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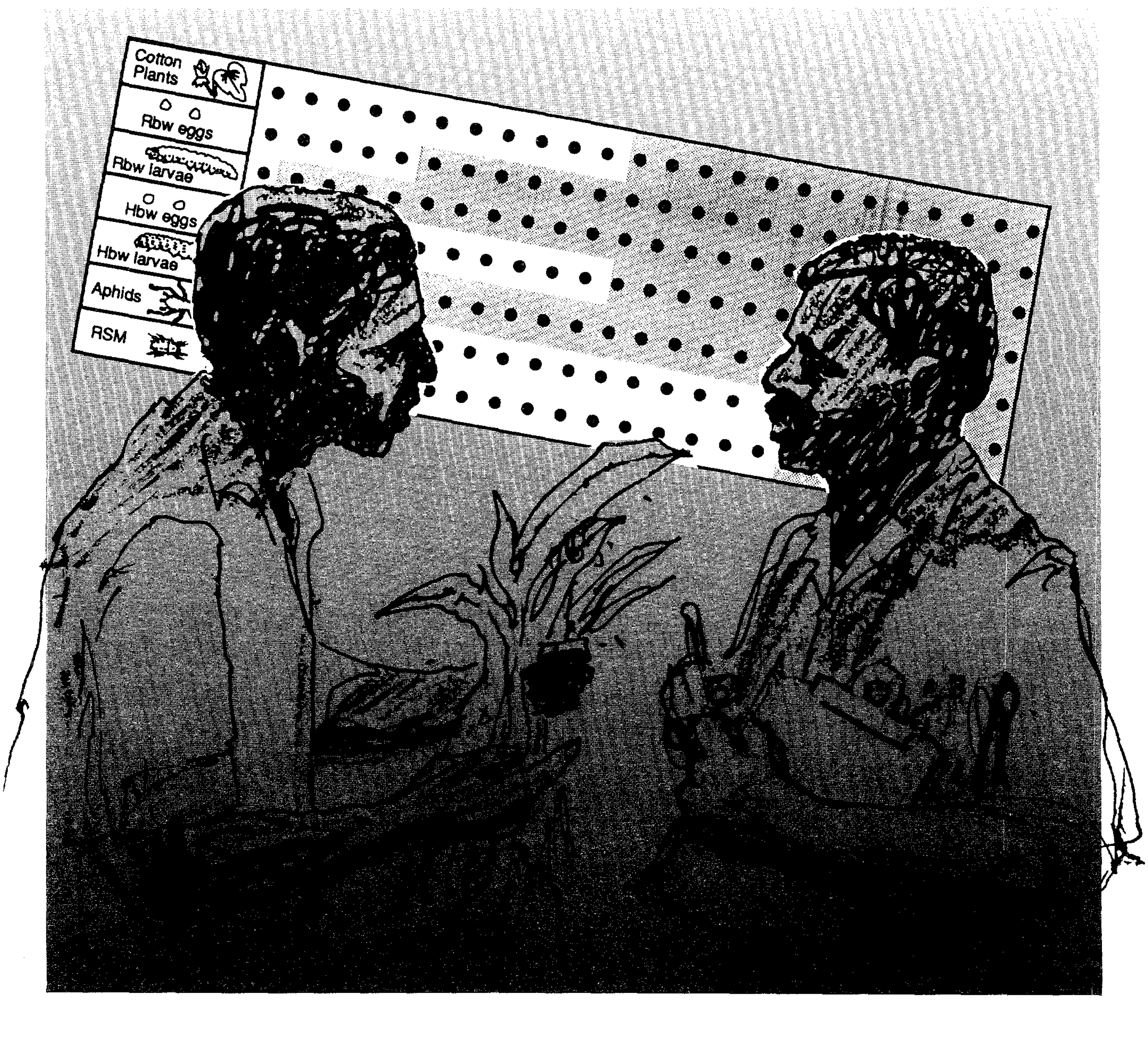
Integrated Pest Management and African Agriculture

Agnes Kiss and Frans Meerman



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Abstract

Integrated Pest Management (IPM) is an approach which combines different pest control techniques and integrates them into the overall farming system. It relies on host plant resistance, biological control and cultural practices, with pesticides introduced only when these non-chemical control methods fail to maintain pest populations below economically damaging levels.

This study shows the relevance of the IPM approach for African agriculture by giving an account of the rationale and historical development of IPM, as well as an overview of pest management issues in Africa. Because crop protection problems and options vary with the level of agricultural technology involved, three types of common African cropping situations are examined: (1) subsistence farming, (2) production based on high levels of external inputs including pesticides, and (3) systems in the process of intensification --which generally involves a transition from low to intermediate or high use of external inputs. The study then examines 11 current IPM projects in Africa to determine how the IPM approach might best be applied, developed, and implemented. The analysis focuses on socio-economic, political, and technical factors which determine the appropriate elements of an IPM program and the degree to which it becomes adopted by crop protection agencies and farmers.

The ultimate goal of any IPM program is sustainable, cost-effective crop protection which is within the capabilities of the users and does not harm humans or the environment. Analysis of the case studies shows how this broad objective is translated into specific situations:

(1) For subsistence agriculture, the goal is to increase the level and reliability of production. Pest management measures should be introduced if crop losses to pests in the field or in storage present a significant production constraint compared to other factors which compete for investment of labor or money. With the poor education and extension services in Africa, techniques should require little if any cash expenditure and should be easily disseminated. They should be based primarily on resistant crop varieties, improved cultural practices (including inter-cropping and crop rotations), and biological control. Pesticide use is not excluded but should be restricted to emergency situations, and should be accompanied by measures to prevent health and environmental hazards and the elimination of biological control agents.

(2) For intensive systems which use high levels of external inputs, IPM provides a means to rationalize pesticide use to reduce costs, ecological disruptions, and environmental and health hazards. This can be done by developing pest density ("action") threshold levels and scouting methods. Farmers can then decide when use of pesticides is economically justified. Pesticide rationalization also includes replacing broad-spectrum products and wasteful or hazardous application methods with more targeted ones and instituting systems (e.g. pesticide rotations) to prevent development of pesticide resistance. Although correcting wasteful and harmful pesticide use may be a first priority, the IPM program should also introduce non-chemical methods to keep pest populations below thresholds and as a substitute for pesticides when pest outbreaks do occur.

(3) For systems in transition from low to higher use of external inputs, the goal is to help farmers increase yields without misusing and overusing pesticides (i.e. without stepping onto the "pesticide treadmill"). This can be done by (i) avoiding agronomic practices which trigger pest outbreaks, (ii) developing non-chemical control methods for farmers, and (iii) ensuring that pesticides (if needed) are used selectively, i.e. with use of thresholds and selection of the most appropriate products and application methods.

Within this framework, prevailing ecological, technical, institutional and socio-economic conditions will determine the best techniques and implementation approaches. Decisions on whether, when, and which pesticides to use may be made in a variety of ways. Researchers or government functionaries may forecast and monitor pests and then either apply pesticides themselves or direct farmers to do so. Other approaches include having trained farmers do pest scouting for a whole area, or having each individual farmer scout his or her own fields and make his or her own decisions. Similarly, the possibility to implement cultural controls which must be applied over a wide area to be effective (e.g. closed seasons, phytosanitary measures, synchronized planting) will depend on the level of organization within the farming community.

An IPM program may involve a number of pest control methods, but only one may be needed. A good example is classical biological control (CBC). The CBC method introduces a new natural enemy species to provide long-term control of target pests. It can be highly cost-effective and places few demands on farmers (aside from restricting pesticide use). CBC provides a permanent solution to a pest problem. Worldwide it has been applied successfully in virtually every type of cropping system and ecosystem and against virtually every type of target pest. The case studies of African projects show that CBC is a good strategy for controlling pests of crops grown over a wide area by dispersed, small-scale farmers.

Based on the case studies, the paper presents recommendations relating to research, extension, farmer training and organization, infrastructure, communication, and agricultural and economic policies to promote the development and adoption of the IPM approach in Africa. Donors can be most effective by supporting programs which: (1) build local research and extension capability; (2) educate extension workers and farmers about the value of the IPM approach and train them in the specific methodologies; (3) ensure that the necessary products, equipment, and infrastructure are present. They must also encourage and assist governments to establish policies which give farmers the incentive and capability to implement economically efficient and environmentally sustainable pest management.

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Preface

Recent World Bank publications have stressed the importance of agricultural growth to the long-term economic development of Sub-Saharan Africa. With arable land disappearing across the continent, increased agricultural production will depend on technology which maximizes yields from lands already cultivated.

Improved crop protection can help increase yields. It is estimated that, worldwide, up to 30% of total agricultural production is lost to animal pests, weeds and diseases each year, with losses in tropical regions higher than in temperate areas. Since the 1940s pest management technology has relied increasingly on chemical pesticides, with annual global pesticide sales exceeding $16 billion by the mid-1980s. Yet, despite their sometimes dramatic short-term effects, heavy use of pesticides has not significantly reduced long-term pest problems and, in some cases, has even aggravated them. High costs and concerns about environment and public health have slowed the use of pesticides in industrialized countries and have induced many farmers to adopt an Integrated Pest Management (IPM) approach. IPM minimizes use of pesticides by manipulating biological and ecological factors to reduce pest populations to economically acceptable levels.

Although overall pesticide use in Africa is still lower than elsewhere, it is growing rapidly in some sectors. Government subsidies and agricultural development often support this growth with programs which make pesticides more accessible and encourage farmers to use them. Too often, the IPM approach has been overlooked or dismissed as too academic, impractical, unproven, or technically demanding for African farmers. This attitude reflects a misunderstanding of the IPM concept, and fails to appreciate its integral role in a sustainable farming system.

This paper is based on case studies and on workshops which brought together researchers, extensionists and farmers. It examines the IPM approach as it applies to different levels of agricultural production and surveys the factors which promote or constrain its adoption. The study demonstrates that building research, extension, and farmer capacities is the key to making IPM a reality in Africa.

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Acronyms

AGRITEX	(Department of Agricultural Extension, Ministry of Agriculture (Zimbabwe)
APC	Agricultural Production Corporation (Sudan)
ARC	Agricultural Research Corporation (Sudan)
ATL	Action Threshold Level
BB	Bacterial Blight
CALA	Agricultural Station of Lac Alaotra (Madagascar)
CBC	Classical Biological Control
CBD	Coffee Berry Disease
CCGA	Commercial Cotton Growers' Association (Zimbabwe)
CILSS	Comité Permanent Inter-état de Lutte contre la Sécheresse dans le Sahel
CRF	Coffee Research Foundation (Kenya)
CRI	Cotton Research Institute (Zimbabwe)
CTC	Cotton Training Center (Zimbabwe)
DDT	Dichloro diphyenyl trichloroethane
ECA	Economic Commission for Africa
ETL	Economic Threshold Level (also known as EIL--Economic Injury Level)
FAO	(United Nations) Food and Agriculture Organization
FOFIFA	Malagache acronym for: National Center for Agronomic Research and Rural Development (Madagascar)
GTZ	Gesselleschaft fur Technische Zusammenarbeit (German International Technical Cooperation)
ICIPE	International Centre of Insect Physiology and Ecology (Nairobi)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IIBC	International Institute for Biological Control (U.K. and others)

INERA	Institut d'Etudes et de Recherches Agricoles (Institute for Agricultural Studies and Research - Burkina Faso)
IPM	Integrated Pest Management
LF	Leaf Rust
Min/Agri	Ministère de la Production Agricole et du Patrimoine Foncier (Ministry of Agriculutral Production and Lands - Madagascar)
MRSTD	Ministère de Recherche Technique et Scientifique pour le Développement (Ministry for Science and Technological Research for Development -- Madagascar)
NGO	Non-governmental Organization
NORAGRIC	Norwegian Center for International Agricultural Development
ODA	Overseas Development Administration (United Kingdom)
OICMA	Organisation Internationale Contre le Criquet Migrateur Africain (International Organisation for Control of African Migratory Locust)
OPSR	Operation Protection Semences et Récoltes (Operation for Protection of Sowing and Harvest - - Mali)
PD	Package Deal (Sudan)
PDC	Pests and Diseases Committee (Sudan)
PPS	Plant Protection Service (Min/Agri, Madagascar)
SNPV	Service National de Protection Végétaux (National Plant Protection Service -- Mali)
SOMALAC	Société Malagache pour l Aménagement du Lac Alaotra (Lake Alaotra Management Company - Madagascar)
SOTOCO	Société Togolaise du Coton (Togolese Cotton Company - Togo)
TL	Threshold Level
ULV	Ultra Low Volume (pesticide application method)
UNDP	United Nations Development Program
USAID	United States Agency for International Development

Contents

1. Introduction

Although crop protection specialists generally agree that Integrated Pest Management (IPM) is the rational and "right" approach to agricultural pest management, many agriculturalists find it irrelevant or inapplicable to Africa. This claim is sometimes based on a perception that IPM represents a "low-productivity" strategy which is incompatible with the agricultural intensification needed to reverse declining per capita agricultural production in the region. On the other hand, the IPM approach is sometimes considered too sophisticated for African agriculture and developing country farmers, or is regarded as a theoretical, largely academic discipline which cannot solve real world problems. This is partly due to experiences with projects which have supported research and development of non-pesticide or reduced pesticide methods but did not involve farmers or address their real needs and constraints.

This paper seeks to dispel these misconceptions by examining development and implementation of the IPM approach in the context of African agriculture. The study does not provide a comprehensive survey of current IPM-related research programs in Africa, many of which are largely academic, with no clear linkage to extension systems which facilitate or monitor adoption of research recommendations in the field. As a result, many of these research projects have little prospect of having any direct impact on agricultural practice. Instead, the paper focuses on selected projects in which issues of relevance, linkage, and follow-up are being addressed and where, as a result, there has been significant reduction of crop losses through improved pest management. Case studies illustrate the approaches which have succeeded and the problems and constraints encountered. The projects examined highlight the technical aspects of developing IPM technologies, as well as the extension measures and socioeconomic and other factors which influence their adoption by farmers and other decision makers.

Through presentation and analysis of these cases, this paper aims: to provide examples where application of IPM (in its broadest, most encompassing sense) has produced positive results in Africa; to identify general constraints to development and implementation of IPM and recommend ways to overcome them; and to identify ways in which development and funding agencies, such as the World Bank, can best promote IPM.

In addition to the case studies, this paper draws upon the proceedings of a workshop on "Pest Management and the African Farmer," held May 22-26, 1989, at the headquarters of the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi[1]. This workshop was organized by ICIPE and the World Bank and sponsored by the Norwegian Government. Researchers, extension workers, and farmers from throughout Africa, as well as representatives of donor organizations, nongovernmental organizations, and the agro-chemical industry discussed their respective roles in generating and disseminating IPM technologies for African farmers. The specific objectives of the workshop were:

(i) to review pest management practices in different African countries;

(ii) to identify successful approaches and opportunities for supporting farmers' efforts at better pest management;

(iii) to examine the socioeconomic, institutional and policy constraints which impede adoption of better pest management practices among farmers and develop recommendations for overcoming them; and

(iv) to examine opportunities for increased private sector involvement in the development and use of IPM among African farmers.

Additional insights came from other IPM workshops in which the World Bank participated. These included a workshop on "Innovations in Pest Management," at Sturbridge, Massachusetts, March 7-8, 1990 -- organized by the World Bank in cooperation with the Massachusetts Department of Food and Agriculture and the University of Massachusetts Cooperative Extension -- and a seminar on Integrated Pest Management, organized by the Norwegian Center for International Agricultural Development (NORAGRIC) and the Agricultural University of Norway.

Drawing upon an analysis of the case studies and the proceedings of the Nairobi workshop, the study presents specific recommendations for government support and donor support and assistance to promote development and implementation of IPM in Africa.

2. Definition and Rationale for IPM

"[IPM]...has already evolved from challenge to token to mainstream to buzzword to cliche, all in the space of about two decades." (Dover, 1988)

Since the beginnings of agriculture, farmers have struggled with insects, weeds, plant pathogens, and other pests[2] which thrive under the hospitable conditions provided by the agro-ecosystem. Generally, pest organisms have great reproductive capacity. Pests in the arid tropics are often of the "outbreak type," rapidly increasing in numbers when weather and other conditions are right. In the more humid tropics, high temperatures and humidity without cold winters or long dry seasons provide ideal conditions for reproduction, survival, and dispersal for many potential pest species; but indigenous biological control agents such as parasites, predators, and antagonists generally prevent large-scale outbreaks. Outbreaks do occur however when the ecological equilibrium is disturbed -- for example by some types of agricultural practices.

Humans possess ingenuity and technology, and the ability to modify the environment. By controlling factors such as soil conditions, water availability, and the genetic makeup of the plants which are grown, farmers can create conditions which favor or reduce pest populations and impacts.

Agricultural research, technology, and extension seek to increase agricultural production in order to meet the growing needs of the human population. There are three main strategies: improve infrastructure and economic factors to maximize farmers' production within their existing capabilities; increase crop productivity through technological innovations, such as breeding and improved agronomic practices; and decrease the proportion of the output lost to pests. The first two strategies are -- except insofar as technological developments and short-term economic considerations contribute to pest problems -- largely outside the scope of this paper.

Reducing losses to pests usually means reducing the number of pests -- either indirectly by increasing biological diversity and making conditions for their survival and reproduction less favorable (e.g. use of pest-resistant crop varieties, crop rotations and intercropping, promoting populations of natural enemies, etc.), or directly by killing them. Farmers have traditionally relied on indirect control measures, supplemented by mechanical means of killing, such as pulling out weeds, removing egg masses from plants, and destroying crop residues. However, the introduction of toxic chemicals (pesticides)[3] over the past several decades has caused an important shift in this emphasis, making it easier to kill large numbers of pests in a short period of time.

The first pesticides used in agriculture were probably crude plant extracts, such as nicotine sulfate from tobacco. However, these natural products are unstable and vary in effectiveness. The first widely used manufactured pesticide was a mixture of hydrated lime and copper sulfate (Bordeaux Mixture), first introduced in France in 1880 to control downy mildew on grapes. Other toxic chemicals, such as strychnine, lead arsenate and zinc phosphide were widely used in the early part of this century. In the early 1940s, the chemical arsenal took an enormous leap forward with the discovery and popularization of synthetic organic pesticides.

The chemical approach was attractive because pesticides killed pests simply and cheaply. Research concentrated on breeding new crop varieties and developing agronomic practices to produce high yields using external inputs (particularly irrigation and fertilizers). It was assumed that pest problems could be easily eliminated with pesticides should they arise. The impact of pesticide application was visible -- users could see pests dying in the field soon after spraying. The effects of chemical control were thus more immediate and easier to recognize and evaluate than those of non-chemical measures.

Use of chemical pesticides grew quickly and became the main type of insect and other invertebrate pest control. Resistant crop varieties and agronomic practices, such as crop rotation and crop hygiene, remained the cornerstone in disease control. This was partly because of a lack of fungicides and bactericides effective against many plant pathogens[4],. Most applied entomological research, however, was directed at testing the effectiveness of new insecticides and developing new application methods. With increasing mechanization and farm size, herbicides also replaced labor as the principle input for weed control. Most farmers who had access to these products abandoned the traditional "preventative" approach of manipulating the local environment to make it less favorable for pest survival and multiplication. They began favoring the "responsive" approach based on killing pests when they appeared. The low cost of some pesticides encouraged high levels of use. In fact, a new form of preventative practice developed in which pesticides often were applied as insurance against pest attack. Pesticides were regarded as fertilizers were -- a necessary element in modern agriculture, with a direct correlation between the amount used and yield increases achieved.

By the early 1960s, however, serious problems began to emerge which brought this unilateral chemical approach into question. With the publication of Rachel Carson's book *Silent Spring* in 1962, environmental and health concerns about pesticide use erupted as public and political issues. They have continued since then to be an important factor in public opinion. After their residues had been detected in wellwater, produce, wildlife and human tissues, a number of pesticides were restricted in use. Because of their impact on soil micro-organisms, the effect of pesticides on soil quality and productivity has also raised serious concerns.

Questions also began to surface about the effectiveness of the chemical approach. Experience was showing that intensive, widespread use of pesticides could, over time, actually worsen pest problems. This was ascribed to the development of pesticide resistance by pest organisms, as well as to the destruction of the natural enemies (predators and parasites) which ordinarily kept pest populations in check. As pesticide resistance decreased pesticides' effectiveness, farmers, in an attempt to regain control of pests, began using higher and higher doses. This process, which became known as the "pesticide treadmill," in some cases caused the virtual collapse of agricultural production. Raising dosages often was more likely to increase the rate at which resistance developed in a population. It eliminated the more susceptible individuals and left the resistant survivors to reproduce. The agro-chemical industry developed new products to replace those made obsolete, but resistance soon developed to these as well, often at a faster rate because of the phenomenon of "cross resistance" to different products. Within a short time, several important insect species became resistant to all of the available classes of insecticides, and resistance of weeds and pathogens to new types of herbicides and fungicides grew quickly. Although generally used at lower doses, the new materials were also often more expensive.

The impact of pesticides on the natural enemies of the target pests also undermined their long-term effectiveness. With the removal of these predators and parasites, many pest species returned at much higher numbers (pest resurgence), and indigenous species, which had previously been economically insignificant, emerged in an important role (secondary pests).

Pesticides failed to provide the ultimate solution to pest problems as was once envisioned. On a local level, chemical control could provide impressive short-term results but, over the long- term, costs went up and effectiveness went down. On a larger scale, pest problems did not decrease. In fact, estimated crop losses to insect pests in the U.S. increased from about 10 percent in 1906 to 14 percent in 1974 (Pimentel, 1976). The reasons for this increase are complex, including intensification of agriculture, increased reliance on high-yielding but susceptible varieties, and expansion onto less suitable land. But a rapid increase in the use of pesticide has been unable to offset it and has in many cases been a contributing factor.

Some entomologists predicted that reliance on chemical pesticides would be a mistake and they continued focussing on non-chemical approaches, particularly biological control. In 1939 at the University of California (Berkeley), researchers began a project to address the problem of periodic outbreaks of the alfalfa butterfly. They found that, although this pest was usually kept in check by a parasitic wasp, this natural control sometimes failed. They initiated a novel system of scouting farmers' fields to assess the populations of parasitic wasps and alfalfa butterfly caterpillars, recommending pesticide application only when the number of caterpillars was too high relative to the number of wasps. In 1954 another University of California researcher developed a similar program for control of alfalfa aphids, relying on biological control by indigenous predators (ladybird beetles) and recommending application of very low doses of pesticide (to minimize impact on the beetles) only when scouting showed it was needed.

To describe the approach, these researchers coined the phrase "Integrated Pest Management" (IPM). It consisted of scouting fields to determine pest and natural enemy populations and limited use of pesticides to supplement the natural biological control when needed (Smith, van den Bosch, Stern and Hagen, 1959). Later, the definition of IPM was expanded to include use of other practices which could suppress pest populations, including host plant resistance and cultural methods (Smith and Reynolds, 1965).

Because the term is now used in many different ways, there are many misconceptions about IPM: it is theoretical, academic, and impractical; it is new and unproven (or, it is just a return to traditional, outdated practice and thus not competitive with modern methods); it is too complex to be relevant to any but the most sophisticated farmers; it is the same as biological control; or it means elimination of pesticides (or, it simply means improving the way pesticides are used).

IPM is not a technology, which may be developed in one place and then disseminated and applied wherever similar crop/pest problems are found. Rather, IPM should be viewed as a ***strategy and an approach to developing technologies***. The strategy is based on four fundamental principles:

(i) integration of the management of any given pest into the overall farming system, as well as integration of all appropriate measures to control any one pest;

(ii) use of biological measures (including plant breeding, agronomic practices, and biological control by natural enemies) to create an environment which discourages the build-up of pests and diseases. Pesticides are used only as a last resort, when other measures fail; to prevent pests from exceeding predetermined threshold levels;

(iii) the objective is to keep pest and disease levels below economically damaging levels (as determined by regular monitoring and surveillance), not to eradicate them; and

(iv) control measures are selected and implemented to minimize hazards to human health and the environment.

This overall strategy is implemented by a range of specific control methods, or technologies (discussed in detail below). Following the IPM approach also means having the capacity to implement these technologies, i.e. the basic scientific data, the system to translate these data into knowledge on the part of the practitioners, and the appropriate equipment and inputs, which must be available at the right time.

3. Pest Management Issues in Africa

The need for IPM

The IPM approach has been gaining force in Europe, North America, and Australia. There are several reasons for this: the initiative of the scientific community, public pressures to reduce pesticide use on health and environmental grounds, and because the unilateral chemical approach is expensive and has caused sometimes intractable pest problems.

In Africa, pesticide use has largely been in areas where high-value export crops are grown. The problems associated with heavy pesticide use have surfaced in these areas. For example, because of pesticide use secondary pests have emerged. These include the whitefly in cotton in Sudan, the red spider mite in cotton in Zimbabwe, and mealybugs and scale insects in coffee in Kenya. Environmental contamination from pesticides is not yet a major regional problem, but it can be important on a local level, leading to fish kills and sickness in humans and livestock. The relatively low literacy and education rates and poorly developed regulatory mechanisms prevalent in most Sub-Saharan African countries make the overall risk of improper and dangerous use of pesticides greater than in elsewhere. Yet, the local constituencies for protection of the environment and public health are smaller and much less influential than in more industrialized countries. The major impetus for decreasing pesticide exposure or hazards usually comes from international NGOs who, in many countries, collaborate with local groups or individuals.

Pesticide cost is a significant issue in Africa. Virtually all pesticides are imported and thus represent a drain on precious foreign exchange. For large-scale cash crop production with high pesticide use, the issue is whether the value of the crop justifies maintaining current levels of use. The issue is often clouded by government subsidies, which are provided in the belief that heavy use of pesticides is necessary to maintain high yields of crops which are the main source of foreign exchange. Meanwhile, subsistence farmers, though suffering significant losses to pests, can afford few purchased inputs of any kind and therefore cannot use pesticides.

Although pesticide use is significant in Africa, the main reason for supporting development and promotion of IPM is that most African farmers are small-scale growers of food crops who lack effective and affordable pest control measures.

Agricultural development in Africa

IPM systems must be developed within the framework of the agricultural diversity of the region. Farmers differ widely in their level of technology and use of mechanization and inputs, such as chemical fertilizers and improved seeds and pesticides. Although there is a continuum of agricultural development, it is possible to discuss several general levels, their specific pest management requirements, and the objectives of introducing IPM:

(i) *for subsistence level agriculture* the primary need is to increase food production through improved crop management, including pest control. Proposed pest management measures must recognize the likelihood of poor extension services, low levels of farming technology, and a general lack of capital and access to inputs;

(ii) *for high-input[5], intensive commercial agriculture* with already high pesticide use, the goal is to rationalize it in order to reduce costs, reduce ecological disruptions which threaten long-term sustainability, and reduce environmental and health hazards. The first step may simply be improved pesticide management, for example by selecting less hazardous products and using threshold levels, followed by the introduction of non-chemical measures which would begin an actual IPM system;

(iii) *for systems in the process of intensification or diversification*, the transition generally involves the introduction of agronomic practices which are likely to increase pest problems. The challenge is to help farmers increase yields without becoming trapped on the "pesticide treadmill."

Each level of agricultural development has its own agronomic constraints and pest management issues. Each also has its own requirements regarding research and technology development, extension and training, infrastructure, supply of external inputs, and institutional framework and capacity. Improved pest management and promotion of the IPM approach must account for these differences.

The case studies in Part 6 provide examples of how IPM components have been developed and implemented at each level. Some of the case studies deal with efforts to reduce excessive levels of pesticide use, while others take a broader approach, trying to introduce IPM at an early stage.

In addition, the study examines a fourth situation: the special cases in which *classical biological control* provides an effective alternative which may eliminate the use of pesticides. In this case, the farming system is only one of several factors which influence whether the approach is appropriate and effective.

Differences within and between countries

Crops tend to fall into one of these levels of agricultural development. For example cotton, rice, and vegetables are frequently grown under intensive conditions using large quantities of external inputs. Millet and cassava, meanwhile, are most often grown by subsistence-level or low-technology farmers using few external inputs. A crop may, however, be primarily a subsistence crop in one area and a market crop in another, and it may be grown by both large scale and small scale farmers. This is increasingly true as many countries are promoting intensification of staple crops for input substitution or export (e.g. rice in Madagascar and Burkina Faso, maize in Zimbabwe).

Pest and disease pressures can differ greatly in different areas and with different conditions of climate, soil, ecology, etc. (e.g. the impact of the cassava mealybug in Ghana is significantly greater in savanna areas than in moist forest areas--Neuenschwander et al., 1989, 1990; irrigated rice under water stress is more sensitive to rice blast disease--Ou, 1985). Other examples of differential impacts include the importance of stem borers in maize in coastal vs. western Kenya and differences in cotton pest complexes found in Zimbabwe, Sudan, and Egypt (spider mites a major pest in Zimbabwe but not Sudan or Egypt; pink bollworms in Egypt but not in Sudan; whitefly in Egypt and Sudan but not Zimbabwe). Small-scale farmers are also more likely to grow combinations of crops on small plots, with implications for both pest problems and feasibility of particular pest management methods (e.g. see case studies on cotton in Togo, coffee in Kenya).

Agricultural sectors within and between countries also vary with respect to key sociological and "managerial" factors such as: (i) the average level of education of farmers, or their general experience and knowledge; (ii) the degree to which farmers are responsible for or directly involved with implementation of pest and disease control (as well as other aspects of crop management); (iii) the strength of research and extension systems; (iv) the availability and reliability of external inputs and equipment, as well as markets for products; and (v) economic and other policies which influence farmers to produce agricultural surpluses or operate efficiently.

4. Technical Considerations

The basic elements of IPM

The IPM approach is based on using an "arsenal" of specific control methods or technologies to reduce pest impacts and maintain pest populations below levels which cause economic losses. The key technologies include:

- *use of resistant crop varieties;*

- *use of disease-free planting materials;*

- *cultural and agronomic practices* that: (a) promote general plant health (good soil preparation, water and fertilizer management, planting methods); (b) help plants avoid pest attack (disease-free planting materials, crop hygiene, selection of planting sites and dates, synchronous planting); and (c) suppress pest populations (crop rotations, cover crops, deep ploughing, intercropping);

- *manual control* (weeding, removing egg masses);

- *biological control* (protecting and encouraging indigenous natural enemies, for example through intercropping or providing refugia; augmenting populations of indigenous species; introduction of foreign species);

- *use of pathogens or microbial pesticides;*

- *selective use of chemical control* (minimizing pesticide applications through use of pest scouting or forecasting methods together with economic thresholds, selective application methods, and using selective pesticides to reduce impacts on natural enemies).

The level of pest control required is important in determining the best mix of technologies, particularly the way in which pesticides are used. Low levels of pest populations or attack may cause significant economic damage, as in the case of insects which act as disease vectors, or where cosmetic damage of fruits or vegetables greatly reduces their value. Zadoks (1987) proposed that the economically tolerable population levels for disease vector species in rice can be as low as one insect per 100-10,000 plant hills. This would make use of economic thresholds based on farmer pest scouting an unfeasible approach.

Developing the appropriate and feasible combination of technologies will depend upon on-site research and testing, the specific pest, the agro-ecosystem, and socioeconomic aspects. Data generated by research must be translated into operational control recommendations that farmers can use. The basic research and the resulting development of technologies can take a long time. One of the key technical constraints to implementation of IPM in Africa is a general lack of practical, proven, effective control technologies (although those that do exist are also inadequately disseminated). The CILSS/FAO/USAID IPM project for the Sahel is sometimes cited as an example of an ambitious program which failed because of a lack of technology. The few years allocated to develop IPM control methods were not enough. Therefore there was little appropriate technology to draw upon for the second, extension, phase of the project. In contrast the FAO-executed rice IPM project in Southeast Asia is a notable success. Although there are many reasons for this achievement, one important aspect is the practical scouting methods, threshold levels, and control methods developed by the International Rice Research Institute over the preceding decade.

As important as the availability of proven technologies is a delivery system which effectively brings these technologies to farmers. This requires an extension system that works closely with researchers and farmers. Often, this is a major constraint in African countries, due to the general weakness of Plant Protection and Extension services.

Pesticide Management

Although IPM does not always involve chemical control, a major reason for developing IPM programs is often the desire to reduce costs and side-effects of pesticide use. These include pesticide resistance, pest resurgence and the outbreak of secondary pests, environmental pollution and human health problems. Various pesticide management tactics can help reduce these negative impacts. The best first step is to reduce overall pesticide use to the minimum, frequently through the use of threshold levels. Other tactics include: using more selective pesticides; better formulations and application methods; spot-spraying; adjusting the amount of pesticide used to the growth stage of the crop; rotating pesticides to avoid development of resistance; etc. A number of these management tactics are demonstrated in the case studies (e.g. spot-spraying in Kenya coffee and Madagascar rice; improved formulations and application techniques and adjusting dosages to plant phenology in Zimbabwe cotton; reducing frequency and area of spraying in Sudan cotton).

Economic threshold levels

Like IPM itself, the term "economic threshold level" (ETL) has been confused with related concepts and terms. Current usage may be traced to Stern et al. (1959) who referred to the "economic injury level" (EIL), defining it as: "the lowest pest population density that will cause economic damage," where "economic damage is the amount of injury which will justify the cost of artificial control measures." This has generally been renamed the ETL and may be rephrased as "the break-even point at which the dollar value for an increment of loss in yield quantity or quality is equal to the cost of a control method that successfully eliminates pest damage and yield loss" (Frisbie et. al., 1989). Stern et al, (1959) and Poston et al. (1983) introduced the idea of an "action threshold level" (ATL), referring to the pest population density level at which, by taking control action at that point, there is little likelihood that the pest population will exceed the ETL. Unfortunately, some authors use the term ETL in place of ATL to describe this action threshold. For the sake of simplicity, this paper will use the general term "threshold level" (TL) to refer to the basic concept of setting a threshold of pest population density by which one determines whether control intervention (usually pesticide application) is warranted.

The use of threshold levels is key to IPM programs that involve chemical control. But it also represents one of the reservations often raised about the appropriateness of IPM for developing country farmers. Typically, the argument is that most farmers in developing countries lack two things with respect to TLs: the information on which to base them and the means by which to apply them. This idea is again based on several misconceptions: first that developing country farmers are inferior in their ability to understand and adopt basic technology; second that a decision-making tool must be completely accurate and perfectly refined to be useful; and third that the only way to determine whether the ETL will be reached is by having farmers carry out sophisticated pest scouting in their fields. In fact, the methods of developing and using ETLs can be adapted to meet the diverse requirements of LDC farming systems and farmers.

Information needed to set TLs

Many people dismiss the concept of TLs as impractical, based on the complex and time-consuming research needed to establish them with accuracy and precision. The elements which go into calculating an ETL include:

(1) increments of pest density or injury per pest;

(2) crop damage response (i.e. yield or quality loss to pest density or the injury);

(3) market value for increments of crop loss, and

(4) cost of control for increments of crop loss (Headley, 1972).

Items (1)-(3) are often lumped under "crop loss assessment". Crop loss assessment research is generally done under controlled conditions on field stations. The results may, therefore, not be fully applicable to the farmers' situation since their anticipated yields in the absence of pest losses are likely to be much lower. The importance of taking overall production levels into account when establishing ETLs is discussed in the case study on cotton production in Togo: differentiated ETLs are recommended based on farmers' different potential yield levels, resulting from the different levels of agronomic methods (e.g. fertilizers, weeding and thinning) they use.

To properly reflect the complexity and dynamic nature of the real world, an ETL would also have to take into account:

(1) changing crop production factors and costs;

(2) the presence of a complex of pest species and their independent and combined impacts;

(3) changing relationships between the crop, pests, and environment with time; and

(4) broad economic costs and "externalities" associated with pesticide resistance (use of a pesticide today may reduce options for using it tomorrow), environmental impacts, and effects of pesticides on neighboring crops and human health (Poston, et al., 1983; Regev et al., 1976; Frisbie et al., 1989).

A precise ATL would go further to require a thorough knowledge of pest status and population dynamics, to know at what point control action is needed to *prevent* the population from building to the ETL. This depends in part on climatic factors which may or may not be predictable. It also requires a knowledge of the levels of natural enemy populations and their probable impact on the pest populations. (It has been suggested that "inaction threshold levels" should be developed, referring to minimum levels of natural enemy populations which can be expected to exercise effective control in the absence of pesticides.)

Clearly, fully defined and precise ETLs and ATLs should be regarded as ideals to be approached rather than realistic goals to be achieved, particularly as they are likely to change constantly. However, the valuable and practical underlying principle is that there is a point at which pest levels are low enough that the damage they cause does not justify the cost of intervention. How precisely that point is identified depends on the level of research done. Years of intensive research have led to the definition of fairly reliable threshold levels which have been widely adopted in some production systems (e.g. cotton, alfalfa, soybean, orchard crops) in the U.S. and Europe. Because of the completely different ecological and economic circumstances, these thresholds cannot be simply transferred to African production systems. Nevertheless they represent a starting point which can then be further refined through local research. This was the approach taken in the case study projects on Burkina Faso rice and Togo cotton, where the TLs introduced were taken from southeast Asia and Zimbabwe, respectively, and verified under local field conditions. In other cases, starting point TLs are based simply on the practical experience of crop protection specialists who have developed a good sense of the effects of injuries and the resulting damage to the crop. Use of an imprecise ETL is still preferable to completely ignoring the trade-off between pest control costs and benefits, which is the case when pesticides are applied simply because pests are seen in the field or expected to arrive.

Implementation of TLs

The original IPM programs in California in the late 1930s/early 1940s were based on a system of researchers carrying out scouting of farmers' fields to evaluate pest and predator densities and determine whether artificial control was needed. Later the responsibility for scouting was taken over by the farmers themselves. Today it is common for farmers to hire pest scouts and even pest scouting firms for this job[6]. Sophisticated scouting methods have been developed based on random sampling and statistical analysis and often backed by meteorological data to help predict pest outbreaks. The more comprehensive and accurate the scouting program, the more information available to the farmer to judge whether the ATL for a particular pest has been reached.

There is no doubt that most African farmers are at a significant disadvantage with respect to implementing scouting programs such as the ones becoming common in U.S. agriculture. In this respect, the objection concerning a lack of both knowledge and means is legitimate. At one end of the scale, countless studies have shown that many small-scale farmers do not recognize pest species or their effects on crops. More visible pest species, such as birds and caterpillars, are often regarded as important while more cryptic pests (e.g. leaf miners), weeds and diseases are overlooked even though they may be having a much greater impact on yields. Furthermore, water or temperature stress may be confused with diseases or insect damage. Recognition of beneficial species is even less common, so farmers who can afford them often reach for pesticides whenever they see insects in the field, even if these are actually beneficial species. Identifying the key pest and beneficial species and then training farmers to recognize them has been a key element in the FAO rice IPM project in southeast Asia.

At the other end of the scale, large-scale commercial farmers might be expected to be interested and capable of implementing U.S.-style scouting programs (assuming that credible ETLs and ATLs have been developed and extended). However, shortages of trained labor, vehicles, and fuel, and unreliable access to appropriate pesticides can make effective scouting difficult or impractical. A different type of problem arises in large, dispersed agricultural schemes where small-scale farmers are accustomed to having a commercial company or government agency take care of pest control, often not even knowing how much they are being charged for the service. These farmers have little motivation or incentive to carry out scouting themselves, while the scouting teams fielded by the parent company or government agency are often ineffective, employing poorly paid staff with little incentive for good performance.

Introduction of pest scouting under these circumstances is not easy. Examples such as described in the case studies on cotton in Zimbabwe and Sudan show that it can be done, but it requires a combination of training, motivation, organization and logistical support which may take a long time to develop. However, a sophisticated field scouting system modeled on the U.S. approach is not the only way to implement pest management based on TLs. Some of the alternative approaches are discussed below and demonstrated in the case studies.

(1) Preventative treatment

Although prophylactic or "calendar-based" spraying is generally regarded as antithetical to IPM, in some circumstances it is actually the most rational approach. Where pest infestations are very predictable and constant from year to year and history shows that natural controls are consistently unable to suppress them, it is reasonable to initiate artificial control at a certain time of the year to target a susceptible stage and prevent populations from building up to damaging levels. This is consistent with the IPM approach as long as research has indicated that this is the best way to prevent ETLs from being reached, that the production benefits justify the costs, and the likely impact on natural enemies has been factored into the equation. Control of many weed species falls into this category, which explains the popularity of preplanting and pre-emergence herbicides.

(2) Forecasting

In the case of some pests and diseases the prophylactic approach may be unavoidable because, once an infestation has started it can sweep through the crop population too quickly for any control action to be effective. This is particularly true in developing countries, where supplementary pesticides are not likely to be available on short notice. In such cases, however, control decisions can still be made on the basis of practical criteria and indicators, such as weather patterns. Forecasting the probable level of pest attack allows farmers to take appropriate action, which may range from changing crops or cultivation practices, to using prophylactic pesticides, to making the necessary advance preparations to be sure that they are able to apply pesticides when needed. In some cases, the rational decision may even be to abandon the crop without further investment.

Forecasting is often used in control of migratory locusts, with control efforts focused in areas where climatic conditions and "greenness indices" indicate that conditions are right for catastrophic outbreaks. Monitoring rainfall is another important element, as many pest problems are strongly influenced by whether it is a particularly wet or dry year (e.g. fungal diseases in many crops; see also the case study on rainfed millet in Mali). Other parameters which may be used for forecasting pest problems include temperature, wind conditions and monitoring populations and movements of disease vectors.

(3) Trapping

Another type of forecasting is monitoring the development of insect populations by trapping the flying adults, for example with light traps or pheromone traps. For many species the probable density of a damaging juvenile stage can be predicted with considerable accuracy from the size of the previous adult generation. Knowing in advance whether it is likely to be a "bad year" permits farmers to use preventative treatments only when they are really warranted.

(4) Pest scouting

While preventative treatments may thus be appropriate for various practical and ecological reasons, in most cases the objective is to introduce some form of pest scouting so that pesticides are used only as a last resort in response to actual outbreaks. Recognizing the diversity of African agricultural systems, it is appropriate to view this as a phased process. Where farmer and extension capabilities are poorly developed it may be best to begin with a form of "supervised control," wherein pest scouts are hired to do random sampling and all farmers in the area are advised whether or not to spray based on their findings. This approach has the disadvantage of generalizing over fairly large areas, within which pest densities and other factors such as maximum yield potentials may vary greatly. Nevertheless, it is a logical first step and is the approach used in several of the case studies (e.g. irrigated rice in Madagascar, rainfed millet in Mali).

A next step may be training selected farmers who can then do scouting on behalf of a more localized group of neighbors (e.g. case study on cotton in Togo). The objective is for each farmer to take on responsibility for scouting his or her own fields, either personally or by hiring scouts. This responsibility must, of course, be linked with the individual farmers' responsibility and capability to make his or her own decisions regarding pest control based on this information. This means that farmers must be trained to apply equipment, and must have the option whether or not to buy pesticides based on their own decision criteria.

The case study on cotton in Zimbabwe is interesting because of the difference between the large-scale and small-scale farmers. Large-scale farmers cooperatively support an institute where they (or their employees) can learn fairly sophisticated pest scouting techniques. Training for small-scale farmers, recently begun with support from USAID, uses methods and devices which are adapted to their relatively lower literacy and numeracy and other constraints (e.g. many have eyesight too poor to see *Heliothis* eggs and must look for larvae instead).

5. Implementation of IPM in Africa

Subsistence level farming systems

Subsistence farmers produce crops (mainly cereals, legumes, vegetables, and root and tuber crops) in diversified cropping systems using few external inputs and obtaining relatively low yields. The primary objective in supporting these farmers is to increase inherent productivity by promoting better overall agronomy and crop management. Pest control is relevant only if it can be shown that losses to pests represent an important production constraint relative to other factors such as crop varieties, seed quality, soil preparation and fertility, water availability, etc.

If pest control is warranted, the most appropriate methods are those which require little if any cash expenditure and external inputs, both because farmers cannot afford inputs and because the low yields do not justify much added investment. At the same time, labor requirements must be taken into account because most subsistence farmers rely on their own or family labor both for farming and to earn off-farm income. Finally, subsistence farmers in Africa are generally poorly educated and very poorly served by overstretched extension systems, so proposed technologies must be relatively simple to disseminate and use. Recommendations should be presented in the form of straightforward technical packages which minimize the need for complex calculations or record keeping. At the same time, they should make maximum use of farmers' skills and their capacity to make judgements on what is feasible or worthwhile.

Researchers must focus on producing operational recommendations, recognizing that research results are not relevant if they cannot be implemented by farmers under local conditions. However, the actual translation of research results into technical packages is a complex process which researchers alone may not be able to carry out, in part because their work is by nature specialized compared with the broad spectrum of needs and objectives of their farmer clients. Extension services should have subject matter specialists in crop protection to help fit IPM research recommendations into an overall extension package.

The characteristics of subsistence agriculture are such that the preferred strategy for crop protection will emphasize use of resistant varieties, coupled with improved cultural practices that are compatible with farmers' labor limitations and other constraints. These may include intercropping, crop rotations, phytosanitary measures, and timing of planting and harvest to escape pest population peaks. However, each of these approaches may be constrained by specific local conditions. For example, farmers may refuse to destroy plant stalks because they need them for building materials or fodder, or they may need to concentrate on other activities during the recommended planting period. Classical biological control, implemented by a state agency or research institution, is also a good option in subsistence agriculture as it requires little or no direct farmer involvement (see below). Pesticide use is not necessarily excluded, but must be low cost and low-hazard not only for the farmers themselves but also for their families and livestock and should not disrupt natural control mechanisms. There should also be a system to advise farmers on when it is appropriate to use pesticides, based either on monitoring infestation levels or on predicting conditions conducive to outbreaks (e.g., see case study on millet in Mali).

Governments sometimes try to make pesticides more accessible to subsistence farmers through subsidies, but this can lead them to abandon equally effective non-chemical methods (e.g. mechanical weeding vs. herbicides in the Zanzibar case study).

In practice, most projects aimed at subsistence farmers are not IPM projects *per se*, but general agricultural development projects which come to have an IPM component. As might be expected, strengthening local research and extension services is a key component. Some projects establish their own, separate research and/or extension systems to serve their participating farmers. This may be easier and more effective in the short term, but will have much less long-term impact than building up the existing national systems. Therefore, any autonomous research or extension systems should be viewed as only a transitional device to catalyze the work and carry on while the new approach is being institutionalized and national agencies are being strengthened to implement it (see, for example, case studies on food crops in Kenya, food crops in Zanzibar, rice in Burkina Faso).

There are also other important institutional needs such as ensuring timely availability of inputs needed to implement IPM recommendations (e.g. a shortage of "sticky glue" against ants and disease-free planting material is identified as an important problem in the Zanzibar case study), and organization within the farming community itself to promote adoption of control actions such as closed seasons, synchronized planting and harvesting dates and phytosanitary measures which must be carried out on an area-wide basis.

High-input farming systems

Although overall use of external agricultural inputs in Africa is low compared to other regions, a number of commercial crops are widely grown in intensive, large monocultures using high levels of fertilizers and pesticides. The most common are cotton, coffee, cocoa, banana, paddy rice and vegetables. Most IPM projects relate to these types of systems because it is here that visible results are most easily achieved in the short term.

The initial focus is usually on rationalizing pesticide use as a means of reducing costs and environmental and health hazards. If the system has entered a "crisis" stage because of pesticide misuse, it may be necessary to make drastic changes in the way pesticides are used, such as eliminating a class of products to which resistance has developed, or greatly reducing applications to allow recovery of beneficial species populations. Reducing the frequency of pesticide application is usually the first goal, generally by introducing the use of application thresholds and some form of pest scouting or forecasting (see Part 4). This may require a basic reorientation to wean farmers and extension personnel away from a "pest eradication" to a "pest management" mentality (i.e. getting them to accept some level of pest attack and yield loss). Other aspects of improving pesticide use include replacing broad spectrum pesticides with narrower spectrum products to reduce impacts on natural enemies and other beneficial species, such as pollinators, replacing wasteful or hazardous pesticide application methods with others that are better targeted at the pests, improving the timing of applications, and introducing pesticide rotations to prevent the development of resistant populations. These improvements may sometimes be difficult to introduce because farmers tend to prefer broad-spectrum products because they want to kill as many different pests as possible with a single application. The best strategy is to educate them concerning the important drawback of broad-spectrum pesticides--the destruction of natural enemies--and demonstrate when this trade-off is not worth it. They also may resist trying unfamiliar products or spending money to replace the application equipment they already have. Sometimes it will be possible to demonstrate that the additional cost is soon recovered through savings in pesticides. Otherwise it may be necessary to provide the new equipment free or at a subsidized rate. Pesticide or equipment manufacturers are often open to supporting this as a means of building markets for new products.

A second objective is to introduce non-chemical methods to help maintain pest populations below threshold levels and, if possible, directly substitute for at least some of the pesticide use (e.g. releasing biological control agents against pest outbreaks).

While the objectives are relatively straightforward, implementation is usually more complicated. There are a number of technical, attitudinal and logistical constraints to be overcome. Advocates of IPM often fail to recognize the importance of these constraints and thus expect more unrealistically rapid implementation. Some of these important considerations are:

(1) The crops on which pesticides are heavily used in Africa are very important to the national economies, so a certain level of production must be guaranteed. A conservative approach is needed because any technology which introduces a risk of significant, sudden reduction in yields or quality is not likely to be accepted even with the prospect of long-term economic benefits. In fact, governments often encourage high levels of pesticide use through subsidies and other incentives at considerable national expense on the misguided premise that there is a direct correlation between levels of pesticide used and crop yields (as there generally is with fertilizers).

(2) The pest management information and advice farmers have been receiving up to this point are likely to have promoted pesticides very strongly. Extension personnel probably lack the training needed to advise on alternatives and may even have direct financial interest in selling pesticides. In many cases, government agencies or private parastatal community associations have developed (e.g. for cotton, cocoa, coffee, banana), which control both farmer extension and supply and delivery of inputs. Pesticide sales representatives also may have more contact with farmers than do extensionists (having better access to transport) and are armed with appealing promotional literature.

(3) A strong psychological and ecological dependency on chemical pesticides is likely to already be established. Farmers have often abandoned many of the agronomic practices which would help suppress pest populations and have come to believe in pesticides as a "quick fix" solution. They may also regard pesticides as the "modern" approach and be reluctant to "regress" to traditional practices.[7] At the same time, continued use of large amounts of pesticides may have greatly reduced the abundance and diversity of natural enemies. For example, in Sudan, surveys showed that of 140 predator and parasite species collected in the irrigated cotton schemes in the 1930s, only 40 could be found in 1986. In addition, secondary pests may have emerged which are very difficult to control.

Under such circumstances "pesticide withdrawal" can lead to much greater losses than would have been the case if pesticides had never been used, so it is risky to move quickly from a strategy of very high pesticide use to little or no pesticide use. Furthermore, pioneering farmers trying to adopt an IPM approach may sometimes be discouraged because continued heavy pesticide use in surrounding areas can reduce the effectiveness of IPM measures. In Kenya, for example, heavy pesticide use in neighboring coffee plantations reduced natural enemy populations in non-treated plantations. In some cases, pests may also move into "IPM" fields from adjacent areas and overwhelm natural controls. On the other hand, in trials in irrigated rice in southeast Asia, natural enemies did effectively control pests in small IPM plots adjacent to pesticide-treated plots.

(4) There is little baseline information available about African agro-ecosystems. For any intensively cultivated area there will probably be little or no data relating to basic ecological interactions such as which pests represent a real economic threat and at what densities, which ones could be well controlled by indigenous natural enemies, or which agronomic practices suppress or promote growth of pest populations. Because farmers probably went directly into chemically-intensive farming practices, partly as a result of the influence of pesticide manufacturers and commodity development associations or other government agencies, research will have been focused for some time on screening pesticides for efficacy and improving application methods. Few alternative control methods will have been identified or tested. The case study on rice production in Madagascar provides a good example of how basic ecological and economic studies can be the key to improving pest management practices: after only a few years' work researchers were able to demonstrate that one of the "key" pests in the system never inflicts enough damage to justify control action, while another can be controlled effectively by treating only nurseries and small "hotspots" rather than the entire area. They also showed that weeds, which had been largely ignored in research, were in fact the major production constraint.

Efforts to promote IPM in commercial farming must also take into account the heterogeneity of the sector, particularly the wide variation in sophistication and knowledge of farmers, their production levels, the types of pest problems they have, and the resources and management options open to them. For example, large-scale cotton farmers in Zimbabwe almost universally follow recommended practices, such as pest scouting and rotating pesticides to avoid the development of resistance to dimethoate. Small-scale farmers have greater difficulty in carrying out pest scouting and making decisions on pesticide spraying, resulting in inadequate control. In Kenya, smallholder coffee growers frequently apply 2-3 times the recommended levels of insecticides, while some large coffee estates use none at all. By contrast, the smallholders under-use coffee fungicides, averaging only one third of the recommended doses, and apply them at the wrong time with the result that disease control is very poor.

Community organization can also be very important. For example, the case study on irrigated rice in Burkina Faso notes that farmers in the Vallee du Kou area are in a better position to implement cultural measures such as synchronized planting and harvesting than those in some other schemes simply because they are better organized. Large-scale farmers are likely to receive more attention and advice both from national extension services and from the private sector (pesticide producers and crop marketing organizations). While advice from representatives of pesticide suppliers does not necessarily result in decreased or rationalized pesticide use, positive collaboration with the industry can help ensure that the products farmers need are available when they need them. This has been important, for example, in the system of rotating pesticides to prevent development of resistance in mites and bollworms, described in the case study on cotton in Zimbabwe.

This discussion of constraints is not meant to suggest that rationalization of pesticide use is impossible or a distant ideal in African farming systems which involve high levels of external inputs. The case studies concerning such systems show that positive results can be obtained. Instead it demonstrates the complexity of the task and the fact that every situation must be addressed individually. In many cases progress may seem frustratingly slow because of the need to overcome a deep-seated prejudice that high levels of pesticide use are unavoidable. In addition, the basic elements for development and adoption of IPM--ecological data, pest control technology, farmer acceptance, farmer skills, institutional and logistical support, and supportive economic policies--may need to be developed as part of the process of implementing IPM.

Intensifying farming systems

Most African governments have set food self-sufficiency and increased production of export crops as national objectives in the face of intractable national debts and populations now doubling every 20 years, and an arable land base which is shrinking because of urbanization and environmental degradation. Helping farmers move from subsistence level farming to higher yielding and reliable production is a major objective of agricultural development programs. This has led to countless projects which promote agricultural intensification and diversification.

Unfortunately, intensification has generally resulted in increased pest problems because it has involved adoption of practices--such as monocultures, reduced fallow periods, elimination of crop rotations, irrigation and year-round cropping, use of high-yielding varieties, irrigation and increased use of fertilizers--which can help create ideal conditions for the development of pest populations. This "side effect" has too often been ignored, based on the premise that if pest problems emerged they could be dealt with by applying pesticides. To some extent, this attitude has been fostered by the pesticide industry, whose salesmen frequently promise that use of their products will guarantee high yields. As discussed above, the common result is entry onto the "pesticide treadmill" of increasing costs and decreasing effectiveness of pest control as well as environmental contamination and pesticide poisonings.

The challenge in transitional systems, and thus in agricultural development in general, is to assist farmers to intensify and increase production without entering this vicious cycle. In practice, this means:

(1) anticipating the implications of new agronomic practices in relation to probable pest problems;

(2) trying to prevent or minimize these problems by selecting agronomic methods accordingly (e.g. through intercropping, crop rotations, tillage practices, closed seasons, etc.);

(3) focussing research on developing feasible alternative control methods, particularly biological controls; and

(4) introducing an IPM-compatible approach to pesticide use from the beginning. This means: (i) supporting basic research to understand the agro-ecosystem and for crop loss assessment; (ii) ensuring that extensionists and farmers understand the principles of IPM and particularly the negative impacts that inappropriate use of pesticides can have; (iii) developing techniques to forecast or monitor pest outbreaks (implemented by farmers, hired scouts or government crop protection staff), and rules for decision making in chemical control, (iv) ensuring that extensionists and farmers have the training, tools and materials to apply these techniques and to use pesticides in an effective and safe way.

The case study on IPM for food crops in Kenya represents an example of a transitional system where a concerted effort is being made to help farmers avoid becoming dependent on pesticides. Most of the participating farmers are currently at a subsistence level but in the process of evolving toward commercial production by increasing yields to the point where they have surplus to sell. These farmers are fortunate in being neighbors of the Mbita Point Field Station of the International Centre of Insect Physiology and Ecology, an internationally renowned center for IPM research. With the help of an EEC funded project, ICIPE is working with target farmers in the area to develop, test and disseminate a range of agronomic and pest management practices such as varietal resistance, early planting, intercropping, biological control and manipulation of pest behavior with pheromones. Yield levels of participating farmers have increased considerably, allowing them to sell the surplus harvest. They use this income to improve their houses, pay school fees, buy plow animals and, significantly, to hire labor for weeding instead of buying herbicides.

The case study on irrigated rice in Madagascar basically concerns a system in the process of transition, as many of the farmers still produce at subsistence levels but others are responding to the government's push for intensification. There was a brief foray into use of much higher pesticide levels under the government-supported, internationally-financed, industry-executed "Taona Zina" ("Fertile Year") program which was similar to the "package deals" described in the case study on irrigated cotton in Sudan. However, this program lasted for only a few years and seems to have had relatively little impact on the agro-ecosystem or farmers' behavior. For example, the program was centered on chemical control of the white African stem borer, provided free of charge to the farmers. Since the end of the program and the supply of free chemicals, farmers have shown no interest in buying pesticides to control this species. Soon after the Taona Zina program began, a cooperative Madagascar/Swiss research project demonstrated that much of the chemical control being promoted in the area, while effective in killing the target pests, was economically unjustifiable: one of the "key" pest species never reached economically damaging levels while the other one was usually effectively controlled by indigenous natural enemies. Weed control was shown to be very important in increasing production, but mechanical weeding was just as effective as use of herbicides.

Classical biological control

In "classical biological control" natural enemies from a different location are released in the area where a pest occurs, to establish stable, self-perpetuating local populations which give long-term control of target pest species (see van Lenteren, 1988). It is distinct from "augmentative" or "inundative" release systems in which natural enemies are bred on a large scale for regular release every season or every few years, and distinct also from systems in which predators, parasites or pathogens are applied much like chemical pesticides to combat a pest outbreak. The latter two approaches also have an important place in IPM and, where effective, are preferable to use of chemical pesticides. However, they represent a more complex and demanding technology than the one to be discussed here. This discussion also does not include practices aimed at protecting or increasing the effectiveness of indigenous natural enemies.

Classical biological control (CBC) is in many ways the ideal pest management approach because it cures the problem instead of simply treating it. There are many well-known success stories including as least 15 insect pests in Africa successfully controlled by introduced natural enemies (Greathead, 1986). The overall success rate is difficult to gauge due to limited objective and quantitative data and a lack of clearly defined criteria for success vs. failure. Hokannen (1985) surveyed information on 3000 introductions against almost 200 target pests worldwide and concluded that just over 35% of introduced natural enemy species have become established in the new site. Of these, about 60% resulted in demonstrable economic or biocontrol success. However the success rate has risen steadily since the 1930's as the field has matured (see also Huffaker and Messenger, 1976; Clausen, 1978; and Julien, 1982 for estimates of success ratios for introductions of insect natural enemies against invertebrates and weeds).

Once an effective biocontrol agent has become established, in theory no further intervention is necessary. In practice, re-introductions are sometimes necessary. While a well-established organism may occasionally die out as a result of stochastic factors, such as a hurricane or a drought, disappearance of biocontrol agents is much more likely to result from inappropriate use of pesticides. This occurred, for example, in Kenya in the 1960s, when biological control of the coffee mealybug was disrupted by use of organochlorine pesticides such as DDT, aldrin and dieldrin.

To maximize the impact of the CBC approach it is useful to identify situations where it is most promising, either because other control options are limited or because of a relatively high likelihood of success. CBC is particularly attractive in cases where other types of interventions are particularly inappropriate or unfeasible. For example, for very low-value crops grown by highly dispersed, small-scale farmers, it may be impossible or uneconomical to disseminate or use external inputs or even many types of cultural controls which demand education and labor. There are also some types of pests which are protected from pesticides by their feeding behavior or other factors so that chemical control is not a realistic option.

CBC has been successfully applied in virtually every type of cropping system and ecosystem and against virtually every type of target pest (Hokkanen, 1985). However, based on theoretical considerations and experience, there are some conditions which increase the likelihood that CBC can be introduced successfully:

(1) relatively simple, ecologically stable or predictable systems such as forests, orchards, pastures, perennial crops or semi-perennial crops (e.g. cassava or sugarcane). For annual cropping systems (e.g. vegetables), generalist predators *tend* to be more successful than specialist parasites;

(2) one or a very few key pests to be targeted for control;

(3) introduced pest species (whose populations often explode in the absence of the natural enemies which control them in their native region)[8];

(4) among insect pests, target species which are relatively sedentary (e.g. honey-dew producing homopterans such as scale insects, mealybugs and aphids are particularly vulnerable because of their life history traits and because the honey-dew can attract the parasites to them); and

(5) among weeds, perennial herbs, shrubs and trees are the best targets.

Weeds have been good CBC targets, yielding on average a higher number of successes in relation to attempts than for insect pests. However, pre-introduction screening for specificity of herbivorous agents is particularly critical because many weeds are closely related to commercially important local plants so that there is a danger of host-switching.

Identifying and introducing a biocontrol agent may require a large investment of time and money (e.g. case study on Africa-wide Cassava Mealybug program). In other cases, however, the process can be simple and the total cost low (e.g. case study on Mango Mealybug in Togo). Unfortunately, it is almost impossible to predict what investment will be needed or whether it will succeed. The key steps in developing a CBC system involve considerable uncertainty about how soon they might be accomplished in any given case: (1) identifying potential biocontrol agents for a given pest; (2) quarantine and screening of candidates with respect to their efficacy and their specificity to the target pest[9] and to eliminate their own hyperparasites and pathogens; (3) multiplication of the biocontrol agents for large-scale release; (4) field release of the biocontrol agents; and (5) monitoring and evaluation of their effectiveness in the field. These elements all require a suitable institutional capability, reliable long-term support in terms of financial and human resources, and often effective international cooperation.

The high costs of identifying and establishing a biological control agent must be weighed against the tremendous benefits when the introduction is successful, thereafter providing cost-free control. There are unfortunately few data available on costs vs. benefits of CBC, in part because of the lack of follow-up field monitoring. Based on the available information, Pimentel (1965) calculated the overall return from dollar investment in CBC as 30:1, compared with 5:1 for chemical control. Greathead and Waage (1983) gave estimates for a variety of projects in the U.S., Australia and several tropical countries, yielding benefit: cost ratios ranging from 5:1 to 188:1.

Perhaps the most detailed analysis has been for the Africa-wide cassava mealybug program. Because of the long process of identifying a suitable biocontrol agent and the regional scope of the program, this has been a complex and costly project. Nevertheless, one independent investigator reported a benefit:cost ratio of 149:1 for the entire program to date, including all start-up costs (Norgaard, 1988). The analysis has been questioned, particularly with respect to the assumptions underlying the benefit side of the equation. But other more precise evaluations also support a high benefit:cost ratio (see case study for details). Unfortunately, while the program is generally acknowledged to be a great success by the international community and African governments, a survey in Ghana and Cote D'Ivoire showed that farmers who are the target beneficiaries knew nothing about the program and attributed the observed decline in the pest to climatic factors.

An evaluation of costs and benefits of the CBC approach should address the relationship between biological and chemical control. Biocontrol agents are usually vulnerable to pesticides[10], so pesticide use must be eliminated or greatly restricted in the area if a biocontrol program is to succeed. This may be an opportunity cost to the extent that chemical control would have provided better crop protection in a particular case or during a particular period of time. However, it also means that direct costs of pesticide use are saved, as are potential indirect costs in the form of health impacts, environmental contamination, ecosystem disruption and development of pesticide resistance.

1. Pest Management and the African Farmer, Proceedings of an ICIPE/World Bank Conference on Integrated Pest Management in Africa, Duduville, Nairobi, Kenya. Edited by Ole Zethner, ICIPE Science Press.

2. In this paper, the term "pest" will be used to indicate any organism which reduces agricultural yields or quality, and the term "pesticide" for any chemical product aimed at killing any type of pest.

3. Throughout this paper the term "pesticides" refers to any toxic chemical used to kill any organism defined as a pest, thus it includes insecticides, herbicides, fungicides, bactericides, rodenticides, nematicides, avicides, etc.

4. Systemic (preventative) fungicides introduced around 1975 quickly became very popular. However, genetic resistance to these products soon began to appear, leading phytopathologists to seek to limit their use through use of economic thresholds (Zadoks, 1989).

5. Refers to external inputs, i.e. synthetic fertilizers and pesticides as opposed to labor and organic fertilizers from crop residues or animals forming part of the farming system.

6. For example, in south central Texas, about 90% of the cotton acreage and 50% of the vegetable area are now serviced by private crop protection consultants (Agrichemical Age, April, 1988).

7. Sometimes farmers will refuse to abandon high levels of pesticide use until a crisis develops and production crashes because of insurmountable pest problems (e.g. cotton production in the Canete Valley of Peru in the 1950s (Hansen, 1987) or in the Ord Valley of Australia (Matthews, 1989).

8. Based on this assumption it would be important to determine whether a pest was introduced from abroad or whether it is an indigenous species which only recently reached economically damaging levels, perhaps as a result of over-use of pesticides. However, Hokkannen (1988) disputes the assumption, noting that his survey revealed no differences in degree of biocontrol success according to whether the pest was native or introduced.

9. Absolutely crucial to avoid the situation, which has happened a number of times in the past, where an introduced biocontrol agent has itself become an economic pest.

10. Except some species which have been artificially bred for pesticide resistance, e.g. strains of the predatory spider mite *Metaseiulus occidentalis* which are resistant to carbaryl, permethrin and organophospate insecticides.

6. Case Studies

Integrated Pest Management for Rainfed Millet in Northwest Mali

by N.D. Jago*

Introduction

The British government has supported work to reduce crop losses to grasshoppers and locusts since the establishment of the Anti Locust Research Center in 1959. The current program began when, faced with the effects of two severe droughts in West Africa (1972-1974 and 1982-1985), the government of Mali requested assistance from the U.K. (Overseas Development Administration) to combat grasshopper pests of millet.

The ODA responded with two planning missions (1983 and 1984) which ultimately led to the start of the present project in 1985. One important and fairly novel feature of the 1984 mission was that it included staff from the ODNRI's Economic, Social and Statistics Department. As a result, the project moved beyond its original narrow focus on pest control in millet and developed into a broader-based IPM program which takes account of the whole farming system. The pest management trials have proceeded in parallel with socio-economic studies to ensure that technologies developed are socially and economically acceptable to the farmers as well as technically effective and feasible.

Millet is of crucial importance to the rural community, but less so in urban areas where rice is preferred. The low market price of millet is one of the many important constraints to increasing production, particularly with respect to expenditures for pest control or other inputs.

Institutional framework

The national institutional framework in which the project operates is very important in understanding its approach and implementation. In 1986 the International Organization for Control of African Migratory Locust (OICMA)[1] was dissolved. The Malian counterpart organization, the Operation for Protection of Sowing and Harvest (OPSR)[2] was replaced by a National Plant Protection Service (SNPV), which absorbed the field staff of the old OICMA and also took on responsibility for control of migratory pests. These field staff were highly trained and introduced into SNPV advanced practices such as regular radio communication. However, their experience was also narrowly focused on chemically-based locust and grasshopper control.

In 1988 an FAO/UNDP project began to strengthen the SNPV to increase its capability to monitor and control locust and bird pests. It works to build the scouting capacity of mobile field teams and capabilities for pesticide application. The ODA project complements the FAO/UNDP project by focusing on SNPV field staff who interact directly with farmers, and focuses on other pests. SNPV is responsible for pre-harvest plant protection and extension, and its agents work in parallel with agricultural extension officers who are under a different jurisdiction. In practice the two cadres have the same work program since the use of chemical pesticides has been regarded as the only practical means of increasing cereal

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production in the rain-fed areas. Little effort has been invested in other approaches, such as extension of new millet varieties.

The ODA project currently operates in a limited geographical area chosen because it is representative of most of rainfed Sahelian Mali (and the broad belt of Sahelian Africa south of the Sahara and between Senegal and Somalia) where crops are grown under a mean annual rainfall of 300-500mm. Therefore, it is anticipated that the results, adapted for local people and customs, will be applicable on a large scale.

Background

The project area and cropping systems

The project area covers 30,000 km^2 just south of the Mali/Mauritania border. Population density is low (5/km2) so there is little competition for land and agriculture is fairly extensive rather than intensive. Rainfall is unpredictable, with droughts at irregular intervals. The main crop is finger-millet, which in many areas forms an almost complete monoculture. Sorghum is sometimes intercropped with millet or replaces it in low-lying spots with heavier soils. While there are quite a few local millet varieties, millet has received relatively little attention from plant breeders. One local variety (Ningare), which was developed by the Dogon people of central Mali, shows some promise of resistance to several important pests. Short-cycle millets, which include most of the so-called drought-resistant varieties, predominate on the fields nearest the villages, where livestock feeding on crop residues provide manure. Chemical fertilizers are rarely used. In the more distant "bush fields" yields are generally lower than in the village fields (except apparently in very dry years); they tend to be cultivated for 4-6 years and then fallowed for 5-15. Both sorghum and millet may be intercropped with cowpea, and women's fields may be planted every 2-3 years with groundnuts but this crop only does well in years of higher rainfall. Various other crops (e.g. wild rice and hemp) planted on field margins and harvested on a small scale assume greater importance in drought years.

The pest complex

The Sahelian ecosystem is characterized by highly variable and irregular rainfall, and enormous east-west belts of vegetation which develop seasonally on the arrival of the monsoon, starting in the south and moving northward. Many of the indigenous fauna (including insects such as some grasshoppers and locusts) migrate seasonally following the movement of the emergent grassland. The herbivorous insects also have the capacity for explosive population growth, resulting in rapid development of astonishingly high densities during the short growing season. At the same time, the relative importance of different pest species seems to change every few years. For example, the millet head miner moth first emerged as a major millet pest in 1972 and persisted until the summer of 1988, when it suddenly declined in many areas. The migratory, explosive and changing nature of sahelian pest complex makes IPM based on a predictive approach difficult. In many cases a responsive approach based on chemical control seems to be the only effective way to deal with the characteristic enormous pest outbreaks. Even the use of pesticides is more complex than in many cases, as it must be flexible enough to respond to continuous and sudden changes in the pest complex. Hence the importance of regular and frequent scouting.

The major insect pests of millet during 1983-89, in rough order of importance, were:

(1) the millet head miner (*Heliocheilus albipunctella*), which destroys the florets and young grains and may cause the head to disintegrate completely;

(2) grasshoppers and locusts (various species) which cause damage at emergence, flowering and the milky grain stage. Early attack (June/July) may trigger 3-4 replantings and reduce the total area planted by 25%. Rough estimates indicate that farmers experience 70-90% crop loss due to grasshoppers every 5 years;

(3) stem borer (*Coniesta ignefusalis*), whose larvae bore shoots and stems from early to mid-season, weakening stems and causing late season lodging.

The impact is greater in drier regions than in wetter ones, as in wetter areas the plants can compensate better for damage sustained. Low levels of infestation stimulate tillering and may actually increase final yield. Infestation is heavier in village fields, which are close to straw houses harboring overwintering pupae in the stalks. Some millet varieties appear to be resistant to this pest;

(4) scarabaeid beetles ("rose chafers"), whose adults feed on flowers and young grains. The heavily manured village fields are more affected because the larvae live on decaying organic matter and roots in the soil. Damage can sometimes be equivalent to that of grasshoppers, but usually they are minor pests and no control is justified;

(5) meloid beetles ("blister beetles"), also flower feeders, but they cause relatively little damage to millet;

Other important pests include rodents (particularly in dry years), birds (village weavers and *Quelea* species) which can cause major losses just prior to harvest, and weeds (particularly *Striga* in wetter years). Weeds are controlled by manual weeding, requiring up to 20 man/days per hectare. Farmers often try to increase production by cultivating a larger area only to abandon the new fields because they cannot cope with the weeds which choke out the millet. Fungal pathogens are undoubtedly present, but are not mentioned as major pests by farmers in the area and have not yet been surveyed under the project. There is rarely surplus millet to store for more than a year, so there is little need for storage pest control.

Socio-economic features and constraints

Villages in the project area consist of assemblages of families divided into households. Fields are cultivated by individual households, with yields being retained by the households in good years and pooled in common family granaries in lean years. The largest, richest 20% of the families own roughly 80% of the wealth, including ploughs, so that they cultivate larger areas per capita than the smaller, less productive families. They also have more free family labor and can release some family members for off-farm income earning employment. Despite their advantages, however, the larger families apparently do not produce more millet per hectare on a given field type than smaller families.

Data on socio-economic constraints to production are difficult to obtain because farmers prefer to conceal their assets for fear of being taxed, or to protect themselves from creditors. They also do not measure the size of their fields with any accuracy and grain production for home use is described in terms of number of months of family supply rather than any standard measure. Nevertheless, socio-economic studies indicate that the main constraints for the smaller families (apart from physical conditions such as poor soil, inadequate rainfall or pest losses) are:

(1) shortage of family labor (particularly as some family members must contribute work to pay off debts to larger families);

(2) high expense of hired labor (particularly needed for weeding);

(3) lack of, and high expense of, animal traction and ploughs;

(4) vested interest of more powerful families in maintaining the status quo, leaving the 80% of poorer families at a disadvantage; and

(5) lack of money to buy inputs (farmers usually express this as inability to buy pesticides and sprayers, due to their belief that this is the only real means of increasing production).

Existing agricultural and pest management practices

Cultivation of the main fields is usually by single share, light iron plough drawn by two oxen or a horse, with crops sown in lines which incidentally facilitate weeding and application of fertilizers and pesticides. Women's plots are cultivated by hoe and are consequently relatively small. Sowing starts in June prior to the first rains and continues into August when the sorghum is planted. Millet sowing is staggered to help spread the weeding period. The staggered planting and frequent need for re-sowing result in a staggering of plant maturation and, consequently, the possibility of cascading crop infestation by pests. Harvesting is also carried out over a long period, making estimation of yields difficult. Different varieties are sown to insure against badly distributed rains. Planting density varies regionally according to rainfall: in 1988 stand density varied from 1,904 to 22,656 stands/ha (current recommendations call for 10,000 stands/ha). There is usually one weeding in wet years and two in dry years, based on intensity of cultivation and availability of labor. Planting and weeding are labor intensive, so labor availability is a serious consideration for introduction of any new technology.

Prior to 1987 pesticides were rarely used. To control grasshoppers farmers relied on destroying egg pods. Bird control is based on using young children to scare birds in the fields and breaking the millet stalks flat just before harvest after the seed has ripened. Some of the millet varieties have a sugary pith which is chewed by children on "bird control" duty, increasing the health hazards of any pesticide residues on the plants. Since its inception, however, SPNV has promoted and introduced the use of more pesticides, mostly provided by external donors. The pesticides and application methods and equipment promoted by SNPV are in fact unsuitable for use by small farmers in the Sahel (see Appendix for details).

The project

Objectives

The ODA project aims to improve national pest management and production capabilities by strengthening and supporting the SNPV. It serves in an advisory capacity, with access to Cabinet and Ministerial levels as well as the Director General and Technical Director of SNPV. Its main components are:

(1) collection and analysis of data through pilot field trials and socio-economic studies;

(2) training of SNPV field staff, and instilling a well planned seasonal calendar and daily routine;

(3) introducing new logistical and tactical methods to increase millet production; and

(4) broadening the SNPV's focus (from a concentration on control of locusts, birds and grasshoppers, inherited from OICMA and OPSR, to the overall farming system), and promoting a strategy of locally tailored IPM in place of the concept of global pest reduction or eradication.

Relationship to national cadres and interaction with farmers

About 25 SNPV and agricultural extension staff are directly involved in the project's activities in parallel with their regular annual program. Every effort is made to promote complementarity, for example the pilot farmers involved in project-related trials are selected so that the regular visits involved lead to regular contacts with farmers over the whole project area. Furthermore the equipment used in pilot trials has gradually become a familiar part of SNPV procedure. Communications relating to pest development, availability of pesticide stocks and distribution of equipment is maintained by radio links and person-to-person contact. Weekly meetings with participating SNPV staff are held to discuss the current situation and adapt tactics in response to seasonal changes in pest populations.

The number of farmers involved in pilot trials has grown steadily: 4 in 1985, 70 in 1986, 180 in 1987, 240 in 1988, 270 in 1989. Pilot farmers are drawn from 50 villages in 4 areas. The project has tried to draw on a representative cross-section, but there has been an inevitable bias toward involving the wealthier and more influential families because the smallest and poorest families may not have enough area to provide two half-hectare plots or have difficulty maintaining the project fields and harvesting trial and control plots simultaneously as is required by the experimental design. In addition to the project's pilot farmers, SNPV has established a system of 60 village brigades, consisting of young men representing all ethnic groups and approved by the village elders, as a key link with the farming community on pest management. SNPV and project staff maintain contact with farmers through regular visits to each village (every 10-15 days) and through daily radio contact.

The project provides expatriate technical assistance, vehicles and other equipment and improved facilities for participating SNPV staff as well as free seed grain, rock phosphate fertilizer and pesticides for pilot trials. It also lends pilot farmers ULV pesticide sprayers to use in project fields as well as in other areas which are strategic for pest control. Project staff, in cooperation with SNPV and agricultural extension staff, provide regular training and supervision on use of the pesticide sprayers. Pesticides are issued to farmers as needed from a village storehouse only under supervision of a responsible officer.

The project has had close contact with a number of other government institutions, NGOs and donor-supported programs, including (but not limited to): the FAO/UNDP project discussed above; ICRISAT[3] and other research institutions which advised on millet varieties for the pilot trials; a USAID program evaluating biological control of locusts using a pathogenic agent (*Nosema locustae*); the (now terminated) CILSS[4] IPM project; and the CILSS/INSAH/-Netherlands plant protection training project based in Niger. It has also cooperated with various British universities, particularly through short-term consultancies and student sub-projects.

The ODA contribution has been about 300,000 pounds sterling/year including expatriate salaries and equipment. The government of Mali provides the salaries of participating SNPV and agricultural extension staff and use of some buildings.

Pest management trials

Project activities center around field trials carried out on paired, adjacent half-hectare plots using a local millet variety (Souna) as the standard. The plots are planted in millet monocultures to facilitate evaluation of harvest results even though intercropping with sorghum is recognized as being better general practice and will be encouraged later.

From 1985-1988 the trials concentrated on the effect of different pesticides on target pests, particularly *Coniesta* stem borers, grasshoppers and *Heliocheilus* head miners. To the extent possible Malian-approved pesticides and locally and commercially available equipment are used[5] although some modifications are required in response to the problems discussed in the Appendix. From 1987 onward, trials of phosphate fertilizers and different pest-resistant local millet varieties were introduced. Data collected from the plots include: information on agronomic practices (e.g. manuring, sowing and weeding dates, plant stands); plant phenology (e.g. dates of flowering and heading); levels of attack by the key pests; dates and types of pesticide use; harvest dates; and yields/ha.

Socio-economic research

The preliminary sociological/anthropological survey (1984) developed into a "agro-economic" research project component which began in 1986, one year after the pest management trials began. The research team is led by an expatriate coordinator and includes a senior Malian graduate (male), a female student and two field assistants. Having a female member of the team proved to be essential for investigation of womens' role in crop production and the household economy, since many details are largely hidden from the men in the Malian community.

The agro-economic team's work focuses on social structures and organization at the village level, the availability of credit and the feasibility of different approaches to providing communities with needed inputs and equipment (e.g. a cereal bank and an equipment fund loan scheme). It also evaluates the results of the pest management trials each year and contributes to the direction of the next year's trials. Through 1987 the agro-economics team focused on surveying:

(1) current farmer pesticide use and farmers' perceptions of the relative importance of different pests;

(2) the millet market, including the effect of government interventions;

(3) credit availability;

(4) socio-economic parameters such as family size, assets, labor availability, agricultural productivity, etc.;

(5) comparisons of farming practices in different sub-regions within the project area; and

(6) economic costs and viability (from farmers' viewpoint) of the project pest management trials.

In 1988 they added studies of women's agricultural inputs and farmers' opinions on investment risk and returns on investment. In 1989 when the whole of northern Mali, including the project area, was subjected to an unprecedented grasshopper outbreak with major crop losses, the team analyzed the economic and social impact of these losses on the pilot farmers and the region as a whole. The results of this study will help provide indices for assessing crop losses to grasshoppers and thus to establish action threshold levels for grasshopper infestation.

Results

Results from the 1988 trials of pesticide application, fertilizer use and different millet varieties are summarized below:

Treatment	Mean yield increase (kg/ha)	Reasons for yield effect:		Cost	% farmers achieving 2.1 benefit: cost ratio*
		Head wt. increase	% Heads/pocket		
1.Ripcord**ULV (all levels of a.I/ha.)	52	+6	0	5740	25
2.Ripcord Granules	64	0	+12	4657	25
3.Carbofuran Granules	122	+33	0	22,127	5
4.Phosphate	234	+40	+16	4250	62
5.Ningare variety	171	+25	0	750	64
* Average annual millet price assumed to be 75 F.CFA/kg. ** Cypermethrin					

Application of aluminum phosphate clearly had a strong positive effect on yield in 1988. However, preliminary analysis of 1989 results are relatively disappointing, with only 3% of farmers achieving the target 2:1 (benefit:cost) ratio. Results with the Ningare variety of millet were similarly encouraging in 1988 but less conclusive in 1989, when yields from hybrid Ningare/Souna and pure Ningare were lower than from the pure Souna variety. 1989 was a very high rainfall year, suggesting Ningare may be intolerant of high rainfall. It was also quite susceptible to late season grasshopper attack.

The pesticide application results indicated that use of Ripcord (cypermethrin) gave fairly good results, although not as high or consistent as fertilizer use or the Ningare variety in 1988. There was no statistical difference in yields with single dose applications of Ripcord ULV ranging from 9-50 g of active ingredient/ha, leading to the recommendation that the lowest dose be used on economic grounds[6]. There was also no difference between yield increases with use of ULV vs. granular formulations of Ripcord. Granular carbofuran produced greater yield increase than did Ripcord, but the very high cost made its use clearly uneconomical. Interestingly, granular carbofuran and cypermethrin were both effective in increasing yields despite the fact that neither had any effect on populations of the millet head miner *Heliocheilus*. This may have some implications concerning the economic importance of this pest. Other studies indicate that the millet plant can tolerate and compensate for significant levels of *Heliocheilus* attack in years with average or good rainfall.

Overall, the trial results to date suggest that pesticide application is more economic in years of low rainfall, when potential yields are low and crop losses to pests relatively greater. (However, there is undoubtedly a minimum level of crop productivity below which no investment in pest control can be justified, at least on economic grounds.)

Tentative recommendations and future directions

Based on the field trials a number of tentative recommendations for increasing millet production have been developed:

(1) farmers should be encouraged to plant immediately after the first major rain, with a weeding shortly before ploughing;

(2) seeds should be treated with fungicides;

(3) SNPV should contribute to better pest management by:

(i) monitoring rainfall in July/August to determine whether it will be a high or low rainfall year

(ii) initiating light trapping to help monitor and predict development of grasshopper, *Heliocheilus* and *Coniesta* populations in August/September;

(iii) carry out routine moth pupa and grasshopper eggpod surveys during the dry season (at the same time, farmers should work on destroying grasshopper eggpods in and near their fields). These survey methods will help SNPV decide whether farmers need to begin pest control in and around fields, using dusts and/or ULV sprays. Estimated action threshold levels (ATLs) are recommended for grasshoppers and some other pests.

(4) farmers should harvest as early as possible in advance of detected southerly movement of grasshopper migrants;

(5) farmers should continue current practice of breaking millet stems to avoid losses to birds and increase mortality of *Coniesta* larvae;

(6) farmers should apply at most one late season ULV spray. If any further treatments are needed they should be considered as emergency operations and thus subsidized by SNVP following current government policy;

(7) chemical control against various highly mobile species (such as the great grasshopper outbreak of 1989) are not likely to be economic (due to re-invasion), so any control action would be based on political or social factors (maintaining morale of rural populations);

(8) late-season control should be directed at protecting specific crop plantings and not at global reduction of pest populations at great distances from cultivated areas. Control measures are most appropriate if there are important areas of cultivation downwind of large populations moving relatively slowly, say 10-20 km/day;

(9) harvested grain on the candle should be protected with pesticide dust formulations applied to the ground in the stack area. If possible, commercial pesticides should be replaced by neem (*Azadirachta indica*) leaves in the future (large numbers of neem trees are being planted in the area under a reforestation program);

(10) in view of the critical importance of economic factors in crop protection methodology, the SNPV should have a small staff attached to its central office charged with an annual survey of economics of crop loss.

Conclusions

The project has shown how production factors and constraints vary with climatic, ecological and socio-economic conditions. Field trials spanning three years of low rainfall and two years of high rainfall have thrown light on how production and risk factors, including pest damage, vary with rainfall. For example, equal populations of *Heliocheilus* caused less economic damage in wetter years due to the plants' greater ability to compensate. There are also important differences between the heavily manured village fields vs. the bush fields and the southern vs. northern regions.

The relative importance of different pests and pest damage patterns are now better understood. For example, the likely impact of early season crop losses can be predicted by combining monitoring of certain climatic conditions and surveying densities of diapausing grasshopper eggpods. Simple sampling techniques have been developed to relate crop loss to estimates of crop damage by *Heliocheilus* and grasshoppers. Based on data collected to date it is possible to recommend estimated action threshold levels for chemical control of some pests at different points during the season. Proposed light trapping and other survey methods will help to improve this decision-making.

Data from the project support claims that SNPV should provide some subsidy for pesticides and implementation of IPM strategies at the farmer level to address the economic constraints of the poorest farm families. The chemically-based IPM techniques proposed (if unsubsidized) appear most appropriate for Souna millet in village fields, in dry years, in the more northern part of the project area.

The high price of some pesticides rules out their use unless subsidized, and some commercially available products are too toxic for use by peasant farmers. The project has been successful in eliminating the use of certain pesticides as unsuitable for control of millet pests. The limits of chemical pest control during major pest outbreaks are now better understood.

It has been possible to demonstrate that, given the farmers' wish to invest in methods to increase millet production, use of pesticides is only one of a series of options. Other options such as better weeding, use of chemical fertilizers, use of better millet varieties and investment in more ploughs may well be more cost-effective. The project helped elucidate constraints to be addressed, such as inadequate availability of farm equipment, draught animals and credit. Given the current ample supply of land, extensive agricultural methods may make more economic sense than intensive methods.

Because farmers face severe labor constraints it is important to design new techniques to complement the existing annual work cycle. For example, there is little possibility to implement methods calling for extra labor during planting or weeding periods or just prior to harvest.

The project has generated technical and agro-economic research data and recommendations, but cannot yet claim to have implemented a functioning IPM system based on these results. An implementation phase is under consideration, to begin in April, 1991.

Additional comments[7]

The Mali rainfed millet project is in line with this paper's proposed approach for improving pest management in subsistence-level agricultural systems (see Sections 3 and 4), in that it: (1) aims to strengthen local crop protection and agricultural extension services, (2) emphasizes establishing a 2-way communication with farmers, (3) aims to base technology development on an understanding of socio-economic factors and constraints, and (4) proposes that technologies aimed at increasing plant productivity (e.g. fertilizers, weeding, more ploughing) may be more cost effective than chemical pest control.

On the other hand, it is notable that the field work has focused largely on improving chemical control. This orientation appears to be dictated in part by the nature of the sahelian pest complex (migratory, changeable and tending to explosive growth). It may also be related to the fact that the current SNPV approach is heavily biased toward pesticide use, so that research aimed at evaluating and improving the pesticide use practices recommended by SNPV could be the best short-term strategy. One would hope that in the long term there would be more emphasis on exploration of non-chemical alternatives. For example:

- there has been relatively little research relating to improved varieties, generally considered the keystone for work on subsistence-level farming systems. Despite the positive results from trials of the pest-resistant Ningare variety, the study proposes that the standard (Souna) millet variety is the one likely to give best results in "new IPM initiatives;"

- the case study notes that there are no known biological control measures to be promoted, but there is no discussion of possible research in this area and the pesticide trials do not appear to include any evaluation of impacts on indigenous natural enemies;

- the importance of crop residues in harboring diapausing pupae of the stem borer is noted, but crop hygiene is not discussed as a control measure;

- intercropping is cited as a good practice in general, but is not discussed in relation to pest management.

The chemical control regime recommended by the project at this point costs about 2000-4000 F CFA per year. However, 1988 trial results indicate only 25% of pilot farmers obtained the target 2:1 benefit:cost ratio using pesticides as recommended. Thus, it is suggested that poorer farmers will not be able to pay for the recommended pesticides and therefore a government subsidy should be considered. This recommendation goes against the basic principles of IPM and seems somewhat premature, particularly in light of trial results which point to better returns from use of improved non-pesticide technologies. As both phosphate use and better varieties already show promise for boosting yields substantially under at least some conditions, it would seem advisable to pursue research on various combinations of these methods.

The intention of the project is that farmers should bear the primary responsibility for implementing pest control. However, the recommended pest thresholds developed so far are based on fairly complex scouting and decision-making (described in detail in an Appendix of the full case study), which farmers could have considerable difficulty learning even with better education and extension than are likely to be found in this poor, low-density area. Thus, the recommendations foresee an important continuing role for SNPV in monitoring and predicting pest populations and advising farmers when chemical control is needed. This observation is not meant as a criticism: as discussed in Section 4 of this paper, such "directed control" may in fact be the most feasible approach when pest problems are complex and farmer and extension capabilities are limited.

1. *Organisation Internationale Contre le Criquet Migrateur Africain.*

2. *Opération Protection Semences et Récoltes.*

3. International Crops Research Institute for the Semi-Arid Tropics.

4. *Comité Inter-Etat pour Lutte Contre le Sécheresse dans le Sahel.*

5. Small scale trials of Neem (*Azadirachta indica*) seed extract were also carried out by Malian and foreign students, but results were not available at the time of writing.

6. There may be some concern that use of very low doses could facilitate development of pesticide resistance.

7. By F. Meerman and A. Kiss.

APPENDIX

Problems incurred with equipment destined for use at farmer level

(i) Equipment is generally too complicated and too costly. Dusters with bellows and blowers invariably break after only a few days in the hands of farmers. Repair often requires tools, like screwdrivers, which are not part of the equipment in a Malian household. In many cases thought to design of terminals and clips attached by hand-tightened wingnuts would solve the problem. Complex piping with different diameters at each end is impossible to repair easily if one end splits. Multipurpose motorized knapsack sprayers are usually too complex to convert from dust/granule to liquid mode (new equipment straight from the carton allowed liquid to leak through the removable plug used in dusting mode directly into the ventilator fan, spilling ULV pesticide over the back of the operator). Serious consideration should be given to making equipment single purpose and very simple.

No manufactured duster can compete for effectiveness, simplicity and cost with the dusting bag. It costs F.CFA 5 (1 new pence sterling) per bag and is easily repaired. Even at their lowest setting the commercial dusters, especially vehicle mounted items, deliver dusts at rates which are too high and wasteful of the limited supplies of product. In recent field trials by visiting technicians from chemical companies, the dusting bag was adopted for this very reason as better than equipment of Chinese and Japanese manufacture.

(ii) Western manufacturers are not interested in making protective clothing and equipment suitable for use at high tropical temperatures and humidities. In practice, protective suits are too expensive, too fragile and above all far too hot. It is also evident that designers have not carried their heavy back-pack mounted equipment for hours under Sahelian field conditions. Noise and weight are so excessive that fatigue is inevitable.

In practice a locally produced, washable, cotton pajama style suit, with a face visor to guard eyes against blow-back, is the best compromise. There are often ways of decreasing the fatigue induced when carrying equipment by redistribution of the load, e.g. batteries carried in a shoulder cartridge, rather than in the equipment held at arms length.

(iii) High volume, pressurized knapsack sprayers are unsuitable because they display pressure retention problems, burst their reservoirs, or have frequent blockages. Their chief drawback, however, is the volume of water required and their weight. Their most practical use is with water-miscible liquid chemicals which are, however, very expensive.

(iv) The vehicle mounted sprayers all have drawbacks. The simple exhaust-nozzle type is best and is rugged, but requires the engine and exhaust system of the carrier vehicle to be in first class condition. Electrically operated systems with spinning disc atomizer cages for producing ULV droplets have so far suffered from major problems with their component plastics, particularly the diaphragms of the pumps used to lift the pesticide from the main reservoir. They have one major advantage; they are light. Another manufacturer who produces a fogger convertible to a semi-ULV system, has a machine on the market which is so heavy that only heavy 4WD vehicles can carry it without sinking or stalling. Field conditions in August-September can be so difficult due to waterlogged ground conditions that vehicle carried equipment must be as light as possible. It must be easily demountable by a small work force and be technically simple. Equipment requiring a trained heating engineer to diagnose and rectify faults is clearly ridiculous. A vehicle carrying spray gear one day may be required to do an entirely different job the next and vehicles in developing countries are in such short supply that a vehicle cannot be devoted solely to pesticide application for months on end.

(v) The ODA project has examined available ULV man-packed, battery operated sprayers and has concluded that certain criteria are essential for practical operation in the Sahel:

- the batteries purchased locally are as cost effective and as efficient as rechargeables. Rechargeable cells and the solar panel systems associated with them are economic and practical only when operated by the plant protection service. They then form part of the same system used to recharge the radio batteries;

- pesticide reservoirs mounted on the spinning disc head must be no larger than 1/2 litre capacity because of the weight bearing on the operators arms;

- all electrical connections must be either sealed at manufacture and be robust, or easily accessible and re-attachable via wing-nut terminals. There should be no switches. Current should be cut by inserting or disconnecting a plug. Switches get broken too easily;

- the batteries should be carried on the shoulder, in the back-pack frame or on a separate strap;

- all filling apertures should have a minimum diameter of 4 inches and be closed by large screw-on caps. A filter should be incorporated in the mouth of the reservoir. The small reservoir at the motor end of the lance should not be detachable, but should be refilled or emptied under gravity from (or into) a back carried reservoir via a pipe and robust tap;

- the main reservoir should ideally have a capacity of 10 litres but should never contain more than 5 litres. This will avoid the double problems of spillage and fatigue;

- the operator should not have to change the nozzle to alter the dose. Pesticide should be formulated in a way that application rate/hectare can be regulated by the speed of walk and the swathe width. This will avoid complicated instructions and the hazard of dismantling the machine in relatively inexpert hands;

- the machine should cost no more than F.CFA 500,000 (ELOO sterling) without batteries.

Strengthening the Plant Protection Division of Zanzibar

by Kees Eveleens*

As discussed in Section 2 of this paper, IPM programs for subsistence level agriculture generally have different objectives and should follow different approaches than those aimed at more intensive systems. In particular, subsistence farmers are often poorly served by research and extension so that any program which intends to develop and disseminate a better approach to pest management must start with strengthening these services. Some projects function by creating a completely autonomous research and extension entity. This may lead to success in the short term, but whatever has been built will probably crumble as soon as the external funding and technical assistance end. The subject of this case study, a technical assistance project funded by the Netherlands, takes a long-term approach by working to strengthen the responsible national institutions.

Background

The setting

Zanzibar consists of two islands, Unguja and Pemba, which are situated just off the east coast of Tanzania in the Indian Ocean. It has a semi-autonomous status within the United Republic of Tanzania, with its own Ministry of Agriculture and constituent departments, among which is the Plant Protection Division.

Agriculture is the mainstay of the Zanzibar economy. Approximately 65 percent of the population is engaged in agriculture, and agricultural produce accounts for 60 percent of the GDP and more than 90 percent of the foreign exchange earnings. Cloves are the most important export crop. The total land area is 245,000 hectares with slightly more than half used for crop production. There are two main agricultural zones:

(1) the relatively deep and rich soils on the western side of the islands (plantation zone), and

(2) the poorer soils on the eastern side, consisting of weathered coral rocks with pockets of fertile soils (coral rag zone).

Almost half of Unguja lies in the coral rag zone, but on Pemba this zone is much smaller, limited to a narrow band along the east coast.

Agricultural practices

Agriculture is practiced in intercropped systems. The main crops are coconut, clove, cassava, banana, rice, sweet potato, pulses, maize, sorghum, and various fruits. The greatest complexity of intercropping is in the plantation zone, characterized by abundant growth of trees (coconut palm, clove, mango), which make up the upper canopy layers. Rice monocrops are also found in some hydromorphic plains within this area.

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Tree growth is more limited in the coral rag area and the cropping associations are simpler, consisting mainly of maize, sorghum, pulses and cassava.

Overall productivity in agriculture is low and, with the exception of some commercial plantations, agriculture is predominantly at a subsistence level.

Institutional framework

The Plant Protection Division of the Ministry of Agriculture (PPD) is formally in charge of all crop protection research and development. There are neither universities nor other research organizations dealing with this. Originally, the mandate of the PPD revolved around the tasks of plant quarantine (primarily related to clove export) and produce inspection. It was only after 1980 that other aspects of crop protection, such as adaptive research, field service and extension, and pesticide application issues began to receive attention.

Pest management issues

In a recent survey of Zanzibar agriculture, interviews with farmers revealed that they consider pest and disease damage to be their greatest production constraint by far (Wirth et al, 1988). In spite of this perception, little quantitative information is available on crop losses aside from an indicative summary list of crop loss assessment figures (Anonymous, 1986). Allertz (1989) also reported that field trials in maize showed that crop losses of up to 30% could be attributed to feeding damage by stemborers.

As with any primarily subsistence-level agricultural system, there are good reasons to promote a non-chemical approach to pest management for food crops in Zanzibar:

(1) farmers have limited means for purchase of pesticides and application equipment;

(2) adherence to necessary safety precautions for pesticide use leaves much to be desired, because of farmers'ignorance of the toxic nature of the compounds involved and the lack of protective clothing;

(3) farmers and extension agents are frequently incapable of calculating the correct dosages for diluting and applying pesticides; and

(4) it is difficult to limit pesticide applications to a target crop in the prevailing intercropped systems.

Alternative methods include mechanical, cultural and biological control, use of resistant varieties. Pesticide use can also be improved to reduce the existing hazards.

The project

Objectives

The main objective and approach of the project is clear from its title: "Strengthening the Plant Protection Division of Zanzibar." The overall purpose is to assist PPD to become more capable and self-reliant in fulfilling its institutional mandate.

Although the PPD is officially responsible for all crop protection research and development work, in practice the scope of these activities is limited to food crops. Crop protection in the economically important plantation crops, clove and coconut, has been the subject of donor-assisted development projects (by the British and German governments respectively) which operate with only marginal engagement of the PPD. Therefore, this PPD support project also focuses on food crops.

General approach

The first phase of the project consisted of: establishment of research accommodations, staff training, execution of a survey programme on agricultural insect pests, establishment of a reference collection, and initiation of a research programme on insect pest biology and control. Information obtained during this phase was compiled in a report entitled "Crop protection manual Zanzibar - tentative first draft" (Feijen et al, 1988).

This report deals only with insect pests, and provides initial recommendaitons which emphasise

IPM-compatible control practices. However, valuable as it is as a first step, this report falls short of providing guidelines for IPM practices directly applicable at the farmers' level. Farmers' application of the recommended practices is hampered by two main constraints:

(1) A considerable proportion of IPM recommendations presented is based on information compiled from elsewhere and not necessarily applicable under local conditions. Consequently, much work is still needed in on-farm verification.

(2) The weakness of the agricultural extension services is a major barrier to dissemination of IPM information and methods to farmers (FAO, 1988). As a result, the PPD staff often has the task not only of formulating pest management strategies, but also of spreading the message to the farm communities.

The solution to the first problem lies in adaptive research and on-farm verification trials in Zanzibar. The second problem calls for improvements in the staffing and logistical support for extension services. Because extension represents a separate institution, it is largely outside the mandate of the PPD. Nevertheless, the project is making efforts to improve information dissemination.

Technical elements

Insect pests

Feijen et al. (1988) contains a compilation of the main insect pests of food crops in Zanzibar and some of their natural enemies. It also provides initial control recommendations which are currently the subject of a program of further adaptive research and on-farm verification trials.

One example where some progress has been made in testing and disseminating recommendations from the draft manual relates to the serious problem of stemborers of maize (*Chilo partellus* and *Sesamia calamistis*). Field trials verified the effectiveness of removing stalks immediately after harvest, supplemented by a selective and relatively low-hazard pesticide treatment consisting of placing granular endosulfan (Thionex) or trichlorfon (Dipterex) into the whorls of young plants. An illustrated extension bulletin (Abubakar and Allertz, 1989) was developed and disseminated to help farmers recognize the pest and understand its biology and to recommend this practice. A recent survey (Arendse, 1989) showed that the control recommendations in the bulletin were adopted by 39% of the farmers interviewed.

A second example from the draft manual concerns controlling homopterus insects such as the citrus blackfly, *Aleurocanthus citricolus*, which are protected from predators and parasites by ants attracted to their honeydew. The PPD has confirmed the effectiveness of the recommended method--ringing trunks of citrus trees with sticky glue to block the ants from reaching the tree canopy--and citrus growers are eager to adopt it. The main constraint has been unavailability of the sticky glue.

Other non-chemical control methods which have been incorporated in crop protection recommendations to farmers include hand removal of leaf feeding caterpillars (*Papilio demodocus*) from citrus trees and destruction of pigeon pea stalks infested with larvae of the longhorned beetle (*Tragicoschema nigroscriptum*).

The primary means of disseminating such recommendations has been through extension bulletins designed for the target audience. The bulletin completed dealt with stem borers of maize, and a second one on control of rice insects is under preparation.

A separate line of work relating to insect pests is the application of classical biological control against the cassava mealybug, in collaboration with the Africa-wide Cassava Mealybug Biological Control Program (see separate case study). The parasitic wasp *E. lopezi* has been released on both Unguja, where early surveys indicate it is now well established, and on Pemba where the mealybug first appeared in early 1989.

Plant diseases

Project activities in plant pathology are at a very early stage, having begun in 1988.

Most attention has been focused on the acute problem of black sigatoka (*Mycosphaerella fijiensis*) in banana, first discovered in Zanzibar in late 1987 and now a major problem on both islands. Ongoing research involves assessment of:

(1) varietal resistance: early results indicate some variation in resistance within the wide range of eating and cooking banana varieties grown on the island;

(2) cultural control: particularly removal and burning or burying of infected leaves; and

(3) use of the fungicide Mancozeb.

An extension bulletin with control recommendations has been issued (Szlavik and Fundi, 1989), focusing on crop sanitation and some information about differences in susceptibility among local varieties. Chemical control is not advised because of its questionable cost-effectiveness.

The survey by Arendse (1989) indicated that 30 percent of farmers followed the recommendation of removing diseased leaves but only 12 percent implemented the necessary second step of burning or burying the leaves.

Mozaic virus in cassava is another major problem. Control recommendations based on use of virus-free stem cuttings have been issued (Begg and Hemed, 1986), but adoption is constrained by a lack of healthy cuttings (Arendse, 1989).

Weeds

Weed problems constitute a major bottleneck in growing rice, a crop which presently receives much attention in the government drive towards national self reliance in food growing. There was a campaign promoting intensification of rainfed rice cultivation using short-term, short-strawed varieties. However, this effort had to be abandoned because of severe competition by weeds (Pers. comm. Mr P. Smyth). In the presently grown longer term varieties, there is increasing use of the herbicide Basagran, which has become the single most used pesticide in Zanzibar. A factor underlying the growing reliance on chemical weed killer is its availability at low prices due to the government policy of subsidized sale of agrochemicals. Some of the consequences of this policy in relation to IPM implementation are discussed in the following section. Meanwhile, no research has yet been undertaken into alternative methods of weed management in rice.

Discussion

For practical purposes it is useful to view the development and implementation of IPM as a stepwise process (OECD, 1977) and to gauge farmers' adoption of the approach in relation to the individual steps involved. Applying this approach to the present case, we find:

Resistant varieties

Work in this important area has received only limited attention so far. The current research program on black sigatoka disease in banana includes preliminary comparisons of resistance among available local varieties.

Cultural control

The method presently advocated for reduction of damage by black sigatoka disease in banana relies heavily on implementation of sanitary measures. However, the extent to which farmers comply with this official recommendation still remains to be evaluated.

Pesticide use

The objective is to use pesticides only as needed to supplement other control methods, and with due consideration of economical and ecological aspects. Pesticide use in food crops in Zanzibar is relatively limited. Almost all materials are procured by the government through import-support programmes and sold to the farmers at cheap rates. Involvement of commercial agrochemical companies is negligible.

From the viewpoint of IPM implementation, the present government-controlled system of pesticide acquisition and distribution has both advantages and disadvantages:

- On the positive side is the possibility to exercise control, both in the choice of compounds to be used (for safety and environmental considerations) and in the issuance of guidelines to users at the time of sale.

- On the negative side, the current system of selling compounds at low prices and with generous credit facilities has a distorting effect on the cost-benefit equation and may result in an excessive use of agrochemicals. For example, the herbicide Basagran is presently sold to rice farmers for TSh. 500 (appr. US $ 2.60) per liter, which is about 1/3 of the current commercial rate. Under conditions of such easy availability, exploration of alternative control strategies is not likely to be considered a matter of urgency. This is regrettable because, as stated by Westerhout (1986), proper application of a combination of sanitation (issuance of weed-free seeds of the recommended rice varieties) and timely application of mechanical weeding could largely remove the need for chemical herbicides.

The recommended method of using granular endosulfan against maize stemborers is an example of progress in developing a chemical control method more consistent with the IPM approach.

Biological control

The first effort in this area undertaken in food crops in Zanzibar involves control of the cassava mealy bug by an introduced parasite. This activity showed that PPD was capable of establishing the required international contacts and fulfilling the technical and logistical needs for the parasite releases. Zanzibar being an island country, there is the possibility that other, potentially effective natural enemies of pest organisms have failed to disperse from the mainland and could be introduced for the benefit of biological control. Furthermore, the proportion of successful classical biological control programs in island settings is relatively high. So far, however, no work along this line or in relation to the impacts of indigenous natural enemies has been carried out due to shortage of qualified staff.

Conclusions

The scope of the project is determined by the mandate of the PPD, which in general involves responsibility for all food crop research and development activities. Against this backdrop, the project does not address itself to any specific pest problem. Rather, it provides assistance to the PPD to develop the institutional capability to cope with the current complex of crop protection problems. The project has made some progress toward this objective, but the lack of an effective, functional mechanism for extension remains a major weakness.

The need is partially and temporarily filled by the PPD, which has taken on the responsibility for dissemination of recommendations from research results, in part through a Plant Protection Field Service created in 1986. At the same time, PPD is providing IPM-oriented crop protection training to village extension workers, who are the critical link in the chain of communication between researchers and farmers.

While IPM calls for a farming systems approach to tackling crop protection issues, this is not really being followed in Zanzibar due to a number of constraints (insufficient staff, institutional fragmentation, poor infrastructure) which prevent effective interdisciplinary team work. Given the limitations, it seems more pragmatic for the PPD to focus on clearly defined, specific problems.

The starting point for selecting pest management is the realization that, under the prevailing conditions of small-scale farming, the use of chemical pesticides should be limited as much as possible. Within this context, the specific methods selected for testing and extension are dictated by practical considerations in view of available options and prevailing conditions. This may include biological control (e.g. cassava mealybug), rational pesticide use (maize stem borer), phytosanitary measures (banana black sigatoka), etc.

The main socio-economic factors influencing implementation of IPM are:

(1) *food aid:* large quantities of subsidized rice will soon be made available under the auspices of the World Food Program. Some predict that, in anticipation of the availability of this alternative food, farmers will slacken their efforts in sanitary practices needed to reduce spread of the sigatoka disease (discussions are underway with Zanzibar authorities regarding a proposal that an individual's access to thefood aid be made an incentive for carrying out these practices).

(2) *pesticide subsidies*: in its drive for food self-sufficiency the government has chosen to promote use of pesticides in the belief that this will increase yields. This can decrease the incentive to explore and adopt alternative methods (as in the case of weed control in rice discussed above).

Acknowledgement

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References

Abubakar, O. and P.G.H. Allertz. 1989.
Mafunza ya mahindi. Ext. Bull. Min. Agr. Zanzibar, April 1989

Allertz, P.G.H. 1989.
Listing of activities under execution by the Field Service Section. In: Semi-annual progress report No. 11 (January-July 1989) of the project "Strengthening the Plant Protection Division of Zanzibar"

Anonymous. 1986.
Report of a joint mission to evaluate the project "Strengthening the Plant Protection Division of Zanzibar"

Arendse, P.W. 1989.
Preliminary report: Farmers' knowledge on and attitudes towards pest problems in Zanzibar. Plant Prot. Div., Zanzibar

Begg, C. and H.N. Hemed. 1986.
Kuzuwia ugonjwa wa mosaic katika mihogo. Ext. Bull. Min. Agr. Zanzibar, December 1986

FAO. 1988.
Report of the FAO/IFAD Cooperative Programme Investment Centre. Zanzibar Agricultural Identification Mission. FAO, Rome

Feijen, H. et al. 1988.
Crop protection manual Zanzibar, tentative first draft

Herren, H.R. 1989.
The IITA biological control programme: It scontribution to the development of sustainable pest control in Africa. Proc. 2nd Int. Conf. Tropical Entomology. ICIPE, Nairobi. July 31 - August 4, 1989

OECD. 1977.
Report of the steering group on pest control under the conditions of small farmer food crop production in developing countries. Organisation for Economic Cooperation and Development. March 1977, Paris

Szlavik, I. and H.K. Fundi. 1989.
Kuzuia maradhi ya black sigatoka katika migomba. Ext. Bull. Min. Agr. Zanzibar, August 1989

Westerhout, J. 1989.
Cheju Pilot Project, Zanzibar.The problems of rainfed rice production. Report on a field visit, June 1986. Euroconsult, Arnhem, The Netherlands

Wirth, F. et al. 1988.
A baseline survey for the identification of farming systems in Zanzibar. Techn. Univ. Berlin, Centre Adv. Training Agric. Dev., Publ. no. 117

Pesticide Management in Cotton in Zimbabwe

by Frans Meerman

Introduction

After tobacco, cotton is the second most important foreign exchange earner in Zimbabwe. About 600 large scale commercial farmers produce half of the total seed cotton production on 61,000 ha. The remainder is grown by the small-scale sector, representing some 86,000 farmers on 131-,500 ha (Cotton Research Institute,1988). Commercial farms are highly mechanized, expertly managed, well served by cotton extension specialists, and use high levels of fertilizers, insecticides and herbicides. The result is seed cotton yields of about 2,100 kg/ha in 1985-1986.

Cotton growing by small-scale farmers has been stimulated. Total cotton production by this sector has increased by 600% since independence in 1980, mainly through an increase in the area sown to cotton. The general level of crop management (pest control decision making, weed control) is low, and relatively little money is spent on inputs like fertilizers and pesticides. The available cotton varieties are not specifically adapted to these low input levels. Farmers have problems getting their inputs on time, and cotton marketing is difficult because of transport problems. Peasant farmers are advised by general extension personnel who, at a ratio of about 1:800 farmers, are insufficient to meet the demand. Combined with poor soil conditions and drought in some areas, these constraints result in average seed cotton yields of about 900 kg/ha (CRI,1988).

Research and development of pest and disease control components by the cotton research institute (CRI)

The insect pest complex

The pest spectrum is similar in the small-scale and large-scale cotton sectors. Some 25 insect pests are described in the 1986 Cotton Growers' Handbook. The cotton and red bollworms are key pests, capable of causing crop losses of up to 60 percent (Gledhill, 1976 in Brettell, 1986). Red spider mites can cause yield losses of up to 40 percent if not adequately controlled (Duncombe, 1977 in Brettell, 1986). Although cotton whitefly has always been a low incidence pest, it might become the major pest problem in the coming years. This is because of the widespread use of pyrethroid insecticides, which can destroy indigenous biological control agents, and because the hairy (hirsute) cotton variety which was introduced because of its resistance against jassids is unfortunately more attractive to the whitefly than are smooth varieties. This situation resembles the Sudan case, where whitefly has become the major cotton pest.

Control of insect pests

The following insect pest control measures have been developed by the CRI:

Table 1. Cotton pest scouting procedures and action thresholds for chemical control, as used in commercial cotton growing in Zimbabwe.

SCOUTING PROCEDURE	PEST	INTERPRETATION
Scout whole plant or top 10 nodes if crop is more than 1.5 m tall. Start at the bottom and work upwards and count the eggs and larvae separately for the different bollworms. Check buds, flowers, bolls and growing points carefully for damage. The aim is to use egg counts to determine when to spray and larval counts to see how effective sprays have been. For example : In the case of Red Bollworm :- (NB — for Heliothis the threshold is 12 eggs/24 plants)	Bollworms	Spray when the following thresholds are reached: i) Actual counts Red: 6 eggs/24 plants; Heliothis: 12 eggs/24 plants; Spiny: 6 larvae/24 plants ii) Accumulated counts When accumulated counts over a three week unsprayed period reach or exceed the above thresholds. iii) Projected counts When the Projected egg count will exceed the threshold before the next scouting date then a spray should be applied before that date.

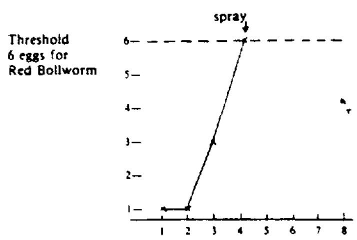

Fig. i: Actual egg count

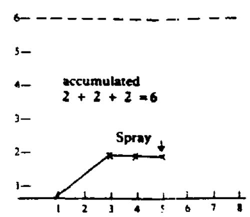

Fig ii: Accumulated egg count

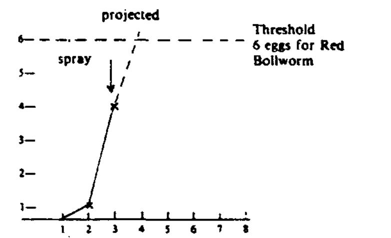

Fig iii: Projected egg count

SCOUTING PROCEDURE	PEST	INTERPRETATION
Check each of the following positions for Red Spider Mites. One leaf in middle of plant, two at the top and the growing point, and grade as indicated below: Record the highest grade found onto the scouting pad as one of :- 0 - Nil, I = 1-10, II = 11-30, III = 30 + red spider mite Add grades and record total on Pest Management Sheet.	Red Spider Mite	Start spraying as soon as Red Spider Mites are recorded. If occuring in isolated outbreaks spot spraying is possible. *Aim to keep the population below a score of 48 on 24 plants.* Cease spraying at first boll split.
Select a fully-expanded leaf in the middle of the plant and count ALL stages of jassid present. Transfer total recorded on 24 plants to Pest Management Sheet.	Jassids	Spray when total count reaches 48 on 24 plants for Albar G501, threshold drops to 24 on 24 plants for Albar K 602 or any smooth leafed variety, or when damage is seen.
Scout for damage symptoms - i.e. 'leaf tattering'. Transfer the number of plants showing symptoms to the Pest Management Sheet.	Lygus	Spray as soon as damage is observed.
Count adult Whiteflies at each of the following positions first two fully expanded leaves at top of the plant and one leaf from the middle. Enter total from all three leaves to scouting pad and total on 24 plants to Pest Management Sheet. (N.B. only count up to 20 Whitefly at each position - record higher counts as 20.)	Whiteflies	Spray when total count reaches 120 on 24 plants. Cease spraying when 20% boll split is reached.
Scout and record Aphid levels exactly as above for Red Spider Mite. Only the highest grade from each plant should be entered on the Scouting Pad. Add the grades and record total on Pest Management Sheet.	Aphids	Spray when scouting reveals i. a total score of 48 on 24 plants. ii. a total score of 36 on 24 plants when the crop is drought-stressed iii. a population build-up just prior to first boll-split to ensure that contamination of the open seed cotton with honey dew does not occur.
When walking through the field scouts should note if any groups of plants have unusually high numbers of stainers on them. Do not count the stainers but record each group of plants as a 'focal point'. The number of stainer 'focal points' should be entered on the Scouting Pad.	Stainers	Spray when there are 6 or more 'focal points' recorded at one scouting. Control is necessary once green bolls are formed.
Look for typical cankerous growth on the bolls and brown angular spots of the leaves. Record number of plants showing symptoms and enter total on Pest Management Sheet. Helopeltis damage may be confused with Alternaria leaf infection. Circular brown lesions on the leaves are usually symptoms of Alternaria infection.	Helopeltis	Spray as soon as damage is observed.
Check each plant and record numbers of plants showing damage symptoms - 'leaf tattering' and curling up of edges. Enter total on Pest Management Sheet.	Thrips	Spray only if infestation is heavy from flowering onwards-early Thrips damage can normally be tolerated in young crops.
Up to commencement of flowering estimate amount of damage to whole field as a percentage of total leaf area affected. Transfer mean to Pest Management Sheet. After commencement of flowering record larval levels on scouted plants and record the total on Pest Management Sheet.	Leafeaters	Spray if damage is 25% or more of total leaf area in whole field up to the commencement of flowering. Thereafter spray if larval levels exceed 12 on 24 plants.

(1) Scouting methods and threshold levels (see Table 1):

Bollworms: red bollworm (*Diparopsis castanea*), 'American' or cotton bollworm (*Heliothis armigera*) and spiny bollworm (*Earias biplaga* and *E. insulana*);

Sucking pests: red spider mites (*Tetranychus cinnabarinus*, *T. lombardinii* and *T. ludeni*), cotton jassid (*Empoasca facialis*), cotton aphid (*Aphis gossypii*), cotton whitefly (*Bemisia tabaci*), cotton lygus (*Taylorilygus vosseleri*), mosquito bug (*Helopeltis sp.*), cotton stainers (*Dysdercus* spp.) and thrips (*Thrips tabaci* and *Caliothrips*);

Leaf-eating insects: cotton semi-loopers (*Anomis flava, Xanthodes graellsii, Chrysodeixis acuta* and *Trichoplusia ni*), cotton leafworm (*Spodoptera littoralis*) and elegant grasshopper (*Zonocerus elegans*).

Based on these threshold levels, an average of 8-12 insecticide treatments are made against bollworms during the 6 month cotton season and the number of acaricide sprays is kept to approximately 6. While the number of applications against bollworms appears high, one should bear in mind that two bollworm species attack the crop simultaneously.

(2) Minimal pesticide dosage

The recommended dosage rates are 2.7 - 12.3 times lower than in other cotton growing countries such as South Africa, Australia (Brettell, 1986) and Togo. This is possible because:

- bollworm sampling is based on egg counts, allowing the sprays to be synchronized with the appearance of first instar larvae. These larvae are easier to kill because they are smaller and, in the case of the cotton bollworm, because they feed at the branch tips where they are more exposed to spray droplets;

- the addition of molasses as an anti-evaporant to pesticide sprays has made it possible to reduce the recommended dosage rates because the spray droplets remain larger and less likely to drift, thus reducing wastage of the pesticide active ingredient;

- dosage rates are adjusted for plant heights[1].

(3) Between-season rotation of acaricides against red spider mites.

The introduction of DDT and carbaryl in the 1960s for bollworm control in the large scale commercial sector caused the destruction of the red spider mite's complex of natural enemies (Blair, 1986). Together with an increase in the cotton growing area, this has changed the status of the red spider mite from a minor pest to the second most important pest after the bollworms. Dimethoate was introduced to control the red spider mites, but after eight years of 5-6 applications per season, high levels of Dimethoate resistance were detected, along with cross-resistance against some little-used organophosphates (Demeton-S-methyl, Thiometon and Disulfoton).

The CRI then tested a large number of acaricides against Dimethoate-resistant spider mites. Five acaricides, from three different chemical groups, were found to give adequate control and were selected for an acaricide rotation scheme. The country was divided in three regions and farmers were advised to use acaricides from one chemical group only for no longer than two consecutive years and then change to a chemical from another group. The rotation scheme was voluntary, so implementation required full cooperation on the part of cotton farmers and the chemical companies. A series of country-wide meetings was held to explain the need for the scheme and the reasons for it, as well as the possible consequences if the scheme were not followed. Chemical distributors have collaborated by selling only the right acaricide for each region and stocks of acaricides that should not be used are taken back from farmers.

Since its implementation in the 1973/74 season, the acaricide rotation scheme has been closely adhered to by the commercial farmers and has resulted in adequate control of the red spider mite. To date there are no signs of spider mites resistance to any of the acaricides used in the rotation scheme.

The rotation scheme is not used in the small-scale sector, because Dimethoate resistance is generally not present there. Carbaryl is still used by many farmers, although at lower dosage rates than the commercial farmers were using in the past.

(4) Within-season rotation of insecticides against bollworms

Chemical control of the bollworm complex (except for the pink bollworm) is based on scouting for *Heliothis* and *Diparopsis* eggs at weekly intervals. Before pyrethroids became available DDT and, later, endosulfan were recommended for *Heliothis* control and carbaryl for *Diparopsis*. *Earias spp.* cause minor damage and are effectively controlled by the spraying against the two major bollworms. Because of the risk of build-up of pyrethroid resistance, as experienced in red spider mite against Dimethoate, and because of the pyrethroids' broad spectrum of activity, which may cause secondary pest outbreaks by the elimination of their natural enemies (e.g. whitefly), a within-season rotation of pyrethroids with endosulfan against *Heliothis* and with carbaryl against *Diparopsis* was developed when pyrethroids became available. From the 1979/80 season onwards, cotton growers have been advised to use pyrethroids for no longer than 9 weeks when both major bollworms are present together in damaging numbers. The shift from endosulfan/carbaryl to pyrethroids and back is determined by calendar dates which are related to the dates of cotton sowing.

Except for coffee, pyrethroids are excluded from use in perennial crops. In annual crops, their use should coincide with the time of use on cotton.

(5) Selected pyrethroids to prevent increased red spider mite attack

The early pyrethroids like permethrin, cypermethrin and deltamethrin introduced for control of bollworms were found to cause increased red spider mite attack. Until 1978, little attention was paid to this phenomenon, because the same effect had been observed after the introduction of carbaryl and DDT. However, when the new pyrethroid fenvalerate was first used in field trials, spider mite numbers were found to be significantly reduced compared to the cypermethrin and deltamethrin treatments. Similar results were obtained with other new pyrethroids in the early 1980s. Since 1984, farmers have been advised to avoid using those pyrethroids which interfere with the natural factors reducing red spider mite populations.

(6) Cultural control

Crop rotation is practiced primarily to prevent soil erosion, but it can also reduce the effects of soil pests and ensure that the emerging red bollworm adults have to search for new cotton fields.

Chemical control of the pink bollworm (*Pectinophora gossypiella*) is considered to be impractical. A legally enforced 2-month closed season, closely adhered to by both commercial and peasant farmers, effectively controls this species.

(7) Varietal resistance

The hirsute (hairy) cotton cultivar grown in the middle altitude regions is resistant to damage by jassids. Resistant cotton cultivars against red spider mite and bollworms are in development.

(8) Biological control

Various indigenous natural enemies, principally predators, have been reported:

- green lacewing larvae (*Chrysopa boninensis, G. congrua* and *G. pudica*); feeding on aphids, bollworm eggs & 1st instar larvae and spider mites;

- spiders; feeding on bollworm larvae;

- coccinellid larvae and adults; feeding on aphids.

An upsurge in whitefly attack is anticipated for the near future, partly because of the widespread use of pyrethroids which interfere with indigenous biological control (Brettell, pers. com.).

Integration of biological with chemical control has yet to come. The present economic threshold levels are based on 35 years of injury-loss experiments at field level, but these levels have not been particularly adjusted for the effect of natural enemy populations on cotton pests. It is envisaged that biological control might contribute to pest control during the early and late stages of crop development, with chemical control being used between these times. Selective pesticides should be used to allow the reversion to biological control towards the end of the season. Research is under way to determine the role of predators in insect pest control.

Control of Diseases

(1) Verticillium disease management

Verticillium wilt (*Verticillium dahliae*), although reported since 1966, has only become a serious problem after the introduction of new cotton varieties in the 1983-84 season in the Lowveld. Since then about 19 percent of the commercial cotton area has been affected and losses up to 20 percent have been reported. The following recommendations have been developed pending the development of host plant resistance: field sanitation, removal of infected plant tissue, ground drench with formalin, crop rotation with cereals (maize and winter wheat) to trigger macrosclerotia germination, removal of weeds as alternate host plants, adequate potassium and phosphate fertilization to promote strong root development, avoidance of overhead irrigation and postponement of inter-row ripping to avoid damage to the root system.

No information is available as to the extent to which these recommendations are being adopted.

(2) Crop rotation

In addition to combatting soil erosion and exhaustion, crop rotation is important because it suppresses nematodes and disease effects (sore shin, *Rhizoctonia solani* and verticillium wilt).

(3) Fertilizer use

Brown spot (*Alternaria alternata*) became a serious problem in the commercial sector after years of continuous cotton growing caused a potassium deficiency which predisposed cotton for *Alternaria* attack. The problem is now solved by use of potassium fertilizer. Peasant farmers use less fertilizer than large-scale farmers and therefore may be confronted with more or less serious *Alternaria* attack.

Training and extension

The Cotton Training Center

The Cotton Training Center (CTC) was established by the Commercial Cotton Growers' Association (CCGA) of Zimbabwe and is situated on a commercial farm, Itafa, adjacent to the CRI near the Midlands town of Kadoma. The CTC runs a commercial 600 ha farm and 3 model communal farms, which are used in the training courses. The Center has residential facilities for up to 300 people and can train over 2,000 people a year. The following courses are run by the CTC:

- *pest scouting course* for commercial sector field scouts; this 9-day course is run since 1972;

• *refresher/follow-up course pest scouting* (commercial sector);

• *cotton production course* for peasant farmers, including pest scouting. The Department of Agricultural Extension of the Ministry of Agriculture (AGRITEX) identifies the participating farmers. CTC has developed a Cotton Course Handbook and the course is sponsored by the EC and USAID. This course is also attended by the AGRITEX extension personnel, working the cotton production areas of Zimbabwe.

• *follow-up production courses for peasant farmers*; this course is developed in close collaboration with AGRITEX, which assists in monthly check pest scouting at the fields of participating farmers;

• *regional course on cotton production* for diploma and degree holders such as commercial farm managers and subject matter specialists of AGRITEX and participants from the Southern Africa Development Coordination Conference (SADCC). This course includes subjects such as as IPM, weed management and cotton diseases. Training material is the CCGA's Cotton Handbook.

• *cotton picking courses*;

• *cotton production course* for students of the University of Zimbabwe.

The commercial sector versus the peasant farmer sector

In the commercial sector, cotton production and pest control have reached high standards. Over the last thirty-five years, high quality research has concentrated on the particular needs of this sector, resulting in an up-to-date Cotton Handbook, addressing all relevant aspects of modern cotton growing including pest control. The small number of farmers (approximately 600) is well served by the CTC training courses. Most of the pest scouts working in the commercial sector have attended the scouting course as well as the refresher course.

Cotton production and pest control in the small-scale sector is less advanced. Cotton growing by peasant farmers was only stimulated following independence in 1980, through the introduction of credit facilities and by a major extension effort. Pesticides are sold in half-hectare "Cotton Packs," containing selected pesticides in quantities aimed to protect one seasons' crop. Although all peasant farmers scout for pests, only twenty percent are able to make a proper conversion of the information obtained from pest scouting into decision making for spraying (Jowah, 1985). The rest of the farmers tend to make fewer than the recommended number of applications against bollworms (5 times, versus 8-12 times in commercial sector) and sucking pests (2-3 times, whereas the Cotton Pack contains 4 applications). However, bollworm control is particularly important at lower yield levels, because every affected boll results in a higher percentage loss as compared to higher yield levels.

Inadequate pest control in the small-scale sector can be attributed to the following factors:

Peasant farmer training and extension

The small-scale sector consists of approximately 86,000 mostly inexperienced cotton farmers, who need to be trained. However, for each 800 farmers there is only one AGRITEX extensionist. Many of these extensionist are not specialized in cotton production. Only 13 percent of the peasant farmers have been trained in pest scouting at the Cotton Training Center. Many others are trained by these farmers.

Pest scouting and timing of spraying

• pest scouting instructions: farmers are told to scout for bollworm eggs, but 2/3 of them do not recognize eggs. Individual plant scouting was said to be too time-consuming and sampling instructions were not followed up correctly.

The overall process, consisting of recording pest levels on scouting forms in the field (see Fig. 1) and transfering the data onto pest management sheets in order to establish if threshold levels has been reached (see Table 4), appears to be too complicated for them.

- trained farmers complained that they had no access to the scouting forms, pest management sheets and writing material.

- scouting and spraying programs are interrupted by other farm operations during the peak cotton growing period, resulting in insufficient boll protection.

Choice of pesticides

Many peasant farmers were not aware of the within-season program for rotation of carbaryl/endosulfan with pyrethroids for bollworm control, or of the existence of specific systemic and contact acaricides.

Small scale farmers may use either hand-held ULV sprayers or hydraulic knapsack sprayers with tailbooms (the tailboom carries four pairs of spray nozzles, which are brought into use in turn based on the size of the cotton). Some farmers buy the wrong cotton pesticide packs for the type of spraying equipment they use.

Pesticide handling

Not one farmer had a weighing scale to measure out wettable powder formulations of pesticides. Tank mixtures are prepared in containers which are larger than the tank of the knapsack sprayer for which the Cotton Packs are designed, resulting in dosage rates which are too low and poor pest control. More than 90 percent of the farmers do not read the "Direction for use" on the label because they are in English instead of the local language and because of the complexity of information.

Application technique and equipment

Many farmers use hand-held lances instead of tailbooms with the knapsack sprayers, resulting in poor coverage. Farmers also have difficulty estimating crop height to determine the amount of pesticides to be used and have problems maintaining proper walking speed, resulting in incorrect application rates.

The following solutions are being developed and implemented to improve pesticide use in the peasant farming sector:

Pest scouting and decision making

For peasant farmers, pest scouting, recording and decision making for chemical control have been simplified by adjusting the sampling pattern, reducing the observation units, and by integrating pest recording with decision making. The CTC has developed a scouting pad to record observations on the number of cotton plants sampled, red bollworm eggs and larvae, *Heliothis* bollworm eggs and larvae, aphids and red spider mites (see Fig. 2). The economic thresholds, indicated by vertical bars, are included for both red and heliothis bollworm eggs and larvae to permit farmers to scout for either eggs or for larvae, which are easier to find. The threshold levels for aphids and red spider mites are given in Fig. 1. The recommended pesticide for each pest is given on the backside of the pad, taking into account the within-season rotation of insecticides against bollworms and the particular cotton growing areas. The advantage of this scouting pad over the conventional one (see Fig. 1) is that pest recording and decision making are reduced to one form, without any need for calculation.

The CRI has developed an improved pegboard (see fig. 3), consisting of a blockboard, divided into five parallel stripes, each of which is drilled with 24 holes. The upper stripe records the number of cotton plants observed, by moving a peg from hole to hole. The other stripes record the pests and life stages, as with the scouting pad. Each pest is represented by a color image at the left of the pegboard (see fig. 3). When a peg shifts from the white into the red area, it means that the threshold for that pest is reached and pesticide should be applied.

Farmer training

Because only a limited number of peasant farmers can be trained at the Cotton Training Center, AGRITEX is selecting participants based on their readiness to take leadership and train a small group of neighboring farmers at home.

Figure 1. Scouting pad for cotton pest, as used in the commercial sector in Zimbabwe.

DATE .... SCOUT ....

Plant No	Red Bollworm Eggs	Red Bollworm Larvae	Heliothis Bollworm Eggs	Heliothis Bollworm Larvae	Spiny Bollworm Larvae	Red Spider Mites	Jassids	Lygus-Damaged Plants	Whiteflies	Aphids	Stainers "Focal points"	Helopeltis Damaged Plants	Thrips	Leafeaters	Others
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
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17															
18															
19															
20															
21															
22															
23															
24															
Totals															

After a final verification of the threshold levels for the Heliothis and Diparopsis larvae and a final molding of the device itself, the pegboard will be introduced on a large scale in the 1990-91 season.

Pesticide selection

Because of the health risks relating to incorrect use and handling of Endosulfan by the peasant farmers, Thiodicarb will be recommended to replace both Endosulfan and Carbaryl for bollworm control.

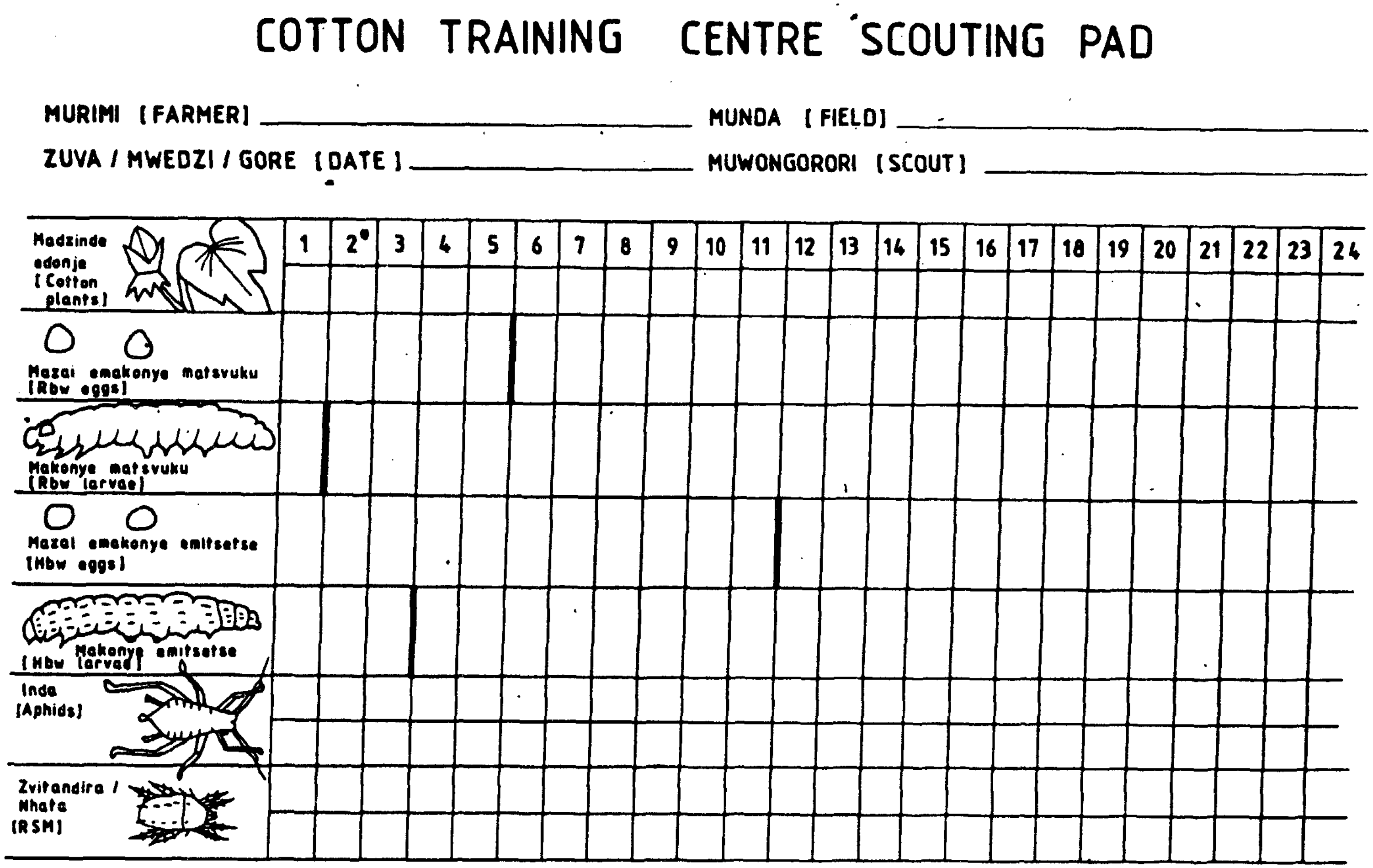
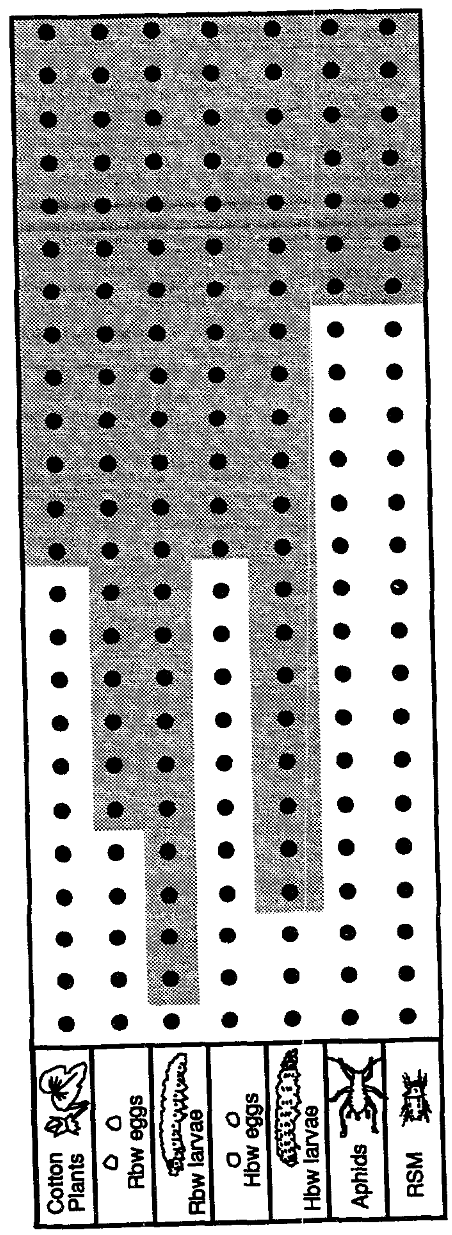


Fig.2. Scouting pad for cotton pests, as used in the small-scale sector in Zimbabwe.

Fig. 3. Improved pegboard for pest scouting in cotton as used in Zimbabwe.



Discussion of current pest control recommendations and their implementation

Implementation of existing thresholds

As a whole, neither commercial nor peasant farmers are currently following threshold recommendations correctly. Many commercial farmers spray an average of 8-12 times against bollworms, whereas application of existing recommended thresholds would probably result in an average of 7-8 sprays per season. It appears that many commercial farmers scout their fields and spray whenever bollworm eggs begin to appear. While not as efficient or desirable as applying threshold levels, this practice is at least a significant improvement over a purely calendar-based approach which can result in spraying even when there are no eggs. Crop-loss assessment research is needed to analyze the profitability of adhering to the recommended threshold levels, to generate evidence to persuade commercial farmers to follow them and thus reduce the number of sprays.

A survey on scouting and timing of pesticide sprays by peasant farmers (Jowah, 1986) indicates that only 20 percent of peasant farmers spray according to threshold levels. The remainder generally spray less often than recommended and, most important, often at the wrong times, resulting in inefficient control. This situation can be improved by teaching farmers how to use the improved pegboard for pest monitoring and for making decisions on when to use chemical control. However, an alternative approach which has been suggested is to have AGRITEX scouts do the actual pest scouting and give general recommendations to farmers based on this information. The advantage of such a system of supervised control would be that all farmers would spray according to threshold levels, provided that they all can be informed in time. The disadvantage would be that such a centralized system cannot take into account variation among individual farms or fields.

Alternative approaches

Research results from CRI suggest that cotton responds differently to pest attack according to its stage of physiological development, indicating that ideally thresholds should vary across the season as well. Research workers have divided the cotton season into four periods, based on crop phenology (day 1-56; day 57-84; day 85-120 and day 121-harvest), and are considering the development of a different pegboard for each period with adjusted threshold levels (Jowah, pers. com.). Such an approach could lead to a reduction in the number of applications against bollworms in the commercial sector and to greater effectiveness of the already lower number of applications practiced by peasant farmers by concentrating them during the crop's most vulnerable development stage.

Another desirable approach would be to develop cotton varieties which perform better under the lower crop management and input levels of peasant farmers, emphasizing resistance and tolerance to pests. This would reduce the need for a complicated chemical control system and the consequences of inefficient pest control. Yield levels would probably also be lower, but the overall economic benefit for the farmers may be the same or even improve.

Biological control

Adjusting threshold levels according to the crop's developmental stage should result in a reduction in total number of sprays. This would enhance indigenous biological control, particularly at early and late stages of crop development.

Practical training by the Cotton Training Center

The CTC is using three model communal farms for practical training. Each farm is run by a single family and cotton is grown according to the recommendations of AGRITEX. It would be interesting to include comparison fields which incorporate the most common suboptimal practices, for example relating to soil moisture conservation, weeding and pest control, to demonstrate to farmers the benefits of adopting the AGRITEX recommendations.

CONCLUSIONS

Until 1980, research, training and extension efforts were directed towards the development of the commercial cotton growing sector in Zimbabwe. Effective pest control has been accomplished basically through the development of a rational chemical control program, based on pest scouting, the use of thresholds and appropriate pesticide application techniques. Pesticide rotation schemes are used to prevent the build-up of resistance. A closed season is used for pink bollworm control. Research on biological control has begun, but there is not yet a true integration of chemical with biological control. The cotton sector as a whole is still largely dependent on chemical control.

The commercial sector has been well served by research and extension and is advanced in practicing pest control. Nevertheless, many commercial farmers are not using pest thresholds correctly and, consequently, are applying pesticides more often than necessary. The small-scale sector is not benefiting from existing knowledge because their production constraints are different from those of the commercial sector. Research is now addressing their particular needs in relation to chemical pest control. A major training effort has resulted in the transfer of knowledge to commercial and peasant farmers, and the development of devices and instructions will stimulate pest scouting and rational pest control decision making by peasant farmers.

References

Brettell, J.H. 1986.
Some aspects of cotton pest management in Zimbabwe. Zimbabwe agric. J. 83:41-46.

CRI. 1985.
Cotton Research Institute Annual Report 1983-1984. Research & Specialist Services, Harare, 196 pp.

CRI. 1986.
Cotton Research Institute Annual Report 1984-1985. Research & Specialist Services, Harare, 190 pp.

CRI. 1988.
Cotton Research Institute Annual Report 1985-1986. Research & Specialist Services, Harare, 227 pp.

Jowah, P. 1985.
Cotton pest management formal survey. Cotton Research Institute Annual Report, 1984-85, 178 pp.

1. (1.7 ltr/ha at plant height <40 cm; 3.3 ltr/ha at plant height between 40-90 cm; 5 ltr/ha when plants are over 90 cm).

Cotton Pesticide Management in Togo

by Frans Meerman

Introduction

Economic importance

Traditional cotton production in Togo started in the 1940s with *Gossypium barbadense* grown in association with yams. Now *Gossypium hirsutum* is produced nearly everywhere in Togo, on small plots of about 0.5 ha. The total cotton area is now 82,000 ha and involves 160,000 farmers. Cotton has become the second most important export product after phosphorus and is the principle source of agricultural revenues for the country.

In the north, farmers grow both cotton and food crops (maize and cowpea) from June to September, the only rainy season. The central and southern parts of Togo have two rainy seasons: maize is grown in the first rainy season and cotton is grown in the second, starting one month before the maize is harvested.

Principle constraints in cotton growing

Yield levels vary considerably among farmers. Fifty percent of the farms obtain yields between 500 and 1000 kg/ha, and only 17 percent of the farmers harvest yields over 1250 kg/ha (SOTOCO-,1986). However, the agro-ecological conditions permit yield levels from 1500 to 2000 kg/ha (Sognigbé and Girardot, 1988). The following factors are responsible for the generally low yield levels:

i) Incorrect crop husbandry practices. Many farmers have started to grow cotton and carry out the following practices improperly:

- date of sowing--farmers tend to sow late;
- sowing density--farmers do not resow and therefore do not attain the recommended density of 100,000 plants/ha;
- date of weeding and hilling-up;
- fertilization (improper timing);

(ii) Poor and variable soil conditions, especially in the North.

(iii) Lack of time for weeding.

Cotton production and marketing

As in many other West African countries, cotton production is organized by a parastatal (SOTOCO-[1]), in this case affiliated with the French cotton multinational company, CFTC). SOTOCO is responsible for the delivery of inputs, farmer extension and cotton marketing. Since the foundation of SOTOCO in 1974, cotton production has increased from 10,000 tons to 80,000 tons in 1986. At the same time, the number of cotton farmers has tripled. In part this growth can be attributed to the favorable cotton prices paid by SOTOCO, the free distribution of seeds and pesticides, and the provision of a credit system for fertilizers.

Inputs and subsidies

At the start of each growing season, SOTOCO establishes the production scheme for each cotton growing region, indicating when to apply the necessary crop husbandry practices, including fertilization and fixing the number of insecticide applications. Until 1989, seeds and pesticides were distributed free of charge through the extension service. Fertilizers are provided on credit.

In 1985, the world market prices for cotton dropped from 800 F CFA[2] to 400 F CFA per kg fiber, making the cotton sector in Togo a deficit sector[3]. SOTOCO responded with the following measures:

i) reduction of the free distribution of seeds in order to reduce the cotton area;

ii) phased reduction of the subsidy level for insecticides from 75 percent in 1989 toward complete elimination in 1993 (levels of pesticide inputs are determined by SOTOCO; farmers are charged for the recommended amount of pesticides and the costs are subtracted automatically from the price paid for their cotton);

iii) reduction of cotton prices paid to the farmers (105 F CFA per kg fibre in 1988).

Extension

Each extensionist supervises eight groups of 30 farmers which he visits every two weeks to discuss the necessary crop husbandry practices (training and visit). He also spends one day every two weeks with the regional extension officer for reporting and feedback and one day with the regional SOTOCO agronomist to discuss the agronomic practices.

Pests, losses and control

Cotton pest profiles

Due to differences in climate (one rainy season in the north of the country versus two in the center and south), two pest different profiles can be identified.

North (in order of importance):

Heliothis armigera (american bollworm)
Diparopsis watersi (red bollworm)
Aphis gossypii (cotton aphid)

Spiny bollworms (*Earias spp.*) and the cotton leaf roller (*Sylepta derogata)* are present, but not in sufficient numbers to cause significant damage. The same is true for the cotton whitefly (*Bemisia tabac)i* and cotton jassids (*Empoasca spp.)*.

Center and South (in order of importance):

Cryptophlebia leucotreta (false codling moth)
Pectinophora gossypiella (pink bollworm)
Polyphagotarsonemus latus (red spider mite)
Aphis gossypii

In all three regions, the pathogen *Xanthomonas campestris* principally attacks the leaves (causing angular leaf spot symptom) and not the bolls (boll rot symptom). The actual level of resistance in *G. hirsutum* var STAM and STAM F against race 15 of *X. campestris* is considered adequate.

Losses from insect pests

Since 1979 the Cotton Research Institute IRCT[4] has conducted field trials[5] at different locations to compare three levels of chemical control of insects:

- zero applications
- 6 applications (calendar treatment program)
- 12 applications

The following results are of particular interest:

i) Losses by insects are high and vary considerably between sites (from 42 percent of potential yield at Kadjalla [north] to 77 percent in Dalanda [center]) and between years (30-72 percent in the north, 49-82 percent in the center and 33-62 percent in the South)[6];

ii) The calendar program of six applications prevented 87 percent of anticipated yield losses under research station conditions in the north and 82 percent in both the center and the south (mean values over period 1980-1987). This level of insecticide use is very near the economic optimum (Jallas et al. 1988);

iii) The yield levels without insect control (but with good crop husbandry practices and correct fertilizer application) are comparable to the yields farmers actually achieve using a standard program of six insecticide applications. This indicates the general low level of cotton production technology of the farmers.

No research has been done to determine losses by insects under farmer conditions.

Trends in chemical pest control

Until 1976 the cotton species *G. barbadense* was grown in association with nyam. Because of the high gossypol content of the MONO variety, insect pests were of no importance. With the introduction of *G. hirsutum* in 1976, chemical pest control became necessary and, until 1980, cotton was treated with seven applications per season (every 12 days from day 50 after sowing). Pesticides used were organochlorines (DDT, Endosulfan), Methyl Parathion and Fenthoate.

Between 1980-1985, the number of applications was reduced to six and the organochlorines were replaced by pyrethroides. With the crash in cotton prices, a further reduction in the use of inputs became necessary.

Field trials conducted by the IRCT have shown no significant drop in yield levels or cotton quality when the number of insecticide treatments was reduced from six to five, or when the dosage (liters/ha) was reduced by 33 percent for the first two and the last of six applications.

Because early aphid, and late spider mite, infestations occur in some years, SOTOCO decided not to drop any of the 6 applications but reduced the dosage in the first two and the last applications by one liter/ha each (33% reduction). This recommendation was adopted in the compulsory technology package for the first time in 1986/87 and has produced a total saving on pesticides between 3.4 and 4 million F CFA per year. There is still discussion as to whether this approach might contribute to the build-up of pesticide resistance.

The cotton research institute has prepared recommendations for the 1989/90 season with the following new elements:

1. Use of a mixture of pyrethroid plus aphicide, or organophosphate plus aphicide, in the north (Savanes and Kara);

2. Use of a mixture of pyrethroid plus acaricide, or organophosphate plus acaricide, in the center and south (Bassar, Centrale, Plateaux-Nord and -Sud);

3. Option to eliminate the acaricide from the last three applications in the center/south.

Non-chemical pest control

The only non-chemical pest control measures currently taken are:

1. Use of cotton variety STAM which has an adequate level of resistance against *Xanthomonas campestris* f.sp. *malvacearum*;

2. Burning of crop residues for control of *Earias spp.*, *Pectinophora gossypiela*, *X. campestris* and *Macrophomina phaseoli* (charcoal rot). (Note: no experimental data for Togo are available as to the effectiveness of this measure).

Reduction of pesticide use

Chemical pest control based on threshold interventions

In 1988 the IRCT entomologist B. Sognigbé visited Cote d'Ivoire and Zimbabwe to study two pest control programs and to see how they might be adapted in Togo. The two systems are based on threshold intervention levels and are explained in detail in Table 3. They differ in the following:

(i) the threshold intervention level, which on average result in 2-5 applications per season in Cote d'Ivoire versus probably 7-8 in Zimbabwe (although large scale commercial farmers in Zimbabwe generally fail to follow the thresholds correctly and consequently actually average 8-12 sprays);

(ii) farmers' involvement; as in Cote D'Ivoire the pest scouting is done by field technicians, whereas in Zimbabwe it is done by the farmers.

Table 1. Comparison of insect control systems in cotton in Cote d'Ivoire and Zimbabwe (large scale, commercial farmers), based on pest monitoring and threshold levels (Sognigbé, 1988).

	PAYS	
	COTE D'IVOIRE	ZIMBABWE
Organisation du réseau d'avertissement	27 postes d'observations 7 equipes volantes 6[illegible] observateurs 8 ingénieurs 70 manouevres	Fermiers
Moyens utilisés	8 véhicules 54 mobylettes 70 bicyclettes 75 loupes 27 abris météo matériel de culture fourniture de bureau radio	Néant
Méthodes d'observation	Relevés parasitaires " climatologiques " phénologiques	Relevés parasitaires
Seuils d'intervention	*Diparopsis, Heliothis* *Earias:* 10 œufs sur 100 pieds *Lygus:* 15 % pieds observés *Helopeltis:* 10 % pieds observés *Sylepta:* 15 % pieds observés *Cryptophlebia:* 30 œufs sur 100 pieds	*Diparopsis:* 6 œufs/ 24 plants *Heliothis:* 12 œufs/24 plants *Earias:* 6 larves/24 plants *Lygus:* dégâte *Phyllophages:* 25 % feuilles attaquées au 12 larves/ 24 plants
Nombre de traitements	2 à 5	8 à 12 *

***Strict adherence to recommended thresholds would result in 7-8 sprays; in practice, commercial farmers usually spray more frequently.**

Based on this comparison, the IRCT drew two conclusions (Sognigbé, 1988):

(i) the Cote d'Ivoire model involves too many field technicians and transport facilities to be feasible for Togo;

(ii) the pest profiles in Cote D'Ivoire and Zimbabwe are comparable to that in Togo, so use can be made of their threshold levels for further research in Togo.

In 1988/89 the IRCT compared the Togo standard program of six regular applications with the Cote D'Ivoire and Zimbabwe threshold systems. A fourth treatment consisted of six regular applications at half the normal dosage of three liters of commercially formulated product per ha, with additional extra spraying as indicated based on the use of thresholds.

The trials were done in farmers' fields and were supervised by IRCT staff. Both farmers and extension staff participated in the weekly scouting rounds and were able to recognize the main groups of pests. The scouting process took an average of two hours weekly for each 0.5 ha. In the south, to scout for endocarpic caterpillars, 100 capsules (bolls) had to be opened every week. Not surprisingly, the farmers showed resistance to this infliction of damage to the crop. IRCT is now working on a scouting method for *Pectinophora gossypiella* and *Cryptophlebia leucotreta* based on pheromone spraying.

The results of these 1988/89 experiments are shown in table 2.

During the 1988/89 season, the general level of pest attack was moderate. The following observations can be made:

1. The use of the Zimbabwe thresholds did not reduce the number of applications in a year with moderate pest attack;

2. The use of the Cote D'Ivoire thresholds did reduce the number of applications, but lowered yields significantly in the south;
3. Reduced doses of insecticides seemed effective.

Adjustment of pesticide usage to fertilizer use and weeding

The economic crisis in cotton production forced SOTOCO to reduce expenditures for inputs and to reduce the price paid for cotton. This blanket approach did not take into account existing differences in crop production technology and profitability. Therefore, in 1987 the IRCT developed recommendations concerning the optimal input levels and crop husbandry practices (Jallas et al.,1988).

Table 2. Yield levels with standard calendar spraying as compared to threshold interventions under controlled and uncontrolled conditions in Togo, cotton season 1988/89 (after Sognigbé, Silvie and Abotsi,1989).

location	n°insecticide appl.	total liters insecticide/ha	yield (kg/ha	sign.
Research Stn. Kolopé	6 (calender	18	2242	n.t.
	5 (Ivory C. tresh.)	15	1982	n.t.
	6 (Zimbabwe thresh.)	18	1978	n.t.
Exp. field (North)	6 (calendar)	18	2114	n.t.
	4 (Ivory C. thresh.)	12	1559	n.t.
	5 (Zimbabwe thresh.)	15	1906	n.t.
Farmer fields (North)	5 (calendar)	15	887	n.s.
	3 (thresh.)	9	875	
Farmer fields (North)	5 (calendar)	18	757	n.s.
	6,1 (calendar + thresh.	6	815	
Farmer fields (South)	6 (calendar)	18	1350	sign.
	3.3 (Ivory C. thresh.)	9.9	1213	at 0.1
Farmer fields (South)	6 (calendar)	18	1398	n.s.
	6.7 (calendar + thresh.)	5.5	1488	

n.t. = not tested n.s. = not significant

Experiments were conducted at seven locations to determine optimum fertilizer use (four levels), pesticide use (four calendar-based spraying programs) and three levels of crop husbandry practices (involving weeding and hilling-up). Recommendations were made as to the optimal combination of inputs and level of technology (see table 3).

Present system for reducing pesticide use

Under the present system, actual pesticide use is reduced by reducing the dosage for three of the six standard applications used per growing season by 33%. This is based on trials showing that the lower dosage levels are equally effective as the standard dose for the first two and the last spray. Under this program, yield levels have been maintained, while between 3.4 and 4 million F CFA are saved on pesticides annually. The system is compulsory because pesticides are provided by SOTOCO and farmers are automatically charged for the costs.

Research has shown that a similar pesticide reduction can be achieved by eliminating the first out of six treatments. This system would have the advantage of saving both on pesticides and on application costs and by reducing impacts on natural enemies.

Calendar spraying versus pest monitoring and the use of economic thresholds

In Togo, reduced pesticide use has been caused by the economic crisis in cotton production, not by the build-up of insect resistance or other side effects of chemical control.

There are two principal ways to reduce pesticide usage. The first is to reduce the number of applications in calendar-based spraying programs, based on detailed knowledge of the population dynamics of the pest species and of the crop phenology. The second is to spray only when a threshold level is reached.

Considerations for choosing between these systems are:

(1) research capacity, funding and time needed to determine threshold intervention levels;

(2) capacity of the extension service to do centralized pest scouting or to deliver the scouting system to the farmers: a calendar-based spraying program requires less training of extension workers and farmers than does a threshold intervention system (pest identification and pest counting, deciding whether to spray).(c) variability of pest attack in time.

When the attack is constant, causing considerable and predictable losses, a calendar-based program may be indicated. When the attack is variable, causing occasionally high losses, a threshold intervention system will be preferred because important savings on pesticides can be obtained in years with low pest attack.

In Togo, chemical pest control experiments over the last 10 years have shown high variability in losses, attributed to variability in insect attack. Therefore, a threshold intervention system will be more appropriate than a calendar based program.

Combining thresholds with a forecasting system can produce more effective control, as a result of better advance preparation and better timing of control operations.

Need for differentiated economic thresholds

The definition of the economic threshold is the level of pest infestation at which the cost of applying the pesticide equals the cost of the damage to the crop if the pesticide were not applied (e.g. Stern, 1973). The use of this concept assumes that all parameters that influence the threshold level are known. This is difficult for parameters like the level of pest infestation, the future dynamics of the pest population, the damage that will be caused by the present infestation, the cost- effectiveness of the pesticide and the potential yield. All of these factors are difficult to quantify and all are variable over time.

Based on the present situation of low cotton prices and the low technology used by Togolese cotton farmers, 5-6 insecticide applications is too high. Three applications would be the best recommendation (Jallas et al.1988).

Jallas and co-workers also suggested dividing the farmers into groups, based on their skills in cotton growing. Eight technology levels are suggested (see table 4). In this system, the use of inputs is adjusted for each level. For pesticide application, this would result in different calendar-based treatment programs by different groups of farmers.

As a first step, 3 technology levels could be defined. Later on, this number could be increased, eventually leading to an individual approach for each farmer (*vulgarisation à la carte*), and extensionists should be trained to bring farmers from one technology level to the next. The application of this group approach system could produce savings totalling 1 billion francs CFA per year (approx. 3.2 million U.S. dollars at 1987 rates).

The recommendations in Table 4 are based on the reasoning that the more a farmer invests in weeding and fertilizer use, the higher the expected crop yields and the more he should invest to protect his crop from losses by pests. However, the sequence of investing in external inputs, such as fertilizers and pesticides, should be based on experimental data indicating which of the factors (weeds,

Table 3. Recommendations for intensification of cotton production: fertilizer use, weeding and pesticides (Jallas et al., 1988).

technical progression	fertilizer at sowing	weeding and thinning at 20 days	weeding and hil-ling-up at 40 days	recommendations NPK kg/ha	Area	Insecticides
1	no	no	no	150	0	0 applic.
2	no	no	yes	150	0	2 applic.
3	no	yes	no	150	50	3 applic.
4	no	yes	yes	150	50	5 applic.
5	yes	no	no	200	0	2 applic.
6	yes	no	yes	200	0	3 applic.
7	yes	yes	no	200	75	4 applic.
8	yes	yes	yes	200	75	6 applic.

soil fertility, insect pests) is in fact the most limiting. Thus, the priority given to pest control in a particular area should be considered with respect to the soil conditions and the availability of labor for weeding.

Discussion

In particular, the potential yield and cost-effectiveness of control vary widely at the different technology levels of cotton production in Togo, making a unique economic threshold figure largely meaningless. This is demonstrated by data from pesticide reduction experiments in Togo. In these experiments, the use of a unique threshold level did not affect farmers' yields[7] but did produce lower yield levels at research station conditions[8].

The clear conclusion is that the same chemical control interventions will not have the same results at different technology levels. It will therefore be important to study pest incidence-injury-loss relationships at different technology levels. Together with data on yield expectations and effectivenss of chemical control at various technology levels, this should determine the correct intervention level for each technology level.

Pest scouting by more advanced farmers

The use of a threshold intervention system demands training of farmers in pest scouting techniques. The results obtained with the pilot farmers are promising. However, the loss of yield from opening 100 bolls each week to scout for endocarpic caterpillars in the south caused resistance among farmers and may not be accepted by them as a practical option. IRCT is now investigating the possibility of using pheromones as a means of scouting for these pests: an effective pheromone is available for the pink bollworm (*Pectinophora*) but not yet for the false codling moth (*Cryptophlebia*).

In general, the possibility for implementing rational pest control systems, based on pest monitoring and decision making, depend on the availability of simple and effective procedures for pest monitoring, decision making regarding chemical control, and pesticide application. Such a system is currently being developed for small-scale cotton farmers in Zimbabwe, and consists of an improved pegboard for pest monitoring and decision making (see previous case study). The new Zimbabwe system represents an interesting alternative to the calendar-based pest control programs proposed for the small-scale cotton farmers in Togo.

In spite of the results with pilot farmers, it is unlikely that any rational pest control system, based on pest monitoring and decision making, will be feasible for farmers who do not manage the basic crop husbandry practices. It would be interesting to study the possibility of pest scouting by more advanced farmers representing a particular agro-ecological area, and let the extension service use these data to develop recommendations regarding if and when to spray for all other farmers.

Farmers' involvement in pesticide decision making

Under the present calendar spraying program farmers are charged for the recommended quantity of pesticides, even if that quantity is not actually applied. It would be interesting to consider the possibility of developing a forecasting system and let farmers decide on pesticide application. The type of forecasting will depend on specific objectives and on constraints like research capacity and funding, but a first step could be to develop a way to determine when at least one of the limiting factors for a pest outbreak is not satisfied. In this way a "negative forecast" can be issued indicating that damaging outbreaks will not occur. Such forecasts are of considerable value to growers because they indicate when control measures are not required and can safely be omitted.

Technical progression for cotton production

As stated earlier, the concept of a unique economic threshold level for different technology levels has some serious drawbacks. Jallas et al. (1988) proposed a technical progression for the intensification of cotton production, with important implications for pesticide usage. This approach is based on the classification of farmers according to their level of technology and the adjustment of the number of pesticide applications to these technology levels (correct fertilizer use and proper weeding). According to this system, a total pesticide saving of approximately 3.2 million U.S. $ per year would be possible.

Such a system would result in the use of different calendar based treatment programs by different groups of farmers. Research should be carried out to determine the optimal timing of spraying within each calendar program. This approach could be a shortcut for the time-consuming and expensive work of developing a differentiated threshold intervention system.

However, a reduction of pesticide use, particularly at the lower technology levels, could result in the local build-up of pest populations. This could seriously affect the whole system if farmers of different technology level are distributed at random. It is difficult to say whether this phenomenon will happen, but one should be aware of the possibility.

Nevertheless it must be said that, from a technical and economical point of view, introducing a forecasting system or a differentiated threshold system is more suitable than reducing pesticide use by introducing a differentiated calendar spraying program.

Farm approach versus cotton field approach

In Togo, cotton farmers do not grow cotton exclusively. They also grow maize and other food crops. However, pest control for food and cash crops cannot be considered separately because of the many ecological interactions in such mixed systems. For example, crop rotations provide a form of pest control, and food crops profit from the residual effects of fertilizers applied to cotton. Therefore, when developing methods for improved pest control, the farming system should be studied as a whole instead of concentrating only on the cotton crop. The same applies to extension activities.

Conclusions

Problems with cotton growing in Togo relate to inadequate crop husbandry practices, poor and variable soil conditions, and lack of time for weeding. Insects do cause considerable losses, but reasonable control is achieved through the use of a moderate calendar based- chemical control program with 5-6 applications per growing season. These chemicals have been 100 percent subsidized in the past, but the subsidy will be phased out and eliminated by 1993 because of the economic crisis in cotton production. In order to reduce the costs for chemical control, research has begun on ways to reduce insecticide use. The first approach has been to reduce insecticide dosage rates in calendar-based spraying programs. This has resulted in considerable savings. The second approach is to address pest control, fertilizer use and weeding concurrently. This approach should eventually result in different calendar-based spraying programs, based on the level of fertilizer use and weeding by farmers. However, pest attack and farm conditions vary considerably, so a pesticide reduction system based on pest monitoring and threshold levels would be more appropriate. With such a system, it would be important to conisder the use of differentiated threshold levels, based on the farmer's technology level and use of other inputs.

A decision would have to be made regarding whether pest scouting should be done by extension-service scouts or by the farmers. Among other things, this choice will depend on the availability of an effective and simple system for pest monitoring and decision making for chemical control The system currently being developed in Zimbabwe, based on the use of an improved pegboard, may serve as an example. While weekly scouting by farmers themselves would require training and discipline on their part, this does not mean they would be reluctant or unable to do so[9]. In addition, developing the type of discipline required for this activity is generally important for improving overall crop husbandry practices.

References

Jallas, E., P.Y Douti, R. Joly, and M. Cretenet. 1988.
Modelisation du rendement coton en fonction des trois principaux moyens de production et de l'environnement. IRCT/CIRAD Station d'Anie-Mono.

Sognigbé, B. 1988.
Traitement sur avertissement. Rapport de mission en Côte d'Ivoire et au Zimbabwe. IRCT Station d'Anie-Mono.

Sognibé, B. and B. Girardot, 1988.
Rapport de campagne 1987, section Entomologie. IRCT Station d'Anie-Mono.

Sognibé, B., Silvie, P., and K. Abotsi. 1989.
Rapport préliminaire 1988, section Entomologie. IRCT Station d'Anie-Mono.

1. French acronym for *Société Togolaise du Coton*

2. One U.S. dollar = 312 F CFA.

3. Studies indicated that at the current input:output prices (that is with all subsidies on pesticides removed) 16% of the farmers will not be able to cover their purchased input costs, let alone obtain a return on their labor.

4. French acronym for Institut de Recherche du Coton et des Textiles.

5. Under normal soil conditions, adequate crop husbandry practices and correct fertilizers application.

6. Mean over 10 years at various locations.

7. Yield levels between 800 and 1500 kg/ha.

8. Good crop husbandry practices, same ecological conditions as farmer fields, yield levels of approx. 2000 kg/ha.

9. Ten Togolaise farmers who carried out pest scouting in their fields in 1989 under a pilot program expressed their satisfaction with carrying out this "chore" and in being a party to the process of making decisions regarding pesticide use (A. Spurling, personal communication).

The Cotton Integrated Pest Management Program in Sudan

by Agnes Kiss

Introduction

Cotton is Sudan's major agricultural export and main source of foreign exchange. The irrigated cotton sector in Sudan has attracted considerable attention and become something of a *cause célèbre* for the international environmental community. The general perception is that the pest management system is entirely dependent on chemical pesticides, that dangerous pesticides are overused and misused, resulting in serious environmental and health problems, and that IPM should be introduced to solve these problems.

In fact, as discussed below, some key elements of the IPM approach have actually been in place in Sudan for a long time, even if the effectiveness with which they are implemented is debatable. Furthermore, pesticide use in Sudan, while far from optimal, is not notably worse than in many other areas which receive little or no attention from outside critics. Even at the peak of 9-10 sprays/season reached in the early 1980's, the level of pesticide use does not compare with the 30-40 applications/year which have at some points been used in other countries such as Nicaragua and Australia (Matthews 1989) [1]. The hazardous pesticides which are routinely used in Sudan are also widely used elsewhere, including other developing countries where capacity for safe handling is no better. In fact, since pesticides are applied by aerial spray teams instead of individual farmers, the cumulative hazard to public health is arguably lower in Sudan irrigated cotton than in many other cases. The use of aerial spraying clearly contributes to environmental contamination, but is again fairly common practice in large-scale cotton production. Much of the concern over environmental and health impacts of pesticide use has been voiced by individuals who have not visited the country. Many who have visited have reported dangerous practices and specific instances of misuse which raise serious concern, but unfortunately there is little monitoring or epidemiological data to support an objective assessment of overall impacts at this time.

Sudan's exceptional "notoriety" appears to be related to several factors: the total amounts of pesticides involved, some specific pesticides used and, perhaps most significantly, the fact that the funding for pesticide procurement comes from international donor organizations. Each of these issues must be examined in context:

(1) The total cost of pesticide procurement for Sudan (mostly for irrigated cotton) in the 1987-88 season was over $50 million, a figure which drew a great deal of criticism. However, the areas involved are also enormous. The government-controlled irrigated schemes cover over 3 million feddans (one feddan is about the same as one acre), of which about 800,000 to 1 million are planted to cotton each year. Several hundred thousand additional feddans are planted to wheat, on which some pesticides are also used. Distributed over the cropping area, this enormous volume of pesticides purchased in 1987/88 represented an average of less than 6 sprays over the course of the season.

(2) Among the specific pesticides used, the greatest concern was over aldicarb (the most toxic pesticide active ingredient known), which was tested and used for several years in the early-mid 1980's. The actual risk involved in using the granular formulation (Temik) was a matter of hot debate, with critics citing the inherent dangers and known problems of diversion and mishandling, while the manufacturer and government officials pointed to a lack of evidence of negative consequences. In any case, the government stopped importing Temik in 1987. A number of other very toxic materials are still used,

however, and the way in which they are applied leaves much to be desired, with respect to both efficacy and environmental and health hazards.

(3) Prior to the 1980's Sudan financed its own pesticide procurement. In the 1982/83 season foreign aid contributed 29% of the total finance. This grew to 75% in 1984/85, and 100% from 1985/86 onward. This dependence on outside funding clearly opens Sudan to much more scrutiny than other countries. Furthermore, in several of the years since 1984, the majority of the funds have come from countries (e.g. West Germany and the U.S.) with strong environmental constituencies and from multilateral organizations (e.g. the World Bank) which the international environmental community follows closely.

While these are probably the main reasons that the issue of pest management in Sudan cotton has received world-wide attention, there is another aspect which is of great concern to both the government of Sudan and the donors: the cost-effectiveness of pest control. While current levels of pesticide application are not necessarily excessive compared to practices in other regions, the disturbing fact is that yield levels using up to 9-10 sprays in the 1980s[2] were no higher than those achieved in the 1950s-1960s with a single spray. In fact, during the 1970s yields of the most valuable, long-staple variety fell from 4.3 kantars/fed (= 1515.8 kg/ha) to 2.1 kent/fed (= 742 kg/ha) despite heavy investment in pest control. The low overall productivity made the value of high levels of investment in pest control questionable. At the peak, pest control represented over 30% of total production costs, and there was clearly a question whether the benefit was worth the cost at such low production levels even in narrow financial terms, leaving aside broader economic costs relating to environmental or health effects.

In response to all of these internal and external concerns, a number of donors have sought to assist the government of Sudan to improve pest management and pesticide handling in the irrigated cotton sector. This case study focuses on an ongoing Sudan/FAO program to develop and implement improved IPM practices. This program receives external funding primarily from the government of the Netherlands, with some contribution from World Bank.

Background

Social and institutional setting

Almost all of the irrigated cotton is grown on large schemes managed by parastatal Agricultural Production Corporations (APCs). The first of the large schemes, the Gezira, was begun in the 1920's. There are now 5 schemes, totalling 3.4 million feddans. The farmers are actually tenants on government-owned land, or employees or sharecroppers working for individuals who hold these highly valued tenancies. In some cases the tenant population consists of people who had been carrying out rainfed farming prior to the establishment of the scheme, while in other cases they are former pastoralists or agricultural people resettled from other areas.

In each scheme the APC is directly responsible for most aspects of production. The APC management implements some aspects directly, such as land preparation and pesticide application as well as buying inputs and marketing the cotton. The tenants carry out planting, thinning, weeding, irrigation and harvesting. Thus, the tenants do not have direct control over pest control operations. However, they do have some influence on management decisions through the respective Tenants' Unions. In addition, the way in which they perform agronomic tasks such as thinning, weeding and irrigation can have a major impact on the level of pest infestations and efficacy of treatment.

The APC management maintains an account for each tenant, into which it deposits payment for the cotton harvested and from which it deducts costs and fees. Many of the tenants are apparently unclear about the details of this accounting system. For example, when the management advances money from the account to enable a tenant to hire laborers for weeding the tenant does not always understand that this is, in fact, his own money and not a donation from the APC. Other tenants have a better understanding of the system and have been increasingly supportive (through the Tenants' Unions) of efforts to reduce pest control costs which ultimately accrue to them.

Pest control methods are dictated by the government's Agricultural Research Corporation, whose researchers make recommendations which must be approved by the Pests and Diseases Committee. APCs are supposed to follow these recommendations, although in practice the crop protection field staff sometimes modify practices based on their professional judgement and assessment of local conditions or in response to limited availability of pesticides or application equipment.

The pest complex

The Sudan irrigated cotton system is often cited as a case where the pest situation has worsened over the years as a result of pesticide misuse (see next section). The major insect pests are:

(1) the whitefly, *Bemisia tabaci*;
(2) the American bollworm, *Heliothis armigera*;
(3) the jassid, *Empoasca lybica*; and
(4) the aphid, *Aphis gossipyii*.

Until the early 1950s the most important pests were jassids and, to a lesser degree, bollworm. Whitefly was important in some years, not because it was present in high numbers but because it transmitted leaf curl virus. Significant infestations, when they occurred, were generally restricted to the late part of the season. Various other insects such as aphids, flea beetles, thrips, pink bollworm and spiny bollworm were also present but generally not considered economically significant. By the end of the 1960's, however, whitefly had become an annually recurrent, season-long pest eclipsing jassids and bollworm in importance. Since then it has remained the most significant economic pest, in part because of its direct impact on yields but more because it excretes honeydew which makes the cotton lint sticky and decreases its market value by up to 20%. Furthermore, existing aerial pesticide application appears to have very limited effect due to the whitefly's habit of feeding on the sheltered undersides of leaves. In the past few years aphids have also emerged as important pests, contributing to the honeydew problem, although they are more easily controlled with pesticides.

The most important diseases of cotton in Sudan are bacterial blight (*Xanthomonas malvacearum*) and fusarium wilt (*Fusarium oxysporum*). Disease control is by cultural practices, use of resistant varieties, and seed treatment using a fungicide/bactericide/ insecticide mixture. A wide variety of weeds also affect cotton production. Weed control using pre-emergence herbicides seems to be cost-effective although it does not eliminate the need for manual weeding later in the season. This weeding is often a major problem because of a general labor shortage.

Insect pest management practices[3]

Non-chemical

Prior to 1945 all pest control was by use of resistant varieties and cultural practices. For example, in 1926 and 1930 regulations were introduced requiring tenants to follow phytosanitary practices (uprooting and burning cotton plant residues, prohibition of rattoon cotton, closed seasons on some vegetable crops) aimed at controlling bacterial blight, leaf curl virus and pink and spiny bollworms. In 1931 the Gezira scheme changed from a 3-crop to an 8-crop rotation as a further means of combatting the build-up of bacterial blight. Varieties resistant to bacterial blight and leaf curl virus were introduced, as well as a hairy-leafed variety which was highly resistant to jassid but unfortunately suffered much higher infestations of whitefly.

At the same time, however, other cultural practices have been introduced over the years which have aggravated the pest situation. These include:

(1) expansion of cotton growing into more humid areas where some pest problems are inherently more severe;

(2) increased planting of groundnut and sorghum which, together with introduction of early-fruiting

cotton varieties, contributed to increased early-season bollworm populations;

(3) introduction of fertilizers and of new varieties which responded with vigorous vegetative growth very attractive to whitefly; and

(4) the elimination of fodder crops from the rotation, which led tenants to continue irrigation much later into the season to provide fodder for their livestock (but simultaneously extending the growing season, which benefits the pests). Among the fodder crops eliminated was Lubia, which served as a useful trap crop for bollworm (attracting females to lay eggs on the plants which were then destroyed by grazing).

Enforcement of closed seasons and phytosanitary measures has also fallen off. Combined with the current crop rotations this means that pest populations can build year-round.

Chemical

Commercial pesticide spraying (against jassid) started in 1945 and was initially very effective, with harvests increasing from 20-65% with a single application. The average number of sprays per season remained about one until the late 1950's, grew to 3-5 in the 1960's and 6-9 since the early 1970's (Abdelrahman, 1989). Large-scale aerial spraying began in 1950 and by 1956 all cotton pesticides were applied was by air. At first only high-volume formulations were used but later ULV spraying was introduced for early season applications. DDT was the first commercially used pesticide, first alone and later mixed with Dimethoate, but agricultural use of DDT was banned in 1981.

The emergence of the whitefly problem has been attributed in large part to the use of DDT and other pesticides which killed adults of the species and its natural enemies but not the whitefly nymphs. There is also some evidence that use of DDT actually stimulates whitefly egg production and increases vegetative growth which favors growth of whitefly populations. Organophosphate pesticides were introduced to kill whitefly but had limited effect against ABW so the use of pesticide mixtures became standard practice.

In 1968 late season sprays were added to control the growing whitefly problem. Unfortunately they had relatively little impact as they killed mostly the adults rather than the nymphs which are the main source of honeydew. The late sprays did, however, kill natural enemies which had previously been an important element in whitefly control: Joyce (1955), showed that, prior to the introduction of late season sprays, 90-100% of late whitefly nymphs in the field were parasitized. Over the years the spray regime has clearly had a major impact on natural enemy populations: Herrera (1986) found only 40 beneficial insect species in the cotton fields in 1985/86, compared with 140 species reported in the 1920's.

Use of economic threshold levels (ETLs) for the key pests was introduced in the 1950's and the APCs established scouting teams to monitor populations. This key element of IPM has thus been in place for almost thirty years. However, the thresholds which were set at that time remained the same over the following decades, and are generally 2-3 times lower than thresholds used for the same pest species in other areas, which means spraying at lower pest population densities. Other criticisms leveled at the system are that the whitefly threshold is based on counting adults instead of nymphs, the bollworm threshold does not differentiate between different life stages of the pest, and the recommended thresholds are the same throughout the entire growing season.

One of the most controversial aspects of pest management in Sudan was the "package deals" (PDs) in which pesticide manufacturers were contracted to control cotton pests on a guaranteed yield basis at a fixed price per unit area. The PDs were successful in increasing production through 1978, but the long-term impacts are still disputed. The system began in 1971 and expanded through 1979/80 (ultimately covering about 45 percent of the total cotton area), but it was abolished in 1981, apparently due in part to increasing problems with whitefly which was reaching higher populations than in non-PD areas. Whitefly resistance to Monocrotophos, Dimethoate and Carbofuran was confirmed in 1982, and many attribute this to regular use of these products (particularly monocrotophos) in the PD areas.

Currently insect pest management is still based on the same ETL/scouting system and aerial spraying of pesticide mixtures. Although there is a policy of selective and partial spraying of heavily infested areas, the use of airplanes makes it economically difficult to limit the areas treated. In recent years cotton breeding has focused more on increasing yields, lint quality and drought resistance than on pest resistance. Whitefly continues to be a serious problem throughout the season and cannot be said to be under control (the estimated financial loss due to stickiness alone for 1986/87 and 1987/88 was $30 million). Aphids have also emerged as an important pest, appearing in much larger numbers and earlier in the season than before. Bollworm and jassid are relatively easy to control with pesticides, but the destruction of natural enemies caused by early-season spraying against these pests is believed to be one of the main causes of development of heavy whitefly and aphid infestations later.

The project

History

The project, now entitled "Development and Application of Integrated Pest Management in Cotton and Rotational Food Crops," has just entered its third phase. It is financed by the Netherlands (Directorate General of Development Cooperation, Ministry of Foreign Affairs) and executed by FAO. Phase 1 began in December, 1979 and continued through September, 1983, after which there was a hiatus of about one year. Phase two, beginning in September 1985 continued through Spring of 1989. There have been three project managers, one during Phase 1, one for the first year of phase 2, and the current one who took up the position in October, 1987. A second FAO expert (biocontrol specialist) has been in residence since September, 1985. The FAO experts work in partnership with the IPM Unit of the Agricultural Research Corporation's Entomology Department. During Phases 1 and 2 the project focused on supporting research on cotton pest management. In Phase 3 the scope has been broadened to include other crops grown in rotation with cotton and to place greater emphasis on extension of research results.

The research program

Under the auspices of the project, the FAO/-Sudan research team focuses on:

(1) gaining a better understanding of the agro-ecosystem, particularly the interactions between the cotton crop and its pests (including their use of alternate hosts) and the impact of natural enemies. Basic ecological studies conducted by the project team are complemented by work of other ARC researchers relating to the effects of different agronomic practices on pest densities;

(2) revising the current ETLs, based on crop loss assessment trials and current economic realities (i.e. cotton prices, pest control costs), and developing better assessment and scouting methods; and

(3) selective control of the key pest species, particularly of ABW because early sprays of pesticide mixtures against this species are believed to initiate the cycle of dependency on pesticides by destroying natural enemy populations. The main strategy of the project-supported work is to examine the effectiveness of indigenous natural enemies in controlling ABW and to explore the possibility of augmentation with introduced *Trichogramma* parasites. Other researchers in the Entomology department are addressing the issue from another perspective, trying to identify more selective pesticides.

Results

Research

Research on these topics has produced important results[4], showing that:

(1) the current ETLs are indeed too low and comparable yields (and less sticky cotton) can be achieved with lower numbers of sprays;

(2) indigenous natural enemies recolonize unsprayed areas quickly and can control whitefly and aphids quite effectively in the late season if they are not

destroyed by early season broad-spectrum pesticide spraying;

(3) there are some important indigenous egg predators of bollworm but apparently no egg parasites. However, introduced *Trichogramma* parasites can become established, survive and spread under Sudanese conditions and can give high egg parasitism rates (up to 70% of all bollworm eggs in December, 1989); and

(4) good crop husbandry and agronomic practices (e.g. thinning, early cessation of irrigation, early picking) are very important in reducing pest densities and in increasing the effectiveness of chemical control.

Implementation

While research results have thus been very encouraging, there have been problems in translating them into field practices. While trials of reduced spraying (doubled ETLs, resulting in 2-3 fewer sprays over the season) have been carried out on increasingly large scale from year to year (about 900 fed. in 1987/88 and 1600 fed. in 1988/89, including control areas)[5], they were always regarded as trials and tenants were guaranteed compensation against any yield loss. This in turn created problems in evaluating the results as tenants had little incentive to maintain good crop husbandry, and sometimes even under-reported yields in the trial areas, secure in the knowledge that they were guaranteed financial compensation for below-average yields. Furthermore, although the destructive effect of using broad-spectrum pesticide mixtures (particularly early in the season) became very evident, the Pests and Diseases committee did not change the practice of using mixtures. Pesticide screening continued to focus on broad spectrum products instead of selective ones with little attention paid to relative impacts on natural enemies. Research continued to demonstrate the importance of agronomic practices but tenants' adherence to these recommendations remained generally poor.

However, there have been some very encouraging developments over the last year. For the 1989-/90 season the Pests and Diseases Committee (PDC) called for the first commercial implementation of the higher ETL/reduced spraying approach on a pilot area of 10,000 feddans (5,000 each on two different schemes). Because this was no longer a research trial, tenants did not receive a yield compensation guarantee[6]. There is a proposal to increase the implementation area to at least 50,000 fed. next season. The PDC also asked ARC for a report on promising selective pesticides and a review of the practice of using pesticide mixtures. For the first time, the PDC decided not to authorize screening of a number of new mixtures which were being proposed for registration. Phase 3 of the Sudan/FAO project also began in the Fall of 1989, with the appointment of an extension specialist to work directly with the APCs and the tenants to "win their hearts and minds" for IPM in the field. The initial "field days" were reportedly very successful and enthusiastically received.

Conclusions

Sudan irrigated cotton represents a classical case of a high-input system where psychological and ecological dependency on pesticides (as well as commercial interests promoting pesticide use) are already high, so there is considerable resistance to change. The negative impacts of increasing pesticide use over many years are evident, in the form of pesticide resistance, the emergence of secondary pests and the paucity of indigenous natural enemies (broader environmental and health impacts are also likely but are not examined in this case study). The cost-effectiveness of pest control practices is also questionable in light of the relatively low yields attained: although there has been some recovery since the nadir during the 1970's, yields are still at about at 1950's levels. According to the basic principles of IPM the investment in pest management should be in line with the anticipated returns, which are limited by factors such as inadequate irrigation and poor land preparation.

IPM is by no means a new concept in Sudan. Essential elements such as varietal resistance and phytosanitary measures date back to the 1920s and, unlike many other places, the use of ETLs and pest scouting was introduced in the 1950's. The problem has been a strong orientation toward pesticides in both research and practice. IPM research stagnated (e.g. ETLs were not revised in almost 30 years) and results which did emerge did not generally lead to changes in practice.

The ARC has competent, well trained scientists, and there is also probably more information and guidance available worldwide for pest management in irrigated cotton than in any other crop. The implementation of new technologies should also theoretically be easier under a centralized management and crop protection department than if each farmer makes his or her own independent decisions. The underlying reasons for the failure to pursue and implement IPM more aggressively thus appear to be related more to policies, allocation of responsibilities, incentives and motivations than to technical shortcomings or impediments. Specifically:

(1) The ARC is responsible for carrying out agricultural research, but is very poorly funded. A significant portion of its operating funds over the years has come from pesticide manufacturers seeking registration of their products (they are required to finance several years of efficacy trials). Thus it is not surprising that pesticide screening has been the primary focus of ARC crop protection research.

(2) The ARC also has little incentive to address cost-effectiveness in its research as it is not directly involved in cotton production and it seems until recently there was little demand by the research "clients" (i.e. the APCs and the government at large) for ways to reduce production costs. In fact, except in the case of pesticide screening, there seems to have been little demand on ARC over the years to demonstrate concrete results from its crop protection research. The revitalizing impact of the Netherlands/Sudan/FAO project has been due in part to its requirement for regular, detailed reporting of research results.

(3) The APCs should have a direct stake in cost-effectiveness, but at least in theory they are bound to follow the ARC's pest control recommendations. In addition, increasing yield is a greater factor in their motivation than cost reduction. The APC managements contract with the government to produce a certain yield within a certain budget. There is little incentive to reduce costs as long as they stay under that ceiling, but penalties if they fail to meet the yield goals. Yield is also the main performance criterion for the crop protection field staff and is the basis on which tenants are paid. Coupled with a firm belief that high pesticide use equals higher yields, this virtually guarantees the unpopularity of a reduced pesticide approach.

(4) The emphasis on yield has also been at the expense of attention to lint quality, at least with respect to stickiness. Research indicates that decreasing pesticide sprays, using resistant varieties and shortening the growing season can reduce the stickiness problem by reducing late-season whitefly and aphid populations. However, these methods may lead to some decrease in yields (e.g. through greater bollworm and jassid attack, although this is not necessarily the case). Currently there is no systematic method for taking cotton stickiness into account in determining payment to the tenants or APC's, despite the fact that stickiness is a major factor in the marketability of the cotton internationally.

(5) The tenants, who are the bottom-line producers and thus have the greatest incentive to reduce costs, have little say in pest management decisions. In general they do not know what pesticides are being applied, or when, or on what basis. The costs are simply deducted from their accounts along with a number of other costs and fees so that, as a rule, they do not know how much they are paying for pest control. Therefore they do not see the value of practices (such as thinning or early cessation of irrigation) which reduce pest impacts but which they believe will reduce cotton yields as well as using scarce labor and depriving their livestock of fodder.

When this lack of knowledge has been addressed-- for example when the proposed reduced-spraying trials were discussed with the Tenants' Unions-- the tenants were very receptive and interested. In fact, in 1987/88 it was the Tenants' Union which agreed to provide the compensation guarantee fund needed to implement the large scale trials. It is important to realize, however, that this positive but simplistic assessment masks an underlying social complexity: many of the people who farm the fields are not actually the legal tenants but sharecroppers whose motivations and incentives are likely to be considerably different than those of the tenants in whose names the accounts are held.

(6) There are no quantitative data regarding costs related to health or environmental impacts of current pesticide use practices.

Although there is concern within Sudan about the environmental and health effects of pesticide use (which has led to the banning of some products such as Endrin and BHC), it is likely that the major impetus for implementing IPM more effectively will be on financial grounds. If this consideration is to stimulate broad-based enthusiasm, the existing market distortions must be addressed. Maximizing profits, based on costs and quality as well as yields, must become the bottom line for all levels involved in cotton production, from the individual tenants to the central government. Those with a direct stake in profitable cotton production must also become more involved in directing research and demanding that it focus on their real problems and come up with solutions in a timely fashion.

The FAO project has helped to revitalize the IPM research program by providing technical and financial support. Equally important, complemented by the efforts of other donors such as the World Bank (in the context of its agricultural lending program and policy dialogue in Sudan), it has brought the importance of the issue to the attention of the government. This has helped to create a more supportive political environment in which IPM is increasingly seen as an economic necessity and a national priority.

REFERENCES

Griffiths, W.T. 1984.
A review of the development of cotton pest problems in the Sudan Gezira. M.Sc. thesis, Imperial College, University of London.

Herrera, J.M. 1986.
Natural enemies of cotton pests. Working Paper FAO IPM Project, Wad Medani. Mimeograph

Joyce, R.J.V. 1955.
Cotton Spraying in the Sudan Geziva -- Entomological Problems Arising from Spraying. FAO Plant Protection Bulletin, 3 (6/7).

Matthews, G.A. 1989.
Cotton Insect Pests and Their Management :Longman Scientific & Technical: Harlow, Essex, England.

1. Resulting in major environmental and economic problems leading to virtual collapse of the production system.

2. Some of which were applications at half the ordinary dose level.

3. For additional details, see Griffiths, 1984.

4. For data and analysis, see FAO IPM project field reports and Abdelrahman, 1989.

5. In the 1986/87 season an area of 793 fed. was left unsprayed for basic ecological studies and to evaluate yields and insect populations compared with a conventionally sprayed control area. The unsprayed area trial was repeated in 1987/88 together with ETL experiments.

6. Cotton yield and quality results for the 1989/90 season were not yet available at the time of writing.

Rational Pest Control in Rice in Burkina Faso

by Frans Meerman

Introduction

In Burkina Faso, per capita rice consumption has almost doubled between 1960 and 1980. However, domestic rice production has not been able to meet both the demands of a growing population and this change in eating habits. Consequently, in 1986 rice imports were almost seven times higher than in 1980 (INERA[1], 1989), with these imports representing about 70 percent of the total consumption.

The "Vallée du Kou," with its 1,045 ha, is the largest irrigated rice area in Burkina Faso, accounting for about 25 percent of the country's rice production. A total of 1037 farmers, each with a plot of 1 ha, work in the scheme, which is itself divided into 10 blocks. The scheme was initiated in the early 1970s with assistance of first Taiwan and later the Peoples' Republic of China. In 1973, mean yield levels of 6.5 tons/ha of paddy rice were obtained. By 1982, yields had dropped to 2.7 tons/ha. The disintegration of both the irrigation system and the farmers' cooperative, as well as problems with soil fertility, were responsible for this sharp decline. The Dutch Government started assisting the project in 1980. In 1985 the rehabilitation of the scheme was initiated with the following objectives:

(1) reorganization of the farmer cooperative, aiming at financial independence;

(2) improvement in the living conditions of the families inhabiting area (currently 15,000);

(3) improvement of rice production through rehabilitation of the irrigated area, improvement of water management, recovery of soil fertility, and introduction of new rice varieties and crops such as maize and wheat which are less water demanding.

As a result of these initiatives, two rice crops were grown in 1987 with a combined mean yield of 9.8 tons/ha/year. In 1988, the first season alone yielded 5.8 tons/ha.

Irrigated rice production in the Vallée du Kou

Constraints in rice production

Most of the farmers in the scheme have been trained in rice growing by the Chinese. At present, the constraints relate to the time needed for weeding, correct timing of application of fertilizers, water management, and leveling of the soil. Farmers of a particular block within the scheme also have difficulty in ensuring that their fields are prepared in time for sowing and transplanting. In some cases, these constraints can result in yield differences of 3,000 kg/ha within the same block.

Insect pests

Major insect pests are the lepidopterous stemborers *Chilo zacconius*, and *C. diffusilineus*, the white rice borer *Maliarpha separatella*, the pink stalkborer *Sesamia calamistis*, and the stalk-eyed borer *Diopsis sp.* In 1986 this borer complex 32 percent losses in the dry season and 3 percent in the wet season (INERA, 1988). Other pests are the rice stem gall midge *Orseolia oryzae* and the rice caseworm *Nymphula depunctalis*. Attack by the rice gall midge rarely comes before panicle development, so it causes little loss. No experimental data on losses by these insects are available, but their importance as pests seems is increasing.

Diseases

Rice blast (*Pyricularia oryzae*) is the most important disease. Chemical control with Kitazine, recommended by the Chinese, was abolished in

1984 because losses in the Vallée du Kou were less than one percent. Although rice blast is more severe in the Banzon and Karfiguéla schemes, it is now becoming more important in the Vallée du Kou.

Development and implementation of IPM components

Varietal resistance

Resistance is available against rice blast. In 1986, the IR 1529 variety was replaced by the IR 4456 because of the development of a new physiological race of rice blast capable of overcoming the IR 1529 resistance genes.

Cultural control

Echinochloa spp. are commonly found throughout the Vallée du Kou. Control of these weeds is important because they are an alternative host plant for *Chilo spp.*. Farmers are fined if they do not clear their fields properly.

Synchronized sowing and transplanting is important to prevent the population build-up of pest and disease organisms.

The larvae of the rice caseworm float on the water, wrapped in a piece of riceleaf. Drainage for about three days effectively controls the larvae because they can not live without water.

Biological control

Two larval parasitoids of the rice stem gall midge are found locally (*Platygaster diplosisae* and *Tetrastichus pachydiplosisae*), but the parasitism rate is high only toward the end of the season (Dakouo, Nacro and Sie,1987). No systematic observations have been made of natural enemies in the field.

Phytosanitary monitoring and threshold levels

In the past, chemical control of stem borers was recommended by the extension service and consisted of a calendar program of 2-3 applications per season, alternating between the pyrethroids Deltamethrin and Cypermethrin. These products were provided by the cooperative and made available through one contact person per block. This system was less than appropriate because stem borer attack and subsequent losses vary considerably between seasons. There was also concern because of the risk of human health hazards, since the irrigation water is used for human consumption and runs off to a nearby lake which is used for fishing. Regarding the calendar program, farmers disapproved of being automatically charged by the cooperative for an amount equivalent to 2-3 pesticide applications, particularly when they did not actually use this amount.

In 1986, research was started to develop a rational stemborer control program, based on phytosanitary monitoring and thresholds. Under this system, weekly scouting rounds are conducted by trained farmers, between day 40 and day 80 after planting out, to establish the number of "dead hearts" caused by stemborer attack during tillering and the number of "white heads" caused by attack during flowering and ripening. Economic thresholds are set at five percent dead hearts and one percent white heads. From the 1988/89 season, weekly observations are made by two trained farmers per block, using the threshold levels as above with the additional proviso that the recommendation to spray a block (100 ha) will only be given when one of these thresholds has been reached in at least five out of the 10 observation sites.

The results of the system are summarized in table 1.

Table 1. Net gain resulting from a threshold system for chemical control of stemborers in irrigated rice in the Vallée du Kou, Burkina Faso (after INERA,1988 and Dakouo et al.,1988).

	Threshold system			Calendar spray program			Financial difference[3] between programs/farmer (US $)		
year	mean n°. applic.	mean yield (kg/ha)	net profit[7] (US $)	mean n°. applic.	mean yield (kg/ha)	net profit[7] (US $)	yield	+ chemical control	= net gain
1987 (wet)[4]	0,8	4673[1]	1325	1,8	4376[2]	1214	+ 84,6	+ 18,8 =	+103,4
1987/88 (dry)[4]	0,6	4484[1]	1268	1,2	4041[2]	1135	+126,1	+ 7,4 =	+133,5
1988 (wet)[4]	0,16[8]	3592[5]	1020	2,0	3961[6]	1096	-105,1	+ 24,7 =	- 80,4

1: Mean over 20 farmers
2: Mean over 10 farmers
3: Without calculating costs for monitoring
4: Stemborer attack is always more severe during the wet season compared to the dry season.
5: Mean over 600 farmers in block 1,1A,2,3,7 and 9, but with inadequate control in blocks 7 and 9
6: Mean over 400 farmers in block 4,5 and 6
7: Based on price of US $ 0.29/kg paddy
8: In block 7 and 9 (total 200 farmers), thresholds were reached 75 days after transplanting; however, due to organizational problems the necessary applications could not be executed.

From this table the following can be concluded:

(1) With the threshold system, insecticide use in the 1987 and 1987/88 season has dropped to 55 and 50 percent of previous levels, respectively. The resulting monetary savings from reduction in inputs are low (0.6 and 1.4 percent of the net profit, respectively), but the net profit did increase 7.8 and 11.8 percent because of the higher yields obtained in these seasons.

(2) Yield levels were higher for the participating pilot farmers during the first two seasons, but lower when the threshold system was applied on a large scale in the 1988 wet season.

It would be interesting to know whether the higher yields of pilot farmers in the 1987 and 1987-/88 season are a result of better crop management or better timing of insecticide application resulting from the monitoring system.

Regarding the 1988 wet season, because of the problems with pesticide application in block 7 and 9, the results of these blocks should be eliminated from the comparison. However, separate data on blocks 1,1A,2 and 3 were not available at the time of printing. Dakouo et al. (1988) give no explanation in their report for the differences in yield with the threshold system versus the regular spray program. Therefore no conclusions can be drawn as to the effectiveness of the threshold system at farmer level and the profit farmers gain by applying the system.

It is worthwhile to emphasize some other aspects of this system:

Extension: for the pilot phase during the 1987-88 season, 20 farmers were selected and trained to apply the system in their fields. One of the project's technicians, who was himself trained with assistance of INERA entomologists, trained these farmers in monitoring. For the near future it is envisaged that the cooperative will pay for a full-time technician to coordinate the system for the whole scheme. The Plant Protection Service of the Ministry of Agriculture did not participate in the system. The training and extension service of the Vallée du Kou project has developed a technical circular on irrigated rice production, mentioning the phytosanitary monitoring system and bringing the spraying recommendations to the attention of farmers. The project has also incorporated the monitoring system in the course material for the family literacy program.

Farmer organization: from the 1988 season onwards, two farmers per block have been scouting ten fields each to establish whether the threshold for the whole block is reached. These farmers are not paid by the cooperative, but will eventually have to receive a financial remuneration. All 100 farmers of each block should be notified whether to spray or not. Although it will be difficult to develop an effective routine to inform them, it is essential for the system.

As farmers reject the current system -- which charges them for pesticides, used or not -- they are highly motivated to participate in the new one. One of the conditions imposed by the system is that the planting date for fields within one block should not differ by more than 15 days. This is to allow generalizations in the spraying recommendations. In practice, differences of up to 40 days are found because some farmers have difficulty in preparing their land in time.

Discussion

Plant versus pest monitoring

The timing of insecticide application is based on observation of leaf and panicle symptoms caused by stemborer larvae within the plant. The recommended pyrethroids can not reach these larvae, yet observations confirm that after each application further development of these symptoms is stopped (Post and Dakouo, personal communication). This can only be explained by assuming that these symptoms are caused by the first individuals of each generation. By early spraying with pyrethroids with residual effect on the leaves, young larvae that hatch from subsequent oviposition can be killed. However, no data are available on the distribution of oviposition in time nor the number of generations of *Chilo spp.* in the project area. Direct monitoring of the stemborer populations should therefore be undertaken. Synthetic pheromones could be used to monitor adult densities, and their use could even be considered for timing the pyrethroid applications. The project has worked with pheromones to this purpose but without success -- apparently the pheromone tried was not the correct one.

IPM starts with good crop management

Irrigated rice production in the Karfiguéla and Banzon schemes is less well organized than in the Vallée du Kou, as illustrated by, for example, inappropriate weeding, lack of maintenance of the irrigation canals (and resulting problems with water management) and the impossibility of synchronizing sowing and planting out. Pests, diseases, and weeds become a much greater problem under these conditions. The system of phytosanitary monitoring as developed for the Vallée du Kou would not be applicable here because of these organizational problems. Sound pest and disease management begins with good organization and management and the correct application of cultural practices. Further refinements such as thresholds for chemical control should be considered later.

Research support

The development of the threshold system has been made possible by the cooperation and involvement of INERA entomologists in the project Vallée du Kou. Up to now this cooperation has been based on the personal interest of the people concerned. For the future, this cooperation should be institutionalized to guarantee research support that will further develop the present pest and disease control program.

Conclusions

A fully farmer-operated monitoring and threshold system has been established in the Vallée du Kou for chemical control of stemborers in irrigated rice. Reductions in insecticide use of 55 and 50 percent, and net profit increases of 7.8 and 11.8 percent, have been attained with this system in the 1987 and 1987/88 seasons respectively. Farmers are motivated to apply the system in order to reduce expenditures on insecticides. However, for the 1988 wet season, a part of the insecticide applications called for under the threshold system could not be applied. As a result it is not possible to conclude why the yield levels were lower with the threshold system compared to the calendar spray program.

Adult education, using the rice production and pest control technology as course material, and farmer organization have contributed significantly to the implementation of the monitoring system. The general incidence of pests and diseases in the Vallée du Kou is also less than in other irrigated rice schemes. This is because of adequate crop management, such as weeding and synchronization in planting dates.

References

Dakouo, D., S. Nacro, and M. Sie. 1987.
Evolution saisonnière des infestations de la cécidomyie du riz, *Orseolia oryzivora* H. et G. (Diptera: Cecidomyiidae) dans le Sud-Ouest du Burkina. INERA, Station de Farako-Bâ, Bobo-Dioulasso. 8 p.

Dakouo, D., S. Nacro, R. Post, and Y. Traore. 1988.
Un système de lutte rationnelle contre les insectes ravageurs sur les périmètres rizicoles au Burkina Faso: la surveillance phytosanitaire et l'intervention sur seuils. INERA, Station de Farako-Bâ, Bobo-Dioulasso. 5 p.

INERA. 1988.
Le système de surveillance phytosanitaire et d'interventions sur seuils au perimètre rizicole de la Vallée du Kou: efficacité, rentabilité, perspectives. INERA, Bobo Dioulasso, 8 p.

INERA. 1989.
Rapport du programme riz et riziculture. Institut d'Etudes et de Recherches Agricoles. INERA, Station de Farako-Bâ, Bobo-Dioulasso. 25 p.

1. French acronym for Institut d'Etudes et de Recherches Agricoles.

Pest and Disease Control in Coffee in Kenya

by Frans Meerman

Introduction

Coffee (Coffea arabica) is the single most important agricultural commodity in Kenya and accounts for 29 percent of the country's export earnings. Some 1100 estates, ranging in size from 4 to over 500 ha account for 30 percent of the national production. The remainder is produced by the cooperative sector, representing some 230,000 smallholders with an average plot size of about 0.5 ha. Yields on the estates vary between 870 kg/ha for non-irrigated to 1550 kg/ha for irrigated coffee; in the smallholder sector (no irrigation) mean yield levels are 600 kg/ha. Besides coffee, the smallholders also grow food crops for their own consumption and other cash crops.

Major constraints in coffee production

More advanced farmers in both the estate and smallholder sectors attain yields considerably higher than the average (1200-1500 kg/ha for smallholders; 2000-3000 kg/ha for estate farmers). This indicates the existence of major yield limiting factors. For the cooperative smallholder sector, these include:

(1) inadequate canopy management (pruning, handling/ desuckering, change of cycle) and weed control

(2) low fertilizer use

(3) improper disease and pest control:

i) smallholder farmers apply only 1/3 of the recommended amount of fungicides to control coffee berry disease and leaf rust. They also spray when infections have already been established, which is too late, resulting in poor control;

ii) copper fungicides applied against leafdoes not reach the underside of the leaves, resulting in poor control. Copper may also be sprayed too late, after infection has occurred. This actually accelerates an epidemic because copper delays the abscision of diseased leaves, which then continue to sporulate (so called 'tonic' effect);

(iii) smallholder farmers apply 2-3 times more broad spectrum insecticides than recommended. Because they can not differentiate well between pests and beneficial insects, they may even spray against natural enemies, causing secondary pest outbreaks and only making the situation worse.

The following constraints contribute to the problem of improper disease and pest control by smallholder farmers:

Technical:

- lack of sufficient number of disease resistant coffee seedlings ("Ruiru 11");

Socioeconomic:

- lack of resources to buy inputs (fertilizers and fungicides) due to delayed and irregular payment for their coffee and the need to spend cash on non-farming activities;

- lack of inputs at cooperative stores and lack of cash to buy inputs elsewhere (inputs are supplied at cooperative stores on interest-free credit);

- lack of time to carry out the necessary agronomical practices because of the need to divide labor between cash and food crops;

• costs of fungicides which have increased 80-100 percent while coffee prices have dropped 50 percent during the last few years;

Educational:

• lack of adequate knowledge on pruning, weed control and pesticide use.

In the plantation sector, a division should be made between the small (4-20 ha) and large (20-500 ha) estates. Most small estates do not use irrigation, have weak crop management and use low levels of inputs (fertilizers, fungicides and mulch for weed control). This restricts their yields to 600-700 kg/ha. Furthermore, coffee quality can be a problem due to inadequate processing at the farm. By contrast, the management of the large estates is adequate and in general inputs are used correctly.

Research and development of pest and disease control components by the Coffee Research Foundation (CRF)

Insect pests

Coffee is attacked by a large number of insect pests. The 1987 edition of the CRF Coffee Growers' Handbook enlists 31 species. The most important are: coffee leaf miners (*Leucoptera meyricki* and *L. caffeina*); antestia bug (*Antestiopsis spp.*); capsid bug (*Lygus coffeae*); giant looper (*Ascotis selenaria reciprocaria*); leaf skeletonizer (*Leucoplema dohertyi*); coffee thrips (*Diarthothrips coffeae*); cottony scale (*Icerya pattersoni*); fried egg scale (*Aspidiotus sp.*); soft green scale (*Coccus alpinus*); root mealybug (*Planococcus citri*) and coffee lace bug (*Habrochila spp.*).

Injury-loss experiments have not been carried out in Kenya and the economic importance of insect pests has not been assessed. Local outbreaks occur and can reduce yields up to 80 percent and more. However, all species are generally kept under adequate levels of control by a complex of indigenous natural enemies, particularly parasitic wasps and predators such as lady bird beetle species *(Coccinellidae)*. During the early 1950s, an exotic parasite (*Anagurus kivuensis*) was introduced from Uganda against the Kenya mealybug, *Planococcus kenyae*. It has kept this pest under control ever since, except during the 1960s, when this control was disrupted by the use of organochlorines like DDT, Aldrin and Dieldrin.

Development of IPM components

Integrated Pest Management (IPM) is the approach for pest control recommended by the CRF. The following IPM components are recommended:

Cultural control:

Good pruning is essential to prevent the antestia bug from hiding in leaf clusters. Antestia bugs are therefore only a problem when farmers do not prune properly (mostly smallholder farmers).

Mulching prevents thrips larvae from reaching the soil to pupate. However, leaf miner incidence is increased, as mulch is an ideal pupation site for them.

Biological control:

Green and brown scale and mealybug species produce sweet exudates, on which ants feed. These ants interfere with the biological control by *Coccinelid* beetles. Skirting and banding the lower trunk with an insecticide keeps off attendant ants, allowing the beetles to exert their control.

The recommendation for control of the helmet scale (*Saisetia coffeae*) and white waxy scale (*Ceroplastes brevicauda*) is to cut off badly infested branches but leave them on the ground to promote emergence of parasitoids.

Chemical control:

To enhance survival and re-immigration of natural enemies it is recommended never to spray more than twice against any pest and to use spot spraying whenever possible. Systemic insecticides like Disyston, Furadan and Temik are recommended against sucking and mining insects (only at large estates because of their high toxicity) to safeguard the population of beneficial insects;

Short-lived organophosphate insecticides like Fenthion and Fenitrothion are recommended and have replaced persistent organochlorines like DDT and Dieldrin in order to safeguard populations of beneficial insects;

The following action thresholds are recommended[1]:

- antestia bug: 1-2/tree, depending on the area
- capsid bug: 4/tree
- giant looper: 10-30 caterpillars/tree, depending on whether there is a crop or whether suckers are needed for the next cycle
- leaf miner: >35 moths/tree
- leaf skeletonizer: 20-30
- caterpillars/tree or >35 moths per tree
- coffee thrips: 1-3/leaf, depending on water stress of trees.

Diseases

Coffee berry disease (CBD), caused by *Colletotrichum coffeanum*, attacks expanding and ripening berries and destroys the bean. CBD is most serious at higher altitudes and during years with high rainfall. Overall losses of 30 percent were recorded in 1967 (Griffiths, 1969). With adequate control at large estates, losses of 5-10 percent will occur in years with average rainfall and up to 30 percent in years with high rainfall. The omission of one or two fungicide applications may result in losses up to 80 percent (Finney, personal communication). Smallholders estimate losses between 44 percent and 69 percent when no chemical control is applied.

At lower altitudes, the coffee leaf rust (LR), caused by the fungus *Hemileia vastatrix*, is the most serious leaf disease, resulting in premature leaf fall and reducing the number of flowers. Bacterial blight of coffee (*Pseudomonas syringae*) is restricted to the higher altitude coffee growing areas. Fusarium bark disease, caused by *Gibberella stilboides* and *F. solani*, is a minor disease.

Development of IPM components for diseases

Cultural control:

Pruning reduces leaf wetness and humidity necessary for CBD infection, sporulation and dispersal. It also enhances fungicide penetration.

Host plant resistance:

The high yielding variety Ruiru 11, developed by the CRF, possesses high levels of resistance against CBD and LR. In 1988, some 1500 hectares were planted with this new variety. However, because of limited seed production, only 1000 ha per year (3 percent of the total coffee area) can be planted with this variety. K7 and Blue Mountain varieties produce higher quality coffee than Ruiru 11, but show only moderate resistance to CBD. Many smallholders grow the very susceptible SL28 and SL34 varieties.

Chemical control:

Preventive spraying against CBD and LR is imperative. Depending on the cropping pattern and variations in rainfall, four different spraying programs are recommended. These programs result in 8-10 applications of organic fungicides against CBD and a total of 5-6 applications of copper and organic fungicides against LR annually. Part of these applications can be combined in tank mixtures. Fungicides account for 25-30 percent of the total production costs.

The introduction of a warning system could reduce the number of fungicide applications. However, its development is hampered by the following:

(1) the extreme variability of the rainfall pattern--the meteorological service is not able to provide

accurate and reliable predictions on rainfall;

(2) the inability of many farmers to spray in time, due to the large acreage (one spraying round can take up to three weeks) or because they do not have their own spraying equipment.

Extension

An adequate extension service is essential to improve the performance of smallholder coffee farmers. Extension services are provided by the Ministry of Agriculture and receive technical support from the CRF. The following delivery methods are used:

- farmer training and visit, involving 3000 extension workers of the Ministry of Agriculture, trained by the CRF;

- technical training by CRF for farm managers from large estates and secretary managers from the cooperative sector;

- publication of technical circulars by the CRF for use by extension workers and farm managers;

- field days in farmers' fields;

- agricultural shows;

- radio programs (in Swahili);

Large estates can appoint well-trained farm managers to address disease and pest control. The CRF provides the necessary training and information (technical circulars).

Constraints in extension relate to:

(1) insufficient manpower to reach all smallholders;

(2) lack of coffee specialists;

(3) CRF's technical circulars, which are too difficult for smallholders to understand.

Given the fiscal constraints of the Ministry, a major expansion in coffee extension activities cannot be anticipated. There is also a strong need to improve the quality of extension.

Discussion

Adjustment of pest and disease control recommendations to yield levels

Yield levels in coffee range from 120 kg/ha (less advanced smallholders) to 2500 kg/ha (advanced estates) due to differences in canopy management, weed control and correct levels and use of inputs (fertilizer, fungicides, irrigation). Crop protection becomes more important when higher investments are made to increase yields. Also pests and diseases may have more impact at higher production levels because trees are more under stress (Logan, personal communication). Therefore pest and disease control recommendations should be adjusted to the production level and the changing economics of coffee growing, and be integrated in the extension package.

At each production level, the 'key' factors limiting yield levels should be identified. Through interdisciplinary research, different recommendation should be developed for each production level. The extension service should provide control recommendations, adjusted to the different technology levels of farmers, and use the appropriate delivery methods. The implementation of the recommendations should be monitored. When the farmers do get higher yields through the correct application of the recommendations, they can be taken to the next production level.

For pest and disease control this would mean that the particular role of every IPM component should be determined for each production level. Some IPM components being developed by the CRF will be discussed below.

Chemical control of insect pests

Different chemical control practices by farmers can be identified:

(1) no insecticide use (particularly the large scale sector (Finney, personal communication), enabling

the natural enemies to do their work, resulting in adequate control levels except for shortlived outbreaks of leafminers;

(2) spraying according to the threshold levels recommended by the CRF (both advanced small and large scale coffee growers);

(3) more spraying than recommended because:

- smallholder farmers have difficulty in discriminating between pests and beneficial insects. As a consequence, these farmers may spray against natural enemies. The availability of an illustrated 'Field guide to natural enemies in coffee' and a portable kit of preserved natural enemies would help extension workers and farmers to recognize beneficial species. This would also make them more receptive to biological control.

- threshold levels are not used: (the smaller estate and cooperative sector uses twice as much insecticide as the large scale sector (Nyoro & Whitaker, 1986);

- very little insect damage is tolerated: at certain large estates, pest control decisions are taken by the estate owner rather than by the farm manager. In some cases, economic pressure and/or partial understanding of biological processes may cause them to use insecticides excessively, resulting in high costs and secondary pest outbreaks. To promote sound pest management, the extension system should therefore also address estate owners.

Since pesticide prices have almost doubled and coffee prices have dropped by 50 percent during the last few years, the expenditure for chemical control should be reduced. Why is chemical control recommended by the CRF when some large estate owners obtain adequate control without spraying? The recommended threshold levels should therefore be revised.

Particular attention should be paid to the coffee leaf miner, as the clearly visible injury caused by this pest seems to trigger farmers to spray (probably too early from an economic point of view). This causes outbreaks of giant looper, stinger looper, leaf skeletonizer and lace bug. Short-lived and localized cyclic outbreaks of leafminers --possibly above the economic threshold-- do occur when no chemical control is applied. The large estate owners argue, however, that chemical control should not be recommended because insecticides interfere with the biological control of leafminers and other pests. The validity of this argument should be assessed by performing crop loss assessment experiments under varying crop management regimes and a cost-benefit analysis. Such a cost-benefit analysis should take into consideration that large estates can take the risk of short-lived and localized outbreaks more easily than can smallholder farmers because of the former's financial reserves and the large acreages which makes it possible to have good yields in the non-infested blocks.

Biological control of insect pests

There is evidence that a many pest problems are induced by insecticide use. Research should be done to identify the mechanisms of disruption of biological control and the feasibility of eliminating all insecticide applications should be investigated.

Occasionally spot spraying has led to local outbreaks of cottony scales and fried egg scales. Mass rearing and release of predatory ladybird beetles (*Coccinellidae*) to enhance their rapid re-establishment might be considered.

During a visit to the Kangaita coffee estate near Ruiru, the farm manager showed coffee trees that had suffered from a severe fried egg scale attack. To control this, he sprayed Teepol (a car wash detergent) which, according to the farmer, attracted the ladybird beetles which then controlled the fried egg scales. This merits investigation along with other ways to enhance populations of natural enemies.

Disease control

Preventive fungicides are used for CBD, LR and BB control. However, a substantial part of the smallholders use too little fungicide and also apply it too late because they mistakenly believe that the fungicides act curatively. This results in ineffective disease control. In fact, leaf rust increases when copper is sprayed too late due to the "tonic" effect. Radio programs might help farmers time their spraying properly, according to the expected onset of the rains.

Research should be undertaken to determine the impact of diseases on crop yield and quality at lower production levels, resulting in recommendations for fungicide use adjusted to lower yield levels.

Copper has been used continuously for the last 25 years at rates of 15-30 kg/ha. During that period, the CBD has spread from humid (high altitude) to less humid (lower altitude) regions. Recent laboratory studies have shown that spores of particular CBD strains germinate faster and at higher percentage in presence of copper (Maithia, personal communication). In addition, sprinkler irrigation has been introduced more and more. Both practices might explain the increase in CBD during the last decades. A critical appraisal of both copper use and overhead irrigation seems to be necessary.

Conclusions

Integrated pest management is recommended by the Coffee Research Foundation as the approach for pest and disease control in coffee. Biological and cultural control measures and a resistant coffee variety have been developed. Economic injury levels have been established to minimize the use of insecticides, and fungicides are used according to the cropping pattern and variations in rainfall.

Coffee production varies between 120 kg/ha and 2500 kg/ha as a consequence of differences in crop management and the ability of farmers to apply the IPM components mentioned. Different biological and chemical control recommendations, along the lines of the suggestions provided above, should be developed to address the particular needs of smallholder and large scale coffee growers.

References

Griffiths, E. 1969.
Kenya's biggest problem. Span 12:2

Masaba, D.M., D.J. Walyaro, and S.B.C. Njagi. 1982.
Country report Kenya; coffee berry disease in Kenya. Proc. 1st Reg. Workshop 'Coffee Berry Disease", Addis Ababa, p.45-69.

Nyoro, J.K., and M.J. Whitaker. 1986.
Factors influencing the adoption of coffee management practices by smallholder coffee farmers in Kenya. Kenya Coffee 51:313-328.

1. These levels are based upon practical experience.

Integrated Pest Management for Multiple Foodcrops in Western Kenya

by Frans Meerman

Introduction

In South Nyanza, western Kenya, small-scale subsistence farmers around Lake Victoria and the foothills of the Kisii highlands grow maize, sorghum, cowpea and beans during the long and 'reliable' rainy season from March through May. Cotton is grown as a cash crop. A second crop may be grown during the short rainy season from October/November to December.

On the Kisii highlands, at altitudes over 1,300 m, rainfall is more abundant and soil fertility is higher. Two rainy seasons allow the growing of two crops a year. Besides cereals and legumes, sweet potato, cassava, banana, coffee and vegetables are grown, generally in intercropped systems. Surplus yields are sold at local markets.

Constraints in food crop production

The following factors are responsible for the relatively low maize, sorghum and cowpea yields (2000-2500 kg/ha, 1500-1800 kg/ha and 130-300 kg/ha respectively) in Kendo Bay Division (Lakeshore) and Oyugis Division (Kisii highlands) (Seshu Reddy, personal communication):

- incorrect crop husbandry practices such as too wide plant spacing, insufficient use of fertilizers, late weeding, use of susceptible varieties, late and unsynchronized planting;
- losses by pests (stem and pod borers);
- post-harvest losses by insects and rodents;
- erratic rainfall in some years

Constraints to improving this situation were identified as follows:

technical: non-availability of resistant high-yielding varieties; improper storage structures, causing considerable post harvest losses by rodents

socioeconomic: shortage of labour; lack of cash and credit to buy inputs and farm implements and to hire labour

educational: lack of knowledge regarding correct crop husbandry practices and appropriate insect control techniques; education levels are low and farmers are not within reach of the agricultural extension system.

Importance of insect pests

Early attack by stem and pod boring insects (*Chilo partellus, Busseola fusca, Sesamia calamistis, Eldana saccharina* and *Maruca testulalis*) and the sorghum shoot fly (*Atherigona soccata*) cause important losses in field maize, sorghum and cowpea. Occasionally armyworm and aphid attack occur. Stem borer losses in sorghum range from 5 to 83 percent. *C. partellus* causes 18 percent loss in maize in Kenya (ICIPE, 1989). In cowpea losses due to pod bugs and borers range from 37 to 48 percent in South Nyanza district. According to farmers' estimates, post harvest losses due to the flour beetle (*Tribolium sp.*), maize weevil (*Sitophilus sp.*) and grain moth (*Sitotroga sp.*) and rodents amount to more than one quarter of the total harvest in maize, sorghum and cowpea (Seshu Reddy, personal communication).

Small-scale farmers practice hardly any control of insect pests; pesticides are not applied (too expensive) and only half of the farmers destroy the crop residues to prevent off-season survival of diapausing stem borers. However, farmers apply agronomic practices without being concious of their insect pest suppressive effect, like intercropping of grain crops with legumes which helps protect against stem borers, and early planting which reduces the exposure of the most vulnerable stage of the crop to stem borer attack.

ICIPE's crop pest research programme

The objective of the crop pest research program is to contribute to a sustainable increase in small-scale food production, through reduction of crop losses due to insect pests by control measures that are environmentally safe and both economically and technically feasible. Integrated Pest Management (IPM) is the approach that has been chosen and the following components are being developed:

(a) intercropping and other cultural practices

(b) host plant resistance

(c) biological control

(d) behavioral manipulation

Research and development of these components is carried out by ICIPE: "bionomics and applied ecology," "plant resistance to insect pests," "biological control" sections and the social science interface research unit. The program involves three stages:

(1) basic research on IPM components at ICIPE;

(2) multi-site testing of promising components at farmers' fields (under ICIPE management);

(3) pilot trials with proven promising components at farmers' fields and under their management, but supervised by ICIPE.

Components (a) and (b) have gone through the stages (1) and (2) and are presently in stage (3). Details on all components are given in table 6.

Implementation at farmer level

In 1986, a joint ECA/ICIPE project entitled *Reduction of Food Losses through Insect Pest Management and Use of Small-Scale and Low-Cost Farm Equipment in Africa* was initiated. The project is being executed by ICIPE in collaboration with Kenya's Ministry of Agriculture and is funded by the Belgian Government through the UNECA.

Farmers' attitudes, perceptions and knowledge regarding agronomical practices, pest problems and their control, and the socioeconomic environment were studied in 1986 by ICIPEs' social science interface research unit. Consequently, 50 farmers in Kendo Bay and 50 farmers in Oyugis Division were identified to participate in the project's implementation phase. The Ministry of Agriculture seconded 7 members of its extension staff for the project. This staff was trained at ICIPE in both the agronomic and pest control aspects of cereal and legume growing.

Farmer training and support

Farmers were trained in the use of improved varieties (pest resistant and high yielding), multiple cropping, adjustment and synchronization of planting dates to minimize pest attack, use of organic fertilizer and manure, proper disposal of crop residuals and the construction of improved storage structures to prevent post-harvest losses.

Table 6. ICIPE's Integrated Pest Management research & development program for stem and pod borer control in maize, sorghum and cowpea (ICIPE, 1989).

Cultural practices

Intercropping sorghum-cowpea significantly reduces *C. partellus* oviposition on sorghum as compared to sorghum monocrop or intercrop with maize. Intercropping cowpea with maize affects the establishment of newly hatched larvae of the cowpea pod borer, and the maize acts as physical barrier to ovipositing *M. testulalis* females. However, intercropping maize and sorghum increases stem borer attack on both crops.

Early planting reduces losses by stem borers and sorghum shoot fly.

Disposal of crop residues prevents diapausing stem-borers to survive the off season.

Host plant resistance

Sorghum: Eight varieties show high or moderate resistance and have good grain yield.

Maize: Four cultivars with borer resistance and good yield characteristics are suitable for cultivation.

Cowpea: One cultivar combines some resistance to the pod borer with good grain yield and quality.

Biological control

11 parasitoids of *C. partellus* and 9 parasitoids of *M. testulalis* have been found; however, their populations are too low to keep pests under control. Inundative release of mass-reared *Trichogramma mwanzei* (egg parasitoid) have provided effective control of *C. partellus* at experimental level. Releases at farmer level have not yet been made.

Indigenous pathogens of *C. partellus, E. saccharina, B. fusca* and *M. testulalis* are being investigated as possible biopesticides. The most promising are: *Nosema sp.* (protozoa), *Panagrolaims sp.* (nematode), *Bacillus thuringiensis* (bacteria) and *Metharhyzium anisopliae* and *Beauvaria* (fungi).

Behavioral manipulation

Using sex pheromones to monitor stem borer populations allows appropriate timing of control measures (e.g. biopesticides). An improved delta trap has been developed for population monitoring of *C. partellus*. The synthetic pheromone of *B. fusca* is used to study the disruption of male-female communication.

The following delivery methods were used:

- 3-days training courses at the Homa Bay Farmers' Training Center (on the use of plow and animal traction and the construction of improved storage structures);

- one-to-one communication between extension workers and farmers;

- farmer-scientist communication.

Besides this training, the farmers were provided with improved maize, sorghum and cowpea seeds, 50 kg of fertilizer, farm implements, construction materials for improved granaries and tractor plowing. All were provided free (except the plowing, which was provided at cost) to help trigger the process of increasing agricultural production.

Results

Yield levels of participating farmers have improved considerably (see table 7). During the projects' implementation phase, the pest populations and damage caused on farmers' fields are being assessed along with the timing of farm operations and the use of inputs such as labour and cash. The effectiveness of the different techniques will be analyzed. Adoption rates are an important criteria for success. The impression exists that improved crop husbandry practices contribute as much, or maybe even more, to the higher yields as improved pest control.

The participating farmers are expected to apply the recommendations after the project ends. They will continue to construct modified granaries because of the improved protection against pests and the need for more capacity to store higher yields. Many farmers show interest in paying for plowing by the projects' tractor and are interested in buying a second tractor for their own use. Non-participating farmers are also heard to ask the national program officer whether they can be included in the project.

The higher yields allow farmers to sell their surplus to the local markets. Farmers have used the extra income to improve their houses, to pay for school fees, to buy animals for ploughing and to hire labor for weeding.

Table 7. Percentage increase in sorghum grain yield when using improved and resistant sorghum varieties in farmers' field trials in two regions in western Kenya, including an intercrop with cowpea ICV 2; long rainy season 1988 (from ICIPE,1989).

	% grain yield increase	
Factor	Oyugis(6)*	Kendu Bay(16)*
LRB 5 mono crop over farmers' mono crop	26.2	53.0
LRB 5 intercrop over farmers' mono crop	48.1	62.0
LRB 5 intercrop over mono crop	17.4	5.4
LRB 8 mono crop over farmers' mono crop	13.4	44.2
LRB 8 intercrop over farmers' mono crop	21.7	61.2
LRB 8 intercrop over mono crop	7.3	11.8
Intercropping advantage (land equivalent ratio, LER)		
LRB 5	1.9	1.6
LRB 8	1.7	1.6

*No. of farmers participating in the trial.

Discussion

Biological control

Indigenous parasitoids and pathogens of stem borers control these pests adequately. Multiple cropping of cereal and legume crops does not significantly enhance biological control. Inundative biological control of *C. partellus* with an egg parasitoid and the use of pathogens as biopesticides are being developed. However, both techniques require the production of bio-control agents and a distribution network for delivery to the farmers. Recurrent costs are involved for mass production and (repeated) field releases. Also, training of farmers is necessary to monitor stem borer populations and to introduce the bio-control agents correctly. In particular, the timing of application of biopesticides is critical with respect to the development stage of the pest species and humidity.

These requirements are very difficult to meet because of the low economic value of food crops, the low education level of the farmers and inadequate extension facilities.

Farmers probably consider agronomic problems and post-harvest losses more important than stem borers, particularly in western Kenya where stem borers attack is less than in the coastal areas.

Currently no insecticides are used against stem borers. Therefore, it is doubtful that subsistence farmers can be motivated to use complicated biological control methods against only one pest, even should parasitoids and/or a biopesticide be distributed free of charge. The feasibility of an inundative biological control system and biopesticide use may therefore be greater in farming systems with higher yield levels of crops which sell at reasonable prices, and where governmental institutions and/or farmers' associations can provide the necessary training in biological control and can support the organization of inputs.

Classical or inoculative biological control does not require any farmer involvement once the natural enemy has established itself, and therefore seems to be more appropriate. ICIPE has recently started a research project, in collaboration with the Dutch Wageningen Agricultural University and CABI, on the introduction of *Apanteles spp.* as parasitoids of *C. partellus*.

Agronomic constraints not addressed by the project

ICIPE's crop pest research program has generated new technology to improve yields and reduce losses by insect pests through cultural practices and the use of improved varieties. Within the ECA/ICIPE project the rate of adoption of the "IPM package" by farmers is used to evaluate the appropriateness of the recommended system. However, farm management and insect control decisions depend on many factors, including pests other than insects. Striga (*Striga hermonthica*) and maize streak virus have become more and more important and should not be left out the IPM package simply because they are not the subject of ICIPE's research. Control of these pests would also maximize the benefit of ICIPE's insect control recommendations.

Follow-up of the ECA/ICIPE project

The ECA/ICIPE project has proven that the delivery of a simple 'IPM package' by motivated extension workers can result in considerable yield improvements by small-scale subsistence farmers. The involvement of ICIPE as a research institute during the projects' implementation phase has been very important for obtaining feedback from farmers to improve the technical recommendations. Now that a basic "IPM package" is available for dissemination, more farmers should be included and the program should be extended to other areas. The establishment of farmer associations and women's groups may prove important instruments to disseminate the knowledge and to provide feedback to research workers. ICIPE should continue to be involved in training of extension workers and should develop new control methods as the present system evolves and as farmers become more and more interested and capable of applying particular control measures, including biological control.

An assessment of the economic costs and benefits of the project both at farmer and (regional) economic levels should provide the government with the necessary information to decide whether to follow the same approach in other areas by organizing farmer training, providing some external inputs free of charge to trigger agricultural development and by establishing credit facilities.

Conclusions

ICIPE has developed a IPM package for stem borer and pod borer control in small-scale food crop production in western Kenya. Recommendations are given on cultural practices and host plant resistance for stem borer control, improved fertilizer use, construction of improved storage structures to prevent post- harvest losses, and better land preparation. Recommendations on other pests like striga and maize streak virus should also be incorporated into the IPM package.

Inundative biological control techniques and the use of biopesticides are being developed. Implementation of these approaches, however, requires trained manpower and involves recurrent costs for mass production and release. These conditions are hard to meet in the small-scale food crop production in western Kenya. Therefore, ICIPEs' recently started classical biological control program might prove more appropriate to small farmers' conditions.

Through the implementation of the IPM package, considerable yield improvements have been achieved at farmer level. Close contact with extension officers and research workers has motivated the participating farmers to continue to apply the IPM recommendations and to share their knowledge with neighbouring farmers.

References

ICIPE. 1986.
Joint project on reduction of food losses through insect pest management and use of small-scale and low-cost farm equipment in Africa: report on the pre-implementation phase. UNECA project JEFAD/-AMS/33. ICIPE, Mbita Point, 63 pp.

ICIPE. 1989.
Achievements and highlights: crop borers 1980-1988. ICIPE, Nairobi, 24 pp.

Integrated Pest Management in Irrigated Rice in Madagascar

by Philippe Zahner*

Introduction

Madagascar is an island of 587,000 sq. km., lying in the Indian Ocean east of the Mozambique coast. The population is estimated at 11 million. Humans first settled the island about 1500-2000 years ago, with successive waves of immigration from Asia and Africa. One legacy of the Indonesian influence is the extreme importance of rice cultivation in the country. The Malagasy people have the highest per capita rice consumption in the world, about 450 g/person/day. A family of eight consumes about 1650 kg of rice per year, which represents the production of about one and one half hectares of paddy.

Madagascar was once an important rice exporter. However, the productivity of the cultivated fields has not increased over the past 60 years while the population has grown at an average 2.8% per year. By the 1970's there were serious shortfalls of rice, leading to importation. The record level was an importation of 342,000 tons in 1982, representing 15% of national consumption and costing the the public treasury some US$ 100 million.

Achieving self-sufficiency in rice by 1990 thus became a major agricultural policy objective. Rice marketing, once a state monopoly, was liberalized in 1986. Since 1982 the government has promoted a variety of efforts to increase rice production, both by rehabilitating irrigation schemes and by increasing the area cultivated. Raising productivity has also been an important focus, through selection of high-yielding varieties, improved seeds and mechanization. Much of the intensification effort has been concentrated on rice cultivation in the densely populated, central High Plateau where there is a strong tradition of intensive rice cultivation. Despite this concentrated activity, rice production in this area is not sufficient to meet the country's needs.

Background

History of the project

Between the High Plateau and the coastal zone, where cultivation is primarily based on extensive slash-and-burn methods, lies the basin of Lac Alaotra. This area is regarded as a potential "grain basket" where rice production could be increased to meet the country's growing demands. As a result, the Lac Alaotra area has been the site of a series of actions aimed at intensifying rice production. For example, a World Bank loan helped the "Lac Alaotra Management Company" (French acronym: SOMALAC) restore irrigation schemes in the area. Great efforts were put into identifying new rice varieties which would perform well under local conditions, and small-scale mechanization was promoted.

In 1982 the government established a program called "Taona Zina" ("the fertile year") which aimed to increase rice production in the Lac Alaotra basin by reducing losses to the African white rice borer (*Maliarpha separatella* Rag) which they estimated reduced annual production by about 30%. The proposed program consisted of chemical control of the pest by aerial spray application over an area of

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60,000 ha. It was to be financed by Swiss bilateral aid and executed by the Swiss pesticide company Ciba Geigy. The Swiss Directorate of Development Cooperation and Humanitarian Aid (DDA) declined to accept the proposal, which it viewed as a commercial operation, but the Swiss Federal Office for External Economic Affairs agreed to support it, as proposed, on a balance of payment aid basis. The Ciba Geigy program was carried out in the 1982/83 season.

Recognizing, however that this approach was not an acceptable long-term solution, the Swiss government invited researchers from the Federal Institute of Technology in Zurich to join the Malagasy Plant Protection Service and agricultural research service (MRSTD) in a mission to evaluate the program. Their conclusion was that the operation had been very well organized and technically implemented by Ciba Geigy, but that there was a fundamental lack of the basic information needed to evaluate the appropriateness and overall effectiveness of the program. They also stressed that this chemically-based approach threatened the ecology of the rice agro-ecosystem. For example, there was concern that the indigenous leafhoppers, currently not of economic importance, would develop into major pests as they have in irrigated rice in southeast Asia.

Based on these conclusions, the Malagasy and Swiss governments agreed to establish a joint research and development project aimed at clarifying the economic importance of rice pests in Lac Alaotra (particularly the stem borer which was the target of the "Taona Zina") and identifying future alternatives to chemical control.

The physical setting

The Lac Alaotra Basin consists of the lake itself, (240 km^2), surrounded by a 600 km^2 area of swamplands which is bordered by 700 km^2 area of paddy rice fields. The basin is surrounded by hills up to 1500 m high, where deforestation has created a serious problem of soil erosion leading to extensive sedimentation of the great expanse of rice fields. The total annual rainfall, about 1,100 mm/year is generally adequate for one rice crop, but its distribution is problematic as the rains often come late.

Sociology

At the beginning of this century the area's population was about 30,000, belonging to an ethnic group called the Sihanaka. This population was later expanded by a steady influx of immigrants of other ethnic groups from the High Plateau. The current population is estimated at 230,000. Following the agrarian reform which began in the 1960's the former large estates have been redistributed to smallholders. Over half of the area now consists of holdings of 3 ha or less, and less than 10% of the land is in holdings of over 10 has.

The land is cultivated either by the actual landholders or by sharecroppers. The proportion of landholder farmers is higher in the large, irrigated schemes managed by SOMALAC (total 35,000 ha) than in the 42,000 ha serviced by the state agricultural service (French acronym: CIRVA), where sharecroppers cultivate more than half the total land area.

Agricultural practices

The peasants of the Lac Alaotra region traditionally produced one rice crop per year, with the dry paddies used for cattle forage during the off-season. Land preparation, using animal traction, begins with the first rains in October/November.

Local farmers follow two types of cultivation practice: (1) direct seeding, in which seeds are scattered onto the mud surface, and (2) replanting, in which seedlings are sown densely in a nursery and transplanted after about 30-40 days. Replanting is generally not done in straight lines (as it is in more populated areas and on research stations). To have a sufficient growth period planting must be completed by December. Weed control is very important during the vegetative growth stage which lasts until early March. The rice flowers in April and matures in mid-May, when it is cut and set to dry in large piles beside the fields.

In the SOMALAC zones average rice yield over the past 10 years has been about 3 tons/ha. In the areas serviced by CIRVA the average yield is 2.2 t/ha. In addition to the irrigated rice the peasants grow crops such as rain-fed rice, maize and manioc in the surrounding hills.

The pest complex

At the beginning of the project the main rice pests were believed to be the white rice borer (*M. separatella*) and the rice hispid (*Hispa gestroi*), called the "pou epineux du riz." The larvae of the lepidopterous stem borer penetrate the stem and develop over 5-6 weeks after which they emerge and pupate in the ground. They cause a reduction in the number of grains in the rice head but no symptoms of attack visible to the naked eye. This makes their populations and impact difficult to quantify and is in striking contrast to many other type of boring insects which cause clearly visible sterile panicles ("white heads"). The hispid is a beetle whose adults feed on the epidermis of the leaves and whose larvae and pupae live in tunnels inside the leaves. They attack young plants preferentially and cause a drying out of the leaves which can reduce rice yields significantly at high densities. Heavy infestations are clearly visible as large white patches in the field.

While farmers are aware of weeds in the fields, the government did not subsidize weed control as an means of increasing production, apparently believing farmers could take appropriate control measures on their own. Rice blast disease (*Pyricularia oryzae*) is also potentially important but its impact has not yet been studied.

Pest management practices

Prior to 1982/83 farmers in the area were responsible for all aspects of pest control with no direct assistance from the government aside from general extension advice. Farmers directed control efforts primarily against the hispid and weeds. Under the "Taona Zina" operation from 1982-1986 insecticide application (Dimecron ULV) against the stem borer was carried out by Ciba Geigy and free of charge to the farmers. Application was primarily by air, but over the course of the 4-year operation Ciba Geigy also developed a terrestrial method for applying Dimecron at 96% concentration using a specially adapted ULV sprayer. The application method is not difficult but there is considerable concern over the hazards of farmers handling this very toxic product at such high concentrations. The free insecticide applications ended in 1986, in effect returning farmers to the pre-1982 conditions.

Weed control was not addressed under the "Taona Zina" program. The most important factor in weed control is water management: the water level in the field must be maintained at 10 cm to enable the farmer to control weed growth with 2,4-D (the most familiar and available herbicide). Without adequate control the composition of the weed community changes: grasses and perennial weeds come to dominate, requiring the use of other herbicides which are more expensive and difficult to obtain. Recognizing the importance of water mastery and weeds, farmers pursue the more labor- and capital-intensive transplanted cultivation mostly in fields where adequate irrigation is assured.

The project

Objectives

The main objective of the Swiss/Madagascar project is to carry out basic research on the irrigated rice agro-ecosystem and use the findings to develop an IPM program which is less dependent on chemical insecticides. The program plan consisted of three phases:

(1) 1984-88:
basic research (economic status of various pests, population dynamics of key pests, composition and impact of the indigenous natural enemy complex, influence of agricultural practices on pest management, identification of resistant varieties, etc.);

(2) 1988-92:
(i) definition of an IPM program based on research findings, and its implementation through support of the regional Plant Protection Service and Agricultural Extension Service, and

ii) research for development of a biological control program for the stem borer: evaluation of the potential for control by indigenous natural enemies (arthropods and pathogens) and of the potential for introduction of exotic biocontrol agents;

(3) 1992-?

(i) field implementation of biological control for the stem borer (if research successful), and

(ii) support for IPM strategies at a national level and (eventually) extension of the IPM program to other regions in coordination with other involved donors such as the West German GTZ.

Institutional framework

The project is based at the Agricultural Station of Lac Alaotra (CALA), a field station of the National Center for Agronomic Research and Rural Development (Malagasy acronym FOFIFA) of the MRSTD. CALA has numerous responsibilities, including maintaining national collections for food crops, producing rice seed and research on rice, maize and other crops. Its diverse staff is important to the interdisciplinary approach of the project. The project staff consists of three Malagasy and three Swiss researchers and Malagasy technicians. The Swiss are paid by the Swiss DDA, the Malagasy researchers by the Malagasy government, and the technical staff by the project itself. Identification of the Malagasy researchers was made difficult by the fact that there are only seven government entomologists in the country. The project research staff works closely with the local agricultural services such as CIRVA and the regional subdivision of the Plant Protection Service, Ministry of Agricultural Production and Lands (Min/Agri), who are charged with the practical implementation of IPM in the field.

Specific research activities for each year are decided through a 3-step process: (i) the project team evaluates results of the past season and prepares a proposal for the next season; (ii) the proposal is discussed on the regional level with staff of the Plant Protection Service and Extension Services (including SOMALAC); (iii) once agreement is reached on a regional level the proposal is reviewed by a national "Rice Team" composed of scientists, representatives of the extension services and commercial operators. This process, while carefully designed to maximize participation by all interested parties does not always work very well in practice as some of the parties fail to participate very actively.

Use of pesticides is officially regulated by the MPARA Plant Protection Service, which has been the principal decision-making authority for pesticide selection in the project. For example, the PPS does not permit sale of Dimecron directly to farmers. One of the project's goals is to strengthen the PPS capacities to make such decisions, to formulate practical and acceptable recommendations and to follow up on farmer acceptance.

Results

Research

Basic research aimed at identifying and quantifying the factors which influence rice yields occupied the first two seasons of the project. Results to date can be summarized as follows:

(1) *Weeds*: The impact of weeds on yields has been quantified, showing that every 10 days delay in weeding results in about a 5% yield decrease. The various weed associations have been examined as a function of cultural practices, leading to specific control recommendations. Studies of farmers' application of these recommendations in their fields have shown that: (i) any type of control of the annual grasses and sedges gave excellent results (20-40% yield increases with a single intervention), but control of perennials was less successful. Overall, either mechanical or chemical weed control gave average yield increases of 20%. As explained above, adequacy of irrigation was the main factor in farmers' decisions whether or not to invest in weed control.

(2) *Stem borer*:

(i) Basic ecological and life history studies of the pest (including monitoring of generations using light traps) showed that there are three fairly distinct flights between the end of diapause (September) and May, and the crop is most vulnerable to attack in February/March.

(ii) The economic impact was studied in detail to establish an economic threshold level for control.

Results showed that, considering the average yields attained in the region and average infestation levels observed, over the majority of the area *intervention could not be justified economically* (contrary to the assumption underlying the 1982-1986 control program). This surprising finding results from a peculiarity of the species: unlike many other rice stemborers (e.g. in Asia) these caterpillars do not destroy the vascular (sap-conducting) tissue during the development inside the stems. Therefore the extent of damage is limited, never reducing yields by more than 30%. Chemical control trials were carried out, but failed to identify any insecticide which was both effective and acceptable from a toxicological and environmental viewpoint.

(iii) A study of natural enemies identified 4 parasites of which one (an egg parasite) is most important. However, natural parasitism levels are not always sufficient to maintain the pest under control because the parasites never attack all of the eggs in an eggmass.

(3) *Rice hispid*:

(i) Early research focused on understanding when and how hispids invade the rice fields early in the season from small "hot spots" of infestation. Life history studies revealed that the onset of rains is the prime determinant of this, and also that adults which appear after mid-March do not reproduce during the current season. Instead they hibernate and are then responsible for the first infestations at the beginning of the next season.

(ii) Economic impact (crop loss assessment) studies showed that up to a threshold level of 0.6-0.8 larvae/leaf the plant can compensate completely for hispid damage with no yield loss. This population density is rarely exceeded in the field.

(iii) The important parasites of hispids are present but in relatively low numbers early in the season; populations later build to the point where they exert very effective control. This "turning point" was reached at succesively earlier points in the season over the years from 1985-1988, indicating that parasite populations were recovering from earlier perturbations (presumably insecticide spraying).

(iv) Based on these research results, a control strategy was proposed involving chemical control only for the nurseries because that is when the crop is most vulnerable and natural enemy populations have not had time to build up. In the open fields hispid control should be left to the indigenous natural enemies. This is true for transplanted rice because: (a) early in the season natural enemy populations are low but the plant can compensate for hispid damage, and (b) later on the plants are more vulnerable but natural enemy populations are high enough to suppress hispid populations. It is also true for direct seeded rice because farmers sow early and at very high densities so that hispid damage may even be positive as a means of thinning the crop. Furthermore, hispids apparently prefer transplanted fields where there are free water surfaces.

(v) Phytopatologists of the Plant Protection Service think that *Hispa gestroi* could transmit a disease of irrigated rice which has recently appeared in the project area. If so, it will be necessary to modify recommendations for hispid control, as much lower population levels of the disease vector could cause severe damage.

Pest monitoring system

Monitoring of stem borer populations was begun under the "Taona Zina" operation in 1982/83. This system was refined and extended over the years, finally developing into a full-scale pest monitoring system implemented by field agents of the Plant Protection Service. The scouting program is implemented at no cost to the farmers. The survey staff concentrate on hispids from October-January and on stem borers from February-April. The region is divided into 8 zones with a separate team of scouts responsible for surveying pest populations in sample plots in each zone. Each team is backed up by a small field laboratory for diagnosis. The survey data are assembled at the Plant Protection center and results available to any interested party.

Because the long-term objective is to transfer scouting responsibilities to the farmers the monitoring program doubles as a training program. The PPS scouts always visit the selected fields in the company of the farmer, showing him what they do and discussing the findings and implications of different options. It is recognized, however, that this training process will take some time so it is anticipated that the PPS teams will continue to operate for some time.

Besides serving as the basis for pest control recommendations, the monitoring program provides essential information on long-term trends. For example, yearly scouting of stem borer egg masses since 1982 indicates that the overall populations of this pest have been decreasing steadily since 1983. While this is encouraging, it is too early to tell whether this is a real downward trend or only one phase in a regular multi-year cycle. Similarly, monitoring of hispids beginning in 1987/88 showed that the impact of parasitism varies from region to region. In the south hispid parasites attain high densities and exert effective control from January on. In the west, despite equally high hispid densities, the seasonal buildup of natural enemies is slower and greater numbers of leaves are affected by the pest.

Implementation of research results

Research results on weeds were extended through use of demonstration plots which allowed farmers to compare the results of different control options and determine for themselves which methods were practical for them. The demonstration plots also enabled extensionists to understand and advise researchers of the types of problems posed in practice. Extensionists also participated in special courses on weed control to make them better able to advise farmers.

In addition to the demonstration plots the project developed educational material to extend simple messages, such as the recommendation to control hispids by treating infested nurseries. The material included a series of pamphlets about the life of the hispid. Similar material was distributed on weed and rat control. The educational material is also being assembled to use in training of extensionists.

Unfortunately, at the time of writing there are no good data available regarding the rate of adoption of these recommendations by area farmers.

Impact on pesticide use

Estimates of pesticide use in the region against different pests are summarized in the following table:

	Treated by state			Treated by farmers		
Period	Stem borer	Hispids	Weeds	Stem borer	Hispids	Weeds
- 1982	?	?	?	?	?	?
1982/83	683	0	0	0	?	ca.250
1983/84	151	0	0	0	?	ca.250
1984/85	——40——		0	0	?	ca.250
1985/86	——104——		0	0	?	ca.300
1986/87	0	0	0	<1	12	ca.300
1987/88	0	0	0	<1	6	ca.350
1988/89	0	0	0	<1	10	ca.400
1989/90	0	0	0	<1	ca.30	ca.400

The government stopped providing pesticide application against stem borers free of charge in 1986, and it is clear that the farmers have not been interested in investing in chemical control of this pest. No data are available on farmers' treatment against hispids prior to 1986, but after that period the PPS monitoring staff kept records. Data on weed treatment are indirect, based on sales of herbicides (mostly 2,4-D). Growth in herbicide purchases is probably related both to increasing cultivated area and to increasing prices for paddy rice.

Problems and constraints

Poor communications infrastructure have been a consistent problem. During the 1983/84 season the road to the field station was impassable from January-April, and in March, 1986 a cyclone destroyed serveral bridges. The situation improved after six bridges and 70 km of roads were rebuilt and rehabilitated between 1986-88 (funded by Swiss disaster aid). In general the tropical climate (cyclones and storms) frequently interfered with field trials. Inadequate facilities were also a problem. The station's water supply system was only re-established in 1987, and an insectarium allowing year-round rearing of pests and natural enemies (essential for biological studies) was only built in 1989.

More important than these material constraints have been institutional problems such as poor integration among the two Ministries (Min/Agri and MRS-TD) with official linkages to the project. At the same time the country was in the midst of a sectoral adjustment which had a major impact on the national budget and thus on the effectiveness of the counterpart institutions. While training Malagasy collaborators has always been a major objective and component of the project, there was never any guarantee that those trained would remain in positions where they could ensure the continuation of project activities.

Finally, it has sometimes been difficult to reconcile the interests of the farmers and those of political leaders. The farmers ideally want recommendations for better extensive rice farming which leaves free time for other activities such as fishing or livestock husbandry which provide them better financial returns[1]. Politicians are interested in intensification of rice culture to meet the growing demands of the urban sector.

Future directions

Proposed future project actvities include:

(1) continuing refinement and adaptation of the general IPM program (identifying resistant and tolerant varieties, practical cultural practices to reduce stem borer and hispid populations, looking for appropriate pesticides, etc.)

(2) developing biological control of stem borers, either through augmentation of effectiveness of indigenous parasites or pathogens, or through introduction of exotics;

(3) studying the ecnomic impact and biology of rice blast disease in irrigated rice, and of the principal pests and diseases affecting other crops (e.g. *Heteronychus spp.* in rainfed rice and maize; *Sesamia calamistis* in maize, etc.);

(4) local farmer evaluation of research recommendations, and transferring capability and responsibility for pest scouting from the PPS field staff to the farmers themselves;

(5) improving the institutional integration of the project, and training to ensure effective take-over of the project by Malagasy staff;

(6) creation of a national level forum to promote understanding and acceptance of the IPM stragegy on the part of government decision makers and commercial operators.

Conclusions

Important accomplishments from the first five years include:

(1) a better understanding of the irrigated rice production system (biological, ecological and socio-economic aspects);

(2) the relative impacts of different pest problems have been quantified and specific control solutions proposed, which involve only very limited pesticide use (resulting in clear economic and environmental benefits);

(3) a pest scouting system has been established and is functioning autonomously (not supported by the project) to serve farmers' immediate needs. This in effect serves as a practical IPM training program for participating extensionists and farmers; and

(4) progress has been made toward developing biological control methods for the stem borer which, under current economic conditions, does not warrant chemical control.

More generally, this project demonstrates the critical importance of investing in achieving a basic understanding of the agro-ecosystem, rather than launching into a chemical control program as a (supposedly) integral part of agricultural intensification. There is good reason to hope that, with the help of this project, Madagascar will be able to avoid the devastating development of secondary pest species which plagues irrigated rice production in many other areas such as southeast Asia.

References

Blanc-Pamard, Ch. 1987.
Autour du riz, le difficile face-a-face des paysans et de la SOMALAC dans la cuvette du Lac Alaotra (Hautes Terres Centrales de Madagascar). Doc. Systemes Agraires, CIRAD, Montpellier, 6(2): 461-479.

1. The average workday earns 3200 FMG for the farmer who practices direct-seeded, extensive cultivation producing about 1.2 tons/ha, and only 1900 FMG to one who practices intensive, replanted cultivation (Blanc-Pamard, 1987).

Biological Control of the Mango Mealybug in Togo

by Frans Meerman

Introduction

Origin and spread of the mango mealybug *Rastrococcus invadens* in Togo

The mealybug *Rastrococcus invadens* was first recorded on Mango trees around the city of Lomé in 1981. This pest species originated in Southeast Asia and was identified and described for the first time by Williams (1986). It is suggested that *R. invadens* was introduced into Ghana and Togo on plant material. *R. invadens* uses multiple hosts; in Benin and Togo alone, 45 plant species are recorded as preferred or fortuitous hosts (Agounké and Agricola, 1988) – mango, citrus, breadfruit, banana and guava being the most susceptible to attack. Losses occur from direct feeding on the leaves and through fungal growth (sooty mold) on honeydew deposits.

R. invadens has spread quickly. In 1984 it was confined to the coast around Lomé and Anécho (Lõhr, 1984), but in 1986 the pest was already found as far as 450 km north of the coast. The present distribution of *R. invadens* is shown in figure 1.

Economic and social effects

In Togo, mango trees are principally grown around the houses and village squares. Beyond that, only 17 mango plantations (in total 240 hectares) are commercially exploited. The production is consumed locally or sold on local markets to middlemen; therefore, no reliable statistics are available on mango commercialization in Togo. Because of its recent introduction, there are no experimental data available on the damage caused by *R. invadens* in Togo. It is therefore difficult to estimate the economic losses caused by this pest.

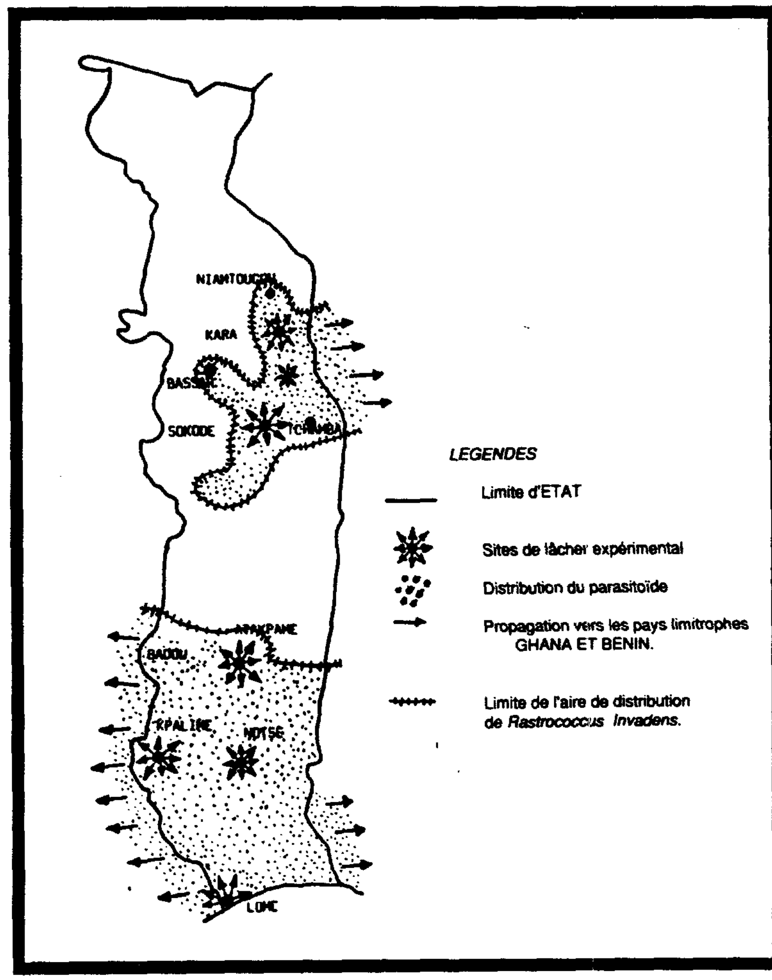

Figure 1. Distribution of the mango mealybug, *Gyranussoidea tebygi* and dispersal of the parasitoid throughout Togo (Agounke, unpublished data).

In Ghana, however, yield losses of more than 80 percent have been reported (Dixon and Korang-Amoakoh, in Moore et al., 1989), and in Togo and Benin, farmers have destroyed affected trees as a control measure. Also, chemical control has been attempted with insecticides like pirimiphos-methyl, but control was not achieved (Agounké and Agricola, 1988).

Besides fruit trees, shade trees such as frangipani (*Plumeria alba*) and *Ficus* sp. and ornamental plants are heavily attacked by the mealybug. The mango and fig trees perform an important function as shade trees, especially around the houses, in schoolyards, along main streets, and in village squares. However, honeydew produced by *R. invadens* and the insects feeding on the mealybug colonies make these shade trees undesirable as shelter. Consequently, *R. invadens* can cause considerable "social losses."

Control

Options for control other than biological

Control of the mango mealybug by means other than natural enemies is technically difficult, expensive, and probably not effective. This is because of the following characteristics of the pest species and mango production in Togo:

(1) the polyphagous nature of *R. invadens* makes it necessary to control the pest on many (non-economic) host plants, which is practically impossible;

(2) the rapid spread of *R. invadens* through neighboring host plants and the transport of fruits and planting material by man makes it difficult and expensive to prevent reinfestation of treated mango trees or areas;

(3) chemical control of fully grown mango trees is difficult and time consuming with ground equipment, even if available (most trees are owned by small farmers and are located in villages, making aerial applications impossible). The handling of insecticides by an inexperienced local population generally leads to ineffective use and virtually guarantees health and environmental hazards;

(4) mangoes are, in a way, a subsistence crop for the rural population; only the surplus production is sold. Therefore, no money is available to invest in pest control;

(5) development and introduction of resistant or tolerant varieties will be time consuming and expensive and would result in a temporary drop in mango production when these new varieties were introduced.

Biological control

Because of past successes with biological control against exotic pests, the FAO granted funding for a proposal by the International Institute for Biological Control (IIBC) for biological control of the mango mealybug. The project began in 1986. The following stages can be identified in the process from pest identification to successful implementation of the natural enemy in Togo (Moore et al., 1989).

(1) Pest identification, study of biology and rearing:

The mango mealybug was identified by Williams (1986) as *Rastrococcus invadens*, a pest species thought to be endemic to the Far East. The biology of *R. invadens* was studied (Willink and Moore,1988) and rearing was undertaken, making use of the quarantine facilities at IIBC, UK.

(2) Screening, selection and identification of suitable natural enemies:

In 1986 the IIBC Station in India began a survey for *R. invadens* and natural enemies. Four species of *Rastrococcus* were found, including *R. invadens*, and one natural enemy, *Gyranusoidea sp.*, was found specific to *R. invadens*. Further screening was done in the UK. The parasitoid was identified as a new species, *Gyranusoidea tebygi* (Noyes, 1988). Willink and Moore (1988) demonstrated the following useful characteristics of *G. tebygi* as potential biocontrol agent:

- shorter development time than the pest species (almost two generations for each one of the mealybug)

- high fecundity of the parasitoid (70-90 eggs per female)

- additional mortality of *R. invadens* through feeding and probing by the parasitoid (in addition to the primary parasitism effect)

- high specificity to *R. invadens*

- easy to rear.

(3) Rearing and release of Gyranusoidea tebygi in Togo and assessment of impact:

In October 1987, 250 individual *G. tebygi* were officially introduced into Togo from the UK. No legal problems were experienced because the parasite was taken into quarantine to eliminate the chance of introducing possible hyperparasites. The rearing of *G. tebygi* started in October 1987 at the Cacaveli Station of the Togolese Plant Protection Service, with assistance from GTZ and IIBC. A simple rearing technique was developed, consisting of rearing *R. invadens* on cuttings of a local *Ficus sp.*, which were then transferred to wooden cages with *G. tebygi* for rearing of the parasite. With this technique, between 1000-1500 parasitoids can be produced per cage of 3 Ficus cuttings in 3 weeks.

The parasitoid was first released at the Cacaveli Station near Lomé during November 1987. This release was followed by releases of 25-1000 parasitoids each at 5 different locations between January and May 1988, covering the main ecological mango producing areas of Togo. At all sites, the parasitoid was established after one single introduction, resulting in significant control of *R. invadens*.

Since then the spread of the pest and the parasitoid throughout Togo has been monitored through weekly observations of the numbers of unparasitized *R. invadens* females and parasitized mummies. Because the Plant Protection Service chose a simple and cheap monitoring system, no data are available on the total mortality of *R. invadens* due to parasitism and host feeding by *G. tebygi*.

Figure 1 shows the dispersal of the parasitoids from the experimental release sites to cover the whole area infested by *R. invadens* (data from Agounké). High numbers of *G. tebygi* pupae are generally found and spectacular control was achieved at all release sites. During an extensive field trip of more than 1500 km in May 1989, I did not observe a single mango tree that did not have both mealybug and parasitoid populations.

Personnel involved

The personnel involved during the implementation phase consisted of four Togolese workers, one doctoral level Togolese scientist and two GTZ scientists. The monitoring of field populations is done at five different locations by extension workers from the Plant Protection Service field stations and two other workers.

Role of extension and mobilization of public interest

Originally it was anticipated that regional extension workers would participate in assisting in the release of the parasitoids in smaller towns and villages, and in educating the rural population about this biological control measure. Due to the rapid establishment and spread of *G. tebygi*, the former role was not necessary. However, it was necessary to increase public awareness that the control of *R. invadens* was achieved by biological means and that chemical control can interfere with this system. Therefore, a great deal of publicity was given to the project in general, and to the few releases of parasitoids in particular, using radio and television and through advisory leaflets.

Cost-benefit analyses

A cost-benefit analysis has been made of the introduction of *G. tebygi* from the project financer's point of view. The economic value of mango production in Togo was estimated from the number of mango producing trees, based on the number of mango seedlings sold. The results are summarized in Table 1.

Table 1. Economic value of Mango and costs for biological control of the mango mealybug with the parasitoid *Gyranusoidea tebygi* in Togo (Vögele,1988).

Economic value (in US $) of crops, attacked by *R. invadens*:	
* Improved Mango varieties	2689,000.00
* Local Mango varieties	645,000.00
* Citrus	4092,000.00
TOTAL	7426,000.00
Costs:	
* Research outside Togo: (identification of pest species; search for, laboratory testing and rearing of natural enemies)	92,000.00
* Development and Implementation in Togo:	167,700.00
* Introduction in Togo: (Mass rearing, multi-site introduction	75,000.00
TOTAL	334,700.00

The project's economic viability would already be established if only slightly more than 1 percent of the economic loss by *R. invadens* were prevented over a period of 4 years. Experts have confirmed that much greater economic losses are in fact being prevented by this biological control system (Agounké, personal communication). From the farmer's point of view any reduction of economic loss through biological control is profitable, as no investments are necessary at all.

The running costs for the Togolese Plant Protection Service amount to US$ 1,100.00 per year for monitoring the pest and parasitoid population in the field.

Discussion

From its probable arrival in Togo in 1981, over the past 5 years the mango mealybug has spread rapidly to ecologically different mango producing areas in Togo. Following a single introduction of the parasitoid *G. tebygi* at 7 locations in late 1987/-early 1988, no infested mango trees can now be found on which *R. invadens* is present without being parasitized by *G. tebygi*, and high rates of control are found around the release sites. However, due to the simple monitoring system chosen, it not possible to quantify total mortality of *R. invadens* due to parasitism and host feeding by *G. tebygi*.

One introduction per release site proved to be enough for the establishment of the parasitoid. Therefore the costs for mass rearing and introduction were very low. Because no measures are necessary to enhance establishment or dispersal of the parasitoid, a self-sustaining and ecologically safe control system has been provided at no cost to the local farmers and with no need for direct involvement on their part.

The success of the project can be attributed to the following factors:

(1) *characteristics of the pest species*: For a number of reasons, exotic and sessile insect pests have proven to be good candidates for classical biological control (DeBach, 1964 and Hokkanen, 1985)

(2) *characteristics of the parasitoid G. tebygi*: *G. tebygi* has a much shorter development time than *R. invadens*, has a high fecundity and host specificity, displays a considerable host feeding rate, has the capacity to establish and disperse under variable agro-ecological conditions and is easy to rear;

(3) *characteristics of mango production in Togo*: The permanent presence of mango trees creates good conditions for biological control by ensuring the permanent presence of both the pest and parasitoid populations. Mango trees are grown around the houses by the rural population and fruits are consumed at home or are sold at local markets. No other investments are made than the planting of improved varieties.

Therefore, the demands of fruit quality can be lower and the required level of control can be less than with commercial mango production. Because no pesticides are used in mangoes, no interference with the biological control agent will occur from within the system;

(4) *good international cooperation*: Although during its implementation phase in Togo the project made use of local available expertise and technology, a wide range of expertise and technology was necessary during the preceding period. Scientists from nine countries and different organizations (Togolese PPS, IIBC, GTZ) have worked together to identify the pest and its place of origin, to look for natural enemies and screen for the best candidate, to study the biology of both the pest and the parasitoid and to develop a mass rearing technique. Thanks to a good international cooperation and understanding this was accomplished within a period of only 3 years.

References

Agounké, D., and U. Agricola. 1988.
Rastrococcus invadens Williams (Hemiptera: Pseudococcidae), a serious exotic pest of fruit trees and other plants in West Africa. *Bull. ent. Res.* 78: 695-702.

Löhr, B. 1984.
Bericht uber einen Kurzzeitaufenthalt in Togo zur Untersuchung einer Schmierlausgradation im Obstbau. Rapport interne de la 'Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)', Eschborn, RFA, 23 pp.

Moore, D., D. Agounké, U. Agricola, and H.U. Fischer. 1989.
Appropriate technology and the implementation of a biological control program against *Rastrococcus invadens* Williams in Togo. Paper presented at DLG Symposium on Integrated Pest Management in tropical and subtropical cropping systems, at Bad Dürkheim, February 8-15, Fed. Rep. Germany, 8 pp.

Noyes, J.S. 1988.
Gyranusoidea tebygi sp. n. (Hymenoptera: Encyrtidae) parasite on *Rastrococcus* spp. (Homoptera, Pseudococcidae) in India. *Bull. Ent. Res.* 78:313-316.

Williams, D.J. 1986.
Rastrococcus invadens sp. n. (Hemiptera: Pseudococcidae) introduced from the Oriental Region to West Africa and causing damage to mange, citrus and other treed. *Bull. ent. Res.* 76:695-699.

Willink, E., and D. Moore, 1988.
Aspects of the biology of *Rastrococcus invadens* Williams (Hemiptera: Pseudococcidae) a pest of fruit crops in West Africa and one of its primary parasitoids, *Gyranusoidea tebygi* (Hymenoptera: Encyrtidae and Pseudococcidae) in India. *Bull. Ent. Res.* 78:709-715.

Vogele, J.M. 1988.
Integrierter Pflanzen und Nachernteschutz in Togo: Die Wirtschaftlichenkeit der Projektaktivitaten. Technishche Zusammenarbeit Bundesrepublik Deutschland--Togo. Universitat Hohenheim, Stuttgart. 34 pp.

The Africa-wide Biological Control Program for Cassava Mealybug

by Agnes Kiss

Introduction

Cassava is the primary staple crop for over 200 million people in more than 35 African countries, and is particularly important as a famine food. A few years ago the International Herald Tribune reported: "a small bug is eating the heart out of Africa," predicting a long-term impact potentially far worse than that of the much publicized droughts. The "small bug" was *Phenacoccus manihoti*, the cassava mealybug (CMB), which was first identified in Zaire in 1973. Together with the cassava green spidermite (CGSM), first reported in Uganda in 1971, the CMB has spread rapidly and is now found in a wide belt from Mozambique through Zaire and the Central African Republic, across coastal West Africa to Senegal and Guinea Bissau. Severe attacks of CMB or CGSM can cause up to 80 percent reduction in root yields. Economic losses from these two pests have been estimated at almost $2 billion per year, and in some areas farmers have begun to abandon the crop altogether. This case study concerns an internationally funded and executed program aimed at reducing losses to CMB by a means which is both environmentally safe and practical for the poorest African farmers.

The project

History

The program grew out of an international workshop on the growing CMB problem, co-sponsored by the International Institute for Tropical Agriculture (IITA) and the Government of Zaire in June, 1977. Recognizing that: (1) cassava is a low value crop grown primarily by widely scattered, poor farmers, and (2) the CMB was probably an introduced pest, and (3) the CMB, like many mealybugs, was very difficult to control with pesticides even if this were economically and environmentally possible, the workshop recommended a dual strategy to attack the problem: breeding resistant cassava varieties and developing a classical biological control program.

Elements of the program

A classical biological control program includes several stages:

(1) identification and collection of potential control agents, such as parasites, predators or pathogens (may first require correct identification of the target host);

(2) quarantine and screening of potential biocontrol agents to ensure that they are effective and host-specific and to eliminate any of their own hyperparasites or diseases;

(3) mass rearing in an insectarium for field releases;

(4) trial field releases to determine whether the species can establish itself (survive, reproduce and spread) in the new environment and can effectively control the target pest species;

(5) if these trials are successful, large-scale releases; and

(6) follow-up monitoring of the establishment and effectiveness of the agent and its further spread from the release sites.

Implementation

The search

The first problem in identifying suitable biocontrol organisms was locating naturally-occurring CMB populations, since the species had never been reported outside Africa. In 1979 IITA researchers chose to go to South America, the original home of the cassava plant, on the assumption that this was the most likely place to look for cassava pests. The theory was that the CMB was present in South America, but so effectively controlled by its natural enemies (potential biocontrol agents for Africa) that it had never been reported. This was the beginning of a widescale search carried on in collaboration with the International Center for Tropical Agriculture (CIAT) in Colombia and the International Institute for Biological Control (IIBC), and funded by the International Fund for Agricultural Development (IFAD) and the government of Canada.

Careful taxonomic work is critical because parasites are the best taxonomists. This was demonstrated by a costly 3-year diversion of the project which occurred when a mealybug species from Venezuela was mistakenly identified as CMB and researchers tried unsuccessfully to rear parasites collected from this species on CMB from Africa (Herren, 1988).

Finally, after more than 30,000 miles of luckless travel by the survey team, the CMB was identified by a CIAT scientist in Paraguay in 1981. This triggered a more intensive study of its geographic and ecological range in the area of Paraguay/Bolivia/Brazil, carried out in collaboration with the Brazilian agricultural research agency, EMBRAPA with funding by the West German international technical assistance program (GTZ).

Screening and multiplication

Over the next several years nearly 60 species of predators and parasites were located by the IITA/-IIBC/EMBRAPA team in the field and forwarded to IIBC laboratories for screening and quarantine, particularly to determine how specific they were to the CMB (i.e. unlikely to move to other hosts in a new environment, with potentially disastrous ecological results). Good biocontrol candidates were sent to the IITA headquarters laboratory in Ibadan, Nigeria for multiplication and further study. Of the large number of species processed and screened, 14 were considered promising enough for trial releases.

Trial releases

The next stage, carefully monitored trial releases to test the effectiveness of these species in controlling the target pest population, was begun later in 1981. Interest soon narrowed to two candidates: a tiny parasitic wasp (*Epidinocarsis lopezi*) and a predatory beetle (*Diomus sp.*). The trials showed that the *Diomus* beetle did well in the dry season when CMB populations are high, but did not survive the following rainy season when the pest populations naturally drop. *E. lopezi*, however, established itself successfully throughout the rainy season and kept mealybug populations in the trial areas under control over the 1982, 1983 and 1984 dry seasons. In the first year after initial release, the parasite spread over the entire IITA headquarters fields and five km into neighboring farms.

Large-scale field releases

Based on these results, the decision was made to go ahead with large-scale releases. In the following years, *E. lopezi* more than justified the early optimism, demonstrating the key characteristics of a successful biocontrol agent: effectiveness under a variety of ecological conditions, persistence, and rapid multiplication and dispersal in the field. By 1985, four years after releases began, scientists confirmed the parasite's presence in 11 countries in an area covering 570,000 km^2. By 1988, it had established successfully in 19 countries[1], over an area of 1.5 million km2.

The success of these field releases on an enormous scale has been due to IITA's approach of working in collaboration with national agricultural programs. It has emphasized training of local technicians to participate in releases and carry out follow-up monitoring, working with international donors to help to establish national biological control programs in 35 African countries. The ABCP project, based in

IITA, continues mass rearing of *E. lopezi* at a new facility recently established in Benin. The parasites are transported by air to receiving countries for release usually within 36 hours to minimize mortality.

Monitoring effectiveness

The ABCP has been unusual among classical biological control projects in placing considerable emphasis on follow-up monitoring of the establishment of the parasite and its impact on pest populations. This includes post-release field surveys of CMB populations and parasitism rates, cassava yields in release vs. non-release areas and changes over time and impacts on other elements of the ecosystem. Research methods range from farmer surveys to computer simulations. The project has also achieved sufficient visibility that other researchers have carried out independent assessments.

Results

The greatest difficulty in evaluating a biological control program is usually a lack of baseline and comparative data. There have been many attempts to estimate the impact of CMB on cassava production in Africa (e.g. FAO, 1985; Walker et al., 1985) but these large-scale estimates have been controversial as the underlying data were poor and many generalizations had to be made. The same is true for estimates of *E. lopezi* impact on CMB populations. For example, Norgaard (1988) consolidated available information on: (i) the value of cassava production Africa-wide (difficult because cassava is grown so widely but on small scale and largely as a subsistence crop), (ii) potential yield losses to CMB (difficult because the very limited data show high variability); (iii) the impact of *E. lopezi* on CMB populations and thus, indirectly, on cassava yields (difficult for the same reasons); and the total dollar cost of the ABCP program to date (sum of donors' contributions). From this information he concluded that an investment of $ 14.8 million has yielded estimated returns of $2,205 million, for a benefit:cost ratio of 149:1. Previously, an IITA team had tried to do the same thing and estimated a ratio of 178:1 based on estimated returns of $ 3 billion (IITA/ABCP 1988).

More precise information is available from studies in specific areas. For example, regular monitoring in two areas in Nigeria showed that CMB populations declined after the release of *E. lopezi* and remained low (Hammond et. al., 1987). Large-scale surveys and exclusion experiments in Nigeria also demonstrated that the parasite could prevent CMB outbreaks (Neuenschwander & Hammond, 1988; Neuenschwander et al., 1986). Estimations of tuber losses[2] to CMB under controlled conditions ranged from 9-75 percent depending on time of harvest (Schulthess, 1987). Studies such as these demonstrated that losses to CMB are patchy but sometimes dramatic (averaging 30 percent) over the savanna belts of Africa, but are generally less severe in forest zones where the pest is less successful and the plant is better able to compensate for attack.

On a larger scale, a 1989 study by Neuenschwander et al. examined *E. lopezi* establishment and impacts through surveys of farmers fields over an area of 180,000 km^2 and a range of ecological conditions in Ghana and Cote D'Ivoire. This study is unique in that it used multivariate analysis to separate the effects attributable to the CMB from those related to varying ecological conditions, agronomic practices and other pests. It showed that CMB populations were significantly lower where *E. lopezi* had been present for more than half the planting season than in areas where it was lacking or had only recently been introduced. Average CMB damage levels were significantly lower in both savanna and forest zones when *E. lopezi* was present. The analysis also showed that CMB was the major cassava pest and its impact on production rivalled that of all the abiotic and agronomic factors. Finally, it estimated the tuber yield increase due to the presence of *E. lopezi* at about 228 g/plant (2.48 tons/ha) in the savanna zone, representing a 50 percent reduction in losses to CMB. These results are very important in that they provide an economic criterion (reduction of yield loss) for success of the program in contrast with the more usual ecological ones (establishment of the parasite, reduction in pest populations).

Neuenschwander et al. also conducted a survey of subsistence farmers which showed that 46 out of 50 recognized the CMB. Those in the savanna zones considered it a devastating pest but most in the forest zones doubted it did much damage (which corresponds with researchers' findings, showing farmers' capabilities to assess losses). Almost all of the farmers in savanna zones where *E. lopezi* had been introduced at least six months before, had observed a significant decline in CMB populations. However, because they knew nothing about the biological control program they attributed this decline only to particularly heavy rains during the 1985 rainy season.

Future directions

All indications are that, given enough time, *E. lopezi* could now spread naturally over nearly all (if not all) of the African cassava belt. However, because of the urgency of the CMB problem a more active approach is being pursued, aimed at releasing the parasite in many more countries. As discussed above, the approach is based on development and collaboration with national biocontrol programs. This involves training, institutional strengthening and providing equipment and technical assistance. One of the major problems the ABCP faces is that its success has been so widely publicized that a sense of complacency has developed. Potential donors often believe that the CMB problem has been solved and ABCP finds it difficult to raise funds to meet the continued high costs of mass rearing and transporting the parasites and supporting the national programs.

The ABCP also recognizes that a single biocontrol agent, however effective, is not really sufficient because it is possible for the pests to develop resistance mechanisms (e.g. encapsulating the parasites' eggs, a sort of immune response). It is therefore continuing to search for other likely candidates for biocontrol of CMB. Finally, CMB is only part of the cassava pest problem, so controlling CMB is only a partial solution from the farmers' viewpoint. The ABCP is therefore also pursuing biological control research programs for the cassava green spider mite, the other major insect pest of cassava. ABCP is also investigating biological control for a range of other pests of African agriculture including banana mealybug, maize borers, cowpea pests, weeds and nematodes.

References

Food and Agriculture Organization. 1985.
Production year book 1984, Rome, 300 pp.

Hammond. W.N.O., P. Neuenschwander, and H.R. Herren. 1987.
Impact of the exotic parasitoid *epinocarsis lopezi* on cassava mealybug (*Pheacoccus manihoti*) populations, Insect Sci. Applic. 8: 887-891.

Herren, H.R. 1988.
Africa-wide biological control project for cassava mealybug and green spider mites, presentation at Integrated Pest Man:gement Workshop, Agricultural University of Norway, Seminar in Asker, Sept. 5-6, 1988.

IITA/ABCP Annual Report and Research Highlights, April 1988.
IITA, Ibadan, Nigeria.

Neuenschwander, P., W.N.O. Hammond, A.P. Gutierrez, A.R. Cudjoe, R. Adjakloe, J.U. Baumgartner, and U. Regev. 1989.
Impact assessment of the biological control of the cassava mealybug, Phenacoccus manihoti Matile-Ferrero (Hemiptera: Pseudococcidae), by the introduced parasitoid Epidinocarsis lopezi (De Santis) (Hymenoptera: Encyrtidae). Bull. ent. Res. 79: 579-594.

Norgaard, R.B. 1988.
The biological control of cassava mealybug in Africa, American Journal of Agricultural Economics 70 (2): 366-371.

Schulthess, F. 1987.
The interactions between cassava mealybug (Phenacoccus manihoti Mat.-Ferr.) populations and cassava (Manihot esculenta Crantz) as influenced by weather. Ph.D. Diss., Swiss Fed. Inst. Technol., Zurich, Switzerland, 136 pp.

Walker, P.T., D.L. Heydon, and E.J. Guthrie 1985.
Report of a survey of cassava yield losses caused by mealybug and green mite in Africa, with special reference to Ghana. Trop. Dev. Res. Inst. London, 82 pp.

1. Senegal, the Gambia, Guinea Bissau, Sierra Leone, Cote D'Ivoire, Ghana, Togo, Benin, Nigeria, Cameroon,, Equatorial Guinea, Gabon, Congo, Zaire, Angola, Rwanda, Zambia, Uganda, Malawi.

2. The value of leaves, which are often eaten as a vegetable, is often overlooked.

7. Conclusions and Recommendations

The IPM approach is feasible for and relevant to African agriculture. It can: (a) promote stable and higher food production in subsistence agriculture, (b) prevent the escalation of pest problems and dependence on chemical control in the process of intensifying agriculture, and (c) reduce costs and negative ecological, environmental and health impacts associated with excessive or inappropriate use of pesticides in high-input systems. The cases reviewed here demonstrate how IPM can be implemented by developing and disseminating appropriate IPM technologies that take into account the particular type of agricultural system involved:

(1) For subsistence level agriculture, the aim is to determine first whether pests represent an important production constraint relative to other factors. If so, the most appropriate technologies for pest management are those which minimize the need for external inputs such as chemical fertilizers and pesticides, are compatible with the overall farming system (e.g. labor constraints, agronomic requirements of other crops) and are made simple enough to be disseminated without the need for highly specialized extension workers and to be used by relatively poorly educated farmers. The emphasis should thus be on varietal resistance, biological control, intercropping and cultural practices to make the environment less hospitable to pests. IPM should be regarded as part of an overall program to address basic constraints which hamper agricultural production, such as poor soil fertility, unavailability of improved seeds and inadequate crop husbandry practices.

(2) For intensive agricultural systems, usually crops grown in monoculture with relatively high levels of inputs including pesticides, the aim is usually first to rationalize pesticide use by stressing the concept of cost effectiveness, i.e. introducing methods for rational use of pesticides through pest monitoring and forecasting and the use of economic threshold levels. This may involve farmers' scouting of their fields on a regular basis, but there are several other options which may be more appropriate under local conditions. Also included in improved pesticide management is reducing ecological, environmental and health hazards by replacing broad-spectrum or highly toxic pesticides with less hazardous or disruptive ones and by improving pesticide application methods. The second objective of IPM in these systems is to develop non-chemical control methods to maintain pests at below-threshold levels or replace at least some of the pesticide use. However, in areas with a history of high levels of pesticide use farmers and extension services are usually strongly committed to chemical control, so transition to a non-chemical orientation may be slow. The ecosystem may also already be significantly damaged, and in some cases natural control mechanisms take some time to rebuild.

(3) The primary focus of agricultural development is to raise agricultural production from a subsistence level to a higher yielding level to produce income for poor farmers and food and fiber for the country. For such intensifying systems the aim is to help farmers increase production levels without stepping onto the "pesticide treadmill." i.e. without becoming dependent on higher and higher levels of pesticide use. Prevention is a key element, i.e. anticipating and trying to avoid adoption of practices which promote great increases in pest populations. Appropriate control technologies are similar to those for already intensive systems, but with some important differences: (i) there is less history of pesticide dependency, so both the ecosystem and farmers are likely to be more adaptable to non-chemical methods early on, and (ii) existing levels of farmers' knowledge, extension services and infrastructure are likely to be lower, so both pest monitoring and pest control methods must be adapted accordingly.

Classical biological control (the introduction of non-native natural enemies to suppress pest populations on a permanent basis) is a very cost-effective and environmentally benign[1] solution which should be investigated and supported whenever possible. In particular, CBC should always be considered (i) for low-value crops grown by widely dispersed, small scale farmers and, (ii) when technical conditions are especially favorable for probable success (e.g. relatively stable agro-ecosystems, sedentary pests or perennial weeds, introduced pests).

There is great opportunity to promote IPM more effectively in Africa. Most crop protection research programs are not currently oriented toward IPM but continue to focus primarily on chemical control. Of the IPM-related research programs that do exist, many are likely to have little impact on agricultural practice because their scope is too narrow (developing non-chemical or reduced-chemical control methods for one pest or the pests of one crop) and because they lack effective 2-way linkages with farmers through an extension or equivalent system. The word "integrated" in IPM should be understood to refer not only to the integration of all available control methods for a given pest but also the integration of pest management into the whole farming system and the farmer's economic activities.

Another pervasive problem is that too much emphasis is placed on development or transfer of specific control technologies. In fact, IPM is *a strategy and an approach to developing technologies*. Implementation of the IPM approach requires on-site research and extension and building the requisite human and institutional capacity may take a long time compared to the usual expectations for straight technology transfer. Governments' and farmers' adoption of the IPM approach also requires a supportive policy environment which promotes attention to cost-effectiveness and does not subsidize non-economic or environmentally damaging practices.

International donors can promote development and implementation of IPM in African countries most effectively by helping to establish the necessary scientific, technical and logistical capacity and helping to impress upon government leaders the benefits and the need to establish supportive policies. Specific requirements include:

Extension

- IPM training courses for extension workers (on its principals and application to specific crops or cropping systems);

- IPM Subject Matter Specialists in Training and Visit extension systems;

- field guides, pamphlets, information bulletins, etc. to help extensionists and farmers identify pests and natural enemies;

- methods and devices for easy monitoring of plant damage, pest and natural enemy populations and rules for decision making in pesticide use;

- incorporation of social science and communications skills in extension workers' training;

- use of participant farmers as informal extension agents--support their work in this capacity (e.g. transportation, direct access to researchers, etc.);

Farmer education, training and organization

- educational materials (written and other media) and training opportunities for farmers on:

(a) implementation of recommended agronomic practices, including cultural practices which help to suppress pest populations (e.g. intercropping, synchronization of planting and harvesting, crop rotation, phytosanitary measures, etc.);

(b) scouting for pests and natural enemies and decision-making for pesticide use;

- education regarding correct selection of appropriate pesticides (active ingredients and formulations) and training in use of pesticide application equipment, including calculation of dosage rates and safety precaution

- training in basic farm management (e.g. cost:benefit principles);

- site visits for farmers (as well as researchers and extensionists) to areas where IPM is being successfully applied;

- educational campaigns to inform farmers of biological control programs being implemented in their area;

Research

- increasing farmers' input into research, to ensure relevance of research and feasibility and acceptability of research recommendations, by:

(a) developing philosophy and mechanisms to support 2-way communication between researchers and farmers;

(b) emphasizing use of on-farm research and verification trials conducted in partnership with farmers;

- emphasis on multi-disciplinary research teams addressing problems in the context of the farming system;

- training, technical assistance and financial support to strengthen research capacity and support for specific research relating to:

(a) pest identification (taxonomy) and causes of crop damage (diagnosis);

(b) basic ecology of the agro-ecosystem and biology of pest organisms (e.g. population dynamics of pest and biological control agents);

(c) crop-loss assessment (economic importance of specific pests under different conditions and at different times in the season and in relation to other production constraints), i.e. economic threshold levels (ETLs);

(d) determining action threshold levels (ATLs), i.e. pest levels and conditions under which intervention is needed to prevent pests reaching ETLs;

(e) analyzing conventional pest control versus IPM, in terms of maximum economic benefits for farmers (not in terms of yield maximization)

(f) identifying, evaluating, screening and rearing biological control agents;

(g) determining impact of agronomic practices on status of pests;

(h) evaluating traditional control methods;

(i) developing non-chemical control methods (varietal resistance, cultural controls and agronomic practices, biological control);

- research on pesticides oriented toward rationalizing and optimizing pesticide use for long-term environmentally, economically and socially sound production, e.g.:

(a) economic evaluations of current and proposed pest management practices;

(b) developing practical methods and devices for monitoring pests and conditions to identify when ATLs are reached;

(c) determining the impact of pesticides on natural enemies;

(d) monitoring of pest populations for development of pesticide resistance (good opportunity for collaboration with the private sector);

(e) developing safer and more efficient pesticide formulations and application methods (e.g. baits, spot-spraying, low volume application);

(f) testing performance, reliability and safety of application equipment under tropical conditions and in relation to the operator's knowledge and capabilities;

(g) investigating pesticide residue levels in foods and the environment;

(h) investigating human pesticide exposure levels (among direct users, their families, surrounding communities);

- adaptive research and on-farm evaluation of IPM methods used elsewhere to determine whether they can be adapted to local conditions;

- strengthened research management to:

(a) improve coordination between governmental institutions responsible for research and extension to get them better in tune with producers' needs;

(b) organize international cooperation needed for classical biological control;

Infrastructure, information and materials

- technical and financial assistance to develop infrastructure needed for research (above);

- improved researchers' access to relevant literature and professional contacts (including budgets for literature and for access to IPM and pesticide databases, arrangements with overseas institutions to provide information as needed, study tours, site visits);

- ensuring availability of:

(a) products and devices needed to implement IPM recommendations (e.g. pest monitoring devices, disease-free planting material, resistant varieties, nontoxic control products (e.g. microbial pesticides, "barrier products" to restrict pest access to plants); improved pesticide application equipment; pesticides compatible with other IPM methods, recommended pesticide rotations and use by small scale farmers';

(b) agricultural credit

- development of climate monitoring/predicting and communications systems;

- development and improved functioning of regulatory systems for eliminating and restricting availability or use of pesticides which have been so designated by responsible government authorities;

- budgets to subscribe to journals and purchase literature, and to maintain professional contacts with other workers and institutions;

- where feasible and appropriate, development of expert systems to which people can go with technical questions and for information on equipment and materials;

Organization

- assistance to farmers' organizations to:

(a) implement a centralized pest scouting and decision making system for pesticide applications;

(b) cooperatively set up or engage a consultant system for problem identification, pest scouting, training, etc.;

(c) purchase and distribute inputs and application equipment on a cooperative basis;

(d) coordinate control practices which must be done on an area-wide basis (e.g. synchronization of planting and harvest, rotation of pesticides, closed seasons);

- institutional reform and logistical support to strengthen coordination between governmental institutions involved in crop protection research and extension;

- productive collaboration with the private sector (suppliers of pesticides and application equipment), e.g. in farmer education and training, in research, in implementing pesticide rotation systems to prevent development of resistance, in production, testing and supply of IPM-compatible products;

Policy

- educational efforts aimed at decision makers to raise awareness of economic, social and ecological aspects of chemical control vs. IPM;

- elimination of pesticide subsidies (following a time-phased approach if necessary);

- fair pricing for crops and farmers' access to foreign currency if needed to follow recommendations for production of crops;

- empowerment of farmers to make and implement management decisions concerning their production systems and methods;

- sectoral studies analyzing economic costs and benefits of agricultural production practices, particularly pest control;

- evaluation of food aid programs with respect to potential impacts on farmers' motivations to increase agricultural production or efficiency and to implement IPM measures.

1. With careful screening to ensure the introduced species do not themselves become pests.

References

Clausen, C.P., (Ed.), 1978.
Introduced parasites and predators of arthropod pests and weeds: a world review. U. S. Department of Agriculture Handbook No. 480.

DeBach, P. 1964.
"Successes, trends and future possibilities," *In*: DeBach (Ed.) 1964. Biological Control of Insect Pests and Weeds. Reinhold, N.Y. 673 p.

Dover, M. 1988.
In: *Journal of Pesticide Reform*, **8** (4), Winter, 1988.

Eveleens, K.G. 1985.
"Historie en actualiteit van de Nederlands-Indonesische samenwerking in het biologisch onderzoek," *Vakbl. Biol.* **65**: 491-494.

Frisbie R., and Mcwhorter 1989.
"Implementing a statewide pest management program for Texas, U.S.A." In: Advisory Work in Crop Pest and Disease Management, J. Palt and R. Asher (eds.). Springer-Verlag.

Greathead, D.J. 1971.
"A review of biological control in the Ethiopian region," CAB, Slough, 162 pp.

Greathead, D.J. 1986.
"Opportunities for biological control of insect pests in tropical Africa." Revue de Zoologie Africaine **100**: 85-96.

Greathead, D.J., and J.K. Waage 1983.
"Opportunities for Biological Control of Agricultural Pests in Developing Countries." World Bank Technical Paper No. 11. The World Bank, Washington, D.C. 44 pp.

Hansen, M. 1987.
Escape From the Pesticide Treadmill: Alternatives to Pesticides in Developing Countries. Institute for Consumer Policy Research, Consumers Union of the United States, 185 pp.

Headley, J.C. 1972.
"Defining the Economic Threshold" in Pest Control Strategies for the Future. National Academy of Sciences, Washington, D.C.

Hokannen, H.M.T. 1985.
"Success in classical biological control." In: CRC Critical Reviews in Plant Sciences, **3 (1)**: 35-72.

Huffaker, C.B. and P.S. Messenger, (Eds.) 1976.
Theory and Practice of Biological Control. Academic Press.

Julien, M.H. (Ed.). 1982.
Biological control of weeds: a world catalogue of agents and their target weeds. Commonwealth Agricultural Bureaux, Slough, U.K.

Neuenschwander, P., W.N.O. Hammond, A.P. Guiterrez, A.R. Cudjoe, J.U. Baumgartner, U. Regev and R. Adjakloe. 1989.
"Impact assessment of the biological control of the cassava mealybug, Phenacoccus manihoti Matile-Ferrero (Hemiptera: Pseudococcidae) by the introduced parasitoitd Epidinocarsis lopezi (De Santis) (Hymenoptera: Encyrtidae)." Bull. Entomol. Res. **79**: 579-594.

Neuenschwander, P., W.N.O. Hammond, O. Ajuonu, A. Gado, N. Echendu, A.H. Bokonon-Ganta, R. Allomasso, and I. Okon. 1990.
"Biological control of the cassava mealybug, Phenacoccus manihoti (Hom., Pseudococcidae) by Epidinocarsis lopezi (Hym., Encyrtidae) in West Africa, as influenced by climate and soil." *Agriculture, Ecosystems and Environment*, **32**: 39-55.

Norgaard, R.B. 1988.
"The biological control of cassava mealybug in Africa. *Am. J. Agric.Econ.* **70**: 366-371.

Ou, S.H. 1985.
Rice Diseases. Commonwealth Agricultural Bureau, Kew, p. 137.

Pimental, D. 1976.
"World Food Crises: Energy and Pests." *Bull. Entomol. Soc. Am.* **22**: pp. 20-26.

Poston F.L., L.P. Pedigo, and S.M. Welch. 1983.
"Economic injury levels: reality and practicality," *Bull. Ent. Soc. Am.* **29**: 49-53.

Regev, V.A., P. Guiterez, and G. Feder. 1972.
"Pests as a common property resource: a case study of Alfalfa Weevil control," *Amer J. Agric. Econon.* **58**: 186-199.

Stern, V.M. 1973.
"Economic thresholds," *Annu. Rev. Entomol.* **18**:259-280.

Stern, V.M., R.F. Smith, R. van den Bosch, and K. Hagen. 1959.
"The integrated control concept," *Hilgaria* **29**: 131-154.

van Lenteren, J. 1988.
"Implementation of biological control," *American Journal of Alternative Agriculture* **3**:102-109

Zadoks, J.C. 1989.
"Does IPM give adequate attentioin to disease control, in particular at the farmer level?" *FAO Plant Protection Bulletin* **37**: 133-150.

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