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An Evolving Systems Approach of IPM in Cotton Perceptions and Prescriptions

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INTRODUCTION

The development of applied entomology may be divided into three phases: The logical order in the past to solve a problem being

1. Identification and classification of elements in the system studied [Taxonomy & systematics]
2. Internal dynamics of each of these elements [Biological, inclusive of physiology & ethology]
3. Identification of inter-relationships of the elements in the system and the impact of external influences [Ecology]

However, in the recent decades a new hierarchical structure is gradually evolving with ecology at the top determining research priorities. Reasons are that: firstly, for control of agricultural pests practical results have not been fully satisfactory. So there has been continuous interference with agro-ecosystem to maintain productivity with the control efforts only giving temporary results and with entailed disturbances. Therefore a holistic approach is needed. Secondly, availability of improved means of research as well as socioeconomic developments besides the general need for agriculture production and of particular importance on environmental awareness require holism.

Man pest confrontations have been one of the most constantly recurring themes of history and in spite of exponential growth of technology these confrontations seem to be of more menace. Therefore pest management has become a complex, economically essential and intellectually challenging field-a field that is on the leading edge of man's probing for a viable, productive and stable relationship with other organisms.

SYSTEMS OF PEST MANAGEMENT

A confusing variety of terms has been proposed to describe pest management strategies but most can be placed in one of the categories shown in Figure 1: Routine, Rational, Integrated or Biological.

- i) Routine pest management implies the use of pesticide as a prophylactic measure, regardless of pest incidence and requires higher levels of pesticide use than any other strategy in a given set of circumstances.
- ii) Rational pest management requires that each pesticide application be justified on scientific, technical and / or economic grounds and involves lower levels of pesticide use than a routine system under similar cropping conditions.
- iii) Integrated pest management system considers the interaction amongst the whole range of organisms with beneficial, neutral and pest status, the long-term aim being to increase the level of pest suppression, which is achieved by natural as opposed to chemicals means. IPM systems involve the use of pesticides lower than routine or rational pest management.
- iv) Biological systems attempt to achieve control of pests by manipulating the interactions amongst organisms present on a crop often by cultural means, without the help of any chemical / pesticide inputs.

Agro-ecosystems are living biological systems with very many components interacting together in complex ways. Figure 2 is a managed cotton ecosystem of dynamic environment composed of and affected by hundreds of variables including weather, control actions, cultural practices and living organisms. Figure 3 can be conceived as the life system of a generalized herbivorous agricultural insect pest. The biological forces at work in any ecosystems are extremely powerful and they are only partially controllable by man and then only for short periods. Interference with any component is likely to affect the rest of the system and so it is important to pay attention to the relationships amongst the variables as well as variables themselves. Integrated and biological pest management systems are classed as holistic in Figure 1 because they attempt to incorporate this component. Rational pest management is placed on the reductionist side because its recommendations are based only on a part of the system studied (e.g. controlled lab and field trials) ignoring still the effects of interactions with the rest of the systems.

Experience of chemical pest control has shown that when contribution of natural pest controlling factors in a crop is ignored pest problems and hence pesticide use can increase inexorably (figure 4).

The 'pesticides treadmill' is a term often given to the typical behaviour of the system which is under stress of pesticides. Here biological forces in the system are all working against the farmers interests to their long term disadvantage and they can control pests only at an ever increasing cost of pesticide application which means pesticide use is not high but is increasing.

Holistic systems of pest management involve harnessing the biological interactions in a crop to the long term advantage of the farmer. IPM is just as much a treadmill as itself, and once the farmers are on it the biological forces acting on the cropping system affect their decision making, involving the search for ways of avoiding pesticide use. So level of pesticide use will be stable or declining. In short in a reductionist system, pest problems are the main driving force on crop protection and decision making, and in a holistic system pest control by natural forces is the controlling influence on decision making.

INTEGRATED PEST MANAGEMENT: CONCEPT, DEFINITIONS, LEVELS

Amongst pest management systems concept of integrated pest management (IPM) is obviously an attractive one to pest managers from practical, academic, advisory and commercial background. However, the meaning of the concept is rarely specified in detail. This vagueness can be tolerated upto a point but when it comes to planning an IPM system, planner must have a clearer idea of what is involved.

As a reaction to the manifold problems perceived to arise from widespread use of pesticides, increasing interest was generated in the late 1960's and the 1970s in 1961. However the credit for initiation of IPM concept goes to Stern and his colleagues who termed it as 'integrated control' as early as 1959. IPM is a variously defined term, however not to be interpreted as insect pest management or insect population management.

FAO of the WHO defined IPM as "a system that, in the context of associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible manner as possible and maintains the pest populations at levels below those causing economic injury".

The council on environment quality defined IPM as “an approach that employs a combination of techniques to control the wide variety of potential pests that may threaten crops. It involves maximum reliance on natural pest population controls along with a combination of technologies that may contribute to suppression cultural methods, pest and disease resistant crop varieties, sterile insects, attractants, augmentation of parasites and predators or chemical pesticides as needed”

Smith et al. (1976) defined IPM as a “multidisciplinary ecological approach to the management of pest population which utilizes a variety of control tactics compatibly in a coordinated pest management system”.

IPM has become to mean different things to different people perhaps the most ambiguous component of the term is “integrated” To many ‘integrated’ refers to control tactics; so to be IPM a system should involve multiple control tactics integrated into a single control strategy. To others ‘integrated’ implies the optional control of the complex of pests that impinge on a given crop. Thus combined effects of weeds, plant pathogens, nematodes and insect pests must be considered in integrated approach. ‘Integrated’ refers to the combined impact of pests within the context of the cropping system and control methods necessary to attenuate those impacts. By necessity, IPM programs are initially confined within disciplinary boundaries of entomology, weed science and plant pathology with either a single pest or few key pests within each pest category as a target. Later programs expand to include interactions among pests and finally become part of a agro-ecosystem management approach that is integrated within agro-ecological and socio-economic matrix of the region. So IPM can encompass all three levels of integration, depending on the stage of program. Even a more holistic level of integration could be possible (Figure 5) however, as research entomologist we need to have influence up to integration at level three thus IPM may be conceived at three levels viz.,

1. Integration of tactics
2. Integration of the effects of multiple pest stress
3. Systems integration

The theoretical basis of each level corresponds to population, community and ecosystem ecology. This approach provides a reasonable generalized model for the design and development of research programs and for their implementation. This bulletin discusses the general concepts related to the 3 levels of integration and consider the need for transition or advancing to systems integration while outlining the general requisites towards design and implementation of IPM programs.

Tactical Integration : Population Ecology

The objective of IPM is to switch from ecologically hostile to a gentle system of crop protection. To achieve this objective crop managers are expected to keep fluctuating pest population from reaching a pre defined economic injury level (EIL). The concept of EIL is central to IPM design and implementation. IPM programmes to date aimed at the integration of tactics to combat a single pest or a guild of pests in the same category have required only the knowledge of species biology (life histories and phenologies) and population dynamics, and such studies have dominated and entomological literature. Considerable progress of success in IPM programs each allowing transfer of technologies among regions exists.

Cotton, in India is damaged primarily by sucking insects at early stages by bollworms at later stages. Based on the knowledge of phenology, feeding preferences, sampling procedures, natural mortality factors and EIL for those species a simple IPM program that has been worked

out at IARI and adopted by farmers which in turn has considerably reduced the level of insecticides used moderately resistant variety with selective application of synthetic pyrethroids at ETL for bollworm control and clear post harvest operations to avoid the carry over of pests as the components of IPM package. Figure 6 enlists the techniques and programs for managing cotton pests under mono and poly cropping systems and in operation under operational research project of ICAR in Punjab and Tamil Nadu. Of late, based on *Helicoverpa armigera* (Hubner) resistance management strategy, insecticide use has been confined to windows related to stages of crop development, so as to slow down the resistance build up and to prolong the life of insecticides.

Thus IPM approach has been fundamentally a reaction against massive reliance of pesticides and the consequent problem of development of resistance, resurgence of target pests, upsurge of secondary pests and environmental contamination. To avoid misuse of insecticides, promoters of IPM program have attempted to replace old pre-emptive treatment schedules with corrective measures based on a system of monitoring pest and beneficial populations and corrective control decision using EILs. Corrective tactics of (selective) insecticide use supplement the deficiencies of preventive tactics viz., biological control by means of parasites, predators, pathogens, plant resistance and cultural methods that are applicable to various categories of pests. Assertion to be made at this juncture is that to us IPM has been so far a broad ecological approach, a pest control utilizing a variety of control tactics compatible in a single pest management system still requiring the evaluation of effects of combination of tactics used under field conditions.

Integration of impact of Pest Complexes : Community Ecology

Biotic communities of crop plants include the cultivated and non-cultivated (weed) plants, microbes, animals including pests and beneficials. The understanding of community level processes such as species diversity and habitat complexity, interaction among organisms at multiple trophic levels and instability of agriculture communities is essential for IPM programs responding to complexes of pests of one or more pest categories. Knowledge of community composition and structure makes possible the anticipation of pest problems that may arise from introduction of a new crop into a region. From a practical standpoint, the analysis of interactions among community components is necessary for the solution to the problem of pest management integration at the grower level. Farmer seldom if ever deal from other sources of stress-particularly stress generated by other pests. Most commonly farmers deal with weed control, nematode infestation, fungal diseases and major insect pests by applying herbicides, respectively. The reality however is that recommendations for these treatments are based on research done on each pest category separately without consideration of interactive effects. If the problems of multiple pests in IPM are to be addressed, more interdisciplinary research will be required so that pest interactions could be quantified. One crucial parameter of IPM that suffers from this deficiency is the establishment of EILs for concurrent multiple pests. Levels of pest complexes are not necessarily the sum of EILs of individual pests complexes are not necessarily the sum of EILs of individual pests although such additive EILs are used for pests of similar impact. Interaction among multiple pests are poorly understood and experimental measurement is usually complex and often yield ambiguous results. However computer models to help to describe pest interactions are proving useful. However, the difficulties of obtaining such data increase geometrically with the addition of each new component.

Integration of Pest Management into Cropping system: Ecosystem Ecology

A highest level of ecological complexity is the integration of pest management into cropping systems. Agro-ecosystems are under human regulation for subsidies of ecology, nutrients and water, for selection of dominant plants and to some extent, for animal communities that are components of agro-ecosystem. One major obstacle to achieve integration at the agro-ecosystem level is the weakness of the experimental base. Traditional experimental designs become cumbersome as the number of variables in the experiments increase to accommodate key biological components and management procedures. Such research is expensive and labour intensive. Further, it must have the support of teams of specialists willing to invest enormous amount of time with little promise of immediately publishable results.

One alternative to controlled experimentation is the monitoring of real field situation. Such long-term studies may be difficult to adjust to rigid statistical treatments, but a wealth of ecological data is a massed each year based on direct observations of natural ecosystems. Such procedures may well prove an acceptable alternative to the seemingly unwieldy experimental approaches to agro-ecosystem management. Thus ecosystem approach is more sophisticated pest management system but not an absolute requirement for IPM development. Despite these difficulties full integration of pest management into production system should remain the ultimate goal of crop protection specialist as a long-term aim.

REQUISITES FOR THE DESIGN AND IMPLEMENTATION OF IPM

Most current IPM programs remain at the first level of integration viz., integration of tactics because of the difficulties in the experimentation required to support the other two levels of integration. Because of the mobility of certain pests and the potentially conflicting regional control actions IPM programs have five fundamental requisites. Requisites are discussed by outlining the essentialities rather than by practical examples.

1. Sound Ecological Foundation Including Knowledge of the Crop / Environment / Pest Complex Interactions

First with crop as the resources the important parameters pertinent for consideration include

- a) developmental phenology
- b) density dependent growth relationships
- c) the effect of weather on plant growth and development especially temperature, light and moisture
- d) mortality of plants and plant due to various causes
- e) the effect of agronomic practices on plant growth and development
- f) estimates of photosynthesis under various conditions (leaf age and light intensity), the dry matter partitions among plant parts besides the source sink relationships (when and where photosynthate goes)?

Secondly, identification of pests to be managed in the cropping system is the important aspect. Among the various kinds of pests viz., key pests, occasional pests, potential pests and migrant pests, it is against key pests, around which IPM systems are built. Also key pests vary between regions for a given crop often limited by climate and other local ecosystem variables.

Thirdly, we should consider and identify environmental factors that impinge upon the pests, which could be natural or manipulated (figure 7). Not but least, all these crop / environmental / pest interactions must be understood for a defined management unit. Keeping in view that variations occur from field to field, area to area or year to year the program we developed should have flexibility to adjust for changes. The variations could be detected by the second requisite of IPM design and implementation here under.

2. Development of Methodologies for proper Monitoring of Pest Incidence, Abundance and Economic Impact

- Monitoring systems are needed
- i) for research into economic thresholds and other exploratory components such as determination of damaging pest stage, knowing the effect of control actions etc.
 - ii) for operational purpose for use by pest managers in IPM.

The formulation of economic threshold is a complicated process and more information is needed on the economic aspects of pest control especially with regard to benefits and hazards, research alternatives and social strategies. An essential pre-requisite to the estimation of EIL is the ability to measure accurately the pest population density/ damage where sampling methods gain importance.

We should also realize that EIL could vary with weather, vigour and maturity of the crop, time of pest infestation, age structure of pest population and size of beneficial population besides marketing standards and commodity prices. The non-consideration of all these factors have contributed to the lack of control action thresholds including the difficulty in establishing meaningful EIL. Also in complex pest attack on the crop it is difficult to know if the effect of combined populations is additive or antagonistic. Research is lacking in this area.

3. Control Tactics that Exploit the Ecological Knowledge based on Agricultural Systems and its Associated Pest Complex

Crop managers have at their disposal a vast arsenal of weapons viz., direct control tactics (Table 1), however no specific prescriptions for an optimal IPM strategy exists for any crop throughout its entire geographic range because of diversity of agro-ecosystem.

An ideal control strategy would rely on preventive measures (plant resistance, biological control and cultural methods) that assure a favourable equilibrium among crop plants, herbivores and natural enemies. An essential component of preventive control is the optimization of crop plant defensive system (i.e.) plant resistance because none of the crops can be commercially grown by relying solely on plant resistance. From this angle the general experimental sequence for developing a pest management program is as in Figure 8. Here the corrective measures- the timely application of selective pesticides – would be restricted to periods of relaxation of the equilibrium or during interim periods when a crop is invaded by a new pest for which no preventive controls are present.

4. Strategies that are Conducive to Economically and Ecologically Stable Crop Production and are Compatible with Socio Economic and Cultural Characteristics of the Potential Users

The disciplinary approach to pest problems involving independent research in weed science, pathogens and entomology is quite important. However equally important is to view IPM as a holistic systems approach requiring an interdisciplinary approach. This is because IPM is unique not in the level of complexity it presents to its practitioners but because of complex systems of changing problems that interact with each other. Hence the alternative is that of developing multi-tactical strategies of IPM. Because of

Table 1. Direct control tactics of pest control

BREEDING PEST RESISTANT PLANTS

- Plant pathogen resistance
- Weeds
- Insects

CULTURAL CONTROLS

- Sanitation
- Destruction of alternate hosts & volunteer plants, crop rotation
- Tillage
- Habitat diversification
- Time of planting
- Water and fertilizer management
- Use of pest free seed / planting stock

BIOLOGICAL CONTROL

- Classical biological control
- Naturally occurring biological control
- Microbial control
- Biological control of nematodes and plant pathogens

AUTOCIDAL CONTROL

CHEMICAL CONTROL

- Pathological selectivity
- Ecological selectivity
- Timing of application
- Placement of pesticides
- Application equipment
- Pesticide formulation
- Application techniques
- Resistance to pesticides

INSECT ATTRACTANTS & REPELLENTS

- Attractants
- Repellents

GROWTH REGULATORS

- Growth regulators as herbicides
- Insect growth regulators

QUARANTINE (?)

ERADICATION (?)

the need to integrate control strategies into production systems, researches have attempted to develop a pest management for operation at growers level as shown in Figure 9.

The recommendation algorithm is nothing but a decision making process. In a simple system, grower merely uses his intuition and experience together with his field observation in determining the choice of control action. In a sophisticated system grower seeks advice of pest control counselors / extension agents especially if control action involves EIL- the recommendation algorithm becomes complex however a better decision in comparison with farmers' intuition because of weather, economic and sampling inputs. Further complex algorithm

results with the incorporation of multitude of complexities that characterize a typical ecosystem. Of late researches adopt techniques of systems science. The family of methods are categorized as systems analysis, a mechanistic approach (engineering) as it is viewed, applies several tools-computer based modeling and simulation, mathematics, statistics, optimization- to the complex problems. The steps of the system analysis that form the basis of pest management system are outlined in Table 2. The frequent references to a system approach in the IPM can be slotted into a framework in Table 2. System analysis has been applied to pest management in a variety of subtly different ways. In the broadest sense computer is used by researches as a tool both to co-ordinate and organize data and also to develop mathematical models. Thus the recommendation algorithm results from mathematical and computer models.

In the system analysis, mathematical modeling using computer is done for descriptive and predictive purposes (stages 2 and 6). The modeling approaches could be of simulation, analytical and/or operational. Also models can be discrete or continuous, static or dynamic and deterministic or stochastic. In pest management work dynamic deterministic discrete or dynamic deterministic continuous models are used.

Steps of descriptive dynamic models include

- i. deterministic of parts of real world to be modeled versus considered environment
- ii. selection of components (subdivisions) of the system being modeled
- iii. component description in mathematical form-relates to the inputs, outputs and state of component
- iv. coupling of various components of the system to the environment

Such computer models are available for cotton elsewhere and not in India.

The implication in Table 2, that the process of system analysis is a linear one, is misleading. Pest management systems are continually changing and evolving and the implementation of the outcome of an analysis is bound to lead to new and unexpected problems, completing the circle by joining up stages 1 and 8. Also new insights gained at any one stage can lead back to reassessment of previous stages. The major iterative pathways in an analysis are indicated in Figure 10. The important point needs attention is that any modeling exercise inevitably involves value laden assumptions about the behaviour of the system hence one has to be explicit considering the implication of assumptions.

Table 2. Stages of systems analysis

Stage No.	Systematic label (Synonyms in brackets)	Decision sequence paraphrased
1	Problem framing (Hypothetical overview, embedding, bounding the problem)	Where are you now?
2	System description (Model building, data collection, casual resolution)	Where are you now?
3	Identification of objectives and constraints (Policy prescription)	Where would you like to get to?
4	Generation of options (Generation of alternatives)	How could you get there?
5	Formulation measures of performance (formulating measures of effectiveness)	How will you know when you have arrived?
6	Predictive analysis (Model modification, model construction, evaluation of alternatives, apply decision aids)	Will it be as good as you thought?
7	Evaluation (selection, decision)	Will it be as good as you thought?
8	Implementation	Go!

5. Efficient Mechanism of Education and Technology transfer

Finally if the IPM is to be adopted, as much effort must go into communication as goes into devising the other steps of IPM design. Communication must be maintained between the researcher and the user communities. IPM in many instances can succeed if applied over wide areas. Decision made by growers in one region may greatly influence the success of IPM in another region some times on totally different crop.

Interactions among researchers, extension advisors professional pest managers and growers are essential to maintain the flow of information in both the directions. So to say, the success of IPM hinges on capacity to reach for the integration of people. IPM research is necessarily multidisciplinary but the integration must not stop at research level.

CONSTRAINTS OF INTEGRATION

Ecological:

- i. The holism of nature and the uniqueness of each species habitat niche characteristic pose constraints to scientifically feasible pest control. Our poor understanding of the influences of management practices on them is a serious constraint to effective management
- ii. The size of the management unit is determined by economic / crop centered factors than by ecologically pest centered conditions
- iii. Geographic location and isolation greatly influence the feasibility of strategies and tactics.
- iv. The evolutionary process such as genetically based resistance to pesticides and genetic adjustment of pest species to pest resistant crop varieties are open ended and ever changing hence management practices efficient to day may not remain so in future.

Economic, Social and Political:

- i. Variation in size of independently managed unit is a basic societal constraint
- ii. The major economic and psychological constraints on IPM are the variation in the criteria used in decision making. While IPM aims in long term ecological approach grower is concerned with short-lived positive effect, especially in economic terms. The simple way of putting this is what is good for the farmer is not good for society and what is good for some farmers is not good for all farmers.
- iii. There is a lack of action threshold for pest complex occurring simultaneously. Also many pest problems are developing very rapidly and by the time potential solutions have been given a firm scientific foundation the solution may not be so longer relevant.
- iv. Expanding levels of integration from a single private owned unit to community or to more comprehensive levels involve an increase in number of people involved in management which increases the cost and complexity of organization.

CONCLUSION

One of the major sources of confusion in discussing the planning and implementation of IPM is: it is often unclear what is meant by IPM. It is arguable whether most pest management systems described as "integrated" are genuinely holistic.

Who does the integration remains a relevant question. Yet their remain major discrepancies between principles and practices of IPM. Farmers still obtain crop protection advice along unilateral discipline lines. System approach, though a sound approach, its spirit may become somewhat dented in application because of complexities in the approach.

From disciplinary angle, natural scientists continue to show a strong distaste for becoming involved in the policy and social sciences; modelers are unwilling to engage in practical field experiments; economists have a tendency to view scientific and political aspects of a

problem as of lesser importance. The organization of teaching and research in government institutes and universities, the awarding of research grants and promotion and the available routes for publication of research papers and reports, all give support to maintenance of rigid academic boundaries and the unbalanced supremacy of the scientific paradigm. The academic world currently favors the specialist and has not yet come to terms with the need to harness also the skills of a generalist. Ideally government or any organization should set up a permanent IPM development team including natural and social scientists and representative farmers and growers, for each major crop led by an experienced systems analyst.

For each crop IPM would evolve by a process of directed selection, aimed at pushing the systems in use to holistic approach from reductionist approach. The development team in charge of directing this evaluation should be a permanent body able to respond to economic, ecological or policy changes with necessary changes in the IPM system.

As an integral part of evolutionary process, pest managers themselves should accept the need to become more sophisticated crop protection ecologist hence warrants for appropriate education in farming community.

Suggested Reading

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