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MINI REVIEW

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## INTEGRATED ARTHROPOD PEST MANAGEMENT SYSTEMS FOR HUMAN HEALTH IMPROVEMENT IN AFRICA

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**Abstract**— In a sub-Saharan African context, limited natural resources, infectious diseases, including those transmitted by arthropod vectors, and chronic exposure to food contaminated with mycotoxin-producing fungi which, among others, are vectored by insects, are among the major constraints to human health. Thus, pest control should be an important component in human health improvement projects. It appears that the advantages of preventive over curative methods are rarely recognised in Africa, with more emphasis being given to the search for the ‘silver bullet’ than to integrated control approaches. Integrated pest management (IPM) systems can be assigned to different decision-making levels as well as to different integration levels, combining ecological (individual pest species, species communities, species assemblages) and management (crop, cropping systems, farms, communities) levels with the respective control systems. These levels produce a highly structured environment for decision-making, in which the use of modern information technology is important. Case studies show that IPM systems are developed and implemented at four integration levels, whereby most work is done on the lowest integration level, addressing a single pest or pest complex attacking a particular crop, group of livestock or human population, and the respective control measures undertaken. Coordinated efforts to develop and implement supplementary IPM systems at higher levels are concluded to be important elements in integrated pest management and a further contribution to human health improvement and poverty alleviation.

**Key Words:** IPM, human health, livestock, crops, information dissemination, decision making levels

**Résumé**— Dans le contexte de l’Afrique sub-Saharienne, les ressources naturelles limitées, les maladies infectieuses comprenant celles transmises par les arthropodes vecteurs, et l’exposition chronique aux aliments contaminés par les champignons produisant des mycotoxines lesquels, parmi d’autres, sont transmis par les insectes, font partie des contraintes majeures à la santé humaine. Ainsi, le contrôle des nuisibles devrait être une composante importante dans les projets d’amélioration de la santé humaine. Il apparaît cependant que les avantages des méthodes préventives par rapport aux méthodes curatives sont rarement reconnus en Afrique, avec plus d’attention accordée à la recherche de solutions miracles qu’aux approches de lutte intégrée. Les systèmes de lutte intégrée (LI) peuvent être attribués à plusieurs niveaux de décision aussi bien qu’à différents niveaux d’intégration, combinant les niveaux écologiques (nuisibles individuels, communautés d’espèces, assemblages d’espèces) et de gestion (culture, systèmes de culture, champs, communautés) avec les systèmes respectifs de contrôle. Ces niveaux produisent un environnement hautement structuré

pour la prise de décision, dans laquelle l'utilisation des technologies modernes d'information est importante. Les études de cas ont montré que les systèmes de LI sont développés et implémentés à quatre niveaux d'intégration, à travers lesquels le gros du travail est fait au niveau le plus bas, s'adressant à une seule espèce de ravageur ou complexe de ravageurs qui attaquent une culture donnée, groupe d'animaux ou population humaine, et les mesures respectives de contrôle entreprises. Il est conclut que les efforts coordonnés pour développer et implémenter des systèmes de LI supplémentaires aux niveaux supérieurs sont des éléments importants de LI et constituent une contribution additionnelle pour l'amélioration de la santé humaine et la maîtrise de la pauvreté.

**Mots Clés:** lutte intégrée, santé humaine, bétail, cultures, diffusion d'information, niveaux de prise des decision

## INTRODUCTION

Pests are considered as any of the various organisms such as fungi, arthropods, rodents and plants that harm crops or livestock or otherwise directly or indirectly interfere with the well-being of human beings (Anonymous, 1996). In a sub-Saharan African context, infectious diseases, including the ones transmitted by arthropod vectors, and limited natural resources, i.e. food (crops, livestock, fodder for livestock) and shelter (Begon et al., 1996), are among the major factors affecting human health (WRI, 1998; Baumgärtner et al., 2001).

Whereas global trends in human health improvements are positive, progress has been slow in sub-Saharan Africa and life expectancy still lags some 25 years behind the wealthiest nations (WRI, 1998). The malarial parasite transmitted by anopheline mosquitoes is the major cause of morbidity and mortality in the African region. Ninety-three percent of the 550 million people living on this continent are at risk; over 90% of the annual global 1.4–2.6 million deaths are reported from Africa (WHO, 1995). A second vector, the tsetse fly (Glossinidae), transmits human trypanosomosis—also known as sleeping sickness. With an estimated 300,000 cases per year, the disease has returned to its epidemic levels of the 1930s (Saini, 1999). In addition, in sub-Saharan Africa, people are being chronically exposed to unsafe levels of various mycotoxins produced by fungi such as *Aspergillus* spp. and *Fusarium verticillioides* Sacc. (Nirenberg), which are vectored by insects (Windels et al., 1975; Munkvold et al., 1997; Sétamou et al., 1998). These mycotoxins have carcinogenic and immunotoxic properties that cause stunted growth and immune suppression in young mammals (Cardwell, 2000; Gong et al., 2002).

Arthropod pests also affect crops and livestock, both directly and indirectly. Directly, because a stable supply of food is a prerequisite to human health, and indirectly, because disease incidence in humans is related to nutrition. In livestock, tsetse fly-transmitted trypanosome parasites cause losses in young stock mainly, amounting to an estimated 3 million deaths annually in Africa (Saini, 1999). Hard ticks (Ixodidae) transmit protozoan (theileriosis and babesiosis) as well as rickettsial diseases and predispose animals to secondary infections (Mukhebi, 1992). Inadequate feed supply has an additional impact on animal health.

Crop production is constrained by abiotic factors and pests (Yudelma et al., 1998). In Africa, work on cotton (Baumgärtner et al., 1986), cassava (Gutierrez et al., 1988), rice (Baumgärtner et al., 1989), cowpea (Tamò and Baumgärtner, 1993; Tamò et al., 1993) and maize (Bonato et al., 1999) demonstrates the effect of multiple stresses on yield formation. Climatic variability, particularly in semi-arid areas, limited use of fertilisers and livestock-mediated nutrient transfers from pastureland to croplands interfere with forage crops. Recent studies at the International Institute of Tropical Agriculture (IITA) showed that pre-harvest pest attacks in maize affects not only the quantity but also the quality of grain, via increased aflatoxin levels, both before and after harvest (Sétamou et al., 1998; Hell et al., 2000). Consequently, solving one biotic problem would also reduce quantitative and qualitative losses by associated organisms and contribute towards the improvement of human and animal health.

Because of the importance of arthropod pests in Africa, the development and implementation of control methods should be an integral part of human health improvement projects. However, based on our experience two aspects are not sufficiently addressed by pest control specialists.

Although the 21st century has been acclaimed as the century of prevention, an emphasis on curative over preventive methods still prevails in Africa. Plant pest control specialists have recognised that the 'silver bullet' approach is not promising and recommended an integration of control methods instead (Lewis et al., 1998) by relying on existing natural control factors (e.g. Roux and Baumgärtner, 1998; Baumgärtner, 2001). Integrated pest management (IPM) has been defined as a control system that, in the context of the associated environment and the population dynamics of the pest species, utilises all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury (Flint and van den Bosch, 1981; Dent, 1995).

We discuss here integrated pest management systems with special reference to the African situation, and explore some case studies along the conceptual lines given by Conway (1984) and Kogan et al. (1999). The present discussion does not treat the adoption and innovation diffusion and their social constraints at the farm level, but rather offers a conceptual framework for IPM research in Africa.

## INTEGRATED PEST MANAGEMENT SYSTEMS

### Background

#### *Integration levels*

Integrated pest management systems are developed for various pest species and species assemblages infesting different systems, relevant for human health improvement, at different ecological, managerial and organisational levels. Kogan et al. (1999), on the basis of ecological and managerial levels, identified IPM systems at three levels of integration. At a fourth level, we propose to combine plant pest ecology and management with the population dynamics and control of human and animal disease vectors (Fig. 1). This level is referred to here as the human health integration level because the human population is an element of the system under consideration.

*Integration level I—species/population-level integration:* Integration of methods for the control of single species or species complexes within

individual crops, a herd of livestock or a human population.

*Integration level II—community-level integration:* Integration of the impact of multiple pests (insects, pathogens and weeds), individually and in their interactions, on the crop or livestock and the methods for their control.

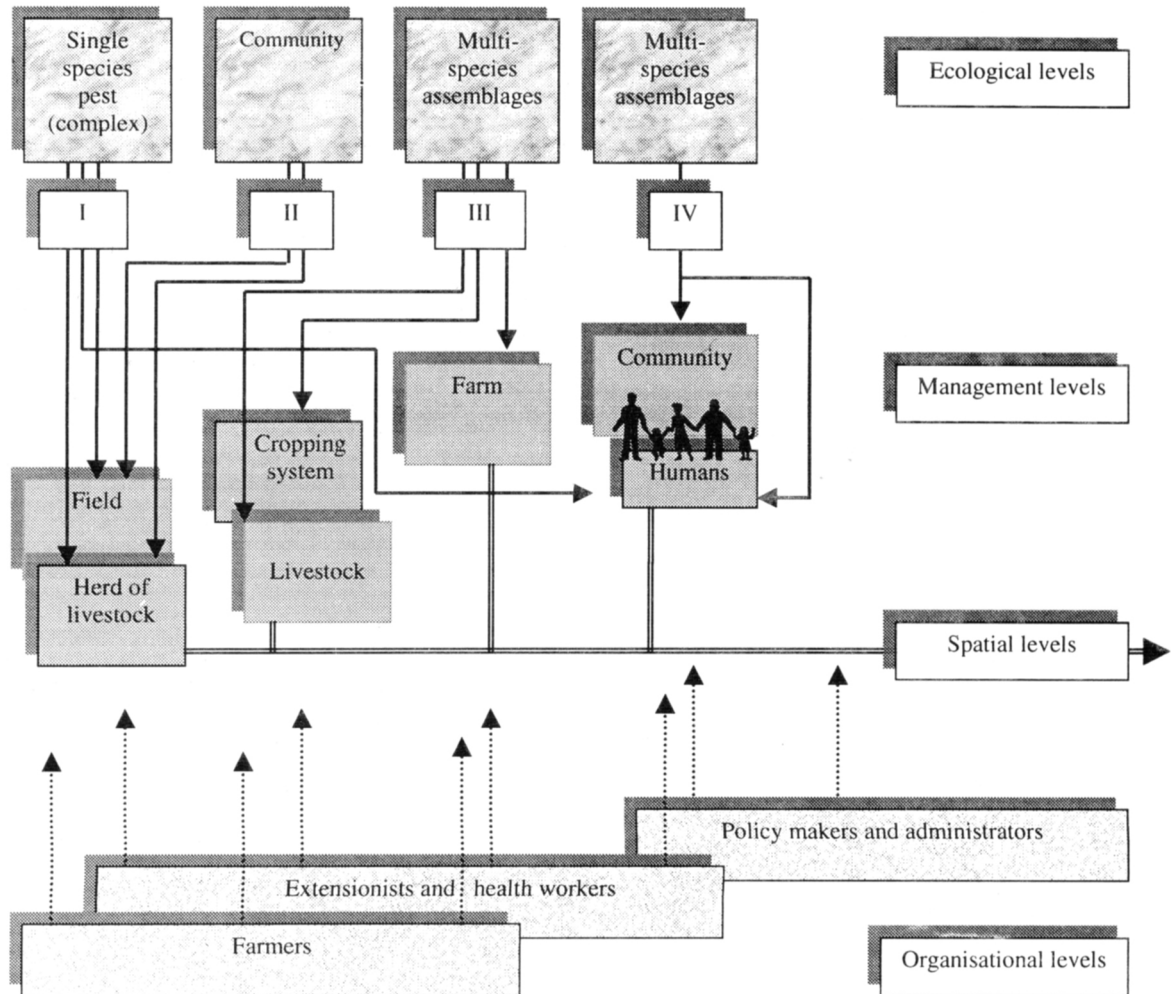
*Integration level III—ecosystem level integration:* The integration of multiple pest impacts and their interactions and the method for their control within the context of the entire cropping system, including crops and the surrounding natural plant cover. The ecosystem level integration level may also comprise integrated management systems developed for livestock by considering wildlife as done in tick control, for example (Mwambi et al., 2000 a,b).

*Integration level IV—human health level integration:* Integration of multiple pest impacts, their interactions and management systems within the context of human health improvement. Among the pest assemblages are infectious diseases and arthropod vectors as well as pests of resources such as livestock, crops, fibres and structural parts of houses. This level is exemplified by integrated disease and resource management systems (Baumgärtner et al., 2001).

The integrated control systems in Fig. 1 are generally developed on the basis of population and community ecology as well as on principles of ecosystem science, in combination with socio-economics (Baumgärtner and Gutierrez, 1988; Dent, 1995; Gutierrez, 1996; Kogan, 1998; Kogan et al., 1999; Huffaker and Gutierrez, 1999).

#### *Decision-making*

In Fig. 1, the four integration levels are combined with decision-making hierarchies proposed by Conway (1984). Thereby, various end users implement the technologies developed at the different levels. To name a few, farmers, ideally assisted by extensionists and veterinarians, take tactical decisions regarding fields, cropping systems, herd and livestock management. Extensionists are joined by social workers and the health service to implement IPM strategies relevant to farmers and communities. Administrators, policy makers and international



**Fig. 1.** The structure of the environment considered in integrated pest management (IPM) system design and implementation, based on concepts put forward by Conway (1984) and Kogan et al. (1999)

organisations are addressing issues ranging from farming to international relations issues.

#### *Decision support systems and information dissemination technologies*

Decision-making in the highly structured environment depicted in Fig. 1 is a complicated task and often has to rely on decision support systems and on efficient information dissemination technologies. In entomology, insect informatics deals with the generation, processing and dissemination of insect-related information through the use of modern information technology, which delivers, for example, electronic

insect records or checklists, CD products, decision-making support systems, networking, multimedia applications, imaging, information retrieval, management information systems, and databases or knowledge bases (Xia, 1998). Among the commercialised products are CD-ROMs containing multimedia information systems, insect images, checklists, books, films and Web sites for insect information services (Xia, 1998).

Computer-aided decision-making support systems for better management of insects have been developed. Recent publications on these subjects include Drapek et al. (1990), Haley et al. (1990), Huber et al. (1990), Knutson et al. (1990),

Stone and Schaub (1990), Coop et al. (1991), Compton et al. (1992), Mann and Wratten (1992), Thorpe et al. (1992), Bao and Robinson (1993), Rhykerd et al. (1993), Twery et al. (1993), Geyer et al. (1994), Weisz et al. (1994), Alfaro et al. (1996), Gottschalk et al. (1996), Shore et al. (1996), De Groot et al. (1998), Spradling et al. (1998). Most of these systems deal with the identification of insects and their damage, while some provide guidelines for management purposes. In general, however, they do not consider the spatio-temporal dynamics of insects systems as a basis for dynamic decision-making, which is the case in intelligent decision making systems (Xia and Baumgärtner, 1999a).

## STATUS OF IPM IN AFRICA

### Background

Zhetner (1995) wrote an overview on IPM in tropical and sub-tropical Africa. Thereby, African agriculture is characterised by a very large majority of smallscale farmers, who cultivate small landholdings of less than one hectare to a few hectares with several crops grown together. Smallscale farming not only dominates subsistence agriculture but is also the normal situation in cash crop cultivation. Often, farmers do not have titles to the land and ownership of the harvest is not restricted to the ones cultivating it. Another important element is the lack of institutions, which has been identified as a major hindrance to agricultural development in general (Eicher, 1999) and presumably to IPM system development and implementation in particular.

Zhetner (1995) also observes that only a few of the food crops, such as cowpea, yams, millet and sorghum and the cash crops cotton and coffee, are indigenous to Africa. Researchers, farmers and other decision makers apparently have lost interest in cultivating many of the indigenous plant species (see for example, NARC, 1996), apparently without assessing their yield potential and possible desirable attributes for IPM systems. The introduction of crops like maize, rice and cassava took place a few centuries ago, but it is only recently that they are widely grown in Africa. In agreement with Zhetner (1995) we suspect that ecological interrelations have not evolved as to reach the maturity of indigenous agroecosystems. This may explain the changes in the status of some

pest organisms or the outbreaks of pests on hitherto unknown host plants (Conlong, 1990; Schulthess et al., 1997). Most serious pests are indigenous, but there has been a large number of accidental introductions making classical biological control an important IPM component (Herren and Neuenschwander, 1991; Zhetner, 1995).

Saini (1998) presents case studies of IPM systems in Africa, such as maize, cotton and vegetable pests. African farmers still rely on many traditional methods, including the use of botanicals, for pest control. The disregard of valid traditional methods and unilateral reliance on synthetic pesticides, exemplified by cotton production systems in the Gezira, Sudan, (Eveleens, 1983), can have serious ecological and economic drawbacks (Flint and van den Bosch, 1981) which should be considered when developing high input cropping systems. To meet zero levels for pesticide residues in export vegetables, many African farmers will have to shift from a pesticide-dominated system to biologically intensive IPM or organic production systems.

### Information dissemination system and decision-making support systems in Africa

In 1995, the International Centre of Insect Physiology and Ecology (ICIPE) initiated several information systems and information networking activities. Among them is the Arthropod Information Network in Africa (AINA) and database activities. Through the support of the United Nations Development Programme (UNDP), ICIPE established the Pest Management Research and Development Network (PESTNET) in 1986 following discussions with several East African countries (Xia, 1998). PESTNET aimed at improving the food security of developing countries in the tropics and sub-tropics, especially in Africa, by relying on the integrated pest management (IPM) concept for a rational control of insect pests of crops and of vectors of human and animal diseases. The relevant information is disseminated through a network of concerned member countries (Burundi, Côte d'Ivoire, Ethiopia, Kenya, Malawi, Nigeria, Somalia, Sudan, Tanzania, Uganda, Zambia and Zimbabwe). Under PESTNET a Pest Management Documentation and Information System and

Service (PMDISS) has been established, and several IPM projects in the member countries were successfully carried out. Both scientists and IPM practitioners received training in information exchange (Xia, 1998). In 1996, additional support from the United States Agency for International Development (USAID) approved the reorganisation of PESTNET as an Africa-wide IPM information networking project.

Informatics has revolutionised the way information is disseminated. More and more information has been disseminated electronically through the Internet. Entomologists worldwide have started to develop insect information systems (<http://www.ent.iastate.edu/List/>) and are currently demonstrating that web-based interfaces are the easiest dissemination media for the final products. Web-based information products can also be published on CD-ROM for off-line browsing. At ICIPE, a new Insect Informatics Initiative started in early 1998. It is planned according to the needs and interests of a wide range of users. An important component of this initiative is the Web-Based Intelligent Insect Management Information Systems, which is designed to facilitate the task of users ranging from policy makers, extensionists and farmers.

Remote sensing, geographical information technology and other areas of Informatics need to be integrated into the development of web-based decision-making support systems. For this purpose an Africa Remote Sensing Data Bank has been established at ICIPE. The data bank is accessible on ICIPE Informatics server (<http://informatics.icipe.org/databank.htm>) and has a mirror site at North Carolina State University (<http://pestdata.ncsu.edu/informatics/databank.htm>), which makes the data accessible to external users. Currently, concise simulation models are being developed and adapted to African conditions as the basis for the development of intelligent decision-making tools addressing the wide range of end users depicted in Fig. 1 (Xia and Baumgärtner, 1999a,b).

### IPM system development and implementation

In Africa, there are examples on the application of modern ecological methods, including geographical information and mathematical models, to population dynamics and disease epidemiology for the design of control systems, such as for ticks (Randolph and Rogers, 1995;

Sutherst et al., 1995; Mwambi et al., 2000a,b; Randolph, 2000), tsetse flies (Rogers, 2000), mosquitoes (Hay et al., 2000) and pests of crops (Bonato et al., 1999) and stored products (Holst et al., 2000). Components of IPM schemes such as different pest control technologies are developed and implemented by farmers and various institutions such as farmers' associations, non-governmental organisations (NGOs), national agricultural research institutions (NARES), international agricultural research centres (IARCs), and international organisations such as the Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO). However, the relevant information is scattered among innumerable publications, often difficult to access, and little attempt has been made so far to compile a comprehensive overview. Nevertheless, the information available indicates that the integration of components into IPM schemes has been achieved in few examples only (e.g. Roux and Baumgärtner, 1998).

An IARC system-wide IPM (SP-IPM) group coordinates IPM-related work carried out at different IARC centres (SP-IPM, 2000). Some of the IPM projects are presented in the centre's annual reports or in the system-wide IPM group's highlights (SP-IPM, 2000). Regrettably, the compilation of a comprehensive list of IPM projects is still incomplete (R. Markham, ex-coordinator SP-IPM, IITA, Ibadan, Nigeria, pers. commun.).

### Case studies

As in Kogan et al. (1999), the choice of case studies is based on an attempt to highlight particularly relevant aspects of the relationship of ecology and IPM, and is no reflection of the level of achievement in IPM development, implementation, or success by contrast to other systems. Here, we exclusively refer to a few illustrative IPM systems, familiar to us, in various stages of development (Table 1).

*Integration level I:* The potato tuberworm, *Phthorimaea operculella* Zeller, infests stored potatoes in Tunisia's rustic shelters (Roux and Baumgärtner, 1998). The IPM systems under development rely on a combination of different control methods with emphasis on mechanical and biological control (Table 1). Noteworthy, the IPM system takes into account the risk a grower

faces when relying on naturally occurring biological control, and makes recommendations regarding the use of virus applications. The onion thrips IPM system under development also relies on naturally occurring biological control factors, but the field situation apparently offers a wider range of control options to be possibly incorporated into the IPM system than the storage situation with *P. operculella*. Among them are host plant resistance as well as cultural methods combined with microbial control (Table 1). The implementation of both IPM systems, particularly with respect to the structured environment of Fig. 1, apparently requires additional work. Kogan et al. (1999) refers to the tick management system in Australia, with reference to Africa, as an integration level I example from medical entomology.

*Integration level II:* Although at some locations only one species may be found, we focus on tsetse fly communities of species attacking livestock and transmitting trypanosomiasis (Table 1). In Ethiopia, for example, mass trapping operations with the involvement of the villagers, were a successful method of tsetse control (Getachew, 1998). There have been attempts to primarily rely on genetic control methods following mass trapping operations. More comprehensive systems under development combine mass trapping methods with herd management. However, Saini (1999) argued that a combined pathogen/vector management system adapted to local conditions and put into the context of sustainable rural development, is a more promising strategy than regional or continental efforts relying on a limited number of control options. If the pest control system is also considering wildlife sometimes confined to reserves or extended to human sleeping sickness transmission, integration levels III or IV are addressed.

*Integration level III:* The IPM system under development for various maize stemborer species relies heavily on host plant resistance and biological control methods including the introduction of exotic parasitoids (Overholt et al., 1994; 1997). Habitat management strategies have been developed for influencing stemborer infestations, for enhancing parasitoid effects and for weed control (Khan et al., 1997a,b; Table 1). The IPM system also considers uncultivated grassland and is being completed with economic

threshold studies and a better integration of habitat management options and classical biological control. The system is being implemented in eastern and southern Africa where it has been widely accepted by farmers.

*Integration level III-IV:* Mycotoxin-producing fungi which cause deterioration of food and feeds are between integration levels III and IV because they are often vectored by a complex of pre- and post harvest arthropod crop pests and they seriously affect human and animal fitness. Studies in Benin show a coincidental appearance of growth faltering and increased illness (symptoms associated with sub-acute mycotoxin exposure) in weaning children fed on foods with a high risk of mycotoxin contamination (Cardwell, 2000; Gong et al., 2002). Recent studies at the International Institute of Tropical Agriculture (IITA) showed borers also predisposes maize to infestations by storage beetles, infections by *Aspergillus* spp. and *F. verticillioides* and subsequent contamination of mycotoxins (Sétamou et al., 1998; Cardwell et al., 2000; Hell et al., 2000). Furthermore, it was shown for *F. verticillioides* that some lepidopteran and coleopteran pest species not only vector the fungus but ovipositing females are also attracted to infected plants and the progenies feeding on such plants have higher survival and higher fecundity (Schulthess et al., 2002; Ako et al., 2003). Because the different biotic problems are interrelated emphasis is given to understanding the interactions between the different pest organisms in space and time, from planting, harvest, storage and processing of foods and feeds, and on the effect of the abiotic environment on them (Cardwell et al., 2000; Schulthess et al., 1997; Schulthess et al., 2002; Sétamou et al., 1998; Hell et al., 2000). Thus, this project also considers the indirect effect of insect damage on blood aflatoxin concentration in infants and their effect on growth and fitness (Gong et al., 2002).

Biological control (introduction BC or enhancing naturally occurring control for stem- and cob borers; classical or microbial control for post harvest pests; competitive niche displacement for *Aspergillus* spp. or the use of fungal antagonists for *F. verticillioides*) and habitat management/cultural control (for all pest organisms) technologies as well as host plant resistance (for all pest organisms) have been developed and the efficacy botanicals (for borers) and Mycosorb® (for neutralising aflatoxin) have

Table 1. Some African case studies for integrated pest management (IPM) systems at four levels of integration defined (Fig. 1) by combining ecological (species communities, species assemblages) and management (crops, livestock, farm, community) levels with respective control systems

Integration level/ Ecological level	Control components in IPM system	Management system implementation	Experiences/ comments	Reference
I <i>Phthorimaea operculella</i> (potato tuberworm)	<ul style="list-style-type: none"> <li>Intrinsic mortality and dispersal of larvae</li> <li>Mechanical control (removal of larvae)</li> <li>Predation (transport of predators with plant material)</li> <li>Viruses</li> </ul>	<p><b>Tunisia:</b> potato rustic shelters. The IPM system has been presented as a strategic decision making tool. Users are farmers and extensionists</p>	Reliance on naturally occurring biological control factors exposes the farmer to a risk that can be reduced by incorporating compatible control methods, such as viruses, into the IPM system	Von Arx et al. (1990) Roux et al. (1992) Roux and Baumgärtner (1998)
I <i>Thrips tabaci</i> (onion thrips)	<ul style="list-style-type: none"> <li>Intrinsic mortality</li> <li>Varietal tolerance</li> <li>Fungal pathogen (<i>Metarhizium</i>)</li> <li>Botanicals (e.g. neem)</li> <li>Irrigation management</li> <li>Mulching</li> <li>Mixed cropping</li> <li>Chemical control</li> </ul>	<p><b>Kenya:</b> Pathogen and botanicals used with promising results. Host plant resistance, irrigation management, mulching and mixed cropping components require additional study. IPM system needs to be designed</p>	The use of neem and pathogens has been demonstrated to farmers according to a modified farmers field school approach	Guzman et al. (1996) Gindin et al. (1996) El Gendi (1998)
II Tsetse flies (Glossinidae)	<ul style="list-style-type: none"> <li>Genetic methods</li> <li>Chemical methods</li> <li>Mass trapping</li> <li>Herd management</li> </ul>	<p><b>Kenya, Ethiopia:</b> Systems combining mass trapping/genetic methods; mass trapping/herd management; and mass trapping/zero grazing in development and implementation phase</p>	The development of location-specific control systems to manage the pathogen/vector-system in the context of sustainable rural development appears to be the most promising approach	Odulaja and Abu-Zinid (1997); Saini (1999)
III Cereal stemborers	<ul style="list-style-type: none"> <li>Habitat management (HM) for influencing stemborers and their parasitoids</li> <li>Biological control (BC) through introduction of exotic parasitoids</li> <li>Botanicals (neem)</li> </ul>	<p><b>Eastern and southern Africa:</b> Users are farmers, NGOs, extensionists. Training with farmer participation is an important component</p>	Species distribution and interactions in space and time important for IPM system research and implementation. Habitat management is also used for weed control	Overholt et al. (1994, 1997) Khan et al. (1997a, b)

Continued next page



Table 1 Contd.

Integration level/ Ecological level	Control components in IPM system	Management system implementation	Experiences/ comments	Reference
III-IV Interaction between maize stem-borers and cob-borers, storage pests, mycotoxin-producing fungi ( <i>Aspergillus flavus</i> , <i>Fusarium verticillioides</i> ) and human/animal health	<ul style="list-style-type: none"> <li>• Host plant resistance (HPR), habitat management, botanicals and BC for reducing borer damage in stem and cobs</li> <li>• HPR, BC, HM and storage techniques and reduction of borer damage for reducing fungal infection and mycotoxin contamination in pre- and postharvest grain</li> <li>• Exclusion of fungus-infected grain from consumption, neutralisation of aflatoxin in foods using Mycosorb®</li> </ul>	<p><b>West Africa:</b> Users are maize and poultry farmers, agricultural and medical NGOs and extensionists. Training with producer participation and especially producer and consumer awareness building about the danger of mycotoxin-contaminated foods is an important component. The overall objective is to improve quantity as well as quality of grain production and thereby of human and animal health.</p>	An understanding of the interactions between and among pre- and postharvest insect pests, fungi and beneficials, and the effect of abiotic factors on them in space and time, knowledge of HPR mechanism, and increasing the awareness of the danger of mycotoxin contamination in foods as well as the role of insects are important for research, implementation and increasing the adoptability of IPM systems	Cardwell et al. (1997) Schulthess et al. (1997) Sétamou et al. (1998) Hell et al. (2000) Cardwell et al. (2000a) Cardwell et al. (2000b) Udoh et al. (2000) Schulthess et al. (2002) Ako et al. (2003)
IV Comprehensive human health improvement system	<ul style="list-style-type: none"> <li>• Mosquitoes: breeding site management and adult control</li> <li>• Tsetse flies: mass trapping and zero grazing systems</li> <li>• Crop pests: design of sustainable crop management systems, inundative releases of parasitoids and use of botanicals envisaged</li> </ul>	<p><b>Ethiopia:</b> Community-driven comprehensive human health and integrated resource management systems are being implemented in rural Bio-Village) and urban (BioFarm) environments. The overall objective is to improve human health</p>	Community participation is important for system design and implementation. Attempts are made to quantify and evaluate ecological processes for improving system structure and functioning as well as for facilitating the transfer of the technology to additional sites	Baumgärtner et al. (2001)

been investigated. For mycotoxins, emphasis is given to nutrition education and conducting public information campaigns about the importance of consuming only good quality grain.

*Integration level IV:* The integrated management scheme relies on the study and management of ecosystems composed of three sets of subsystems namely, disease vector subsystems, resource management subsystems, and a decision support system (Baumgärtner et al., 2001). Two ecosystems in rural and urban Ethiopia are studied and managed with the objectives of enhancing both sustainability and ecosystem services (Baumgärtner et al., 2002). Briefly, environmental sustainability is achieved by holding the scale of the human economic system within the biophysical limits of the ecosystem (Goodland, 1995). Ecosystem services are conditions and processes through which natural ecosystems sustain and fulfill human life (Daily, 1997). Among them are (1) production of goods, e.g. forage, timber, fibre, pharmaceuticals; (2) maintenance of biodiversity; (3) life support functions such as the purification of air and water, the mitigation of floods and droughts, the decomposition of wastes, pollination, pest control, and moderation of weather extremes; (4) support of diverse human cultures; and (5) provision of aesthetic beauty and intellectual stimulation that lift the human spirit.

Briefly, an integrated control scheme implemented with community participation comprises a system of grazing measures, including zero grazing, to disrupt the spatio-temporal coincidence between livestock and disease vectors, tsetse fly mass trapping technology and drug administration to sick animals. The integrated control scheme of malaria is, in the initial phase, a combination of mosquito breeding site management methods, protection of humans from adult mosquitoes by screening the houses and the administration of drugs against the malarial parasites. A sustainable resource system requires the reorganisation of the matter flow between producers (plants), consumers (livestock, humans, fish) and decomposers. The original system was unsustainable as it linked consumers to producers but the processes of organic matter decomposition and plant fertilisation were not adequately established (Baumgärtner et al., 2002). The design and implementation of integrated ecosystem management schemes on the basis of ecological

principles (e.g. Curry and Feldman, 1987; Baumgärtner and Gutierrez, 1988; Gutierrez, 1996; Di Cola et al., 1998, 1999), the adoption of appropriate technologies, the enhancement of environmental sustainability and ecosystem services, and community participation resulted to fast improvements in human health status (Baumgärtner et al., 2002).

## CONCLUSION

Conway (1984) and Kogan et al. (1999) proposed useful concepts for assigning IPM systems to different decision-making levels as well as to different pest control integration levels, combining ecological (species, communities, species assemblages) and management levels (crops, cropping systems, farms, communities) with respective control systems. These levels produce a highly structured environment for decision making, in which the use of modern information technologies, for information dissemination and exchange, becomes very important. In Africa, farmers, IPM specialists including researchers and policy makers would benefit from additional investments into this important area. In the design of IPM systems preventive methods should be preferred over curative methods, and the advantage of compatible as well as of biologically sensitive methods should be recognised.

Case studies show that IPM systems are under development and implementation at four integration levels. Our experience indicates, however, that most work is done on integration level 1 addressing a single pest or pest complex attacking a crop, a herd of livestock or a population of humans and the control measures undertaken. Coordinated efforts to develop and implement supplementary IPM systems at higher levels are important elements in integrated pest and resource management and a further contribution to human health improvement and poverty alleviation.

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