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Operations and Comparative benefits of Integrated Pest Management over single component methods in plant protection practice

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Abstract
The modern approaches to integrated pest management evolved in the late 1950s based on theories and researches which unfortunately are so distantly far away from the reality of IPM application in practice. This review presents a perspective that leads to a definition of what IPM is in the context of a developing country. It attempts a basic exploration from evolutionary standpoint of IPM of the basic, strategic and applied definition of the operations of IPM in practice. It also attempted to clarify which of the IPM strategies and approaches have been productive at any one time and how far they have responded to new discoveries and the ever changing needs and constraints imposed by society. Although experience has provided crucially important guidelines for IPM research and development work for now and for the future, yet these guidelines now need to be reconsidered in relation to new inputs from fashionable biotechnologies that are currently being given high priority in practice.

Introduction

A compelling array of literature exists on the concept, theory and practice of integrated pest management (IPM) (ICIPE, 1991; Altieri, 1993; 1995; Blommers, 1993; 1994; Barfield and Swisher, 1994; Anon, 1998a; b; Boller *et al.,* 1998). The modern approaches to IPM evolved in the late 1950s with the definition of integrated control by Stern *et al.* (1959). However in practice, most of these approaches have dealt mainly with theory and research results, much only distantly related to and far away from what actually happen in reality on the farms. Thus, one wonders how much of these research outputs have been directly or indirectly productive in terms of assisting farmers to take advantage of the best combination of control tactics required for a given pest challenge compared with the yield, profit and safety of alternative mixes that are available. Indeed, there are better than one method of pest management that are cost effective and amenable to a wide range of pest control tactics. There are also several other single component tactics in practice which sadly enough, had received so much emphasis in practice but remained unduly in focus and imposed on the population. This review presents a perspective that leads to a definition of what IPM is in the context of a developing country and an exploration of basic, strategic and applied definition of the operations of IPM in practice.

Historical Perspectives and evolution of modern IPM technologies

Modern Integrated Pest Management (IPM) concepts and practices evolved gradually in the late 1950s perhaps due to the explosion in the use of pesticides (Stern *et al.*, 1959). In years preceding this time, many researchers, scientists and users of chemical pesticide products had perceived pesticides as the ultimate solution to all the menace of pest infestations in the environment (Minks *et al.*, 1998). This was because pesticides at this time had recorded landmark successes particularly with regard to the management of some hitherto difficult pests (Mohamed and Teri, 1989; Morse and Buhler, 1997). No doubt the use of chemical pesticides had resolved some of the critical issues of the time being characteristically quick acting; bringing down devastating pest populations to very low levels within a very short time. This attribute along with the relative ease of handling and ready availability made the chemical approach to gain acceptability and popularity among other control options. Yet, the widespread use of synthetic pesticides had brought alongside, high ecological implications to the extent that human survival and existence on the planet became threatened (Atteh, 1984; Armes *et al.,* 1994). Sadly enough, many scientists and researchers abandoned the traditional plant and pests ecological studies as well as other other non-chemical alternatives to pest management. The consequence was the birth of a new generation of scientists with very little experience in the use and adoption of non-chemical approaches to pest or plant management. However, pests' resistance to pesticides, especially to insecticides had made researchers and growers to search for alternatives methods (Khush and Toenniessen, 1992), hence IPM.

IPM definition in Practice

In practice, IPM is a method that incorporates several pest management strategies to maintain crop profitability, minimizes pest selection pressures and environmental impacts (Mumford and Norton, 1984; Norton and Mumford, 1993; Mumford and Norton, 1994; Norton and Mullen, 1994; Oka, 1996; Ooi, 1996; National Research Council, 1996). It is used to manage pest populations below economically damaging levels in an environmentally friendly manner by cutting down drastically, the undue dependence on synthetic pesticides (Laurenson *et al.*, 1994; Knight, 1997; Kogan, 1998). Put simply, it involves using the best mix of different control tactics for a particular pest problem in order to get comparably higher yield, profit and safety (Laurenson *et al.*, 1994). Once a pest reaches a dimension which exceeds the economic threshold level, it becomes imperative to device the best way to prevent unacceptable yield losses. In practice, the concept of Economic Thresholds integrate crop value and management costs with biological information on the relationship between pest damage and yield; weighing the options and evaluating the cost, benefits, safety and risks of devolving the various management strategies. The Food and Agriculture Organisation (FAO) of the United Nations as presented by Bajwa and Kogan (2002) describes Integrated Pest Management as *the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest* *populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment.* Thus, IPM emphasizes the growth of a healthy crop plant with the least possible disruption to agro-ecosystems and promoting all such activities that encourage natural pest control mechanisms". This explains why the FAO promotes IPM as the preferred approach to crop protection, considering it as a *"pillar of both sustainable intensification of crop production and pesticide risk reduction*".

IPM is designed to be a sustainable system of crop protection involving the use of a combination of cultural, biological and chemical measures, including plant biotechnology in practice. It aims at providing a cost effective, environmentally sound and socially acceptable method of managing pests in agriculture. It is an adaptable range of pest control methods that is cost effective and yet environmentally acceptable and sustainable (Perrin, 1997). It involves the use of an intelligent combination of pest control tactics to prevent pest damage; balancing pest management with profitable crop production and environmental protection. It is also economically sound as it saves money and can be easily adopted and applied wherever pests are found.

Elements and Objectives of IPM

There are three basic elements of Integrated Pest Management of insects and these are: maintaining insect populations below levels that cause economic damage; using multiple tactics to manage insect populations, and the conservation of environmental quality. The main objective of IPM is to manage insect populations to reduce their pest status to a tolerable level. Reduction of insect pest status implies that a tolerable level of insect pest exists that will not cause economic damage and that this tolerable level should be expected in any agro-ecosystem (Omoloye, 2008; 2009). Complete extermination of a pest is therefore not feasible and desirable and should not be encouraged in practice. The acceptance of pest population at a set tolerable level sets pest management differently from many other approaches to pest control. Thus, conserving the environment quality and its associated interacting biotic and abiotic factors such as air, water, soil, wildlife, and plant life is an important element of integrated pest management (Omoloye, 2008; 2009). All the farm operational practices that maintain environmental quality can conserve natural enemies and this in turn helps in lowering the pest status of target insect pests. Thus, such pest management tactics that have minimal impact on the environment will contribute to the stability of agricultural systems.

Development and Implementation of IPM Strategies in crop protection

Developing IPM strategies in crop protection requires good knowledge and information concerning all normal inputs required for growing the particular crop (Metcalf and Luckmann, 1994; Mellon and Rissler, 1998). This knowledge is supplemented by an understanding of the life cycle of the pest as well as the best management options and practices that will disrupt its life cycle preferably at its weakest link. This underscores the need for an understanding of the principles guiding the pest management approach rather than just applying the control simply because it is just the way it is always done. In practice, IPM is not a finished package that is handed down to the farmer but rather a carefully planned process of getting the farmer to act by providing all assistance necessary to act and get involved in making decisions; executing them based on sound judgement and understanding of the situation on the farm. The farmer is therefore not passive, but actively capable of making decisions to alter or adapt these practices to reduce pest problems or encourage the crop to withstand, overcome or tolerate the pest.

IPM consists of a series of pest management evaluations, decisions and controls directed at keeping pest populations below economic threshold levels and not just a single pest control method (Ma Shih-chun, 1976; Barfeld and Swisher, 1994; van Lenteren, 1995; Matteson, 2000). It works by following the following specific steps (Ma Shih-chun, 1976; Matthews, 1997; 1999; Matteson, 2000). IPM sets an action threshold first before any pest control action is taken. This is a point at which pest populations or environmental conditions indicate that an intervention in form of pest control action must be taken to prevent economic damage (Omoloye, 2008; 2009). Mere sighting a single pest does not always mean control is needed. The level at which pests become an economic threat is critical to guide future pest control decisions.

The implementation of an integrated pest management system occurs normally along a continuum; from those that are largely dependent on prophylactic control measures to multiple-strategy biologically intensive and therapeutic approaches (Crawley *et al.*, 1993; Craig *et al.*, 1997). The practice of IPM is usually specific in nature and in most cases; the individual tactics devolved are determined by the particular crop/pest/environment scenario (Barfeld and Swisher, 1994). Thus, each site normally has in place, a management strategy for Preventing, Avoiding, Monitoring, Inspecting and Suppressing (PAMIS) pest populations. For best practice however, it is imperative that the tactics to be used in pest management at any one time should include at least three of the four PAMIS components identified. The rationale for at least three of the four approaches presupposes that the success achieved in the prevention strategy will often make either avoidance or suppression strategies unnecessary. Each of these approaches constitutes specific objectives to achieve in the management of any particular insect pest and most often directly influence the choice of a pest management tactic.

Prevention: This is the deliberate action taken by a farmer to alter the crop environment in order to make it less habitable or attractive to pests (Omoloye 2008; 2009). It is the practice of keeping a pest population away from infesting a field or site. This usually should be the first line of defence and may include such tactics as using pest-free seeds and transplants, preventing weeds from reproducing, irrigation scheduling to avoid conditions which are conducive to disease development, cleaning of tillage and harvesting equipment between fields or operations, using field sanitation procedures, and eliminating alternate hosts or sites for insect pests (Bajwa and Kogan. 2002). By such environmental alteration, the pest is disallowed from getting established. This is often done when an insect invasion is anticipated or presumed to be likely. The general objective is to forestall a major damage before it eventually occurs. The preventive action taken may include any applicable method of proven effectiveness against the particular pest. It could also be chemical or non-chemical method.

Avoidance

This approach is usually practiced when pest populations already exist in a field or site but the impact of the pest on the crop can be avoided through some cultural practices. Examples of such tactics include crop rotation such that the crop of choice is not a host for the pest, choosing cultivars with genetic resistance to pests, using trap crops or pheromone traps, choosing cultivars with maturity dates that may allow harvest before pest populations develop, fertilization programs to promote rapid crop development, and simply not planting certain areas of fields where pest populations are likely to cause crop failure. Some tactics for prevention and avoidance strategies may overlap in most systems.

Monitoring, inspection and proper identification of pests

This is achieved through surveys or scouting programmes, including pest trapping, weather monitoring and soil testing where appropriate. Monitoring and inspection activities are performed as the basis for pest suppression activities. It is not all insect population located around the crop environment that would require control except those ones that are economic pests (Ridgeway, 1990, Rogers, 1992; Schlyter and Birgersson, 1999). Many organisms are innocuous while some others are even beneficial (Way *et al.*, 1977). Pests are identified accurately and monitored in order for IPM programmes to work, so that appropriate control decisions can be made in conjunction with action thresholds. This removes wastage, ensuring that pesticides are used only when they are really needed. Records should be kept on pest identity, incidence and distribution for each field or site. Such records would form the basis for crop rotation and selection, determination of economic thresholds, and suppressive actions. Use of a monitoring system to carefully follow pest trends is essential to determine if a pesticide will be necessary and, if so, when it would be most effectively applied. Ideally, monitoring systems are based on known economical or aesthetic threshold levels (Morse and Buhler, 1997; Minks and Kirsch, 1998). Unfortunately, in many cases, these thresholds are not specifically known, and so are determined to reflect local conditions and threshold levels tolerated by many and not of specific site. A professional scout is often used, who may be employed by one or several farmers. Since these scouts visit several areas, pest trends are more easily recognized and useful information from one area can more easily be used to assist others. Tools required for scouting vary with pest problems, scout training and clientele budget. The first attribute of a good scout however is a set of probing eyes and an inquisitive mind supported by a standard 10X hand or pocket lens, soil profile probe, spade, cup cutter, pocket knife, tweezers, scalpel, collection vials and paper bags, and field identification.

Suppression

This refers to all actions taken to reduce a pest population on site. Suppression activity always becomes necessary to avoid economic loss if prevention and avoidance tactics are not successful. Suppression makes use of all other tactics. For example, cultural suppressive practices include narrow row spacing or optimized in-row plant populations, alternative tillage approaches such as no-till, planting cover crops or application of soil or vegetative mulches. Physical suppression tactics may include mowing for weed control, baited or pheromone traps for certain insects, and temperature management or exclusion devices for insect and disease management. Suppressive biological control includes mating disruption for insects and is usually considered as alternatives to conventional pesticides, especially where long-term control of a troublesome pest species can be obtained (Carozzi and Koziel, 1997). Effort should be made to conserve where naturally occurring biological control agents exist (Barducci, 1972; Bateman and Thomas, 1996, Barlow, 1998; Bottrell *et al*., 1998; Bateman, 1999). Chemical pesticides are important and will always be relevant in IPM programmes (van Emden and Peakall, 1996). However, these should be applied as a last resort in suppression systems using the following management tips: (1) The cost: benefit of application should be confirmed prior to use; using economic thresholds where available; (2) Pesticides should be selected based on least negative effects on environment and human health in addition to efficacy and economics; (3) Precision agriculture or other appropriate new technology should be utilized where economically and technically feasible in order to limit pesticide use to areas where pests actually exist or are reasonably expected; (4) Sprayers or other application devices should be calibrated prior to use; (5) Chemicals with the same mode of action should not be used continuously on the same field in order to avoid resistance development; and (6) Vegetative buffers should be used to minimize chemical movement to surface water.

IPM Requirements for selecting appropriate pest management methods

A major task before a pest management specialist or farmer is the determination of the status of a particular pest whether as key or otherwise. Once established, it becomes necessary to initiate control or put in place, some practical measures that will put the pest under check. To achieve this, it is important that the pest be identified correctly. Once the pest identity is known, it becomes easy to get information on the pest biology and ecology. Selecting appropriate method of pest management could be difficult as there are different methods available for use in pest management.

Most pest management methods are directed at either manipulating the crop, the pest or the crop environment (Way, 1978); and any of these methods could be preventive or therapeutic depending on when it is applied before or after pest infestation. The use of any of these could also be for short, medium or long terms. The selection and final adoption of any method would depend on the economics and characteristics of the pests, the host and the host crop environment. The following principles adapted from Omoloye (2009) are key to selecting appropriate methods to incorporate in an IPM.

-Economics of control in which the benefits derived from the chosen method justify expended cost of control.

-No introduction of complications at any time after adoption and application.

-Not harmful to the local biotic community especially the natural enemies
-Easy to operate and should not pose any danger to operator or other non-targets.
-Readily available and affordable to resource poor farmers

IPM in Practice
IPM methods are to be developed for various insect pests in order to have an effective and sustainable IPM program (Yaninek and Schultess 1993; Raheja, 1995; Zethner, 1995). To effectively practice this holistic management option, the following are germane:

- Determination of the pest status whether it is a major (key) pest, minor pest, occasional pest, potential pest or straying pest in order to initiate control
- Full understanding of the pest's population dynamics in relation to the seasonal abundance
- Correct identification of the pest to know which stage is really destructive to the host plant.
- Proper understanding of the pest's biology- reproductive, developmental and behavioral.
- Ecological understanding of the pests in the area of nutrition and population ecology in relation to the abiotic factors
- Cost implications of the control methods to be involved in IPM-the control methods should be economically beneficial to the end users.
- Assurance that the control options will not create new problems or complications to the user or the biotic components of the ecosystem where it is used.
- The ease of operating the methods as well as its availability is to be put into consideration before its release to the end users.

Steps in IPM

- Identification of the species associated with a particular host
- Quantification of the pest in terms of population density and its interactions with its ecology
- Determination of the population level whether or not it is tending towards economic injury levels and determination of the intrinsic growth rate.
- Specification of the type of control required by the pest with a view to identifying the tools or resources required for its management.
- Application of the control methods to suppress the insect's population.
- Evaluation of the efficacy of the control methods, strategies and tactics used is confirmed by carrying out a re-sampling of the pest.

Single Component Pest Control Methods Commonly Used In IPM
Several methods are available for managing insect pest populations. These are often categorized as either chemical or non-chemical methods. Most non-chemical approaches are either used to prevent infestations from initially occurring, or to minimize the severity of infestations. Most often, chemical control become justified when non-chemical approaches such as the use of pest resistant varieties, cultural, physical, mechanical, and biological controls are inadequate.

Cultural Controls
Cultural controls exploit the factors related to growing the crop that have potential to negate or minimize the occurrences of pests. Examples include planting pest-free seeds; good farm

sanitation and hygiene, destruction of old plant residues to reduce the spread of pests; early or late planting; early or late harvest dates to avoid pest losses; providing optimum growing conditions to minimize stress on the crop; crop rotations and mulching.

Mechanical and Physical Controls

Mechanical controls involve the use of equipment or devices that are manually operated to exclude or disrupt the life cycle of pests. It includes such other devices like barriers that exclude pests like fencing, row covers, and plastic mulches. Disruptive operations include ploughing, discing, hoeing, and cultivation. Physical controls on the other hand utilize some physical component of the environment, such as temperature, humidity, or light to the detriment of pests.

Biological Controls

Biological control is the use of living organisms which function as parasites, predators, or pathogens to manage pest populations (Oka, 1996; Ooi, 1996). Natural enemies keep in check many pests and potential pests but they are very susceptible to being killed or hampered by pesticides (Wratten *et al*., 1995; Xia, 1997). Pesticides should be used sparingly and only when needed in order to promote the efficiency and effectiveness of natural enemies (Hussey, 1978; Jago, 1991; Waage and Barlow, 1993.). It is important to choose wherever possible, chemicals that are the least toxic to natural enemies (Birch *et al*., 1999). Some pathogens have been commercially developed for use as biological insecticides. The best known example is the bacterium, *Bacillus thuringiensis* (Bt), which is effective for controlling certain caterpillars and beetles. Several Bt products are on the market (Liu *et al.,* 1999). Bt is formulated as a bacterial spore powder or as a flowable concentrate commonly mixed with water and applied as a spray (Copping, 1998). The performance of Bt products against caterpillar pests is usually increased when mixed with a spreader-sticker. Bt has no contact insecticidal activity and to be effective, the spores must be ingested by pest. Good coverage and spread of treated foliage surface usually increase the likelihood of spore ingestion (Copping, 1998; Bell *et al.*, 1999). Bts are often excellent choices for pest control because they are very safe to humans, other animals, and beneficial insects (Storer *et al*., 1999). Examples include *Metarhizium anisopliae* and *Beauveria bassiana.*

Chemical Controls

Pesticides are chemicals that are used to kill, repel, or otherwise lower pest infestations to protect crops from damage (Wijnands, 1997; Wilson *et al*., 1998). Though pesticides pose many potential risks, they also provide the following important benefits:

1. Pesticides are readily available and easy to use.
2. Where resistance is not a problem, pesticides are generally highly effective for controlling pests.
3. Pesticide treatments can be rapidly implemented as needed with minimal lag time.
4. Pesticides can be used over large areas to control large populations of pests.
5. Pesticide treatments are often cost effective, especially if the alternatives require large increases in human labor.
6. No effective, reliable, non-chemical alternatives are available for many

pests and chemical pesticides are the last resort.

Pesticides are used in IPM programs when no effective alternatives are available to keep pest populations from reaching damaging levels. The emphasis is to maximize the benefits and advantages that pesticides offer while minimizing any potential risks (Wijnands, 1997; Wilson *et al*., 1998). Whenever a pesticide treatment is needed, selection of the chemical should be consistent with the pesticide label and all state and federal laws and regulations. Additional considerations include: effectiveness against the target organism, compatibility with the host plant, effects on beneficial organisms, degree of environmental and user safety, and cost (Cohen *et al*., 1994). Wherever possible, a material that is least toxic to humans and other non-target organisms, and unlikely to contaminate ground and surface waters are highly desirable.

Host plant resistance by genetic engineering and IPM

Planting resistant varieties can prevent or minimize pest infestations and injury (Sharma, 1993). Conventional plant breeding is being revolutionized by techniques for transferring resistance genes from unrelated plants for enhancing host plant resistance (Khush and Toenniessen, 1992; Prins and Zadoks, 1994; Moscardi and Sosa-GoHmez, 1996; Carozzi and Koziel, 1997). Such techniques are faster, more precise and allow access to a greater array of desirable genes than traditional methods (Waage, 1996a, b; Snow and Palmer, 1997; van Emden, 1999). Such genes include those that encode toxic proteins such as lectins, proteinase inhibitors, trypsin inhibitors, cytokinins and chitinases (van Emden and Peakall, 1996; Carozzi and Koziel, 1997; Snow and Palmer, 1997). The method has the potential for encouraging developments that are impending, including combining portions of genes for broader pest spectrum efficacy (Cohen, 1998).

IPM Operations vis -a- vis Single Component Methods

IPM operation could be short-term or long term (Katre, 1996; Kenmore, 1996). In a situation where there is outbreak, the immediate response to suppress the pest population without giving considerations to the cost of control as well as the environmental impact of the control is referred to as Short term IPM. Short term control can include mechanical, cultural, biological and chemical methods. Whereas, long term IPM requires identification of the key or major pest and their ability to cause damage, their effects on yield and the cost of control as well as putting the environment into consideration in the selected control options.

Conclusion

Integrated pest management is a robust ecological approach to solving insect and other pest problems. It utilizes different pest control tactics directed at the entire complex of pests in a crop ecosystem. It is a sustainable system which assures high quality production in an environmentally safe and economically wise manner. It is also a crop protection system which has serious implications for both methodological and disciplinary integration of the socioeconomic contexts of farming systems. It is also a sustainable agricultural approach that is founded on a sound ecological platform with focus on the entire pest complex rather than individual species in an agroecosystem. It advocates a pest management system that is well coordinated with production practices in order to achieve desired economical protection from pest damage; while reducing hazards to crops, human health, and the environment to the barest minimum. This pest management system is more preventive than therapeutic. It is described by its operations which utilize all appropriate management techniques such as enhancing natural enemies, using semiochemicals, planting pest-resistant crops, adopting cultural management and using pesticides judiciously.

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