, 1992). Some might argue that the use of these parasitoids is a placebo (Hoy, 1994) and the low pest pressure in recent seasons is due really to the reduction in insecticide use, but clearly high yields have been obtained where pheromone monitoring has been integrated with biological control and a severe cold winter also minimizes the pest population. In this area there are other problems such as infestations of aphids and red spider mites requiring chemical spot treatments and the lack of crop rotation, with six to seven years of cotton before changing to lucerne for three years, and this has increased the incidence of *Verticillium* and *Fusarium* wilt diseases. The situation is already changing as the area of cotton has decreased to allow for crop diversification and increased food production.

In a similar irrigated cotton-growing area in north-west China, emphasis on biological control has replaced a schedule of 10–12 insecticide sprays by conservation of certain important natural enemies. This encouragement of coccinellids was achieved on large estates by planting poplar trees as wind-breaks and increasing crop diversity by growing sugarbeet and winter wheat in blocks in close proximity to the cotton. This contrasts with other areas of China referred to later.

In Egypt, an over-use of insecticides directed at *Spodoptera littoralis* in the 1950s had led to a high incidence of resistant leafworm populations so, as the Government authorities were responsible for pest control, they reverted to the manual removal of egg masses and stopped the irrigation of berseem (*Trifolium alexandrinum*), the overwintering host plant of *S. littoralis*, by 10 May to reduce the migration of this pest to cotton (Salama, 1983). The impact of drying the berseem was to force the main natural enemy of the leafworm, the lacewing (*Chrysoperla carnea*), to migrate from the berseem to the cotton fields where it survived on undetected egg masses. However, the problem of pink bollworm (*Pectinophora gossypiella*) remained because farmers were keeping the cotton stalks in the villages for winter fuel and so up to five insecticide sprays were applied, mostly by aircraft, until recently. However, as a result of over 10 years research by the UK Natural Resources Institute, Chatham (Critchley *et al.*, 1985), the use of the pheromone gossyplure has been adopted (Critchley, 1991). Initially trials had examined aerially applied formulations, but in 1992–94, an area of about 0.5×10^6 feddan (0.21 ha) was treated with manually-applied slow-release dispensers. These are of two types: a thin plastic tube filled with the pheromone and a wire which allows the tube to be twisted around the plant's main stem, and a 'rubber band' type of dispenser through which the main stem continues to grow when it is placed on the top of young plants.

By using the pheromone, the number of insecticide applications has decreased to between one and two and in some areas no spray has been applied. The timing of these sprays is dependent on crop scouting and there has been a change to the use of manually-carried spraying equipment. However, there is concern that in using a highly selective pheromone instead of sprays, populations of spiny bollworm (*Earias insulana*) will increase. The relative absence of serious *Helicoverpa*

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armigera infestations is possibly due to crop diversity, a sequence of maize and tomato crops being sown at different times throughout the summer providing trap crops and diverting the bollworm away from cotton. The success of the programme in Egypt has been due largely to area-wide implementation controlled centrally by the Plant Protection Department through the individual Governorates. There is a real risk that this system could break down with increasing emphasis on privatization, leaving the individual farmers to decide what crop protection measures are required.

In Uzbekistan, north-west China and Egypt, cotton is grown under irrigation, but in many of the semi-arid areas of the world, cotton growing is dependent on erratic rainfall, so there is less scope for crop diversity and natural enemies have to survive through a long dry season. In Zimbabwe and Malawi, where severe *H. armigera* populations on cotton are undoubtedly derived from extremely large areas of maize, adoption of an IPM programme including insecticides has progressed in steps from the 1920s. The initial cultivars, such as Cokers Wild imported from the USA were highly susceptible to jassid (*Jacobiella facialis*) damage, but jassid resistant varieties selected from Indian cottons at Barberton in South Africa (Parnell *et al.*, 1949) enabled a low yield to be obtained despite jassid infestations. In the 1930s, regulations were introduced to prohibit ratooning of cotton in order to reduce the severity of the red bollworm (*Diparopsis castanea*), but despite these nationally observed control tactics yields remained low until the 1960s. Then a specific chemical control programme was recommended and a new cultivar, Albar, was released with resistance to *Xanthomonas campestris* pv. *malvacearum* as well as jassids. Widespread use of acid-delinted seed has also reduced the incidence of seed-borne disease. The cotton was also rotated with maize and other crops.

The choice of insecticide was limited and the timing was based on twice weekly crop monitoring (Matthews and Tunstall, 1968), which later was facilitated by the development of a simple pegboard (Beeden, 1972). Initially the use of DDT was recommended, but subsequently this was replaced by certain pyrethroids for *H. armigera* control, when populations exceeded an action threshold of 0.5 eggs per plant. The actual severity of infestation varied between localities and seasons due in part to the effect of rainfall on the previous host plant maize. Other bollworms – the red and spiny – and cotton stainers (*Dysdercus* spp.) were controlled by applying the carbamate insecticide carbaryl. Unfortunately application of these insecticides for bollworm control led to infestations of red spider mite (*Tetranychus* spp.) so dimethoate, which was also used if aphid infestations needed control, was added to the spray programme. Later this organophosphate was replaced by an acaricide rotation scheme. Apart from a limited choice of insecticides, much emphasis was placed on correct application to minimize the dosage required to control early instar larvae before they damaged buds and bolls, and on adjusting the dosage in relation to plant height to increase the amount applied approximately in proportion to the area of foliage that required treatment.

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In francophone Africa, jassid resistant cotton cultivars were grown and the close season observed, but chemical control was based on a calendar schedule with a mixture of a pyrethroid and organophosphate insecticide applied at ultra-low volume (usually 3 litres ha^{-1}) (Cauquil, 1987). However, there is now a trend to using conventional formulations at very-low volume (c. 10 litres ha^{-1}) through spinning disc sprayers, as this allows greater flexibility in choice of insecticide at each spray date (Cauquil and Vaissayre, 1995). Efforts are also being made to change from a fixed schedule to a system of crop monitoring to decide when to spray.

In the USA, much attention has been given to breeding for multi-adversity resistance (MAR) to cotton pests. New cultivars include Tamcot HQ95 (MAR5) and Tamcot Sphinx (MAR6), which have high levels of resistance to four insect pests and six plant pathogens as well as resistance to water stress (El-Zik, 1995; El-Zik and Thaxton, 1989; 1996). A successful IPM programme was developed using these short-season Tamcot varieties and based on a model developed by Walker and Niles (1971) in response to problems created by insecticide resistant budworms (Adkisson and Nemec, 1966). Early harvesting and area-wide removal of crop residues reduced the over-wintering boll weevil population, so that in the following season the crop was able to set bolls for at least the first 30 days of flowering without encountering an economically damaging boll weevil infestation. This reduced the need for insecticides which were only applied in relation to field sampling and economic thresholds (Reynolds *et al.*, 1982).

The above examples of IPM implementation are quite different in terms of insecticide use, although in each case it is accepted that a spray may be required if pest populations exceed an action threshold. In contrast there are areas where an IPM programme has not been achieved.

DISASTER CROPS

In the eastern part of China along the Yangtze and Yellow River valleys, unrestricted use of pyrethroid and other insecticides has led to a high level of resistance in the bollworm (*H. armigera*) and an increase in aphid infestations where cotton and wheat are grown in relay. There is quite a range of different methods of cropping used by farmers in this area with an extended period over which cotton is sown and this encourages a build up of insect pests. Two decades ago there was a well organized production of *Trichogramma* spp. with releases on over 0.5×10^6 ha of cotton annually (Anon, 1977), and the use of the hunting wasp (*Polistes jukahamae*) (Hussey, 1977), combined with the use of *Bacillus thuringiensis* and interplanting with sorghum to attract coccinellids and *Chrysopa* spp. (Way, 1977). Recently IPM techniques have been supplanted by overuse of insecticides. The mis-management of insecticides was to a large extent related to the variety of agronomic practices, including choice of variety, time of sowing, crop rotation and fertilizer use adopted by individual farmers (Le Rumeur, personal communication). Subsequent failure to achieve adequate control of the

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bollworms and aphids due to resistance has led to a decrease in yield and, in certain districts, the area sown to cotton has declined.

Similarly in India, where pigeonpea and many other host plants of *H. armigera* are grown, pest populations have caused so much damage that it was not surprising that farmers wanted to use insecticides. Manufacturers of active ingredients have to supply local formulators as well as sell their formulations to farmers, so there is a very large range of products available with inadequate advice to growers. This has led to a serious uncontrolled over-use of insecticides, usually poorly applied with inexpensive syringe-type sprayers. Inadequate spray coverage resulted in poor control of the early instars so farmers repeated sprays often at higher dosages. The low concentration and high volume of the sprays also failed to control the larger larvae so yields were low and bollworm resistance to pyrethroids and other insecticides is now extensive.

There are several other areas where excessive or incorrect use of insecticides has led to major problems. Even as early as the 1950s the cotton industry in the Canete Valley, Peru suffered a set-back when DDT, HCH, sulphur and toxaphene dusts were applied (Barducci, 1973). Extensive use of aerial application, often with over 30 sprays per season of DDT, parathion and toxaphene caused the death of and poisoned thousands of people, while in Mexico the crop was abandoned in many areas due to insecticide resistance and the cost of excessive spraying. In the Sudan relatively few aerial sprays so reduced the impact of natural enemies that the cotton crop suffered major outbreaks of whiteflies (*Bemisia tabaci*), the honeydew and subsequent sooty moulds made the lint sticky so that it was downgraded (Eveleens, 1983). More recently the action thresholds to trigger the use of insecticides have been increased to delay the start of spraying and reduce the number of applications (Stam *et al.*, 1994).

In Pakistan, yields of cotton were increased significantly by the introduction of insecticides, but the release of a new high-yielding cultivar with an additional 2% lint led to a dramatic fall in production due to the rapid increase in leaf curl virus (Mansoor *et al.*, 1993). Increased and earlier application of organophosphates to control whiteflies, the vectors of the virus, that migrate from melons and other crops, has had a detrimental effect on the natural enemies of the bollworm, *H. armigera*, so this pest has also increased in importance. The number of spray applications has increased and local distributors are selling various generic products, some of which are too toxic to be applied through manually operated sprayers. As in many other cotton-growing areas, the crop is flood irrigated. This flooding must reduce the survival of soil-inhabiting carabids and other important natural enemies of the bollworm compared with growing the cotton on ridges or beds and using alternative irrigation systems. As yet there is little published data on the effect of irrigation on biological control.

In each of these examples, there has been significantly less organized advice to farmers who, without adequate training, have misused chemical control while endeavouring to maximize their income in the short-term. Problems of poisoning because small-scale farmers have used the older, highly toxic pesticides have

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frequently been ignored by the authorities. The disasters have encouraged efforts to introduce integrated pest management, but adoption in many of these areas has been difficult and slow due to the scale of the problem and lack of co-operation between organizations and personnel.

INSECTICIDE RESISTANCE MANAGEMENT

Insecticide resistance has also been a major factor for Australian cotton farmers. In the 1970s production in the Ord Valley in the northern part of Australia ceased when it became impossible to control *H. armigera* as the number of sprays increased to over 30 per season (Hearn, 1975). In the Ord, irrigation and temperatures throughout the year are suitable for crops such as sorghum, and this allowed pest populations to continue to increase in the absence of natural enemies decimated by the extensive use of broad-spectrum insecticides, particularly DDT + toxaphene and parathion at that time. Later in Queensland when resistance to pyrethroids was detected (Gunning *et al.*, 1984), an insecticide resistance management (IRM) strategy was implemented immediately as growers, scientists and the agrochemical companies collaborated in an effort to avoid a repetition of the Ord debacle. The IRM strategy confined the use of pyrethroids to a defined period each year on all crops (Forrester *et al.*, 1993) in order to reduce the selection pressure on the major pest *Helicoverpa armigera*. While this strategy enabled farmers to continue growing cotton, in contrast to other countries which did not have an IRM policy (Cox and Forrester, 1992), an alternative IPM programme is urgently needed and research on genetically engineered cotton and other tactics are currently being developed.

Pragmatic resistance management strategies are not new and in Zimbabwe the acaricide rotation scheme (Duncombe, 1973) was introduced as soon as red spider mite populations became resistant to dimethoate on farms where it had been used on vegetable crops throughout the year as well as on cotton. However, in contrast to the situation in most other cotton growing areas, insecticide resistance has not been a problem with bollworms probably because sprays are only recommended in relation to an action threshold. However, part of the reason may be that there are very large areas of maize and sorghum as well as extensive uncultivated areas with some wild host plants that are not treated with insecticides and this maintains a susceptible population. While there has been considerable research into the different mechanisms of resistance, insecticide resistance management in the field in most other cotton growing countries has so far relied on recommending a maximum number of applications, usually one to three of any one type of insecticide per season. In some countries, notably Israel and Egypt, a definite programme of different insecticides has been promoted and in Mississippi, USA the recommendations suggest that pyrethroids should be confined to Phase II of the season between 1 July and 15 August (that is similar to the Australian and Zimbabwe programmes), and mixed with ovicides or Bt products to manage the tobacco budworm (*Heliothis virescens*). Timing of sprays should be based on twice-

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weekly field checks. Application of the organophosphates, profenofos and sulprofos, is also not recommended before 1 July and then only if a pyrethroid fails to control tobacco budworms.

NEW TACTICS

Lure and kill

The boll weevil (*Anthonomus grandis*) has been a major pest problem in the USA and Central America throughout the twentieth century and has now extended its range as far south as Argentina. By combining its pheromone, grandlure, with an insecticide on a cardboard sleeve placed over a series of sticks positioned around cotton fields, it is possible to attract the weevils to the 'weevil sticks' in the spring and kill them before they enter cotton fields (McKibben *et al.*, 1990). In North Carolina, problems of boll weevil control had led to severe curtailment of cotton production as early insecticide sprays against the weevils led to severe bollworm infestations in the absence of their natural enemies. Now, with the stick controlling the initial infestation of weevils, farmers have increased the area sown to cotton (Smith, 1994). The technique has also been used in Nicaragua (Daxl *et al.*, 1995).

A similar approach has also been investigated in Egypt in relation to *S. littoralis* (De Souza *et al.*, 1992; Campion, 1994) and also *P. gossypiella*, the latter by using the gossyplure pheromone formulated with insecticide in a paste-type of formulation. Using a dispenser, a small quantity of the 'lure and kill' formulation is applied at intervals to the leaves.

Genetically engineered cotton

Plant breeders have made considerable progress in incorporating into cotton cultivars the gene to express certain toxins from *Bacillus thuringiensis* (Gannaway, 1994). Early trials have shown that some of the lepidopterous pest populations, notably bollworms and budworms, are significantly reduced so that fewer sprays may be required. Thus in the Mississippi Valley non-*Bt* cotton required on average 5.5 treatments for budworm/bollworm control, whereas no sprays were needed on *Bt* transgenic cotton (NuCOTN), which yielded 222 kg ha^{-1} more fibre than the non-*Bt* cotton (Davis *et al.*, 1995). However, there is already evidence that other pests, notably hemipteran bugs and the boll weevil, can cause more damage in the absence of insecticide sprays directed at bollworms. The commercial release of cotton with one *Bt* gene is already causing concern, as many scientists feel that pests will soon become resistant to *Bt* following selection in a similar manner to the response to insecticide sprays. A combination of high toxin expression to kill heterozygotes with a policy in which up to 25% of each grower's land is sown to non-transgenic cotton in order to provide refuge for susceptible moths, is one favoured strategy to combat resistance. It remains to be seen if sufficient discipline exists to implement such a strategy successfully in all countries. Currently additional *Bt* genes are being added to increase the number of endotoxins produced in an effort to delay the onset of resistance. Those in favour

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of genetic engineering believe that a combination of genes expressing different toxins and enzymes can ultimately replace the *Bt* gene and eliminate the need for spray applications to all but a few insect pests. In contrast agrochemical companies are involved in developing transgenic cotton with an emphasis on crop cultivars resistant to their herbicides, such as bromoxynil and glyphosate, thus encouraging greater use of chemical weed control. In particular the use of herbicide-resistant transgenic cotton varieties will allow application of a wider range of herbicides that were previously not suitable for cotton and control weeds that have become dominant after the application of standard cotton herbicides (Wilcut, 1995).

IPM STRATEGIES

IPM has been implemented in countries which have invested in long-term research aimed specifically at the key factors which are thought to sustain crop production. While some basic research has played an important role in the initial development of control tactics, successful IPM has been achieved when scientists have extended their studies to applied on-farm research and encouraged farmer participation. Analysis of farmer reaction to new technology and appropriate modifications of the recommendations has enabled the extension of IPM more readily than where there has been little attempt to address the problems encountered by farmers confronted with new approaches to pest management.

Furthermore adoption of IPM has been more widely achieved in countries with a centralized crop protection programme. Thus in the former Soviet Union and Egypt, once the new recommendations were accepted, for example, the release of *Trichogramma* spp. and the use of gossyplure, adoption of these techniques was rapid over a large area. Where there was less centralization, IPM could still be achieved where there was good cooperation within the farming community. In Zimbabwe, the Commercial Growers Association was a focal organization that encouraged the publication of a handbook so that recommendations could reach the farmers. Simplified instructions were available in the vernacular and selected extension staff received training. Updated information on the pest situation was provided weekly on a radio programme. Later a Cotton Training Centre was established (Burgess, 1983) to train farmers and their assistants to monitor pest populations.

Another important aspect of this programme was the limited set of recommendations, especially on the choice of insecticides and dosage, that has enabled an effective resistance management strategy to be implemented. Simplified instructions also allowed the introduction of the pegboard to facilitate small-scale farmers' decisions about when to spray and which insecticide to use. Research on application technology led initially to the development of the rear-mounted tailboom on knapsack sprayers to improve spray distribution on the crop (Tunstall *et al.*, 1961) and reduce operator contamination (Tunstall and Matthews, 1965).

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Table 2. *Cotton agro-ecosystems*

Farming system	Vegetation	Winter	Country example	Control methods for cotton pests
Irrigated	desert	cold (<0°C)	Uzbekistan	Release of parasitoids
Irrigated	desert	cool	Egypt	Conservation of natural enemies, pheromones
Rainfed	savannah	cool/dry	Zimbabwe	Closed season, resistant cultivar, limited insecticide use with scouting
Rainfed	tropical	warm	Uganda, Cote d'Ivoire (South)	Closed season, restricted use of insecticides

Trials on farmers' fields and collaboration with the extension staff revealed that a lack of water in many of the cotton growing areas prevented many farmers using knapsack sprayers, so ground-based ultra-low-volume spraying (1–3 litres ha^{-1}) using hand-carried, battery-operated spinning disc sprayers was evaluated (Matthews, 1973) and introduced to extensive areas of Africa, notably Mozambique, Tanzania and francophone Africa. However, the problems of registering additional oil-based formulations, their cost and the need for greater flexibility in the choice of insecticide in relation to pest populations has now resulted in a major change from ultra-low volume to very-low-volume (5–15 litres ha^{-1}) spraying using water-based formulations (Mowlam *et al.*, 1975; Clayton, 1992). In some situations an adjuvant is mixed with the spray to reduce its volatility; in Zimbabwe molasses have been used for this purpose.

In Asia, following the adoption of the FAO IPM rice programme involving small-scale farmers in a tropical lowland irrigated farming system (Kenmore, 1991) in contrast to the situation for many cotton growing areas (Table 2), much emphasis has been put on the 'farmer field school' approach. The aim is to get individual farmers to recognize the importance of beneficial natural enemies and only to use an insecticide if it is really necessary. Frequently cotton farmers would use chemical control too early in the season when plants can still compensate for some damage or indeed can be stimulated to produce more flower buds by a small infestation.

New initiatives to implement IPM are now underway in cotton growing areas most affected by problems of insecticide resistance in China, India and Pakistan. Initially small-scale trials supported by the Asian Development Bank compared farmers' current practice with a proposed IPM programme and untreated plots. In Pakistan small-scale trials releasing *Trichogramma* spp. also started. Generally the plot receiving IPM yielded as well if not better and more economically than those receiving the farmers' treatments, and the untreated plots continued to give the lowest yields. There is considerable interest and a market for untreated

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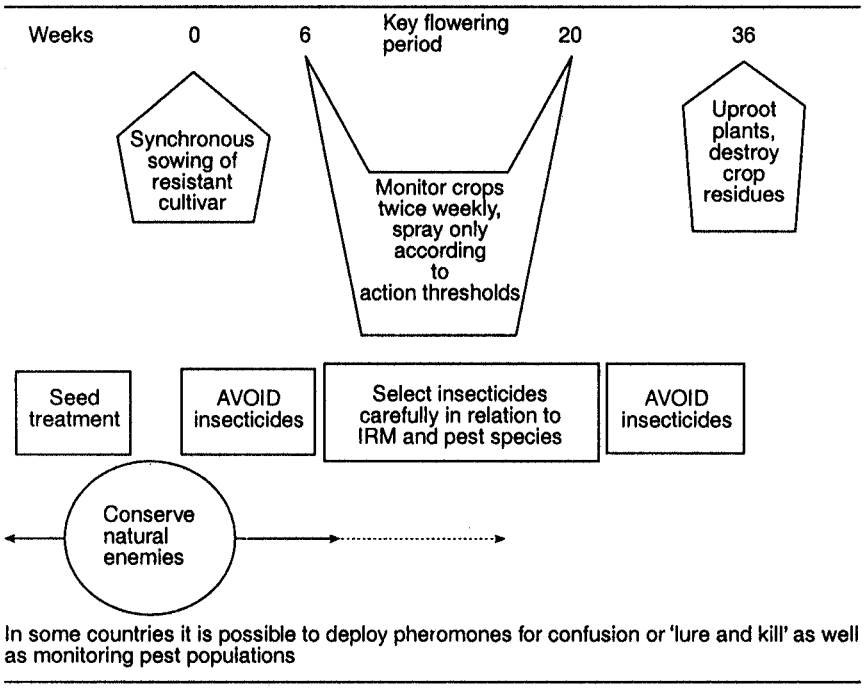


Fig. 1. Integration of some of the tactics that can be used in an Integrated Pest Management programme. In some countries it is possible to deploy pheromones for confusion or 'lure and kill' as well as monitoring pest populations.

'organic' cotton but, as yields of untreated cotton are so low, it would have to be grown in areas with extremely low pest populations, otherwise the price of cotton would have to be considerably higher to compensate for the low yields and poorer quality of fibre.

One of the problems for IPM has been the initial emphasis either on one pest or one crop, but, as other crops within an area have a major role in the survival of polyphagous pest populations and the survival of natural enemies, integrated pest management has to be broadened to include crop agronomy relevant to each agroecosystem. This realigns the scope for integrated pest management and necessitates integrated crop management to ensure that the potential yield is sufficient to be economically viable and appropriate for the locality. A programme suitable for the irrigated sector, whether in an area with extreme cold winters as in Uzbekistan or in other areas, such as the Sudan or Pakistan, will need to be significantly different for the rain-fed crop in the semi-arid tropics.

If IPM is to be more successful, appropriate and imaginative field research is a key foundation to provide the framework on which the IPM programme can be built. For example, the development of the cotton insect pest recommendations in central Africa (Fig. 1) was possible because of the long-term support for the research station in Gatooma (now Kadoma), initially by the Cotton Growing

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Corporation set up in the 1920s and subsequently with local finance and project support from the UK Government. FAO has also actively provided research inputs into areas such as Nicaragua (Falcon and Smith, 1973), Pakistan (Vaughan, 1978) and the Sudan (Eveleens, 1983; Stam *et al.*, 1994) to assist local scientists in the development of IPM programmes. The scale of such research, involving different trophic levels, now needs closer integration of all the disciplines, individuals and public and private sector organizations in a community-wide programme if the different tactics are to be successfully integrated and, most importantly, implemented by small-scale farmers. Such programmes involving the training and active participation of farmers, and the support of politicians, will need a long-term commitment to develop a dynamic and sustained means of crop production.

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