Integrated pest management: Looking back and forward

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Since the 1950s, there has been unprecedented concern over the environmental and public health problems associated with the use of chemical pesticides on the basis of the message carried in the book 'Silent Spring' that deals with a new pest management strategy that integrates disciplines like agronomy, genetics, biology, and chemistry. Thus, this strategy forms the Integrated Pest Management (IPM). Efforts to implement IPM revealed poor adoption in case of resource poor farmers, though effective for industrial farming areas. Yet, the preferred approach for the present and future is IPM. Farmers desire that IPM strategy should be simple, easy to operate with sizeable economic returns. Thus, much depends on developing a perspective of stewardship rather than domination over nature. If tradition is made the foundation for modernity coupled with use of such chemical levels that enhance overall efficiency, its acceptance by farmers is assured. That would ensure ecological viability and economic sustainability to crop production endeavours.

OVER the past years, high academic, industrial, and financial support have been extended to plant protection in general, and integrated pest management (IPM) in particular. The annual estimated losses through pests and pathogens of crops (pre- and post-harvest), soil nutrients robbed by weeds, and ill health of animals run into several billion dollars in value. However, both the chemical and non-chemical measures have failed. Further, IPM strategy which used chemical pesticides as the last resort has a long recorded history; with divisive debates and discussions on it. All reports, publications and media coverage either whole-heartedly promoted an environmental agenda or rejected such an agenda outright. This review on the subject outlines historical perspectives, examines the strengths and weaknesses of its various components, provides current academic strategies that suggest the policy frame for research extension and adoption in the field, and illuminates the hazy and controversial areas to reconcile the two major concepts: chemical warfare to eradicate the pest – a flagrant act; and management to control the pest as a sovereign remedy.

Historical developments in pest control and management

Ascent of chemicals and pesticides

The forerunners of today's chemical pesticides appeared early on in history. The Sumerians used sulphur to control insects and mites around 2000 BC. Biblical writings frequently refer to the plagues caused by locusts; remains of grain-eating beetles were found in vases in king Tutankhamen's tomb dating back to 1350 BC. With the birth of Christianity, rituals were developed to control pests that caused havoc. Romans added many formulations with olive oil and sulphur for controlling pests. Pest management by the Chinese showed high degree of sophistication growing out of their long experience with rearing silkworm moths. Historical records exist that show the use of herbs, oils and ash to protect seeds and stored grains, as well as biological methods to control growth of caterpillars and beetles in citrus orchards, using predatory ants. A large part of renewed interest in pest control grew as a result of dramatic growth in agriculture and improved crop production with improved irrigation methods and use of fertilizers. The discovery of organic pesticides – chemicals that could be easily manufactured – proved to be of great success and won the appreciation of the farmers.

The four groups of organic insecticides (organochlorines, organo-phosphates, carbamates, and pyrethroids) are in use in our win over nature, of which DDT is the flagship chemical, and which fetches for its discoverer, Paul Muellers, the Nobel prize[1]. In a decade's time, a gigantic industry for the manufacture of various insecticides was established in the industrially-developed countries, which subsequently expanded its base in the developing countries as well.

Major policy shift: Descent of chemicals and pesticides

Globally, agriculture has switched to the use of machinery as labour saving, earliest practised in US. In both India

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and Japan, land is a limitation which has been compensated by the HYV technology, based on use of fertilizer and modern irrigation practices to increase the yield. The use of pesticides in the post-war industrial agriculture of US, and the green revolution in India witnessed three periods. (i) Euphoria and the crisis of residue (1945–55). (ii) Confusion and the crisis of environment (1955–72). (iii) Changing paradigms (1968–to date). In the first period the success of industrial agriculture was hailed, and the use of pesticide, which gave boost to the pesticide chemical industry, made termination of some insect pests a reality. However, this was followed by a period of confusion and doubt due to the two warring groups for and against the use of pesticides. The book by Carson[1] virtually gave a death blow to the indiscriminate use of chemicals to control pests. Further clinching evidence in support of Carson came from the ban imposed on the use of DDT for crop protection. The final period – changing paradigms – marks the beginnings of ecologically friendly policies and the serious search for alternatives, giving birth to IPM where chemicals are to be used only as a last resort.

The book by Carson essentially brought two issues into sharp focus: (i) Chemical pesticides can be dangerous to human beings as well as the environment and should be used as the last resort. (ii) There are biologically-based alternatives to synthetic pesticides, and these ecologically friendly methods need to be studied and implemented. The message though reasonable in the light of our current problems, but when first appeared whipped up reactions; often from people who had not read it and by the people who had vested interests in chemical industry. But, devastation wrought by indiscriminate use of pesticides, for example DDT, has brought home the message of Carson, and recent policy makers are in tune with her message. Thus, the policy adopted by World Bank since 1982 is to finance projects that do not seriously compromise public health or cause irreversible environmental deterioration. However, the World Bank objective should be to focus on the IPM approach for sustainable agriculture.

Some of the experiences of US agriculture have further weakened the popularity and wider acceptance of chemical control of insect pests and pathogens: (i) Over the period 1942–74 losses from pathogens increased from 10.5 to 12% and those due to insects doubled from 7.1% to about 13% despite a ten-fold increase of insecticide application[2]. (ii) Losses from weeds declined over the same period in USA largely because of improved technology of mechanical cultivation in addition to the use of herbicides[3]. The former has been attributed to: increasing resistance of pathogens and insects to pesticides; the destruction of natural enemies of certain pests; and reduced practices of crop rotations and crop diversity with greater reliance on continuous culture of mono crops. In the tropics as well, these factors are operative to which must be added the problem of resurgence of pests following repeated insecticide applications. Since the 1950s, such resurgence has been documented for green rice leaf hopper and plant hopper after the use of broad-spectrum insecticides, such as DDT and BHC, to control such major pests of rice in Asia as the rice borers[4].

Thus, whereas chemical control is philosophically based on a sense of nature dominated by human technology, the term management emphasizes the comprehensive nature of the approach together with the ecological realities[5].

Integrated pest management

Perspectives

The term pest management was first used by Bartlet[6], and later on elaborated by Stern[7], as a concept of integrating the use of biological and other methods of controlling pests. This was later broadened to include the coordinated use of all biological, cultural, and artificial practices. Subsequently, various authors advocated the principle of incorporating the full array of pest management practices together with increased-production objectives, thereby making it into a total system approach[8]. Since IPM deals with pesticide management and not pest management, it cannot be denied that its major thrust is for reduction of insecticide use. This approach needs to be further researched to understand the complex interaction between ecology, agronomy, biology, and climatology to develop it into an ecologically-based disease and insect control strategy, which represents only a part of an overall crop-production system.

In integrated pest control (IPC), pesticide is used only when the size of pest population warrants less damage to the natural enemy complex and the environment, with ultimate economic benefit accruing to the farmer. Currently, this covers any combination of different control technologies, although it is central to the concept of wiser use of pesticides. The combination of these two strands, IPC and pest management, have resulted in the IPM. Moreover, IPM is the philosophical 'precursor' for another popular philosophy: sustainable agriculture[9]. The present IPM thesis is a composite of disease management and integrated crop management (ICM).

The total system approach

Essentially the IPM paradigm is: (i) Eradication not as the goal, but only application of minimal level of control that will maintain the pest below the economic damage threshold. (ii) It accepts multiple techniques in preference to following only one pest management strategy. (iii) The no-option goal in reducing the levels of pesticide use, and least or no damage to the non-target organisms and ecosystems. (iv) The need for indigenous knowledge of agricultural systems and pest life cycles to complement basic science and technology[10]. IPM may thus be an excellent fit for industrial agriculture, but its transfer to resource-poor farmers in developing countries is problematic. Technological change is not socially or culturally neutral[11]. The transfer of strategies of developed countries where IPM succeeded to developing countries showing different ecological cropping patterns and cultural practices, is naive. Furthermore, IPM programme so far operated only to limit pest populations. Thus, a pesticide management programme objective which relegates the pest management objective which is equated to 'treat the symptoms' approach would be a major strength of real IPM. Also, though deemed as more complex to academic and extension officers and farmers, there is the need for more simple and straightforward solution to determine the economic threshold for each crop location set up. The terms pest control or pest management or crop management prefixed as 'Integrated', endorse a need for a total system approach wherein there is a meeting of minds, materials, and methods.

Adoption of IPM by poor

IPM originated in the high-input agricultural systems of developed countries, particularly North America. For developing countries, the regular use of pesticides is limited to the relatively small areas of high-value commercial crops and vegetable gardens in the urban environs. The major obstacle for the widespread adoption of IPM in developing countries has been brought into focus by Gooch[12], Corbet[13], Morse and William[14], World Resource Institution[15,16], and Huis and Meerman[17]. The major findings of these studies are: (i) The limited economic returns accruing in traditional farming systems rarely carry economic justification for pesticide use. Nearly all the cultural practices under cropping systems with many varieties confer enough control over pests to be within economic threshold of pest damage. (ii) Crops grown in developing countries, largely on small holdings, by resource-poor farmers meet local need and nearly none for export. But in developed countries, commercial crops of great value for export, like cotton, and the increased demand for livestock, aim for maximum yields and not economic maximization.

IPM components

Agronomic and cultural: There exist a number of physical and mechanical methods of pest control which are non-chemical in nature and farmers traditionally have more confidence in these methods. Some of these could be modified, thereby leading to more effective and economical methods of pest control. For example: (i) Storage of food grains suffer from an array of pests, resulting in significant loss both in quantity and quality. Such damages can be reduced through use of low-energy radiation, thereby reducing moisture content in grains to safer levels. The electrical properties of the pests are sufficiently different from the matrix such that the pest tissue is heated more than the grain and this either repels or kills the pest without a fire hazard. The development of affalotoxins in the storage of peanut is prevented. (ii) Some serious diseases, like the red rot of sugarcane, are prevented when the sugarcane setts (seed material) are allowed to remain in boiling water for a short while and then used for planting. (iii) Traditional practice of preserving many of the vegetable seeds is to set the seed in dry dung cakes which are subsequently preserved in mud pots, along with dried neem leaves. The seeds retain their viability and vigour when sown. (iv) A more widely practised method of soil sterilization to eliminate the pests and crop diseases is achieved through burning crop residues, sugarcane trash, rice stubble and straw: a process known as 'rabbing'. Many of such traditional practices of merit, are slowly losing ground.

Although cultural methods do not usually offer a high level of pest control, these typically involve minimal extra labour and costs. More recently, one strand of IPM approach is to revive cultural methods of control. A healthy plant exhibits high degree of tolerance to pests and diseases. The converse is also true. Therefore, some practices like right time of sowing, harvest, deep ploughing, etc. do help pest control by its avoidance. Furthermore, crop sanitation, i.e. removal of sources (foci) of diseases, such as diseased and damaged plants, leads to reduction of pest population.

Experimental results on irrigated rice in Philippines showed that use of chemical sprays, wherein nine sprays are used per season, gave a net benefit of 11,846 pesos/ha (excluding health costs), while natural control, adopting only more integrated and sustainable practices, registered a net benefit of 14,009 pesos/ha[18].

Biological: Biological control encompasses a wide spectrum of use of biological organisms and biologically-based products including pheromones, resistant plant varieties, and autocidal techniques such as sterile insects. It also includes such cultural practices as crop rotations, mixed and multiple cropping with varying plant densities, and genetic heterogeneity.

Paul DeBach[19], an authority on biological control, estimated that using natural predators led to at least 120 species of insect pests under some degree of control. Most successful cases of its use in India are in: (i) control of sugarcane stem borer pest with the related parasite *Trichograma* sp.; (ii) control of prickly pear with cochneal insect *Dactylopus* sp.

Use of biological control resulted in saving the staple food crop cassava in Africa, grown over 200 mil acres, and benefited the farmers to an estimated value of

$ 3 billion. This project used massive aerial spraying of the parasite, a tiny wasp, on the mealy bug[20]. Biological control of weeds has also been widely reported in: the use of spore suspension of a fungi *Phytophthora palmivora* for control of weeds in citrus in US, and a dry powder formulation of *Colletotrichum gloeosporioides* for the control of weeds in rice and soybean[21].

Thus multiplication and release of known natural enemies in standing crops has succeeded well since first tried in the 30's. It is still in practice, though strongly eclipsed by the synthetic pesticides.

This is an ecologically sound approach to pest suppression because, once established, it is quite permanent, non-disruptive, and often self-perpetuating.

The promotion of bio-pesticides (e.g. Trichoderma, Trichogramma, Helicoverpa NPV, Spodoptera NPV), which are similar to what the natural enemies or the host plants produce in their defense, hold promise for the future. These have largely reduced the use of chemical pesticides.

Chemical control as the last resort in the IPM philosophy could be availed with enhanced and accurate knowledge of pest behaviour and insect population cycles. This would enable scientists and farmers to pin-point and restrict chemicals to the time and place where it is most effective against the pest and least harmful to the environment including human health. Moreover, the resistant varieties of crops need vigilant monitoring. Pest outbreaks sporadically may adopt to a widely planted resistant cultivar before the resistant factor has ever been useful in reducing economic losses due to pest[22].

The use of pheromones now widely used on cotton commercially worldwide for mating disruption, resulted in control of pink boll worm in Egypt, Pakistan, Turkey, and Greece where these have been successfully deployed as stand-alone control products. In India, development work is well under way for the control of rice stem borer *Scirpophaga* spp. by mating disruption, following its very successful deployment against the striped stem borer (*Chilo suppressalis*) in Spain.

A diverse group of natural molecules that may also be regarded as potential herbicides termed as 'allelo-chemicals' are now known. These compounds are released by a plant into its immediate environment to retard or prevent the growth of other plants so as to achieve competitive advantage in a given environment. Chemicals with such allelopathic potential are present in virtually all plants and may be released by the volatilization of root exudates, leaching or decomposition of plant residues[23,24].

Semio-chemicals: Modern pest management switched over to the use of naturally occurring chemicals, some made by insects themselves and used to control their behaviour. These are the semio-chemicals: the broad term for insect attractants and other behaviour-modifying chemicals widely adopted as key components of IPM. These are the pheromones (sex attractants and aggregation agents). The development of active pheromones for most major pests and their formulation in lures for deployment in custom-designed insect pest traps, is increasingly providing information required to complement and sustain rational insect/pest management systems. Thus, monitoring traps offer four benefits: (i) early detection and location of infestation, (ii) an indication of the severity of infestation, (iii) determination of the most favourable time for control measures to be applied, and (iv) a quality control aid. Pheromones claim several advantages such as: (i) highly active at low concentrations, (ii) total volume for the world needs is a few pounds per year, (iii) though their synthesis is complex and costly, it needs only a well-equipped lab and not an industrial unit for their production, and (iv) no side effects and no residue problems. All that it needs is monitoring, attract, kill, and mating disruption. Research on semio-chemicals can provide an alternative to outsmart pests without synthetic pesticides. Pheromones as an industry have not yet developed. Total 1991 sales were only $ 38 million from 17 North American firms that synthesized 139 different products.

The two significant products, boll weevil and pink boll worm pheromones, must face two barriers: (i) natural extracts from female codling moth glands were 1200 times more powerful and effective in attracting male moths than an equivalent amount of synthetic product, (ii) the product being sensitive to light decomposes into inactive compounds and therefore should be used only after sunset and (iii) low doses will not be enough and higher doses would combine waste and cost.

However, semio-chemicals have not proven to be a commercially attractive alternative to pesticides. The reasons are many and complex, but the bottom line is: pesticides are cheaper to buy and apply than pheromones; are easier to use; and are more consistently effective[25].

Genetic engineering: Pest resistance represents the ability of a specific crop variety to produce a larger crop of acceptable quality compared to ordinary varieties, given the same level of insect (pathogen) population. The inheritance of resistance to specific pest is controlled by a single gene, monogenic (specific) or more than one, polygenic. It is difficult to determine how long a newly developed resistant variety will remain resistant. Hence constant vigilance on resistance functioning is recommended. Four types of resistance recognized are: avoidance, non-preference, antibiosis, and tolerance. For cultivated crops grown on large-scale by a single variety, like IR-8 rice in India, both vertical and horizontal resistance become imperative.

Some 10 to 15 generations of insect pests are required for the manifestation of resistance. Currently, more than 500 species of insects show resistance to one or more chemicals and few serious pests resist nearly all the poisonous pesticide chemicals. Indigenous people in their traditional methods in the centers of evolution of specific crop are well aware of varietal resistance to pests. It is on record that South American Indians grow cassava as their staple food, and in Brazil 22 varieties are recognized, 50 in Peru, and 140 in Rio Negro.

The promise of engineered resistance is through breeding crops for pest resistance. Such resistance should preferably be horizontal than vertical. CIMMYT's Tuxpeno group of maize lines has been notable for disease resistance. The incorporation of resistance to streak virus in some new maize materials by the International Institute for Tropical Agriculture (IITA) has deservedly been recognized. Such technologies add the dimension of resource neutrality in technology development. The solution to pests showing resistance may lie in using bio-engineered plants that do not overkill the pests. Thus, resistance management in transgenic plants might include production of lower doses of toxin, multiple toxins, and sporadic rather than continual toxin release. Further, escape from toxins could be provided in transgenic crop by designing crops that turn off toxin release at a certain point in plant development or release toxin only in specific tissues rather than entire plant.

Bio-engineered crop plants: In terms of integrated management of pests, the most important breakthrough has been the use of genetically engineered crops to confer resistance via the inclusion of genes expressing Bt toxins, cowpea trypsin inhibitor or secondary plant metabolites[26]. Transgenic crops with enhanced resistance may be used within the IPM programmes[27]. *Bacillus thuringiensis* (Bt) products are the most frequently used for natural biological control. But Bt spray is active for a short period and very expensive too. A better way to circumvent this problem is to insert bacterial genes producing the toxins directly into the plants on which the insects feed. A number of crop varieties such as corn, cotton, potato, and tomato are commercialized wherein each transgenic crop contains genes effective against an important pest of that crop. The pest insects feeding on these transgenic crop plants are quickly poisoned and thus there is no need to spray the fields with insecticides. But Bt genes as such may not express as efficiently as plant insecticidal genes[28].

At present, 28 varieties of genetically engineered plants expressing several agronomic traits have been allowed to go for commercialization in the United States. Some of these are commercialized in South America, Japan and Australia. Economics-wise, a potato farmer in US spends \$ 359 per acre for chemicals against Colorado potato beetle, while Bt seeds cost only \$ 22.5.

Concerns over introducing transgenic plants focus on four major areas: (i) human health risks associated with food contamination, (ii) potential for the transplanted genes to jump across crop plants to weeds, (iii) increased herbicide use that would result from planting herbicide-resistant crops, and (iv) pest resistance to transgenic organisms. The control of gypsy moth pest on fruit trees with Bt sprays was successful, but the size of success was uncertain. Yet, it is preferable to chemicals. *B. thuringiensis* is a common spore-forming bacterium that is non-pathogenic to warm-blooded animals but is highly pathogenic and specific to larval butterflies and moths. The effectiveness of Bt is due to the protein secreted by the bacterium, that kills the moth.

There appears to be little risk to trying most bio-engineered plants with considerable potential to reduce the use of chemical pesticides. The gene products produced by transgenic plants do not suggest toxicity to people or animals. The transgenic plants in super markets need no labelling as they are deemed identical to conventional varieties as food products in all respects. One problem with transgenic plants is that negative ecological consequences would result from some traits being incorporated into crops, especially herbicide-tolerance. The concern here is that an herbicide-tolerant domesticated crop/plant could revert to a wild weedy state to become a pest[25]. A recent workshop at M.S. Swaminathan Research Foundation, Chennai related to bio-safety issues concerning transgenic plants, recommended that each country should develop a set of safety guidelines which should be flexible to accommodate case to case variations and emerging technical developments[29].

Herbicide use for weed control: Crop plants suffer severe competition from weeds for three important inputs: solar energy, water, and nutrients. About 250 species, or 0.1% of the world's flora, are known to be sufficiently troublesome as weeds in crops. Of these, 70% are found in 12 families, 40% alone being members of Graminae, and Compositae. Interestingly, 12 crops of five families provide 75% of world food, and the same five families provide many of the worst weeds. Weeds act as reservoirs of disease organisms and as alternative hosts for insect pest. Some major crop pests actually prefer to lay their eggs on weeds rather than on crop plants. Some of the known reasons for persistence of weeds are due to C4 photosynthesis, high seed production per plant, seed maturity coinciding with the harvest of the crop plant, resistance or tolerance to herbicides, ability to overcome mechanical control by vegetative regeneration, and discontinuous germination over prolonged periods[30]. Biological control of weeds are on record. Thus use of spore suspension of fungi *Phytophthora palmivora* for control of weeds in citrus in US and a dry powder formulation of *Colletotrichum gloeosporioides* Sacc. for weeds in rice and soybean, are illustrative[21].

A diverse group of natural molecules that may also be regarded as potential herbicides, are the allelo-chemicals.

Table 1. Relative importance of pest management technologies

Pest management technology	Per cent change in respondents indicating 'very important'
Scouting and threshold	51.4
Pheromone technology	46.8
Plant resistance to insects	45.6
Modelling	39.6
Biotechnology	35.2
Growth regulators	30.1
Biological control	25.4
Cultural control	7.1
Legal controls	0.2
Synthetic pesticides	– 37.0

These chemicals are released by plants into its immediate environment to retard or prevent the growth of other plants so as to achieve a competitive advantage in a given environment. Chemicals with such allelopathic potential are present in virtually all plants and may be released by volatilization, root exudation, leaching or decomposition of plant residues.

Thus, weed control of tomorrow, will require the farmers to work not against, but with the weeds.

Biotechnology: This is a generic term that includes many techniques to provide a wave of new products for pest management. However, the main hope for IPM is largely based on the use of genetic engineering techniques, or more precisely the recombinant DNA technologies. It is ironical that IPM will benefit from a technology that is largely under the same control of multinationals that produce pesticides and that generate products having negative environmental impacts similar to those of pesticides. However, this industry should focus on using genetic manipulation and other techniques to increase the virulence and host range of biopesticides, instead of designing them as mere complements to natural strengths. Biotechnology, relative to other technologies, needs careful assessment. The possibilities of a more lasting progress in ecologically sound pest management and sustainable agriculture will result from agro-ecological research focused on redesigning the structure and operation of agricultural ecosystems[31]. The results of recent survey in US on the relative importance of various pest management technologies show its importance (Table 1).

At CIAT (Columbia) improvement of cassava production researches see the potential of biotechnological tools to increase access to genetic diversity and efficiency of field testing. On the basis of molecular marker technology, 'candidate gene' loci for resistance have been identified. At CIP (Peru) genetic maps of two important crops, potato and cassava, and analysis of their quantitative resistance traits are in progress[32].

We have on hand a landmark document of UNEP and CIPE under the caption *Beyond Silent Spring*[33], and an illuminating literary achievement on the subject by Mark L. Winston[25] which are of immense guidance with a balanced approach for a pragmatic policy on this subject. Both the books are woven on the same basic strands: mutually supportive of the polarized perceptions, and divisive insights.

The future of IPM

IPM embodies an ecological approach to the pest problem with the sole objective of reducing or eliminating use of chemical pesticides. The gains are reduction in costs of production, more economic access of food to the poor, and conservation of the resilience and integrity of the ecosystem. On a reasonable computation, a land saving of 40 to 50 mil.ha of land is a reality. The common way of measuring pesticide chemicals use (as kg/acre) that widely differ in their active toxicity ingredients may not be correct and may lead to such levels which are uneconomical and more hazardous as well. The TU (toxicity units) and TPU (toxicity persistent unit) indexes are simple measures related to potential for exposure to chemicals with health effects. The need for extension agencies to guide the farmers is urgent and imminent[34]. All available and recorded evidence, as of today, eloquently endorses that pests can at best be controlled or managed, but not eradicated.

Conclusions

If the green revolution is to be sustainable, a modified IPM based on ecological principles close to nature is the only alternative. Looking back, is to capture the traditional wisdom of our agriculture, while looking forward is to avail relevant modern advances of science, of which IPM is an essential component. With the former as the foundation and the latter as the superstructure, sustainable food security system can be built: the need of the next millennium.

1. Carson, R., *Silent Spring*, Penguin, London, 1962.
2. Pimentel, D., *Bull Entomol. Soc. Am.*, 1976, **22**, 20–26.
3. Pimentel, D., *Socio-economic and Legal Aspects of Pest Control*

Strategies (eds Smith, E. H. and Pimentel, D.), Academic Press, New York, 1978, pp. 55–71.
4. Metcalf, R. L., *Annu. Rev. Entomol.*, 1980, **25**, 219–256.
5. Geier, P. W., *Annu. Rev. Entomol.*, 1956, **11**, 471–490.
6. Bartlet, B. R., *Agric. Chem.*, 1956, **11**, 42–44.
7. Stern, V. M., *et al.*, *Hilgardia*, 1959, **29**, 81–101.
8. Lewis, W. J., *et al.*, *Proc. Natl. Acad. Sci. USA*, 1997, **94**.
9. Allen, W. A. and Rajotte, E. G., *Annu. Rev. Entomol.*, 1990, **35**, 379–397.
10. Bradfield, C. S. and Swisher, M. E., *Food Rev. Intl.*, 1994, **10**, 215–267.
11. Smith, E. H., *IPM: Insect Science and Its Application*, 1983, vol. 4, Nos 1–2, pp. 173–177.
12. Gooch, D., *Chem. Ind.*, 1993, no. 6, p. 174.
13. Corbet, P. S., *Prot. Ecol.*, 1981, **3**, 183–202.
14. Morse, S. and William, B., *IPM – Ideals and Realities*, Lynne Rienner, Boulder, London, 1997, p. 180.
15. World Resources Inst., *World Resources*, Oxford Univ. Press, New York, 1994.
16. World Bank, *IPM Strategies and Policies*, Monograph Series No. 13, 1997.
17. Van Huis, A. and Meerman, F., *Int. J. Pest Manage.*, 1997, **43**, 313–320.
18. Rola, A. and Pingali, P., *Agricultural Policy and Sustainability* (ed. Faetf, P.), World Resources Inst., Washington DC, 1993.
19. Paul, DeBach, *Biological Control of Insect Pests and Weeds*, Reinhold Pub. Corp, New York, 1964.
20. Consultative Group of International Agric (CGIAR): 25 Year Annual Report, Washington I
21. Watson, A. K., *Curr. Adv. Herbicide Res.*, 1989,
22. Gould, F., *Bio-Science*, 1988, **38**, 26–33.
23. Putman, A. R., *Weeds*, 1985, **2**, 583–589.
24. Hathway, D. E., *Molecular Mechanisms of Her* Oxford Univ. Press, 1989.
25. Winston, L., Mark, *Nature Wars*, Harvard Univ.
26. Evans, K. A. and Scarisbrick, D. H., *Crop Pro* 403–412.
27. Hildeer, V. A. and Hamilton, W. D. O., Crop Developing World, British Corporation Protectio
28. Sane, V. A., Nath, P., Amiruddin and Sane, 1997, **72**.
29. Shantharam, S., *Diversity*, 1997, **13**, 19.
30. Andrew, C., *Herbicide and Plant Physiology*, C London, 1992.
31. Luna, J. M. and House, G. J., in *Pest Managem Agricultural Systems*, Soil Water Conservation Iowa, 1990.
32. Joshi, H. and Merril-Sands, D., *ASM News*, 1998
33. UNEP, *Beyond Silent Spring*, Chapman & Hall,
34. Barnard, C. M., Padgitt and Uri, N. D., *Int. Pe* **39**, 161–167.

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MEETINGS/SYMPOSIA/SEMINARS

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