Current approaches for management of cotton pests and diseases in India

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ABSTRACT

Managing biotic stress in cotton has been dependent on the various pesticide molecules that are becoming available for cotton where farmers took extra-care to see that all the fruiting forms are retained in tact to be harvested fully. This paper discusses the solutions that have arisen out of the country-wide monitoring of insecticide resistance in key pests as well and the use of alternate strategies such as biological control and host-plant resistance.

Introduction

India is one of the two countries of origin of cotton the other being Peru. Fifty years ago India grew cotton over 5.89 million hectares of land with a production of 3.1 million bales. Today, cotton occupies an area of 8.87 M hectares with a total production of 14.5 M bales of cotton (CICR Annual report 2001-2002). With increasing population, the requirement for cotton rose dramatically and in 1999-2000 productivity was 320 kg lint ha^{-1}. Over the last 50 years productivity increased by 221 kg ha^{-1} from an extremely low 88 kg ha^{-1} (Agrl. statistics at a glance, 1999). This phenomenal growth in cotton productivity was attributed largely to hybrid cotton technology (Paroda and Basu, 1990). About 20 major popular hybrids occupy nearly 40 % of the total cotton area and contribute to over 50 % of the total cotton production. With successful exploitation of this technology on a commercial scale, further increases can be brought about through integrated crop management programs of which IPM is a crucial component. This is especially true since there has been no significant expansion in the area under cotton cultivation in recent years and the targets can now be met through good management programs. While India has the largest area in the world under cotton (Table 1), it still ranks amongst the lowest in its productivity.

India is perhaps unique in its cotton cultivation. The four commercialized *Gossypium* species are grown commercially in different regions of the country. *G. hirsutum* and *G. arboreum* are grown in the North Zone comprising the Punjab, Haryana, Rajasthan, and parts of Uttar Pradesh. The Central Zone comprising of Gujarat, Madhya Pradesh, and Maharashtra is home to *G. hirsutum*, *G. arboreum* and *G. herbaceum* while all four species (including *G. barbadense*) are grown in the South Zone (Basu, 1995). Table 2 indicates the expected area under the four species in the years to come. Sixty-five percent of the area under cotton is predominantly rainfed, while the remainder is irrigated. The irrigated cotton belt is largely confined to northern India.

Changes in the cultivars and cultivation practices have effected changes in the dominance of various pest species. Intense efforts to thwart herbivory in cotton crop made it notorious as a pesticide intensive crop in the last few decades, in India as elsewhere in the world. Today, India uses chemicals including pesticides in public health and agriculture to a total of US $640 M of which US $560 M worth pesticides are used in agriculture alone. Of this, insecticides worth US $320 M are used for the control of bollworms and sucking pests and US $222 M of this is apportioned to bollworm control (Ghosh, 2001). In this context, alternate methods of pest management, such as IPM becomes relevant, as there is emphasis on the judicious use of pesticides in combination with other methods of control.

Pest losses in cotton

Insects, mites, pathogens, weeds, nematodes, rodents and birds constitute the pest complex of cotton. Of the biotic stresses, insect pests cause by far, the highest economic losses. Of the 1326 species of insects found on cotton, the sucking pests (jassids and whitefly) and the bollworm complex are designated as the key pests of cotton. Apart from a direct effect in the reduction of yield by these pests, it has been realiszd that their damage contributes to a high trash content in the lint resulting in lower international prices for Indian cotton.

Losses due to bollworms are more or less consistent throughout the sub- continent. However, losses due to sucking pests are variable. During the year 2001-02 heavy losses due to bollworms were reported in Punjab (20%), Haryana (50%) and Rajasthan (70%) (AICCIP annual report, 2001-02). During 1999-2000 and 2000-01 the avoidable losses due to all major pests were 32.3% and 26.2%, respectively. Sucking pests, in two years, caused a loss of 18.1% and 13.5% respectively while bollworms caused loss of 26.57% and 16.23% respectively (CICR Annual Report, 2001). A special mention should be made of the cotton whitefly Bemisia tabaci that has been reported to be a major pest in 16 of the 27 major cotton growing countries of the world, especially during the mid to late cotton growing season. It has also become a serious pest of cotton in recent years in several cotton growing regions of India, especially in the northern parts of India. The problem assumes a serious dimension in relation to the *Cotton Leaf Curl Virus* (CLCuV) being transmitted by the whitefly. Losses caused by CLCuV have seen a reduction in the number of harvestable bolls 15–87% and a loss in boll weight of upto 39% (Singh *et al*., 1999). Bacterial blight and gray mildew are diseases that affect cotton in rainfed and dryland conditions while root rot and cotton leaf curl, are diseases that affect irrigated cotton in the north zone in India. These diseases limit productivity of lint to the extent of 12-23%. Many of them need critical favorable climatic and host conditions to emerge as a biotic threat for yield destabilization. Diseases in cotton have low yield reducing impact unless they become epidemic. Due to the consistent breeding efforts, we now have inbuilt resistance to bacterial blight, grey mildew and traditional wilts. Loss estimates due to plant parasitic nematodes have been put between 9-15% in India.

Integrated pest management refers to the intelligent selection and use of pest management tactics that results in favorable ecological, sociological and environmental consequences (Rabb, 1972). It has also been defined as one or more management activities carried out by farmers that result in the density of potential pest populations being maintained below levels at which they become pests, without endangering the productivity and profitability of the farming system as a whole, the health of the farm family and its livestock, and the quality of the adjacent and down stream environment (Whiteman *et al*., 1995). IPM recognizes that complete control of a pest is neither required nor desired. It emphasizes the maintenance of pest populations below the economic threshold level (current figures for cotton insect pests has been presented in Table 3) and demands the initiation of pest management tactics before the economic injury level is reached. This concept is coherent with administrators and scientists in India. However its implementation under field situations has not been easy since the average Indian farmer has a low literacy level and fragmented land holdings with multiple crops. Therefore cotton pest management strategies for India have to be designed in such a way so as to ensure that they are in consonance with ground realities of the Indian farming system. Plant protection specialists in various research institutions have to assemble their technologies to fit it into this complex and heterogeneous cropping environment of Indian farms.

Managing biotic stress in cotton was dependent mainly on a plethora of chemical molecules where farmers concern was to ensure the retention of all fruiting forms, intact untill harvest. This paper discusses the imaginative alternate strategies such as adoption of insecticide resistance management strategies, biocontrol-based IPM, host plant resistance, harnessing of low cost methodologies to sustain small growers, maintain a healthy crop to harvest good quality fiber and bring in economic and social benefit. The different approaches have been evolved in such a way to ensure that the cotton grower is able to reduce the cost of cultivation allowing the market price fluctuations which an anticipated in the coming years to be met with more confidence.

Management strategies

Pest monitoring

Monitoring of pests and diseases is necessary for timely action to be initiated. Use of light traps and pheromone traps to monitor insect populations is being recommended. Regular scouting is undertaken by progressive farmers for determining bollworm populations in the egg stage for effective management.

Seed treatment

This is a practice that has been followed primarily for protecting the young seedlings from disease. Historically, organomercurial compounds dominated the seed treatment market. This was gradually replaced with new chemicals such as Thiram, Mancozeb, Carbendazim etc.

Today we have new generation compounds that offer excellent sucking pest control. Jassids, aphids and other sucking pests are better managed with seed treatment allowing a delay in the application of broad spectrum foliar sprays (Russell *et.al*., 1998). Imidaclorprid (Gaucho 70 WS) is a chloronicotinyl molecule used at 7.5 g a.i/ kg of seed and offers protection upto 45 days after sowing against sucking pest such as aphids and jassids. Thiomethoxam (Cruiser 70 WS) and acetamiprid are newer products useful for seed dressing (Leicht, 1993). However, imidacloprid, on account of its high toxicity has been discouraged as a seed-dressing agent for farmer application by the government of India. Approval has been granted for its application by seed companies for seed treatment prior to sale. It has, however, been permitted for use as an early season spray (Confidor®) as and when required. Use of these neonicotinoids is being recognized as a popular technology especially for cotton hybrids as it is cost effective on account of the low seed rate for hybrids. Bt hybrids (MECH 12, 164, 184) seeds are also being treated with imidacloprid. The use of neonicotinoid treated seed is an important component of leaf curl virus management where it has been reported effective in vector management. Seed treatment chemicals like imidacloprid 600 FS, imidacloprid 70 WS, thiomethaxam 70 WS and carbosulfan 25 DS, reduced both the CLCuV and vector incidence for two consecutive years (Singh *et al*., 2002). Seed treatment with carboxin, carbendazim, or carbosulfan protects the cotton crop against fungal soil borne diseases. Mancozeb seed treatment was reported to keep root rot disease to low levels in infected soils (Monga and Raj, 2000). In addition, protection against seed borne diseases is ensured by storing seeds under low moisture conditions and by the use of acid delinted seed.

Host plant resistance

The basis for any sound IPM program is the choice of an appropriate cultivar that fits well into the production system.

The most desirable characteristics of a cotton cultivar or hybrid is that it should possess reasonable pest tolerance, short and early duration, good fiber qualities, coupled with high yield.

Both morphological and biochemical mechanisms in *Gossypium* spp. have been found to mediate resistance against jassids, whiteflies and the bollworms. Morphological characters such as hairiness of leaves, toughness of leaf veins, thickness of leaf lamina, length of hair and angle of insertion are reported to be associated with jassid resistance. The pubescent genes H1 and H2 has been used to provide jassid resistance to cultivars in India. However extreme pubescence has been reported to have an adverse effect on agronomic traits (Uthamasamy, 1995).

Of the cultivated cottons, *G. arboreum* and *G. herbaceum* are resistant to the leaf hopper. Among the wild cottons *G. tomentosum*, *G. armourianum* and *G. raimondii* by virtue of their pubescence are resistant to sucking pests. *Gossypium arboreum* types as compared to *Gossypium hirsutum* types are more resistant to jassids and whiteflies. Morphological attributes such as red leaf, glabrousness, okra leaf and fregobract are known to confer a high degree of tolerance to *Helicoverpa* and whiteflies. Red leaf has an adverse effect on agronomic characteristics especially in environments with high yield potential.

Most of these attributes have been used by breeders to screen for resistant sources and cultivars, such as Kanchana, LK861 and Supriya, have been developed which have considerable tolerance to whitefly. Cotton genotypes, DHY286, Mahalakshmi, MCU15, Krishna, Sujatha have been identified for resistance against jassids. These sources of resistance can be used as parents in crosses. Some exotic hybrids (six *G. hirsutum* x *G. barbadense* interspecific hybrids, five from Israel and one from India, and two intraspecific *G. hirsutum* hybrids (Fateh and LHH144) were tested for their resistance to white flies under field conditions. Table 4 lists the prominent cotton cultivars that have resistance to pests and diseases.

Biochemical features such as levels of gossypol, phenol, tannin, and heliocides of squares and bolls have been found to impact host plant resistance to bollworm significantly. Genetic research has shown that gossypol, anthocyanin, phenolics, and related compounds are amenable to selection and they can be increased to levels effective for useful insect control. While these features have been commercially exploited to a certain extent in the genotypes of the US (Jenkins, 1995), their utilization in the Indian context has been limited. Cultivars or hybrids that show resistance to Helicoverpa armigera, the major cotton bollworm under normal pest pressure do not exhibit the same level of resistance in an outbreak situation. Use of some traits has limitations that relate to the occurrence of different insects in the production system, as a character, which is useful for the control of one pest may be contra-indicated for another.

Effective host plant resistance has been employed against Verticillium wilt in southern India. Three *G. hirsutum* lines, KH-13-146, 15 KW-2 (MB) and 9-KW-2 (MB) have been observed to be resistant to both *R. solani* and *R. beticola*. Molecular approaches to utilize pathogen-derived resistance factors are being employed to develop diagnostic tools for bacterial blight disease in cotton (Chakrabarty, 1999). Newer strategies such as the activation of inducible defense mechanisms of plants by compounds such as ASM (acinbenzolar S-methyl), an activator of broad-spectrum disease resistance, are new tools in crop health management. These are to be evaluated with the Indian varieties and hybrids in developing resistance against grey mildew disease and others where genetic resistance is still elusive.

A national *Gossypium* gene bank of was set up at the Central Institute for Cotton Research (CICR), Nagpur in 1976 and today it boasts 9607 accessions of both cultivated and wild species of cotton which are accessible to both the Government and the private industry for purposes of research that includes resistance breeding. Many tolerant accessions have been identified from within the germplasm repository and a few are listed in Table 5.

Cultural methods

Utilization of cultural methods of pest control has seen limited success. Many of these practices lapsed with the introduction of effective and easy to use pesticides. Utilization of oviposition trap crops such as marigold, in cotton in South India, is a popular cultural practice for improved *H. armigera* management. The use of redgram/cowpea intercrop in cotton production systems has been reported to enhance numbers of beneficial fauna thus aiding crop protection. Grazing of harvested crop stubbles is a recommended practice to prevent carryover of pink bollworm pupae. This is quite often carried out in Indian cotton production systems. Castor is popularly grown around cotton as a trap crop in Andhra Pradesh for *Spodoptera* control. These methods are cheap, sustainable and are readily adopted by farmers. Of the cultural methods of control, cropping practises, close seasons and crop rotation are adopted in cotton cultivation. Although no legal enforcement of the close season is prevalent in cotton production systems of India, in many areas farmers leave cotton fields fallow during the peak summer months of May and June. This close season is of fundamental importance for key pests such as *P. gossypiella* and has been introduced in most cotton growing countries (Matthews, 1994).

Cultural practices have a significant effect in the case of soil borne pathogens. Crop rotation, soil amendments with organic material and mustard cake reduced root rot incidence drastically. Ammonium sulfate and intercropping with moong bean (*Vigna aconitifolia*) have consistently reduced root rot incidence. Soil application of zinc sulfate @ 24 kg/ha was also found suitable in reducing the incidence of root rot (Raj *et al.*, 1999).

Mechanical methods

De-topping in cotton to prevent egg laying by *H. armigera* has been considered as a recommendation. It was found that de-topping of terminal leaves would result in the reduction of eggload in the crop. This practice appears to be feasible only in Central India where genotypes are comparatively short statured to those of North and South India. Thinning of plants to maintain optimum plant populations and mechanical picking and destruction of egg masses of *Spodoptera* are a popular practices in Andhra Pradesh. Handpicking of older larvae of *Helicoverpa* especially during outbreak years, 2-3 days after pesticide application, is a recommended practice to contain resistant *H. armigera* larvae. The use of light traps is popular in some regions of the country (eg. North India) and is especially directed at noctuid moth control. Yellow colored sticky traps for whitefly control form part of the recommended package of practices for whitefly endemic areas in India. The use of pheromone traps was initially envisaged for mass trapping of moths. However, considering limitations such as cost, attraction of the relevant species demonstrated the efficacy of pheromone traps for its purpose, they are now recommended mainly for pest monitoring. They are now reasonably popular for pink bollworm monitoring in North India. Studies at CICR in collaboration with the Bhabha Atomic Research Centre have explored the generation of suitable pheromone blends for monitoring of mixed species bollworm populations and the design of appropriate traps to suit the Indian farmer.

Biological control

Entomopathogens such as *Nuclear Polyhedrosis Virus* (NPV), the egg parasitoid, *Trichogramma minutum*, the larval parasitoids, *Bracon* sp. and *Apanteles* sp, lace-wing, *Chrysoperla carnea*, and coccinellids, *Menochilus* and *Chilomenes* have been used extensively in field trials. Table 6 lists commonly found natural enemies with their peak period of occurrence in the cotton ecosystem. The emphasis in India on biological control has been on the augmentation of natural enemies, involving mass production and release of natural enemies at certain critical periods in the life cycle of the pest when natural enemy populations are at low levels. *Trichogramma* has been extensively used the world over to suppress lepidopteran pests in a number of cropping systems. Effectiveness has been established in India, in the sugarcane, tomato and potato ecosystems (Sithanatham *et al*., 1973, Yadav *et al*., 1985). Chrysopids offer great scope in the suppression of sucking pests in cotton. A mass production technology has been developed at Gujarat Agricultural University, Anand. Over 60 million eggs could be produced in a month, sufficient to occur 100 hectares of irrigated cotton. Of the several pathogens that have been extensively studied, viruses have been found to be the most promising. As many as 35 viruses have been reported from different insects (Pawar and Thombre, 1991).Results of field trials with *Helicoverpa* specific NPV (Ha NPV) on chickpea (Mistry *et.al*., 1984), at Tamil Nadu (Jayaraj, 1988) and Maharashtra (Pawar *et.al*., 1990) have been promising. NPV as sprays against *H. armigera* have been reported effective in cotton (Dhandapani *et.al.*, 1987), sunflower (Rabindra *et.al.*, 1985). Pigeon pea (Pawar and Thombre, 1991) and tomato (Mistry *et.al.*, 1984). *Spodoptera* NPV was found effective in cotton, tobacco and cauliflower (Jayaraj, 1988; Ramakrishnan *et.al*., 1981 and Chaudhary and Ramakrishnan, 1990).

CICR has played a major role in the establishment of small biocontrol factories in Vidarbha region of Maharashtra. These small-scale units are capable of producing *Trichogramma*, *Chrysoperla* and HaNPV. A low cost technology for the mass production of Bt has been introduced. Protocols are also available for mass production of major natural enemies. The basic laboratory host for the multiplication of *Trichogramma* and *Chrysoperla* is *Corcyra cephalonica*, the mass rearing of which is done on cheap local grain. The eggs and larvae thus obtained are put to use in the production of various natural enemies. From a production of 200 000 larval equivalents (LE) per year of HaNPV per year in 1997-98, these enterprises are confident of producing 2.5 million LEs per year per bio-factory unit (Rajendran and Basu, 1999). It must be mentioned here that in India, State Governments offered a heavy subsidy on the production and purchase of HaNPV.

As part of the All India Coordinated Cotton Improvement project (AICCIP), an extensive networking system between ICAR, National Institutes and State Agricultural Universities bio-intensive models of IPM have been tested. These modules lay emphasis on the release of bio-agents with good management practices, which are prevalent or that can be adopted in particular.

Cotton production systems, especially the irrigated areas of North India and Andhra have witnessed rampant misuse of insecticides in the past. This has resulted in the virtually complete elimination of bio-agent populations. It must be emphasized that reduced pesticide use has demonstrated the restoration of bio-agents, with yields being initially low, but once natural enemy populations are restored, higher yields are obtained (Asanov *et al.,* 2001). Globally however the direct impact of the non-chemical control component of IPM has usually led to only modest enhancement of yield, rather slight increases in the importance of beneficial insects and modest reductions in pest damage.

Biocontrol-based management of plant diseases is being adopted today. Several antagonists such as phylloplane and rhizosphere flora have been identified to be potentially useful for bio-control of cotton pathogens. Seed treatment with *Glyocladium virens* and *Bacillus subtilis* to suppress colonies of *Fusarium oxysporum* are recent approaches adopted in India before planting. Several strains of *Trichoderma viride* successfully protected cotton plants against root rot caused by *Rhizoctonia solani*, *Sclerotium rolfsi*, the application of seed treatments with biological products using a talc base is feasible (Mathiavanan *et al*., 2000).

Endopytic bacteria, such as *Agrobacterium sapardae*, *Bacillus pumilus*, *Phyllobacteria rubiacearum*, *Psuedomonas putida* and *Bakholderia solanacearum* show potential for the biocontrol for the vascular wilt pathogen (Chen *et al*., 1995). These bacteria can survive within cottonseeds up to 28 days after inoculation. Soil application of *Trichoderma harzianum* controlled damping off by *R. solani* and gave an excellent crop stand (Monga, 1997). Culture filtrates of *Trichoderma* and *Gliocladium* species reduced root rot pathogens and with suitable organic amendments, these organisms were found to perform better as antagonists of cotton root rot (Monga, 2001). Improved strains of this fungal antagonist with additional copies of the proteinase gene, prb1 (Flores *et al*., 1997) could also provide better ammunition against rhisosphere pathogens such as *R. solani* and *R. beticola*.

Botanicals

Plants are the richest source of renewable active chemicals that can check pest populations. The use of botanicals is another important component of IPM, of which neem is of prime importance. About 67 commercial neem-based formulations are currently available. The active principles in the neem seed and other plant parts are azadirachtin and its analogues, which by virtue of contact and stomach action, possess ovicidal, antifeedant and growth regulatory properties against insects. Neem has been reported to be compatible with parasitoids (Mani, 1994; Regupathy and Mahadevan, 1993) and predators (Schmutterer, 1990; Natarajan, 1990) in the cotton ecosystem. It is certainly possible and advantageous to include neem products in IPM programs (Tadas *et al*., 1994) especially with an estimated 18-million neem trees in India, each with a potential to produce 0.7 tonnes of fruit. Farmers have been made aware of the economics, safety and environmental benefits of neem. This component of IPM was already in practice as an indigenous technology and is a low cost management tool. Refinement in the preparation of sprayable formulations from neem seed has been brought about in many cotton growing regions with farmers being trained to collect neem seeds and process it during the off-season in addition to other techniques. These include the addition of soap as an emulsifier and the addition of neem oil, which reconstitutes the water-extracted azadirachtin to a more effective formulation. Neem suffers the disadvantage of having reduced stability when exposed to sunlight. Research is being directed to improve its stability with the addition of UV protectants to formulated products. Other plant products that are in use include water extracts of *Calotropis, Ipomoea* etc.

Chemicals

The Indian farmer is heavily dependent on insecticides for pest control since these products are ready to use, readily available and provide visible amelioration although they are not cost effective in all cases. A substantial regional difference in pesticide use exists. Andhra Pradesh, Karnataka and Gujarat account for 65% of the total consumption and Andhra Pradesh alone accounts for 34%. The per-hectare pesticide consumption is highest in AP (1023 g), Haryana (889 g), Punjab (834 g) and Tamil Nadu (778 g). During 1997, Andhra Pradesh alone consumed pesticides worth US $85 M (Puri, 1998). Rampant misuse and gross overuse of insecticides have resulted in resistance in almost all insects to major groups of insecticides (Kranthi *et al.*, 2002). In the late seventies organophosphates such as monocrotophos, endosulfan were being widely used. With the introduction of pyrethroids and its near-miraculous effect in the initial years on all lepidopteran pests of cotton, farmers grossly misused this molecule. This was especially true of irrigated cotton regions. By the end of 2001, it was found that resistant *H. armigera* were present in all parts of the country (Kranthi *et al*., 2001). It is unlikely that any pyrethroid susceptible *H. armigera* populations can be found in the country. A worrisome development has been the emergence of spurious and substandard formulations of insecticides and botanicals. Pest control failures encouraged farmers to undertake tank mixes of insecticides that worsened the situation because these were not recommended and were highly unscientific. The year 2001-02 witnessed a serious bollworm outbreak in North India. The reasons proposed are many of which the repeated spraying of pyrethroids, lack of availability of newer molecules on time and use of injudicious tank mixes are important.

Insecticide resistance management (IRM)

A novel strategy was devised to provide a practical, robust plant protection package to ensure favorable economic, sociological and ecological consequences. This involved the use of insecticides highly compatible with IPM while taking into cognizance the existence of resistance to insecticides in various insects of the cotton ecosystem. A wide database on the in-season changes in resistance and between years has been generated across North, South and Central India against the major cotton pests (Kranthi *et al*.,2001, 2002). This was established with the setting up of five major insecticide resistance laboratories across the country in a networking project. Details of this are not discussed in this paper. On the basis of the data base insecticide resistance management strategies have been formulated and implemented in parts of Andhra Pradesh, Tamil Nadu, Maharashtra and Punjab through funding by the Indian Council for Agricultural Research, Natural Resources Institute, UK, Department of International Development, UK and ICRISAT, Hyderabad and Punjab and Tamil National Agriculutral Universities. Currently, the Government of India is funding an US $350 000 project for the implementation of IRM strategies in the 26 newest insecticide using cotton-growing districts of India, in the year 2002-03. CICR is coordinating the inputs from government institutes, agricultural universities and the Indian Council of Agricultural Research in expanding this work to the 260 villages, which between them use almost 80% of the insecticides applied on cotton.

The basic concepts of IRM suggest that particular insecticides should be used when resistance to that material is low, that natural enemy populations should be disturbedas little as, that different groups of chemicals are alternated and that sucking pest tolerant genotypes are grown to avoid early season insecticide sprays. Summarised, IRM means cultivation of sucking pest tolerant cultivars, zero insecticides till 60 days after emergence of the crops, adoption of window strategies with no endosulfan beyond 90 days, no organophosphates till 90 days, use of bio-rationals if available between 70-90 days and the use of pyrethroids only after 110 days (CICR, 1999). IRM strategies draw strength from the fact that it is supported by voluminous, meaningful, peer reviewed and published laboratory and field data. Its sustainability is enhanced by the fact that it does not rely on the supply of free inputs to the farmer. The impact of insecticide resistance management can be seen from Table 7.

Insecticide resistance strategies have been adopted in several countries such as USA and Australia since the early nineteen nineties. Strategies suitable to the Indian ecosystem necessarily had to be developed since neither the pest situation nor the crop production practices were common between the countries. Globally, the more rational use of insecticides, through scouting-based systems and proper targeting of appropriate materials in IPM systems, has led to reduction in pesticide costs often exceeding 50%, thereby greatly enhancing cotton production profitability (Russell *et al*., 1998).

Transgenic Bt cotton

This is a promising seed technology option is now available to the Indian cotton farmer. Cotton genotypes have been successfully transformed with a gene from the soil-borne bacterium, *Bacillus thuringiensis*. The gene is responsible for the production of a protein toxin within the cotton plant that has been found to be effective against wide array lepidopteran insect pests. Monsanto introduced the gene into a cotton genotype in the US in 1993. Commercialised as the "Bollgard technology", it has impacted cotton production in Australia, China, Argentina, and United States during the last 5-6 years with minimal problems of field control failures. India conducted its field trials using transformed Indian genotypes MECH 12, 162 and 184 that contained the Bt gene developed by Monsanto together with the varieties of a leading player in the seed market, Mahyco. The gene was transferred through traditional methods of backcrossing. The Government of India permitted the commercial cultivation of Bt cotton in April 2002. In its first year of cultivation, MECH Bt hybrids occupied an area of approximately 80,000 hectares in Central and South India and is expected to occupy at least 50% of the hybrid cotton area in the country in the next 5-10 years (Mayee and Rao, 2002). The technology ensures the protection of transgenic plants from damage by most lepidopterans thus requiring minimal insecticide sprays. However, MECH BT hybrids are not protected from the attack of *Spodoptera litura* against which the Cry 1Ac toxin incorporated in the current Bt varieties is ineffective. This Bt technology also does not eliminate the requirement for sprays against sucking pests since MECH hybrids are susceptible to sucking pest attack with or without the addition of the Bt toxin. However, new cotton genotypes that are sucking pest resistant in addition to harbouring the Bt gene, are in the pipeline, and will be marketed by seed companies. This technology promises a bright future since it provides genetically engineered seeds that have the capacity to perform with relatively fewer inputs (Ghosh, 2001). From the field experiments conducted in India, cotton productivity was found to be increased by the inclusion of Bt by 23-60% in 1998-99 and 29-88% in 1999-2000 (Table 8). The net profit and the cost benefit ratio obtained in the first year of commercial cultivation have been presented in Table 9. After large-scale field trials, MECH 184 ranked first, while MECH 162 was suitable for rain-fed areas and for drought-prone situations and that MECH 12 had superior fiber quality and higher boll weight suited for areas with assured irrigation.

The government-funded biotechnology networking program aimed at transferring the Bt gene into popular varieties being grown in India is very strong. With the collaboration between at least five premiere research organizations, we now have the Bt gene introduced into LRA 5166, LRA 516, Bikaneri nerma, Sahana, and the G. arboreum genotype, RG 8. Currently, plants that tested positive for Bt presence in southern blots and ELISA are being grown under poly-house, contained, facilities before release. Bt detection kits have been developed by CICR and have been commercialized. One of them, marketed as "Bt Express" has been patented by the ICAR. These kits are being used routinely by seed companies and government research laboratories for the detection of Cry1Ac toxin in their breeding and transformed material. Farmers are using them to check for the quality of supplied transgenic seed.

New molecules for IPM

New molecules are likely to appear in the Indian market in the next two to three years. Some are being tested under the All India Co-ordinated Cotton Improvement Project (AICCIP) while others, like Spinosad and Indoxacarb, are already available in the market. The advantages of the new generation compounds are that, in addition to being effective at low dosages, like pyrethroids, they are reasonably safe to natural enemies. Essentially, they are highly IPM compatible. Several molecules such as chlorphenapyr, IGRs, pymetrozine, avermectins and resistance breaking pyrethroids are in the pipeline. However, two molecules need special mention- since they are commercially available in India.

Spinosad It is effective against lepidopteran insects including *Helicoverpa* through the activation of the neuronal nicotinic acetylcholine receptors, leading to neuro-muscular fatigue and paralysis. Spinosad comprises a mixture of spinosyn A (65-95%) and spinosyn D (5-35%). Structurally it is a macrocyclic lactone, safe to ladybird beetles, *Chrysoperla*, *Geocoris* and *Orius*, spiders, predatory mites and parasitic wasps. Spinosad 48SC is recommended at the rate of 50 g a.i/ha

Indoxacarb It belongs to the oxadiazine group and has contact and stomach action. Like most insecticides, this is a nerve poison, but acts by blocking the sodium pump. It is reported to be effective against pyrethroid resistant *Helicoverpa*. Applied at a low dose of 75 g a.i/ha, indoxacarb has high selectivity compared to conventional synthetic pyrethroids, OPs and carbamates. The only drawback appears to be its current high cost.

New molecules need to be introduced with caution. Generation of base line toxicity data for any new molecule that may shortly be introduced in the market is an important prerequisite to enable the detection of any development of resistance. This is especially important for the cotton ecosystem, which consumes more than 50% of the insecticide used in the country. On the introduction of new molecules and after intensive study under the All India Coordinated Cotton Improvement Trials insecticide resistance management programs for these new materials should be incorporated into IRM programs for cotton. This would help increase the life of the molecule by delaying the development of resistance. Short-term contractual projects are being conducted at the Central Institute for Cotton research to determine the baseline toxicity of some molecules that are in the pipeline for release.

Management of cotton nematodes

Reniform (*Rotylenchus reniformis*), root-knot (*Meloidogyne incognita*), lance (*Hoplolaimus* sp.) and lesion (*Pratylenchus* sp.) nematodes have been reported to be important in cotton. They are responsible for up to 10-12% yield losses in different regions and seasons. Many of them aggravate the damage when present in association with soil-borne pathogens such as *Rhizoctonia*, *Fusarium* and *Pythium*. Low cultural practices cost, have been effective in keeping damage at low levels. Rotations with crops like *Capsicum*, *Tagetes*, *Zinnia* and natural rotations with field crops have had a great impact in reducing nematode populations. Current emphasis of management has been on resistance breeding and biological control. Variety B4 Empire has been found to be highly resistant to root- knot nematodes. Similarly, *Paecilomyces lilacinus*, which parasitises the eggs of the root-knot nematode has shown good promise as a bio-control agent. *Pasteuria penetrans* has been suggested as a potential bio-control agent against root-knot nematode for the last decade.

The future

In the next five years cotton cultivation in India will emerge strengtened by the availability of Bt transgenics varieties and hybrids. Resistance management strategies which are being developed for the transgenic technology, specifically designed for the Indian farming systems will be disseminated. Pesticide consumption may reduce drastically with sustainable, cost effective, pest management programs in cotton. Awareness about new innovative technologies among the farming community will increase. Emphasis will be on parameters such as fiber quality in an endeavour to attract the international market. The cotton farmers and the cotton industry need to be suitably geared-up to meet the challenges of globalisation.

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Table 1. *Area, production and productivity in some of the cotton growing countries of the world.*

Country	Area (000 hectares)	Production (00 M.T.)	Productivity (Lint in kg ha^{-1})
USA	5282	3742	708
Brazil	858	900	1049
Egypt	315	272	864
Uzbekistan	1441	963	668
China	4032	4420	1096
Australia	500	704	1407
India	8148	2384	293
Pakistan	2912	1750	601
Turkey	667	880	1319
Israel	15	23	1586
World Total	31595	19251	609

Table 2. *Species composition – alteration expected (thousands ha).*

Species	Current area		Projected 2006-2007	
	Varieties	Hybrids	Varieties	Hybrids
Hirsutum	3000	3800	2200	4100
Arboreum	1500	< 500	1800	100
Herbaceum	400	Nil	500	Nil
Barbadense	-	200	-	300

Table 3. *Economic threshold levels for cotton insect pests.*

Pest	Economic Threshold Levels
Aphids	10 aphids/ plant or 15-20 % infested plants
Jassids	2 jassids/ leaf
Thrips	10 thrips/leaf or 15-20% infested plants
Whiteflies	8-10 adults or 20 nymphs/ leaf or honey dew on leaves on 50 % of the plants
Spotted bollworm	5-10 % fruiting body damage
Pink bollworm	5-10 % fruiting body damage
American bollworm	5-10 % fruiting body damage

Table 4. *Important varieties resistant to insect pest and disease.*

Variety	Resistant	Area for which recommended
Abhadhita	Bollworms	South zone
LK.861	Whitefly	South zone
Bikaneri narma	Jassids, Bollworms, *Alternaria*	North zone
Eknath	Fusarium wilt	Central zone
Kanchana (LPS.141)	Whitefly	South zone
Kirti (CICR HH.1)	Jassids	Central zone
Mahalakshmi (1301DD)	Jassids, Bollworms, Verticillium wilt	Rainfed areas of Andrah Pradesh
Rohini	Fusarium wilt	Central zone
MCU.5VT	Verticillium wilt	South zone
G.Cot.13	Fusarium wilt	Central zone
Arogya	Bacterial blight	Maharashtra ,TamilNadu
Supriya	Whitefly	

Table 5. *Promising germplasm lines against key pests of cotton.*

Jassid	*Helicoverpa*	Whitefly	*Earias*	*Pectinophora*
Acala	Ambassador	Tx URHU 1-78	Stoneville 731N	LH- 96-4
Acala Monel	Kandaya 19	Tx ORSC-78	Coker 100A	
L-716 SR	Pee Dee 0695	Tx Maroon 2-78	Empire	
320 F-Pakistan	MHR 10		XG 15	
Aboharia	DHY 286			
JBWR-34	EC 44772-20-1			

Table 6. *Some natural enemies in the cotton ecosystem.*

Name	Target pests	Period of occurrence
Orius sp	Aphids immature stages of jassids and whiteflies	July- September
Geocoris sp	Aphids and immature stages of jassids	July - November
Cathecona furscellata	Early instars of *H.armigera*	August- November
Chrysoperla sp	Aphids, jassids, eggs and young larvae of bollworm	June- November
Menochilus and Coccinella sp	Aphids, jassids, eggs and young larvae of bollworm	June - September
Eucelatoria sp	Bollworms	August- October
Apanteles sp	Bollworms	August- October
Campoletis chloridae	Bollworms	September- October
Sisyropa formosa	Bollworms	September - October

Table 7. Outcome for IRM crop management scheme: participating farmers compared with matched control farmers from nearby villages.

	Punjab	Tamil Nadu	Andhra Pradesh	Maharashtra
Number of farmers	40	92	135	2300
Reduction in pesticide use % (No. spray)	-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.

Table 8. Increase in seed cotton yield in Bt hybrids over local checks (kg ha^{-1}).

Hybrids	Central Zone	South Zone
MECH-184 Bt	544	723
MECH-162 Bt	588	785
MECH-12 Bt	107	751

(Source: Mayee and Rao, 2002)

Table 9. Cost of plant protection and net profit in Bt over local checks (.48 Rs/$ US).

Hybrids	Reduction in cost of plant protection (Rs/ha)	% Reduction	Net profit (Rs/ha)
MECH-184 Bt	1432	50.38	11566
MECH-162 Bt	1432	50.33	10972
MECH-12 Bt	1118	39.29	7041