Includes CD-ROM of selected CPP/IPMSA publications, 1989-2001

PERSPECTIVES ON PESTS

Achievements of research under the UK Department for International Development's Crop Protection Programme, 1996–2000

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Edited by Anne Sweetmore, George Rothschild
and Simon Eden-Green

NR INTERNATIONAL
Natural Resources International Limited

Department for International Development

The Department for International Development (DFID) is the UK government department responsible for promoting development and the reduction of poverty. The policy of the Government was set out in the White Paper on International Development published in November 1997. The central focus of the policy is a commitment to the internationally agreed target to halve the proportion of people living in extreme poverty by 2015, together with associated targets including basic healthcare provision and universal access to primary education by the same date.

The renewable natural resources (RNR) research strategy funded by DFID's Rural Livelihoods Department (RLD) has the primary purpose of generating benefits for poor people by applying new knowledge in natural resources systems. The bilateral component of the strategy is organised as eleven research programmes, the largest of which is the Crop Protection Programme (CPP). The CPP is managed by Natural Resources International Limited (NRIL).

Natural Resources International Limited

NRIL specialises in managing programmes and projects in the natural resources, environmental and rural development sectors, as well as in such cross-cutting areas as institutional development. The company is owned by the University of Greenwich, the University of Edinburgh and Imperial College of Science, Technology and Medicine, University of London (incorporating Wye College), and draws on the expertise of these and other institutions, both in the UK and overseas. In addition to the Crop Protection Programme, NRIL also manages the Crop Post-Harvest, Livestock Production, Forestry and Post-Harvest Fisheries research programmes on behalf of DFID.

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Preface

In order to help define strategic priorities for generation of new knowledge, the then UK Overseas Development Administration (ODA; now Department for International Development, DFID) implemented a Renewable Natural Resources Research Strategy in 1989. Reduction in loss and damage caused by pests was a major element of this strategy, reflecting the long tradition of experience and expertise in this area established by UK development programmes since colonial times. Work on crop protection was coordinated under the Integrated Pest Management Strategy Area (IPMSA) and management was delegated to the ODA's executive agency, the Natural Resources Institute (NRI). The IPMSA[1] continued until 1995 when a major revision of the Research Strategy was published as what became popularly known as 'The Yellow Brick', on account of its size and the colour of its covers. This established a framework of six Production Systems, corresponding to agro-ecological zones or cropping systems, and sought to guide and link the work of 11 component natural resources research programmes covering different sectors. The IPMSA became the Crop Protection Programme (CPP) and remained under NRI management until 1996, when the Institute became part of the University of Greenwich. Shortly afterwards management was transferred to Natural Resources International Limited (NRIL).

Although some of the work started under the IPMSA continued under the CPP, there was an increasing emphasis on integration of research within cropping systems, as well as a shift in geographical focus towards semi-arid cropping systems in sub-Saharan Africa and the Indian subcontinent. Important objectives for the programme are to link high-quality research more closely to clearly identified demands from those affected by pest problems, and to package and promote outputs for use by those best able to adapt and implement research solutions for the benefit of poor communities.

The DFID's White Paper on International Development in 1997 set clear targets for elimination of world poverty, and reaffirmed the role of research in improving the livelihoods of poor communities and the quality of the environment in which they live. This presented the CPP with both a challenge and a responsibility to develop accessible solutions to pest constraints affecting poor communities, and to make knowledge available to those able to adapt and implement it. In pursuit of that objective, this publication highlights many of the projects carried out under the first phase of the CPP. It begins with an assessment of the ways in which pests contribute to poverty and the importance of pest management for sustainable livelihoods. It has not been possible to report all the projects that have been funded during this period, but a full list of projects is appended, together with contact addresses of participating organizations. Accompanying this publication, in the form of a compact disk (CD-ROM), is a searchable list of technical papers and reports produced by projects funded under the CPP since its inception, together with updated references to many of those produced under the IPMSA. All projects produce Final Technical Reports, copies of which can usually be obtained on application to CPP Management. Details of recent or current projects, some of which follow up results reported in these highlights, can be found in DFID's Natural Resources Information System (NARSIS) database at www.narsis.org or via the CPP website at www.nrinternational.co.uk.

The timetable for research to achieve impact can be lengthy and unpredictable, and achievements of this programme owe much to the past efforts of others. This publication aims to disseminate knowledge that has been gained over the past 4 years, to improve awareness of the programme, and to acknowledge the efforts of those who have carried out the work or have contributed to the knowledge base on which it has been founded.

I wish to thank the editor, Anne Sweetmore, for her tireless efforts to assemble this information from numerous and often lengthy project reports and for dealing with many queries and communications with project partners; Jill Lenné and Karen Wilkin for contributing to the introductory sections on poverty, livelihoods and the environment; George Rothschild for critically reviewing the technical content of the highlights; and Len Budd, Angela Milligan, Tina Rowland, Rob Fenn and Christine Wheeler for checking and editing the accompanying bibliography.

Simon Eden-Green
January, 2001

[1]See HILLOCKS, R.J. and EDEN-GREEN, S.J. (1998) *Research Highlights under the Integrated Pest Management Strategy Area 1989–95*. Chatham, UK: Natural Resources Institute on behalf of Natural Resources International Ltd.

Pests and poverty: the continuing need for crop protection research

The DFID Crop Protection Programme is committed to the development and promotion of socially and environmentally acceptable management technologies to reduce crop losses from pests[1] in developing countries. Improved pest management is an essential part of a holistic approach to crop improvement, substantially contributing to poverty elimination, enhanced livelihood security and reduced environmental degradation. Excellent progress has already been made in the development, application and promotion of a broad range of pest management technologies which farmers have already adopted and continue to adopt, especially in South Asia and sub-Saharan Africa, home to most of the world's poorest people.

Without the advances made by agricultural research over the past 30–40 years, including crop protection technologies, the effects of poverty would have been far worse. Studies show that economic growth, particularly agricultural growth, has contributed to a threefold increase in food production over the past four decades (Lipton and Longhurst, 1989). History records no increase in food production that was remotely comparable in scale, speed, spread and duration.

Further support is essential to meet the challenges of producing even more food from even less land, using technologies that have minimal adverse environmental impacts and contribute to poverty elimination. Technologies such as host-plant resistance, judicious use of pesticides, biological control and integrated pest management (IPM) will have an increasingly important role to play in the future.

WHO ARE THE POOR?

The poor are a very heterogeneous group, differentiated by gender, age and ethnicity, and they face different opportunities and constraints. Vast numbers of the world's poor are dependent in some way or another on agriculture, whether as producers, consumers, labourers, small entrepreneurs, or all these categories at once. The economic impact of improved agricultural technologies can benefit:

- producers, through increased productivity and/or greater profitability
- agricultural labourers, by generating employment and improving health
- agricultural traders, transporters and local food processers, by providing an assured supply of product
- consumers, through increased availability and quality of food, and lower prices.

We also need to recognize that poverty is dynamic, the poor shifting in and out of different poverty levels over time. This means that it is important to understand the processes by which these shifts occur and the role of agricultural research in catalysing change.

IMPORTANCE OF AGRICULTURE

Agriculture is the most important economic activity in most developing countries. Over 60% of the economically active population and over 50% of the rural economy are involved with agriculture. Meeting basic food requirements is the first priority of the poor, who may spend up to 80% of their income on food (Lipton and Longhurst, 1989). Ensuring food entitlement is a major priority for poverty elimination in most national development policy frameworks.

Raising productivity and overall crop production are key to enhancing food security and agricultural incomes at national and household levels. These requirements should be addressed in the early stages of a sequential process for eliminating poverty (UNDP, 1998). Continued agricultural growth is a necessity, not an option, for most developing countries (Hazell, 1999) but must be compatible with, rather than in competition to, protection of the environment and the natural resource base.

A central component of agricultural growth is the 'enabling environment' within which technological development takes place. This is the complex of policies, markets, culture and laws that shapes people's ability to turn new knowledge and technologies into productivity and production increases; and to translate these, in turn, into better food security and incomes. For consumers, traders and petty entrepreneurs, it determines the overall supply of produce, their individual access to it, their ability to respond to demand for sold-on or processed foods, and so on. At national and regional levels, the enabling environment can shape policies that encourage economic growth while reducing degradation of the natural resource base.

PESTS AND POVERTY

Globally about 50% of all food and cash crops are lost to pre- and post-harvest pests. Even with existing protection levels, based on significant advances in crop protection research during the past 40 years, about 30% of pre-harvest crop

1. The term 'pest' is used throughout this document to refer to weeds and fungal, bacterial, viral and phytoplasma pathogens, as well as to insect, nematode and vertebrate pests that affect crops. The term is qualified when it is used to specify a particular group of pests.

yield is lost annually. Without protection, and especially in developing countries, these losses are even higher. Pests are also dynamically changing in response to new environments and selection pressures (sometimes imposed through the misuse of protection practices) by evolving new, often more damaging variants. Crop losses negatively affect all categories of the poor. Continued crop protection research is essential to keep pace with these changes by extending and improving existing successful technologies and developing new, more robust methods to meet future challenges.

Pest problems add to producers' risks, and divert resources from other priorities (school fees, inputs for cash crops, etc.) if pest control inputs have to be purchased, or if time is diverted from other activities to pest control practices such as weeding. Crop failure due to pests may mean an individual farm family will starve because of the direct loss of food, loss of income, inability to repay debts, lack of money or credit to buy inputs for the next cropping season, and a variety of other effects. This initiates a downward spiral from which it is very difficult for the household to escape. If the crop failure is widespread – not unusual as a result of pest outbreaks such as locust plagues or wind-dispersed pathogens – not only will producers move into abject poverty, but those groups who depend on producers, including agricultural labourers, traders, transporters and processers, will also suffer.

IMPORTANCE OF CROP PROTECTION RESEARCH

Much of the increase in food production globally during the past 40 years can be attributed to research, including crop protection research, with internal rates of return of 30 to 50% (Pinstrup-Andersen *et al.*, 1997). Agricultural research has a high poverty elimination pay-off, and reduction of losses from pests in both food and cash crops is an integral part of the development of successful agricultural technologies.

As producers, poor farmers may gain from increased yields and profits as a result of new technologies provided by crop protection research. As consumers, the rural and urban poor may gain from more reliably available, cheaper, safer, higher quality food produced through environmentally friendly pest management strategies. When food prices decrease and stabilize, the poor gain proportionally more than the rich (Lipton and Longhurst, 1989). As landless agricultural labourers, the poor may gain from increased employment opportunities as a result of increased production and more labour-intensive technologies (but not necessarily higher wages). They may also gain from improved health due to safer management technologies, such as crop varieties with pest resistance which need judicious use of (or no) pesticides. As petty agricultural traders, transporters and local food processors, the poor may benefit from an assured supply of the product.

Since the 1970s, host-plant resistance has been increasingly successful in controlling many important pests of staple food crops, with substantial and continuing benefits both to small-scale, poor farmers and to the environment. The value of natural and enhanced biological control is increasingly being realized and developed as the backbone of many successful IPM programmes.

Pest management – whether based on genetic, cultural, biological or judicious chemical control practices or their integration into an IPM strategy – has successfully increased production, increased profitability, decreased food prices, improved yield stability, reduced economic risks, increased employment, and improved the environment for the benefit of the poor, especially over the past 30 to 40 years. DFID, through its support for crop protection research, has made a major contribution to this progress (Table 1).

TARGETING RESEARCH OUTPUTS TO THE POOR

GEOGRAPHICAL TARGETING

The Crop Protection Programme has a strong geographic focus on the poor, with approximately 60% and 30% of projects and programme budget targeted at sub-Saharan Africa and South Asia, respectively. These regions are the 'hot spots' of poverty and malnutrition, with more than 70% of the world's most food insecure – more than 800 million people (43% in South Asia, 24% in sub-Saharan Africa; Pinstrup-Andersen *et al.*, 1997) – who do not have enough dietary energy and protein. In addition, of the estimated 160 million malnourished children globally, approximately 100 million live in Asia and 40 million in sub-Saharan Africa. Bolivia, the only other country outside these two regions where the Crop Protection Programme supports several projects, is considered to be one of the poorest countries in Latin America; the focus here is on the fragile and erosion-prone hillsides, home to many resource-poor people.

PRODUCTION SYSTEM TARGETING

The Crop Protection Programme also targets the poor by prioritising production systems which have a high concentration of poor people and/or where investment in that production system will contribute to poverty reduction elsewhere.

For example, the semi-arid production system is home to about one billion people, of whom approximately 350 million (44% of the global total) are poor, food insecure, and mostly involved in agriculture. The largest proportion of the Programme's budget presently supports projects developing technologies to combat damaging pests of staple cereals and associated legumes and cotton, as well as migrant pests (Table 1).

Similarly, a considerable proportion of the poor live in rural forest-agriculture production systems and

Table 1. Contributions of the Crop Protection Programme to poverty elimination on priority crops in key production systems in sub-Saharan Africa and South Asia

Crop/Project*	Production system	Pests	Management strategy	Poverty elimination target
Rice in South Asia (R6519, R6643, R6739); Rice in sub-Saharan Africa (R6763, 6658, 6738)	Land-Water High potential	Tungro, sheath blight, yellow stem borer, weeds, rice yellow mottle virus, nematodes, blast	Resistance, cultural control, IPM	Major food source for most of the world's poor: decreased losses; increased production, reduced inputs, increased profits for producers, cheaper rice for consumers, safer working environment for labourers.
Maize in eastern and southern Africa (R6642, R6921, R6654, R6582, R6653)	High potential	Streak, *Striga*, ear rots, gray spot, termites	Resistance, cultural control, IPM	Major food source for the poor: decreased losses, stabilised yields, increased availability, increased profits for producers, cheaper maize for consumers, increased employment opportunities for labourers.
Cassava in Uganda (R6614)	Forest-Agriculture	Mosaic virus disease	Resistance, biocontrol	Major food security crop: decreased losses, increased food availability, increased profits for producers, cheaper cassava for consumers.
Banana in East Africa (R6692, R6582, R6580, R6579)	Forest-Agriculture	Sigatoka leaf spot, fusarium wilt, nematodes, viruses, weevil	Resistance, cultural and biocontrol, IPM	Major food for the poor: decreased losses, reduced costs of production for producers, increased food availability for consumers, increased employment opportunities.
Cotton in India (R5745, 6734, 6760, 7004)	Semi-arid	Bollworm	Resistance management, biocontrol, IPM	Major base of the rural economy and export crop: reduced costs and increased profits for producers, increased employment opportunities and safer environment for all.
Vegetables in sub-Saharan Africa (R6146, 6799, 6615, 6616, 6629, 6620, 6764, 6657)	Peri-urban	Diamond-back moth, fungal diseases, nematodes, viruses, weeds	IPM, biocontrol, biorationals, resistance, cultural control	Major base of the peri-urban economy: decreased losses, secure and profitable livelihoods for producers, safer food for consumers, safer working environment for labourers.
Coffee in eastern and southern Africa (R6782, R6807)	Forest-Agriculture	Diseases, insect pests	IPM, biocontrol	Major base of the rural economy and export crop: decreased losses, increased production, higher quality, lower production costs, reduced health risks for producers and labourers.
Groundnut in sub-Saharan Africa (R6811)	Semi-arid	Rosette virus disease	Resistance, IPM	Major food and cash crop: decreased losses, increased production, greater profitability, increased food availability for consumers, women will benefit most.

*Examples only are given.

depend on agriculture for their livelihoods. The Programme also invests a large proportion of its budget in developing technologies for management of serious pests of banana, root and tuber crops, perennial cash crops and agroforestry species (Table 1).

Growing urbanization in developing countries has made it necessary to manage serious pests of staple foods (such as rice and maize) and nutritional crops (such as vegetables) to meet the needs of increasing numbers of urban poor. Hence the Programme has recently increased spending in the peri-urban production systems.

Production systems may have different levels of poverty and different proportions of categories of the poor: producers, landless rural labourers, petty entrepreneurs and rural and urban consumers. Care is taken to balance contribution to high yields with reduced inputs for poor producers and reduced food prices for poor consumers. It is inevitable that sometimes technologies are developed that favour one category of poor at the expense of another.

FUTURE NEEDS

World population will grow substantially over the next 20 years, and 95% of this growth will occur in developing countries. The world's farmers will have to rapidly increase food production (Pinstrup-Andersen *et al.*, 1997). Severe food shortages, increased poverty, livelihood insecurity, political and social instability, and environmental degradation could occur in many developing countries early in this century unless more food is produced and prices are kept low.

The proportion of the world's population living in urban cities is predicted to grow from just under half in 1999 to almost 60% in 2025. Most of this increase will be in the developing world, and in secondary rather than primary cities. Urbanization and economic growth are likely to bring about changes in preferences in types of food consumed and in food safety and quality (Wiggins *et al.*, 2000). DFID-funded crop protection research will track these changes to ensure that it targets crops upon which the poor depend.

The agricultural productivity increases needed to lift rural and urban populations of low-income developing countries out of poverty and food insecurity without doing irreparable damage to the environment will be possible only if the appropriate government policies are pursued and continued investment in agricultural research is supported. Enlightened policies, together with the introduction and development of pest-resistant varieties, have generally resulted in reduced pesticide inputs, use of safer chemicals, and improved farmer safety.

Without DFID's support for agricultural research for development, including significant support for crop protection research, poverty in developing countries would have been far worse. The extent to which the growth of poverty is slowed, food security is improved, livelihoods are made more sustainable, economic growth continues, and natural resources are used more wisely in the future will depend on even greater investment in agricultural development, including crop protection research.

The Crop Protection Programme focuses on what it can do best to contribute to poverty elimination: developing pest management strategies that contribute to reducing losses; increasing and stabilizing yields; reducing pesticide use; and reducing economic risks. Such strategies will benefit human health, the environment, food safety and water quality; increase employment; increase incomes; and decrease food prices. Some of these objectives, however, can be achieved only through working in collaboration with other programmes within DFID and with a multitude of external partners, through well defined uptake pathways. The integration of the different contributions throughout DFID is key to ensuring that research results lead to poverty elimin ation.

Crop protection scientists, working in collaboration with breeders, agronomists and social scientists, have been able to bring many important pests under control in many developing countries during the past 30 to 40 years. Future success will depend on continued investment in improved pest management practices and their integration with crop improvement programmes. Strategic partnerships with international and national agricultural research services and non-governmental organizations will contribute synergistically to increasing yields and improving production efficiency, and will ensure environmentally friendly inputs to agriculture, all of which contribute to the elimination of poverty and sustainable livelihoods for poor producers and consumers, landless labourers and small agribusinesses.

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Integrating crop protection research and sustainable livelihoods

With a new goal of improving the livelihoods of poor people through sustainably enhanced production and productivity of renewable natural resources, there is a need to shift from how crop protection affects pests and crops, to how it affects people. Although the emphasis remains on producers, there is now a more explicit appreciation not only of farmers, but also of others such as consumers and labourers. The following examples illustrate the contribution of crop protection research to sustainable livelihoods.

BETTER MANAGEMENT OF NATURAL RESOURCES

One of the challenges in crop protection research is to sustain natural resources whilst managing losses due to pests, thereby increasing productivity. This is particularly important in areas of higher crop intensity where there tends to be greater potential for pest damage. Projects within the Crop Protection Programme are contributing to sustaining natural resources in such areas as:

- reducing pesticide use to control insect pests and vectors of tomato viruses (R6627) and cotton pests (R6734 and R6760) in India;
- tackling insect pests on vegetables in Kenya (R6615) and Zimbabwe (R6620);
- reducing the risks of spread by contaminated seed of persistent soilborne diseases of cotton and tomato in Tanzania (R6761 and R6627);
- understanding and enhancing natural enemies of rice pests in Bangladesh (R7296), minimizing effects on non-target organisms which may include other food sources for the poor.

Enhanced productivity in agricultural landscapes reduces pressure on natural resources elsewhere, as for example in the promotion of leguminous agroforestry trees for which the Crop Protection Programme provides support in eastern Africa (R6736).

A MORE SUPPORTIVE AND COHESIVE SOCIAL ENVIRONMENT

Farmer-based crop protection research, information acquisition and management strategies may all benefit from group rather than individual action. For example, the formation of farmer research groups to control sorghum fungal pathogens in Kenya (R6581); area-wide group action to implement chemical control systems, as in fruit and vegetable pest control in Pakistan (R6924), and access to reliable sources of planting material with resistance to virus diseases of cassava in Uganda (R6614) and Tanzania (R6765) and maize in Uganda (R6642). Some crop protection interventions may not be feasible without collaboration between farmers, and research may be needed to assess the feasibility for adoption of a technology over a large area, as with group action for use of pheromones to control rice yellow stem borers in India (R6739).

SECURE ACCESS TO FINANCIAL RESOURCES

Areas where crop protection strategies can affect financial capital include increased income through improved crop yield or quality, as with management of African cassava mosaic disease (R6614); and increased net income through reduction in the costs of crop protection methods, for example for cotton in India (R6734), yams in Ghana (R6691), and many other projects.

IMPROVED ACCESS TO EDUCATION, INFORMATION, TECHNOLOGIES AND TRAINING, BETTER NUTRITION AND HEALTH

A wide range of stakeholders benefit from improved knowledge about crop protection targeted at the poor. A range of projects within the Crop Protection Programme have developed diagnostic tools that allow researchers, extension workers and others to identify important diseases of rice (e.g. R6643 and R6519) and vegetables (R6657 and R7266), and many stakeholders have participated in targeted workshops. To gain the best advantage from integrated pest management, farmers need to know about the biology of the crop, the pests and their natural enemies. This means building on farmers' existing knowledge and enhancing their capacity to observe and experiment, encouraged by a farmer-field school approach, and/or having pest experts available to give advice to farmers.

Reduction in crop losses in general can contribute to improved nutrition for the poor, directly, e.g. through research on finger millet blast in Kenya (R6733), or indirectly, through increased food availability and lower prices for poor consumers. The effects of pesticides on the health of labourers, farm families and possibly also consumers are a major issue, especially in crops such as vegetables where high levels of pesticides are commonly used. Project R7071 works with a community based NGO in north-east India to reduce the quantity and/or toxicity of chemicals, and a cross-cutting project is exploring with small-scale manufacturers constraints on production and adoption of environmentally benign microbial pesticides in India (R7299). Other health problems addressed by the programme include control of the allergenic weed *Parthenium hysterophorus* in India (R6695), and toxins from fungal pathogens causing ear-rots of maize in Africa (R6582).

The effects of crop protection practices on labour may be more complex. For example, projects aiming to reduce the labour and drudgery of weeding have potentially significant effects on the time and effort spent by disadvantaged groups: it is often the children (instead of attending school) or women (prevented from doing more productive jobs) who are involved. But weeding can also be a valuable source of rural income, and the shift to less labour-intensive methods has potential consequences for the distribution of rural income.

BETTER ACCESS TO INFRASTRUCTURE

Both researchers and farmers are affected by physical capital. For example, pest forecasting and surveillance systems require sufficient infrastructure – roads, radio, computers etc. – to monitor and analyse pest movements (relevant to migrant pest projects such as R6762, R6788, R6822 and R6823). Good roads and radio services are necessary for the extension services to serve farmers in more remote areas. Access to water can affect planting times and weed control methods.

POLICY AND INSTITUTIONAL ENVIRONMENT

The policy and institutional environment is a major determinant of the type, effectiveness and impact of research. The Crop Protection Programme will increasingly invest in identifying and, where appropriate, supporting suitable institutional partners (public or private), with a much clearer focus on target crops and countries. Research activities will be attuned with the priorities and policies of target countries, where these reflect the needs of poorer communities. Policy and institutional environments are rarely static, and where opportunities arise the Crop Protection Programme will seek to influence the policy and institutional environment, as has already happened in India, through interaction with national IPM policies under the National Agricultural Technology Programme.

SUSTAINABLE LIVELIHOODS FRAMEWORK

The Sustainable Livelihoods Approach has been adopted by DFID as a way of analysing poverty issues and formulating more effective development strategies to alleviate poverty. This analysis of how pest management strategies can work for particular groups of people is being followed by the Crop Protection Programme. The Sustainable Livelihoods framework is helping the Programme to assess the impact of new crop protection technologies and their potential benefits for the poor, and to identify areas that need to be strengthened to encourage the uptake of sustainable pest management practices.

Lack of uptake of crop protection technologies by poor farmers is usually due not to the quality of the technology, but to the lack of a pathway or mechanism for uptake and promotion. The Programme places great emphasis on building robust uptake pathways in all newly commissioned projects, by including at the planning stage activities for ongoing interactions between collaborators. In some cases long-standing collaborative research relationships are being further enhanced; in other cases efforts have been made to bring new partners into the fold, including NGOs and the private sector. Linkages to functional regional research networks in sub-Saharan Africa (ASARECA, Association for Strengthening Agricultural Research in Eastern and Central Africa; SACCAR, Southern African Centre for Co-operation in Agricultural Research; CORAF/WECARD, West and Central African Council for Agricultural Research and Development) and South Asia (APAARI, Asia-Pacific Association of Agricultural Research Institutions) are being sought. The programme is increasingly acting as a broker and a catalyst to promote the uptake of crop protection research outputs by poor farmers.

Crop protection and the environment

The mission of the Crop Protection Programme is to develop, through research, improved, environmentally acceptable crop protection strategies which are appropriate for small-scale farmers in developing countries. Priorities are set and approaches selected that respond to demands from farmers and consumers, or from those intermediate users who will adapt or apply improved technologies on their behalf.

Agricultural systems in developing countries have evolved as a delicate balance between crop and pest communities and traditional low-input farming systems, and are often particularly fragile and vulnerable to change. Through partnership with intermediary organizations, the Crop Protection Programme aims to develop and promote appropriate IPM strategies that reduce pest damage, through careful integration of available pest control options that are sustainable and best suited to local needs. They involve rationalizing (and usually reducing) the use of agrochemicals, and maximizing the impact of biological and cultural components to provide environmentally sound pest control that is less dependent on external inputs and more accessible to the poor. The importance of IPM was highlighted in Agenda 21, the action plan of the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, and has since been the basis of numerous national and international proposals and initiatives.

Developing more environmentally acceptable and sustainable approaches to crop protection is a fundamental component of the Crop Protection Programme. Many projects are developing biological and cultural methods of pest management aimed at minimizing damage to non-target organisms whilst decreasing pest populations to levels where they do not cause economic injury to the crop. These methods are essential components of an integrated pest management (IPM) approach. Some examples are:

- The assessment of biocontrol agents to control pests, e.g. smut and rust species are being used to control the weeds itchgrass (R6690) and Parthenium weed (R6695), respectively; the pathogens *Pasteuria penetrans* and *Verticillium chlamydosporium* are used for control of root-knot nematodes (R6611).
- The development and use of viral and fungal biopesticides, e.g. a viral insecticide to control diamond-back moth in Kenya (R6615); research into the use of the fungal entomopathogen *Metarhizium* sp. to control termites in maize (R6653).
- Development and testing of resistant crop varieties such as tomato varieties resistant to leaf curl virus (R6627), or rice varieties resistant to tungro disease (R6519).
- Pheromones to disrupt mating, e.g. for diamond-back moth in Kenya (R6615).
- Assessment of cultural methods such as planting density and timing of legume cover crops for weed suppression (R6690); development of simple, non-chemical seed treatments to reduce sorghum head smut in Kenya (R6581).

The successful development of environmentally sustainable controls that are appropriate for poor farmers has a number of requirements.

- Firstly, there is a need for researchers to understand the biology and diversity of pest species in order to develop controls such as biopesticides and varietal resistant lines. Projects such as R6583 (banana nematode resistance) and R6738 (rice blast and scald resistance) are investigating the variability of these pathogens in order to provide information for development of improved resistant lines.
- Interactions between pests and natural enemies have to be understood by researchers in order to assess the potential of the use of such predators and parasitoids for effective pest control. For example, the effectiveness of parasitoids in controlling whitefly was assessed in project R6627. Project R7296 is researching species interactions in farmers' rice fields in Bangladesh.
- Pest management controls need to be robust enough and stable enough to meet farmers' requirements. Poor farmers may not be able to afford to adopt biological controls if their effectiveness is highly variable when applied in their own fields. Projects such as R6615 are working on refining biological controls to provide increased efficacy under field conditions. Project R7299 is researching issues of production and uptake of biopesticides in order to meet the needs of farmers.
- Environmentally sustainable pest management often requires more precise application of controls and increased understanding of pests and natural enemies by farmers themselves than is required for pesticide application. Projects such as R7266, based in Kenya and Zimbabwe, have developed field handbooks and posters to enhance farmers' knowledge of pests and natural enemies, so that they are better able to take up IPM methods. Some pest

management strategies require group action by farmers in order to work most effectively: for example, in project R6739 which has developed pheromones for control of yellow stemborers in rice, the potential for effective group action by farmers is one of the research issues.

The use of pesticides remains a significant component of plant protection for many farmers. Minimizing pesticide use by better selection and application can have a major impact both on the environment and, directly and indirectly, on human health. Selective use can also reduce the likelihood of insect resistance building up quickly. For example, over half the pesticides in India are used on cotton, so that projects such as R6734, on insecticide management strategies in cotton, which have reduced insecticide use by up to 70%, have had an impact and raised local awareness about the misuse of pesticides. Vegetables are another crop where pesticide use is often high. Project R6620 in Kenya is researching improved ways of using pesticides more effectively and safely, in addition to integrating these with biological controls. In India, project R7071 is working with local NGOs to reduce the level of pesticide use on dry-season vegetables.

In recent years, the use of herbicides has been increasing rapidly across many farming systems; however the effects of herbicide residues in the environment are not well understood. Project R7347 is investigating the effects of herbicide residues on non-target organisms in irrigated rice systems in south Asia.

Improved methods for the management of *Striga*: nitrogen, tolerance, screening and cultural practice

R6921

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Striga species are root parasitic weeds that infect staple crops (maize, sorghum, millet and upland rice) throughout some 40% of the cereal-producing land of sub-Saharan Africa. They are responsible for significant reductions in yield, sometimes even resulting in total crop failure. Smallholder farmers suffer most from the parasitic weed, and there is an urgent need to identify practical control methods. This project has made progress in understanding the mechanisms through which *Striga* affects its host, and has begun to identify sources of tolerance and/or resistance to *Striga* in small-grain cereal crops that can be used by plant breeders. Methods have been developed to allow *in vitro* studies of the parasite's life cycle that can be used in rapid screening to detect early infection in the field. Progress has also been made in understanding how nitrogen fertilizer and the timing of its application influence the response of cereals to infection by *Striga*.

ISSUES

Striga species are weeds that parasitize the roots of cereals, infecting major staple crops (maize, sorghum, millet and upland rice) throughout ~40% of the cereal-producing land of sub-Saharan Africa. The two most important weed species are *S. hermonthica* and *S. asiatica*. Yield losses of 30–50% are common under heavy infestations, and infection sometimes results in total crop failure. It is not uncommon for farmers to abandon severely infested land or to adopt a different cropping pattern in an attempt to overcome the problem. It has been estimated that grain production in Africa is threatened by *Striga* on 44 Mha (3.2% of the world's arable land) which represents an economic loss from infection of US$3–7 billion.

Striga is therefore a serious economic problem, and is arguably the most important biotic factor constraining the production of major cereal subsistence crops in semi-arid tropical Africa. The weed is a particularly critical problem for resource-poor households in the densely populated drier areas of West, East, central and southern Africa, as it is commonly associated with low soil fertility and continuous cropping.

Despite major efforts to identify sources of resistance to *Striga* species, completely resistant cereal cultivars have not been identified, although cultivars of cowpea resistant to *S. gesnerioides* are now known. In sorghum, pearl millet and maize there are as yet no reliably resistant varieties. It is critical to identify firstly how *Striga* reduces host yield, and secondly how management practices can best mitigate the effects of the weed.

ACHIEVEMENTS

Work was carried out through a combination of laboratory studies and on-station and on-farm field studies, principally in Tanzania but with some activities in western Kenya.

- Cultivars have been identified that perform well in the presence of *Striga*, e.g. the maize cultivar Staha.
- Useful traits and characteristics in cereals have been studied that will allow breeders to develop potentially useful cultivars. Reducing the number of *Striga* plants that the host supports does not exert a major impact on grain enhancement, since competition for resources between host and parasite is not the primary mechanism responsible for yield depression. Delaying attachment of the parasite to the host's root system is one of the most useful traits for alleviating the effects of the parasite.
- Novel sources of resistance in wild relatives of maize are being investigated, which may be used in the medium term to alleviate the impact of *Striga*.
- Early application of nitrogen lessens the impact of *Striga* more effectively than later application, but there are important genotype × environment interactions that can modulate its efficacy.
- The project has provided education and training to local scientists and extension workers in Tanzania and Kenya, in collaboration with colleagues from target institutions. Basic scientific information on *Striga*–cereal interactions has been provided to researchers in both developed and developing worlds to facilitate the development of new control strategies.

FUTURE

The findings from this study, together with those from a previous project in Tanzania (R6654; see page 2), form the basis of an ongoing collaborative programme (R7564) that aims to complete screening and farmer evaluation of resistant cultivars; to incorporate these into integrated management strategies with a particular emphasis on matching resistant cultivars with soil fertility levels; to multiply selected sorghum lines for registration and release to farmers; and to identify sources of resistance in maize. The latter will also be addressed in collaboration with colleagues at the International Maize and Wheat Improvement Center (CIMMYT), building on achievements from this programme.

Publications: see Bibliography on CD.

Integrated control of *Striga* in Tanzania

R6654

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Striga is one of the most important weeds in East African smallholder cereal production, affecting 40% of the cereal-producing areas of sub-Saharan Africa. Serious infestations can cause total crop loss. This project has worked with farmers to select from the most resistant sorghum lines currently available, and a start has been made to assess the productivity of these lines when used in combination with other *Striga* control measures, by conducting trials in four villages of two zones in Tanzania. Preliminary work has also been carried out on identifying sources of resistance in finger millet and rice. *Striga* resistance in sorghum was shown to be less pronounced at sites with low fertility, but it can be enhanced by applications of manure or by intercropping. Efforts to introduce farmer participatory methods new to some of the study areas, and to extend knowledge of *Striga*, an 'invisible' source of crop problems, have resulted in knowledgeable farming communities who will provide a resource for further investigations.

ISSUES

Parasitic weeds in the genus *Striga* are widespread constraints to the production of staple cereal crops in semi-arid areas of eastern and southern Africa, including finger millet, sorghum and upland rice. They have been estimated to infest some 40% of the cereal-producing areas of sub-Saharan Africa; *S. hermonthica* alone may now infest over 10 million hectares. Semi-arid areas of Tanzania lie in a zone where the three most significant *Striga* species infesting cereals (*S. asiatica, S. forbesii* and *S. hermonthica*) all occur. Reports of 5–30% loss of potential yield, with crop failure at heavily infested sites, are common for various parts of Africa. Other consequences of *Striga* infestation include farm abandonment, now difficult in the face of a shortage of productive arable land, or a change of cropping pattern to less favoured, albeit resistant crop species.

A number of sorghum breeding lines have been produced elsewhere in Africa, and specifically by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), in an attempt to introduce parasite resistance into lines adapted to Tanzanian conditions. However, due to limited local funding these had not been screened, and findings from on-station trials had not been followed up on-farm within affected farming communities.

This project aimed to support national programme efforts to develop integrated methods for the management of *Striga* in Tanzania through farmer participatory research. Potentially resistant sorghum lines were obtained for screening, and investigations were carried out on the problems of *Striga* in finger millet and upland rice. This work collaborated with project R6921 which has investigated the effect of nitrogen on parasitism of maize by *Striga*, and has undertaken detailed laboratory studies to describe mechanisms of tolerance to *Striga* in the sorghum lines tested in the field. The aims of the project were to develop and evaluate practices for the control of *Striga* species in cereal-based cropping systems in Tanzania, integrating techniques appropriate to smallholder farmers.

ACHIEVEMENTS

A series of on-station and on-farm trials were undertaken to investigate components of an integrated system of *Striga* management for sorghum, finger millet and rice in Tanzania. This work was supported by glasshouse studies conducted in the UK. Sorghum lines were selected on the basis of low susceptibility and farmer preference in on-farm trials in the Lake Zone (*S. hermonthica* infested) and Central Zone (*S. asiatica* infested). Farmers showed particular interest in the early maturing line P9405, obtained from Purdue University, USA, which also performed well at a site infested by *S. forbesii*. This was also tested in combination with the application of animal manure or a legume intercrop. Efforts are now needed to multiply

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Left, Striga asiatica*; right,* S. hermonthica

selected lines for wider testing prior to registration.

Studies of farmers' perceptions of the *Striga* problem indicated that they have little understanding of the life cycle or biology of the parasite – this is a considerable constraint to the process of farmer evaluation of control options. Posters were produced to inform both extension workers and farmers about key aspects of *Striga* biology and control.

S. hermonthica is a problem on finger millet in the Mara Region of Tanzania. Pot screening of local landrace lines did not reveal any resistance. Laboratory and green-house systems for screening this crop were demonstrated as suitable.

S. asiatica is associated with declining soil fertility and falling yields of upland rice in Kyela District, southern Tanzania. Work was undertaken with farmer groups formed by district extension staff to evaluate rice cultivars and practices for improving soil fertility. Lines which had shown partial resistance to other *Striga* species in West Africa (R5228) were susceptible. Farmers indicated a clear preference for tall, vigorous rice lines with aromatic grains, and have requested the opportunity to evaluate a number of lines on larger plots. Application of urea at 25–50 kg N per ha reduced the parasite density in rice and improved yields. The parasitic weed *Rhamphicarpa fistulosa* was identified as a constraint to lowland rice production in Kyela.

The project has demonstrated that *Striga* resistance in sorghum is less pronounced at sites with low fertility, but it can be enhanced by applications of manure or by intercropping. No resistance has been found among the finger millet lines made available to the project for screening. Partially resistant *Oryza glaberrima* and *O. sativa* rice lines from West Africa were tested but were not favoured by farmers, and did not show high levels of resistance.

During two seasons, unusual conditions of drought in some areas combined with excessive rainfall in others meant that few crops went through to yield. A critical assessment of the economic value of the management practices investigated was compromised by the difficult weather conditions and associated pest infestations. It therefore proved difficult to take crops to yield in on-farm trials. In the villages of Dodoma Rural and Urban Districts food became particularly short during early 1999, and a number of participating farmers were forced to leave their farms in search of work and food. Farmers at some sites were unable to leave their plots until the crop matured, and removed and consumed sorghum heads as they ripened.

Involving farming communities in the assessment of *Striga* management options has required the introduction of new methodologies in some of the areas of Tanzania where the project has been working. Although the use of farmer research groups is well established in the Lake Zone, these are not well known in other areas, including Dodoma. It therefore took some time for research and extension staff to fully embrace this way of working. By the end of the project the group approach had become well established in the study villages, and these will provide ideal locations for further studies.

FUTURE

As the project developed there was increasing interest in Tanzania in addressing the *Striga* problem. With the establishment of Zonal Research Programmes, *Striga* has now been identified as a priority issue via zonal internal programme reviews in Eastern, Central, Lake, Southern Highlands and Southern Zones. Expertise on *Striga* research remains concentrated at Ilonga, the Eastern Zone research centre. As other zones have begun to develop their programmes, it was requested at the stakeholder workshop that follow-on work should help back-stop efforts to develop and promote *Striga* management recommendations at the zonal level. In Kyela, the District Council has allocated funds so that district and village extension staff can continue to work with *Striga* researchers from outside the district until 2002.

Research is continuing with inputs from NRI, Sheffield University and the national programme, with an emphasis on farmer cultivar selection, matching sorghum cultivars to differing soil fertility conditions, and the development and testing of 'learning tools' which will facilitate the promotion of *Striga* management options to farmers (R7564).

Moisture conservation through improved weed management in conservation tillage systems

R6655

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April 1996–September 1999

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Weeding accounts for up to 60% of the labour used in maize production in Zimbabwe. Because of poor returns from cropping (particularly in semi-arid regions), and an acute shortage of draught animal power and labour in many households, conservation tillage/weed control systems need to be based on low-cost, labour-saving technologies. This project follows up previous on-station research into low-cost weed management, using a participatory technology development approach. A range of crop establishment and weeding practices have been developed with and assessed by farmers, and information to support further promotion of their use has been made available to extension agencies. A good understanding has been developed of the extent to which combinations of practices can be used by, and be of benefit to, households in different resource categories.

ISSUES

Approximately 90% of the smallholder farmers in Zimbabwe are located in semi-arid areas which are marginal for the production of most annual crops due to unreliable rainfall. As in much of sub-Saharan Africa at the smallholder level, excessive weed growth is a major constraint to the adoption of conservation farming practices and increased crop production.

Previous research in Zimbabwe (R5236) demonstrated how weed management influences the availability of soil moisture, and examined weeding regimes in terms of crop water-use efficiency and grain yield. In addition to site effects, the level of weed infestation a farmer has to deal with is a reflection of cultivation history, and varies with changes in primary tillage, planting and in-crop cultivation practices. These are all linked to and influence soil moisture availability to the crop. Tillage, crop establishment, and weeding must therefore be considered as an integrated system; little benefit is to be derived from studying components in isolation.

Results from on-station trials showed that combining weeding with a plough or a cultivator with planting using a ripper tine to create planting furrows could provide a low-input draught tillage/weeding system. This project sought to take the work to the next stage, in which farmers could evaluate the recommended technologies for themselves.

Using knowledge of farmer resource categories, the aim was to use participatory research techniques to develop a better understanding of farmers' perceptions of weeds and weed control, and to provide extension staff with guidelines for the wider testing and promotion of a range of crop establishment and weeding options. In Zimbabwe this contributes to the Participatory Extension Approach adopted by Agritex (the national Agricultural Extension Service) and NGOs, by providing farmers with information on which they can base the selection of weed management practices relevant to their circumstances.

ACHIEVEMENTS

Trials were planned and implemented with farmers in Masvingo Province, in collaboration with Natural Resources System Programme project R4840, on three soil types: the sandy toplands and valley bottom wetlands of the hydromorphic *vlei* margin, and seasonally inundated *vlei*. Technologies were initially tested in replicated researcher-managed trials, then assessed by farmers themselves using paired plots. Three farmer groups were identified according to access to resources such as labour and draught animal power, and involvement in the market.

Table 1. Farmer preferences for crop establishment and weeding in Zimuto based on pairwise ranking

Soil type	Stage	Method	Score
Topland	Crop establishment	Hand hoe	1
		Rip	3
		Open furrow	3
		Third furrow	0
	First weeding	Hand hoe	0
		Cultivator	2
		Plough	1
	Second weeding	**Hand hoe**	2
		Cultivator	1
		Plough	0
Vlei	Crop establishment	Hand hoe	1
		Rip	0
		Open furrow	2
		Third furrow	3
	First weeding	**Hand hoe**	2
		Cultivator	0
		Plough	0
	Second weeding	**Hand hoe**	2
		Cultivator	0
		Plough	0

0 = considered unsuitable
1 = only used because resources for other methods not available
2 = suitable method (crop establishment) and best method (weed control)
3 = best method (crop establishment)
Methods in bold preferred

Weed problems and farmers' current weeding practices were described in both areas. Major problems with sedges and perennial grass weeds were identified at *vlei* margin and *vlei* sites. Timely planting on residual moisture ahead of the onset of the rainy season is essential in these ecologies to allow weeding to be completed before surface water accumulates. Farmers appreciate the need for practices that enhance soil moisture conservation on the topland in dry years and enhance drainage in the wetland fields in wet years. Better-resourced farmers own cultivators. Female-headed households tend to weed with a hoe; women lack the skills and experience to undertake weeding with draught animals. The use of a ripper at planting, for example, allows timely crop establishment and will be of benefit to more than 60% of households who own draught power. The ways in which weed management needs to be modified when a ripper is used, compared to traditional methods of ploughing and planting, have been evaluated and information is now available, based upon farmer assessment criteria, on which to base promotion of the technology to farmers. For resource-poor households who may be unable to gain access to a ripper or cultivator, the project has demonstrated that weeding can be undertaken with the existing mouldboard plough and the advantages and disadvantages of this practice have been described. These outputs can be used by extension services to better target promotion of improved weed control, within an overall package of tillage/crop establishment/weed control methods, to farmers with differing access to resources.

During the final season, on-farm assessments were all farmer-managed. Following exposure of farmers to the practices tested during the previous two years at field days, volunteers carried out assessments using paired plots on their own fields. These compared their existing methods, usually third furrow planting and hand weeding or ox-cultivation, with an improved

Planting furrows created with a ripper tine in a weedy fallow. Insets: top, a ripper tine; below, ripper tine attachments made by a local blacksmith

Group meeting discussing the strengths and weaknesses of different crop establishment and weeding technologies

method. The preferred options for crop establishment and weeding, as indicated by farmer groups in pairwise ranking completed during the season, are shown in Table 1. Perceptions of weeding methods strongly reflect the unusually heavy rainfall experienced, and the consequent inability of farmers to weed with animals in the *vlei* and much of the topland and *vlei* margin.

Project staff assisted farmers with a simple record-keeping scheme. The records were maintained in the form of participatory budgets, with group discussion and a formal survey undertaken to establish farmers' perceptions of each technology option. An economic analysis was undertaken to establish costs and benefits, and likely value to households with differing levels of resources.

All this information has been used to develop the leaflet *An Extension Guide on Participatory Assessment of Crop Establishment and Weeding Methods*. Given the variations in soil and climatic conditions faced by farmers, as well as the differences in access to key resources, it is difficult to provide firm 'blanket' recommendations. Rather, the project has clarified the range of options that are appropriate to each category of household, and provides guidance to extension workers on the information farmers need when assessing which practice to use.

During the project, farmers became particularly interested in adopting a ripper tine. Bolted onto the existing plough, this allows for rapid, timely planting and has a low draught requirement. Agritex staff collaborating with the project undertook workshops for rural blacksmiths in the area to provide instruction on making the ripper assembly and on implement maintenance in general.

In addition, during the course of the project a detailed quantitative assessment was undertaken of water uptake by weeds, and the relative effects of mechanical weeding and frequency on weed transpiration, the infiltration process, and the soil water regimes that develop. The information collected was used to further refine the soil-water balance component of the predictive model PARCHED-THIRST. The model can now be used to examine the effects of different weeding practices on maize yield in semi-arid areas.

FUTURE

Transfer of the project outputs to farmers is proceeding through a number of channels. Establishment and weeding practices developed and tested by the project have been incorporated into the on-farm programmes of an International Fund for Agricultural Development (IFAD)-funded project for Midlands and Matebeleland, and the DFID-funded CARE Small Dams Project in Masvingo Province.

Outputs from this work have also led to the implementation of further DFID-funded work in Zimbabwe. A project is now being funded by the Livestock Production Programme (R7352) to examine the problems involved with the use of draught animal implements identified by this project, involving field work to examine the impact on crop productivity of implement availability, maintenance, and farmers' knowledge of correct implement settings. New work has also started to investigate opportunities for improving production in the *vleis* through the use of sustainable tillage/weed management practices (R7473). Both projects are using the participatory technology development approach evolved by this project.

Control of water hyacinth in the Shire River, Malawi

R6392

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Water hyacinth is the world's worst aquatic weed. It causes considerable disruption to communities, particularly to fishermen and housewives. It blocks access to water, disrupts fishing efforts, harbours harmful aquatic disease vectors and snakes, disrupts water transport and hydro-electric power generation, and damages wetland biodiversity and fish abundance. The weed has been controlled in several tropical countries by the introduction of specific biological control agents. This project has introduced several self-sustaining biological control agents into the Shire River, Malawi, and evaluated the socio-economic impact of the weed on local communities and its effects on wetland biodiversity. Community education and participation was a major feature of this work.

ISSUES

Water hyacinth (*Eichhornia crassipes*) is an aquatic weed with enormous growth potential. Relative growth rates may be between 2 and 20% plants per day. Even a 2.5% relative growth rate would lead to a doubling of water hyacinth in less than 1 month.

A 1993 socio-economic study of the fisheries sector in Malawi described the weed as one of the greatest constraints on the fisheries of the Lower Shire valley. Water hyacinth competes with indigenous water plants, leading to a reduction in the diversity of plant and animal life. A preliminary study of the effects of water hyacinth on biodiversity in Lake Victoria showed that fish species diversity and abundance, as well as biodiversity of other species, were at significant risk from water hyacinth. Water weed infestations also harbour vectors of diseases (including schistosomiasis, malaria and encephalitis), and disrupt water transport and hydro-electric power generation.

Classical biological control, which is self-renewing and self-sustaining, is the preferred means of controlling water hyacinth.

ACHIEVEMENTS

Four biological control agents were introduced during the course of the project. Two of these, the weevil species *Neochetina eichhorniae* and *N. bruchi,* established readily and were reared in large numbers (over 100 000) for release throughout the length of the river. Both species were established and well distributed by the end of the project. Two other insect species, a mirid bug, *Eccritotarsus catarinensis*, and a moth, *Niphograpta albiguttalis*, were also introduced but had not been confirmed as having established by the end of the project. A fifth species, the mite *Orthogalumna terebrantis*, was already present on water hyacinth in the Lower Shire at the start of the project, and was successfully redistributed throughout the Shire river.

The full effects of the agents established will not be seen for 2 years, once their populations have built up sufficiently for maximal impact on the weed. The biocontrol agents appeared to be growing and increasing more quickly in the Lower Shire than in the Upper Shire, probably due to more favourable climatic and nutrient conditions lower down the river.

The project carried out a socio-economic survey (participatory rural appraisal) to identify the problems that local communities associate with the weed. The survey confirmed that water hyacinth is a major problem for communities in the Shire River, and has established a baseline against which future surveys can be judged.

Permanent sampling plots were set up to evaluate the impact of water hyacinth on the succession and biodiversity of aquatic species. The data showed that water hyacinth has a profound effect on ecological succession in wetland habitats. Stable mats of the weed provide support for the invasion of indigenous aquatic plants which are then able to colonize the area much more effectively.

Meetings and open days were held with fisheries extension officers and local community groups, at which they were informed of the objectives of the project, the dangers associated with the weed, and the principles of controlling it using introduced insects and mites. Local communities assisted with releasing and redistributing biological control agents. Extension messages were conveyed to local communities through posters and radio jingles in local languages.

As well as establishing procedures which will lead to the permanent suppression of water hyacinth, the project has put in place mechanisms for monitoring the impact of the weed and biocontrol agents from a socio-economic perspective, and the effects on biodiversity and wetland plant communities. Suppression of the weed through biological control, which is likely to be in the order of 75–90% by weight, should lead to substantial benefits for local communities.

FUTURE

Biological control of water hyacinth takes several years. Since the start of the project, the weed has been found in several rivers north of the River Shire, and also in Lake Malawi. These areas are being addressed as part of a World Bank-funded project, and CABI Bioscience and PPRI are supporting the Fisheries Department to continue the biological control programme.

Publications: see Bibliography on CD.

Improving the health of seed yams in West Africa

R5735, R6691

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White yams (*Dioscorea rotundata*) and yellow yams (*D. rotundata-cayenensis*) originated in West Africa, and have been a staple food there probably ever since man first inhabited the area. They are thought to be one of the first crops tended by man in the region. It is likely that cultivation practices have changed little over the centuries, and yams remain a relatively difficult and labour-intensive crop to grow. Generally it is necessary to plant large tuber pieces in order to obtain reasonable yields, and clean planting material has been difficult if not impossible to obtain. The main objective of this project was to adapt, develop and test a menu of phytosanitary treatments/practices applied to minisett or seed tubers, in order to provide an effective package of measures for control of major yam pests and diseases. This project built on previous work using well tried techniques (including fungicidal seed dressings, hot-water treatments and tuber selection) to improve the health of seed yams produced from minisetts. A simple preplanting treatment with fungicide (one of the benzimidazoles or conazoles) was the most effective of the methods tested, and has the potential to make the minisett technique for rapid production of seed yams much more reliable, and hence to sustainably increase the productivity of yam cultivation in West Africa.

ISSUES

The cultivation of yams in West Africa remains a difficult, risky and labour-intensive practice for most farmers. Traditionally, relatively large pieces of tuber are used as planting material, making for a very low multiplication rate. This reliance on vegetative planting material also means that carry-over of pests, viruses and diseases from one crop to the next is a major problem, and reliably disease-free planting material is difficult and expensive to produce. The minisett technique has been promoted as a possible means of increasing the multiplication rate by including a crop produced from small (~25 g) tuber pieces (minisetts) in the production cycle. The seed yams produced from minisetts in the first season are planted to produce ware yams in the second season. At the commencement of this work (R5735) in 1992/93, the minisett technique had not been taken up by many growers in West Africa because the unpredictably poor germination and survival of the minisetts made it unreliable, and it was seen to be more time-consuming and difficult to manage.

The aim of this project was to test and adapt a menu of phytosanitary treatments/practices to improve the germination and survival of yam minisetts, and in doing so, to help establish facilities and train staff in Nigeria in methods of tuber crop disease research. Links were established with previous research at the Federal University of Agriculture, Makurdi/University of Reading (R5675; R5738, see *Research Highlights 1989–95*) on aspects of the epidemiology of yam anthracnose disease. In the second year of the project a link was established with the International Institute of Tropical Agriculture (IITA) and field trials were conducted at the high-rainfall field station at Onné near Port Harcourt.

ACHIEVEMENTS

Field trials to compare the efficacy of a range of fungicide treatments of yam minisetts were established at several locations in Nigeria. The results collected from these trials indicate that the mortality rate for minisetts can be significantly reduced by a preplanting application of a systemic fungicide such as one of the benzimidazoles (benomyl, thiabendazole, carbendazim) or conazoles (imazalil). Water yams (*Dioscorea alata*) were generally more amenable to the minisett technique than white yams (*D. rotundata*). For white yams, even with the best fungicide treatment mortality was still often as high as 50%. Neem leaf powder, the only 'natural' and

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Table 1. Average number of yam minisetts per plot surviving to produce a mature plant with various fungicidal seed treatments, with or without insecticide

	White yam				Water yam			
	With carbosulfan		Without carbosulfan		With carbosulfan		Without carbosulfan	
Benomyl	**14.6**	**	**12.6**	**	22.66	**	**19.66**	*
Thiabendazole	5.3		**13.6**	**	20.00		17.33	
Imazalil	**10.6**	**	6.0		20.00		18.00	
Tolclofos-methyl-	5.6		2.0		20.66	*	19.00	
Pencycuron	1.0		4.3		14.00		17.33	
Iprodione	**13.0**	**	5.6		20.00		21.33	*
Sulphur	7.0	*	7.6	*	15.00		15.33	
Neem	5.6		2.6		18.66		11.66	
Control	1.3		1.0		14.00		13.33	
	LSD$_{(0.05)}$ = 5.61				LSD$_{(0.05)}$ = 6.27			
	LSD$_{(0.01)}$ = 7.51				LSD$_{(0.01)}$ = 8.39			

* = significantly better than control at 5% level, ** = significantly better than control at 1% level.

locally produced treatment tested, gave very variable results in these trials.

None of the preplanting fungicide treatments had a significant carry-over effect on the storability over the dry season of yam tubers produced from the treated minisetts. At Makurdi, storage losses were primarily due to rotting initiated by rodent attack, while at Onné storage losses were primarily due to desiccation, or rotting of tubers predisposed by harvest damage or insect attack.

Pre-planting treatment of mini-setts with an insecticide such as carbosulfan or aldrin, or incorporation of an insecticide such as carbofuran or diazinon into the planting hole, appeared to have no significant effect on the survival or ultimate yield from the minisetts of either water or white yam at the sites used.

In a separate experiment at Makurdi in 1993 it was found that coating minisetts with paraffin wax before planting (in an attempt to reduce their desiccation) resulted in most of the minisetts rotting. The fungus *Aspergillus niger* was usually visible underneath the wax coating of the rotted yams when they were exhumed.

Treatment of minisetts of white yam with a range of different growth regulators at different concentrations showed that the cultivar used (D'anacha) is extremely sensitive to gibberellic acid, with the lowest concentration used (immersion in 2.5 mg/l for 1 h) causing 100% inhibition of germination. None of the hormones tested significantly improved the rate of sprouting or survival of the minisetts.

Hot-water treatment of yam minisetts prior to planting had very variable results. The white yam variety D'anacha was very sensitive to hot water, and almost all minisetts treated for even the shortest time failed to sprout and rotted in the ground. The water yam variety UM680 was much more tolerant of these treatments, although none of the treatments conferred a significant improvement in sprouting, establishment or ultimate health compared with the control, untreated minisetts.

Assessing the yield and quality of seed yams from a minisett trial in Nigeria

The project has shown that a simple preplanting treatment with fungicide is an effective method of making the minisett technique for the rapid production of seed yams more reliable, providing a viable alternative to the traditional method of planting large pieces of yam to ensure survival. Small demonstration trial plots to show the effect of the best preplanting fungicide treatments were set up at several locations in Nigeria.

A further project (R6691) was centred in Ghana to investigate the identity and role of tuber-borne diseases of yam. The project demonstrated that there was a significant yield advantage to using yam-planting material collected from sites where apparent disease incidence was low. Yam mosaic potyvirus was the most commonly detected virus of white yam in Ghana, and most transmission from one crop to the next appeared to be vertically via the tubers. Tubers collected from areas with visually high disease incidence (crops that appear unhealthy) also did not store well over the dry season. All this reconfirmed the importance of tuber-borne infection and the need to produce or select and use clean, healthy planting material.

FUTURE

Recently, much of what has been learnt through the various projects about the uptake and adoption of crop protection research outputs has been collated for a short programme development study (R7504). This should help in guiding the development of future work on yam crop protection.

Characterization of sweet potato and cassava virus diseases

R6617

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April 1996–March 1999

This project covered two whitefly-transmitted viruses of root crops, sweet potato virus disease and cassava brown streak. The whitefly-borne component of a sweet potato virus disease causing increasing losses in East Africa was identified for the first time as a distinct strain of sweet potato chlorotic stunt closterovirus (SPCSV). Characteristic symptoms of the two main diseases caused by SPCSV in sweet potato were described, and an ELISA-based method for detecting the virus has been developed and proven in Africa. Polyclonal antiserum has been developed using bacterially expressed coat protein. Differences in the incidence of the virus disease in Uganda and Tanzania have been mapped in districts around the perimeter of Lake Victoria: areas where chlorotic stunt was rare tended to have few whiteflies throughout the year, or a very disease-resistant cultivar predominated. The causal agent of cassava brown streak disease was found to be a single virus (CBSV), a member of the *Potyviridae* family. CBSV is most closely related to the whitefly-transmitted virus sweet potato mild mottle virus; these two viruses now form the only two sequenced members of a genus called the Ipomoviruses. The first reliable test for this disease, a PCR detection method, has been developed. Three distinct isolates of CBSV have been found in Tanzania and one in Mozambique: this diversity explains the different symptoms reported here and previously with experimental host plants. Preliminary work was carried out towards developing a reliable polyclonal antiserum for field identification. Given the importance of sweet potato and cassava to rural livelihoods, and the major yield losses incurred annually in these crops in many areas of East Africa, the project will contribute substantially to increasing crop yields in the region as superior resistant varieties are developed.

SWEET POTATO

ISSUES

African sweet potato production is concentrated in East Africa, especially in the countries around the perimeter of Lake Victoria. Sweet potato is an important crop throughout much of East Africa, grown particularly by women around the homestead for daily food and to sell for family needs. It is also grown extensively in some areas as a cash crop, sold particularly to the urban poor as a staple food. Sweet potato is valued for its ability to yield in poor soils and to provide food quickly following the onset of rains. In East Africa an epidemic of African cassava mosaic virus has caused widespread destruction of the cassava crop, and sweet potato production has risen dramatically in compensation.

Sweet potato virus disease (SPVD) is the name used commonly in Africa to describe a range of severe symptoms on sweet potato generally attributed to virus infection. Symptoms vary with plant genotype but typically include stunted plants with small, distorted leaves. Affected plants commonly produce less than half the yield of symptomless ones. SPVD is considered to be the most damaging disease of the crop in the region, with average incidences of 30% and greater being found, and many crops have much higher levels of disease.

The presence of a whitefly-borne component of SPVD was confirmed by a previous project (R5878). Resistant varieties are being actively sought by national sweet potato programmes in Africa, particularly the Ugandan National Potato Programme (UNPP), and by the International Potato Center (CIP), as resistance is considered to be the most effective means of controlling the disease. This required a suitable means of accurately diagnosing the component viruses. A further aim of the project was to examine the variability of the virus within East Africa by a range of serological and molecular methods, so as to assess the likely durability of resistance.

ACHIEVEMENTS

The whitefly-borne component of SPVD has been identified as

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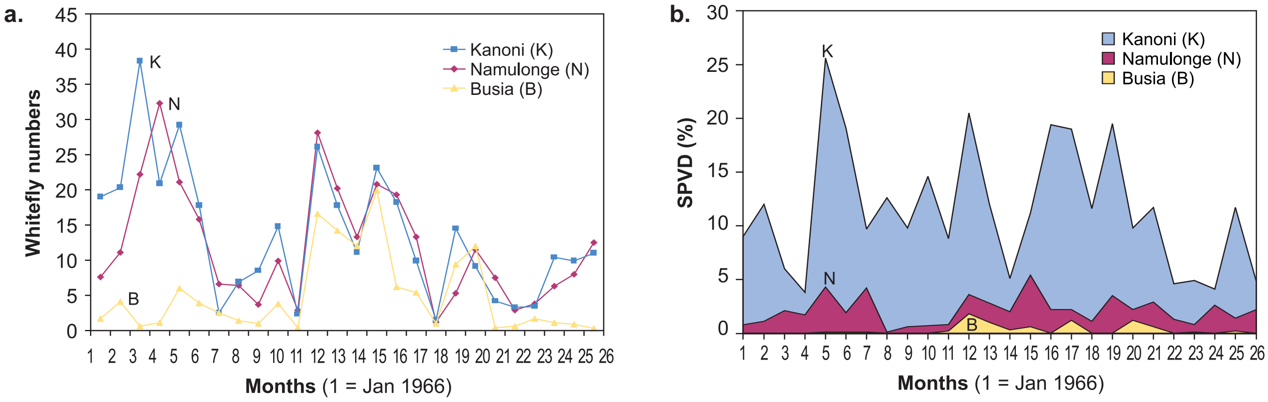

Figure 1. a. Numbers of adult whiteflies, and b. incidence of SPVD during 1996 and 1997 in farmers' fields around Kanoni (K), Namulonge (N) and Busia (B)

SPCSV, both by showing its general association with the disease, and by inducing SPVD through controlled virus inoculations. An ELISA-based method of detection has been developed and tested. This method has been taught locally to Ugandan and Kenyan national programme staff and to Makerere University students, and through international meetings, to other workers from the region. CIP has been closely involved with all the project's work, and has provided a key route for disseminating the detection method. The method is currently being used at NAARI, for example, by the senior sweet potato breeder, contributing to an understanding of the inheritance and mechanism of resistance in sweet potato to SPVD.

Comparison of SPVD-affected sweet potato (left), showing the severe stunting effect, compared with an unaffected plant (right).

The variability of SPCSV has been investigated. There appears to be a single serologically identifiable strain of SPCSV throughout eastern and perhaps all of southern Africa. This strain is distinct from, and appears to be more severe than, a strain found in West Africa. Small serological and nucleotide sequence differences have been found within this East African strain. This finding provides scientific support to UNPP's role of providing superior sweet potato genotypes and seed stocks to all East African sweet potato programmes. The small differences found within the East African strain of SPCSV support UNPP's policy of using broad, quantitative sources of resistance rather than more specific single gene sources (although the latter is largely because no single gene sources of resistance are available). This should lead to varieties with durable resistance.

Preliminary results have shown that sweet potato varieties may have limited adaptability, and so may not be useful in some regions; and that the areas where most of the UNPP superior resistant varieties are currently being disseminated are largely areas where SPVD is relatively unimportant. However, the results of this work do provide clear evidence that SPVD-resistant varieties can provide effective control where they can be grown. The significance of whitefly numbers in the epidemiology of SPVD in different areas of Uganda has been investigated (Fig. 1). Results show that resistant varieties can protect nearby crops of susceptible varieties by limiting the local inoculum levels of SPVD, and local phytosanitation may also assist control.

FUTURE

To fully exploit these results, SPVD-resistant sweet potato varieties will be tested (R7492) in areas where SPVD remains a serious problem, to confirm that resistance is maintained, and that the available SPVD-resistant varieties are broadly adapted to yield well in those areas. On-farm trials have revealed that, whilst resistance is generally maintained, the yield of NAARI varieties is not always superior to local landraces.

The second phase of the Inter-Centers Initiative on Whiteflies and Whitefly-borne Viruses begins in 2000. The component on sweet potatoes in Africa will again be managed by CIP and will have three main components: the dissemination of information on the importance, identification and control of SPVD; evaluation and distribution of superior, SPVD-resistant sweet potato varieties; and the evaluation of local phytosanitation practices.

CASSAVA

ISSUES

Cassava is a major food staple in sub-Saharan Africa. It is a drought-hardy crop, and can survive and produce a yield where cereal crops fail. As much as 85% of the cassava root dry weight is starch, making it the highest yielding calorie source per hectare of all the staple crops. Cassava is a staple food for 500 million people, and 11 out of the 12 countries where consumption per capita exceeds 100 kg each year are in Africa.

Necrosis in CBSV-infected cassava which makes the tubers inedible.

Cassava brown streak disease (CBSD), so called because of the brown lesions that sometimes appear on the young green stem of affected plants, causes damage to the edible roots. Cassava is propagated through cuttings and as such is particularly prone to virus problems because infection tends to build up in selected clones. Natural spread of CBSD occurs, and the vector is believed to be a whitefly. Diagnosis of CBSD is difficult because immature leaves of infected cassava are symptomless, and symptoms vary greatly with the variety of cassava and environmental conditions (see R6765, p. 13). A sensitive detection method was required both to support breeding programmes for cassava, and to detect the spread of the disease in previously unaffected regions of Africa.

CBSD was first reported in the 1930s, but despite the disease being assumed to be a virus, its aetiology has remained obscure. The main aim of this work was to identify the virus/es that cause CBSD, using molecular tools.

ACHIEVEMENTS

This project has identified the virus that causes cassava brown steak disease as an Ipomovirus (family: Potyviridae). Previous work had suggested that the cause was two viruses, a carlavirus of 650–690 nm, and a potyvirus accounting for the presence of pinwheel inclusion bodies. Through sequencing, polymerase chain reaction (PCR), partial purification and Western analysis, this work has shown that the carlavirus-length virus previously isolated is the Ipomovirus sequenced here. The Ipomovirus also accounts for the presence of pinwheel inclusion bodies. The differences observed in symptoms of the disease, especially on secondary host plants, can be accounted for by isolates of this Ipomovirus. No evidence for a second virus was found.

A reliable and repeatable RT-PCR test has been developed as a result of sequencing part of the virus genome. This test has been used to detect the virus even in the young leaves of cassava that are not yet showing symptoms of the virus. The extreme symptom differences with these isolates are thought to be the main reason a second virus was mistakenly linked with this disease in the past. The potential uses of this test are to identify further isolates of the virus, to screen for the virus in plant breeding programmes, and to provide quarantine measures by which unaffected areas and countries can remain free of the disease.

FUTURE

To use this test effectively, more testing on cassava in East Africa is required. There is a need to obtain samples of infected cassava from across East Africa. Further research on isolate differences is required to ensure the test will work for all isolates, and cassava varieties need to be tested against all isolates of the virus if these varieties are going to be promoted under the assumption that they are resistant.

This work has found a number of isolates of the virus from just a small area of the affected region. These isolates differ from one another by as much as 10% at the DNA level across their coat proteins. Cassava brown streak disease has been found over a large region of East Africa, and the extent to which this virus may differ in sequence could be enormous. If this is the case, the PCR test may prove ineffective for other regions with uncharacterized isolates of the virus. Further work is needed to explore the diversity of this virus throughout its range.

Traditional breeding methods have given rise to cassava varieties that are believed to be more resistant to pests and diseases than other varieties. However, this work with CBSV isolates raises a question about so-called resistant varieties. In this work, different isolates of the virus gave rise to different severities of infection, which has implications for selective breeding – particular cassava varieties may be selected for resistant qualities which are not, in fact, reliable, as the variety may have only been challenged with a 'weaker' isolate of the virus. Further work is needed to clarify these issues.

Management of cassava virus diseases in southern Tanzania

R6765

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September 1996–August 1999

Cassava is the staple crop for large areas of southern and coastal Tanzania and also in northern Mozambique. Although it has poor storability once harvested, cassava can be kept in the ground and harvested as required, and it therefore has a major role as a food security crop even in areas where there are alternative staples. Virus diseases are a major constraint to cassava production in Tanzania. In this region cassava is affected mainly by two virus diseases, cassava mosaic disease and cassava brown streak disease. This project set out to develop management strategies for cassava virus diseases. Socio-economic and biological surveys were carried out to assess the importance of the diseases and identify appropriate control measures. A 'tolerant' cultivar, Nachinyaya, identified by the project has now largely replaced CBSD-susceptible cultivars in some areas. Systems have been developed for the production of virus-free stocks of cassava for producing virus-free planting material. Management recommendations include the use of more tolerant varieties and of virus-free planting material, and phytosanitary measures such as roguing.

ISSUES

Vegetatively propagated crops such as cassava are prone to virus infections. At least 17 different viruses of cassava have been described, of which eight are known to occur in Africa. The main research focus in Africa has been on the viruses causing cassava mosaic disease (CMD) and cassava brown streak disease (CBSD). Surveys conducted by a previous project (R5880; *see Research Highlights 1989–95*) showed that both viruses were present in Tanzania. Subsequent surveys found that CBSD was the more important disease in coastal Tanzania, but any management strategy would have to take account of the virus disease complex as a whole.

The contribution made by cassava to sustainable livelihoods in the coastal region of eastern Africa is twofold: firstly it is the main subsistence crop, and secondly it provides a source of income through the sale of fresh cassava root and stem cuttings for planting material. CBSD affects livelihoods directly by causing root damage which both decreases yield and makes fresh roots unmarketable. Decreased incidence of CBSD would allow smallholders to increase the amount sold for cash or decrease the area of cassava grown, which could then be used for other more valuable crops such as maize or groundnut. CBSD has its main impact on food security because the severity of root necrosis increases with the length of time the crop is in the ground.

The aim of this project was to develop management strategies for cassava virus diseases in Tanzania in order to minimize cassava losses due to the disease, and increase food security.

ACHIEVEMENTS

Activities consisted of on-station and on-farm field trials; biological and socio-economic surveys; the organization of farmer research groups in five villages; and basic research to identify the means of transmission and spread of CBSV.

CBSD was found to cause reductions in root yield of up to 68%, with a further 7–20% loss in quality. The quality loss is due to those roots which are unmarketable or the necrotic tissue which farmers' families have to cut from the roots before they can be dried for storage.

Disease surveys were extended to the East African coast from the Kenya border through Tanzania to the Zambesi river in Mozambique. CBSD was recorded for the first time in Mozambique, where it was present at very high incidences. A number of local Tanzanian cultivars have been identified as having some resistance to CBSD.

Surveys in southern Tanzania have shown that CBSD is rarely found above 1000 m, and is present at low incidences above 600 m.

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Between 300 and 600 m it is present at moderate incidences, and high incidences are found mostly below 300 m. It is not possible to draw strict divisions between these zones based on altitude, and occasionally high incidences may be found at altitudes above 300 m, depending on the planting material. Little spread of the disease appears to occur at higher altitudes. This has influenced the design of disease management systems. At low altitude, where incidence is high and spread is rapid, phyto-sanitation must be used with resistant (or tolerant) cultivars. At mid-altitude, where disease incidence is moderate and there is less spread, virus-free planting material would be helpful provided farmers continue to select their planting material from symptomless mother plants. At high altitude, where little spread occurs, selection of planting material and roguing should provide sufficient control.

Socio-economic surveys revealed that farmers in the Southern Zone of Tanzania were highly aware of 'root rot' as a problem, and it was mentioned as the primary production constraint by more farmers (36%) than any other factor. The disease was also present at very high incidences in Zambesia Province of Mozambique where there is almost complete reliance on cassava for food security.

Table 1. Constraints to cassava production as perceived by farmers in the Southern and Coastal Zones of Tanzania

Southern Zone (respondents = 247)		Coastal Zone (respondents = 50)	
Constraint	**Number of farmers identifying constraint**	**Constraint**	**Number of farmers identifying constraint**
CBSD	89 (36%)	Theft	19
Soft rot	56	Vermin	38
CMD	47	Mealybug	12
Mealybug	16	Shortage of planting material	30
Insect pests	10	Diseases	18 (36%)
Vermin	7	Lack of knowledge of disease control	1
Juma (pupal stage of mealybug)	12	Lack of capital	1
Rodents	4	Weed control	3
Labour shortage	3	Poor soils	2
		Too much rain	2
		Poor variety	3
		Low yield	1
		Low manpower	1

Screening techniques have been developed to assess the reaction of cultivars to CBSD, based on evaluation of both above-ground and root symptoms. Cultivars have been identified with resistance or 'tolerance' to CBSD. The 'tolerant' cultivar Nachinyaya identified by the project has now largely replaced the CBSD-susceptible cultivars in Mtwara. There is strong demand for planting material of Nachinyaya.

Systems have been developed at Naliendele and Kibaha research stations for the production of virus-free stocks of cassava for producing virus-free planting material. This is vital for cassava; for example much of the planting material in the World Vision cassava improvement programme in Mozambique was later found to be infected with CBSD. A stock of three local cultivars was produced by the end of the project, ready for further multiplication and distribution.

The design of disease management systems is assisted by some knowledge of the epidemiology and means of transmission of the virus. Some understanding of the epidemiology was gained, but it was not possible to transmit the virus with potential whitefly vectors in transmission tests, and there is still no certainty as to the vector. The most likely candidates remain the whiteflies (*Bemisia tabaci* and *B. afer*). Trials conducted in Tanzania have shown conclusively that CBSV spreads from a line source from plant to plant within a field, and that the main period of spread coincides with the peak periods of whitefly infestation. However, it remains a priority to identify the vector.

Five villages have been identified for further work on disease management. Two of these are in the low-altitude areas of high disease incidence, two in the mid-altitude and one in the high-altitude areas. Farmer research groups have been set up in each of these as a preliminary to further adaptive research on CBSD management.

Awareness of the disease has been raised and information provided on symptom recognition. The screening methodology developed has been adopted by the National Programme in Tanzania, the Southern African Roots and Tubers Research Network (SARRNET) in eastern and southern Africa, and the DFID/World Vision cassava improvement programme in Mozambique.

FUTURE

Although the tolerant cultivar Nachinyaya has been adopted spontaneously by farmers, unfortunately this does not represent a long-term solution because, although tolerant of root necrosis, it is still susceptible to infection by CBSV, and further work is required in this area. A number of local varieties with resistance to CBSD have been identified in Tanzania and Mozambique. A new project (R7565) began in January 2000 to promote control measures and to multiply and distribute resistant cultivars to farmers.

Control of African cassava mosaic disease

R6614

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Cassava is an important crop to small-scale subsistence farmers in Africa, and is relied upon as a food reserve when other crops fail. The recent epidemic in Uganda of a severe form of cassava mosaic disease (CMD), caused by a virus and spread by a whitefly vector, has meant that some local varieties of the crop have failed completely, with a major effect on food security. This project studied farmers' use of cassava varieties and their responses to the epidemic in order to develop socially acceptable control strategies. Investigations were carried out on the strains of virus causing the epidemic, the whitefly (*Bemisia tabaci*) responsible for disease spread, and their interactions. Resistant varieties were studied, and a model of the epidemic's progress formulated to assist in forward planning.

In Uganda, farmers' participation in on-farm trials and variety multiplication and their access to extension information and training were found to promote earlier adoption and greater use of cassava varieties resistant to CMD. This epidemic involves a different strain of the virus, known as the Uganda variant. The resistance identified to this disease is partial: plants will develop inconspicuous symptoms and can still provide clean planting material, a phenomenon known as 'reversion'. This is important for preventing build-up of infection, particularly as reproduction of the whitefly vector is significantly higher on severely infected varieties. Planting material has been diffused from participating farmers to others through local social networks, with the support of community-based multiplication initiatives. Improved yields from resistant varieties have helped towards eliminating the problem of food shortages, and interest has been expressed by farmers in technologies for cassava processing and ultilization. The findings obtained in Uganda are highly relevant to other countries in the region experiencing the onset of the CMD epidemic.

ISSUES

Cassava is a major crop for subsistence farmers, particularly women, for domestic use and as a food reserve in times of drought. In many areas sales of fresh and dried cassava are an important source of cash income for poorer households.

Cassava mosaic disease (CMD) is the most damaging insect-borne disease of African crops, and in Africa is arguably the main disease of cassava. Estimates of average yield loss of cassava in Africa due to CMD range from 15 to 50%. Unlike the usual situation in much of Africa, where CMD is endemic and fairly stable, a major epidemic of a severe form of the disease has been expanding southwards across much of Uganda since the early 1990s. By 1995 two-thirds of the country had been affected, and famine and associated deaths were being widely reported in local newspapers and to a Government Commission of Enquiry. A similar catastrophe has now occurred in western Kenya, where cassava was locally the main staple food, and in north-west Tanzania. The epidemic was associated with increased abundance of the whitefly vector (*Bemisia tabaci*), and more severe CMD.

The project was established to help farmers to combat the disease through the use of resistant varieties and phytosanitation, and to obtain a better understanding of the processes driving and sustaining the epidemic.

ACHIEVEMENTS

FARMERS' CONTROL STRATEGIES

Farmers' strategies under different degrees of infection pressure were monitored in Mubende and Mukono districts in Uganda at regular intervals along a fixed transect, perpendicular to the path of the epidemic. Farmers' main adaptations to CMD infection were a switch from local to resistant varieties, and increasing the area planted to other crops, losing both biodiversity and a valuable source of nutrition in cassava. The price of cassava increased at and immedi-

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ately behind the epidemic front.

The acceptability and subsequent adoption of improved cassava varieties by farmers was influenced both by cassava variety attributes and by the farmers' socio-economic status (family size, age, off-farm activities, education, access to credit). Clear targeting of farmer categories is necessary; their participation in on-farm trials and multiplication promotes earlier adoption and intensity of use, as does their access to planting material, information, training and extension recommendations.

AHEAD OF THE EPIDEMIC FRONT

A study with farmers' groups in two areas of Iganga district, in the pre-epidemic area, explored what level of intervention could best prepare farmers for the disease. Five 'intervention' groups were given resistant material, training and extension support; five 'non-intervention' groups were given resistant material without additional training or extension input. Progress of the disease epidemic was more rapid than anticipated, reaching some sites within 6 months. Knowledge and understanding of CMD and the adoption of improved management practices were higher among the intervention group, and both sets of groups did better than neighbouring individual non-participants who had limited access to improved varieties.

RESISTANT VARIETIES

Many local and introduced varieties have been evaluated by the Cassava Programme in a series of formal experiments and on-farm trials in different agro-ecologies and in pre-epidemic, epidemic, and post-epidemic areas. The main findings are described below.

There are great differences between varieties in their susceptibility and response to infection by CMD. Susceptible varieties include Ali Matumba (Tanzania), Bao and Ebwanateraka (Uganda). Bao and Ebwanateraka are popular and highly productive varieties where CMD is not a problem and post-epidemic farmers will return to using them. Resistant varieties include the introduced TMS 30572 (released in Uganda as Migyera) and the Ugandan selection SS4. These varieties, especially Migyera, are being multiplied in quantity for release to and by farmers. Intermediate varieties include the International Institute of Tropical Agriculture (IITA) introductions TMS 30337 (released in Uganda as Nase 2), TMS 60142 (Nase 1) and TMS 4(2)1425. An important feature of these varieties is that they grow and yield satisfactorily despite high CMD incidence.

Resistance to CMD is of the quantitative, rate-reducing type that is sometimes referred to as 'partial' resistance. There was no obvious relationship between the number of whiteflies recorded on a variety and the incidence of CMD; partial resistance to infestation by whiteflies and to infection with CMD are separate and unrelated attributes. The virus is incompletely systemic in the most resistant varieties, which generally develop inconspicuous symptoms and may ultimately recover. Such plants can be a source of virus-free material when cuttings are collected for propagation. This 'reversion' phenomenon is an important feature of resistant varieties, restricting the progressive build-up of infection that would otherwise occur with successive cycles of propagation.

Some varieties (such as the local Ugandan variety Ebwanateraka) have been so badly affected by the epidemic that they have been

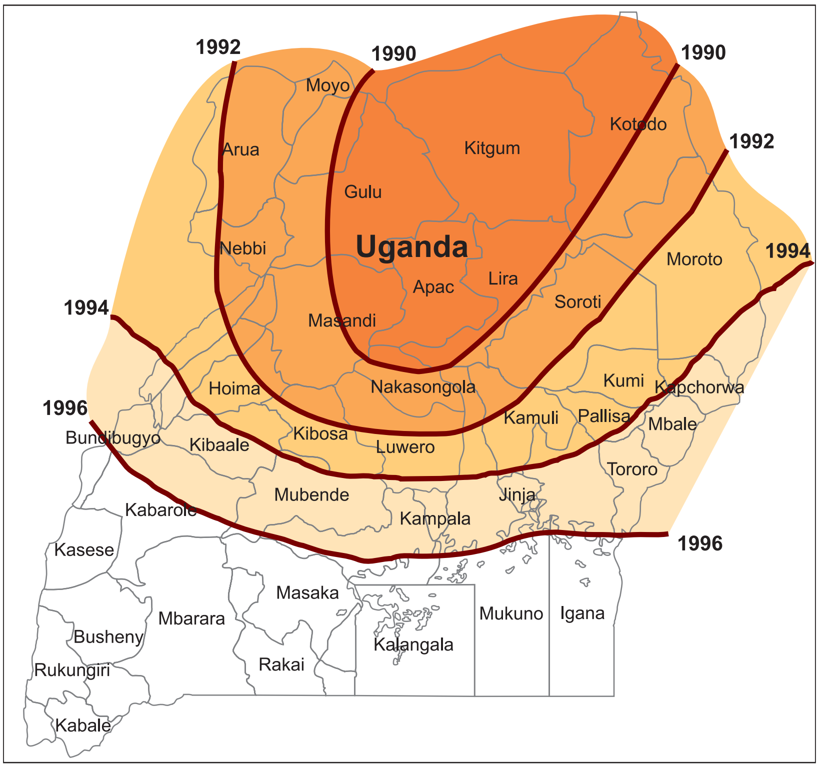

Figure 1. Progress of the cassava mosaic disease (CMD) epidemic front through Uganda. Areas along the eastern border with Kenya were affected in 1994 and the epidemic was first reported in Kenya in 1995. During the project the epidemic continued to move southwards across Uganda and around the northern shore of Lake Victoria into western Kenya and northwest Tanzania as predicted. In Uganda the epidemic reached the research station at Namulonge in 1995, Kampala in 1996, and the northern shore of the lake at various times between 1996 and 1998. The epidemic has crossed the Tanzanian border on the northwest side of Lake Victoria, and in 1998 severe damage was reported in the Bukoba area

largely abandoned. Others partially withstood infection and they have become increasingly important, especially in areas where officially released varieties have not been readily available.

The fact that CMD still affects the growth and yield of resistant varieties means that there is little obvious incentive to adopt phytosanitation measures involving the selection of 'clean' virus-free planting material and the removal (roguing) of any diseased plants that occur. But there would undoubtedly be substantial yield gains from adopting this approach.

A susceptible cassava variety amongst CMV-resistant plants

EPIDEMIOLOGICAL MODELLING

A mathematical model of the processes driving the CMD epidemic has been developed which allows the importance of different epidemiological factors to be assessed. By judging how management interventions will affect these parameters, their likely impact on CMD incidence can be predicted.

VECTOR ENTOMOLOGY

As the project started, reports of a new form of the virus were confirmed; this epidemic form has become known as the Uganda variant, UgV. The possibility that a new biotype of the vector, *B. tabaci*, might be associated with the epidemic also needed clarification. Key results were as follows.

Bemisia tabaci collected from epidemic and pre-epidemic areas were maintained as separate cultures at NRI. RAPD DNA 'fingerprinting' revealed considerable variation between them, but there was no evidence for distinguishable epidemic or pre-epidemic groups. Reciprocal crossing experiments between epidemic and pre-epidemic colonies showed that there is no mating barrier between these populations.

Host-specific strains of *B. tabaci* from Uganda and India were crossed. Indian cassava *B. tabaci* did not mate successfully with either Indian cotton or Ugandan cassava *B. tabaci*. The fecundity and survival of *B. tabaci* reared on healthy plants of susceptible (Ebwanateraka) and UgV-resistant (SS4) cassava varieties were similar. The fecundity of *B. tabaci* reared on UgV-infected Ebwanateraka cassava was significantly increased: the argument for adopting phytosanitation is strengthened by this evidence that whiteflies build up preferentially on virus-infected plants, which could be a source of resistance-breaking virus strains.

Bemisia tabaci collected from areas ahead of the epidemic can transmit UgV. At the epidemic front UgV appears to out-compete and displace normal African cassava mosaic virus (ACMV), as most diseased plants contained UgV alone or mixed with ACMV; very few plants at the front contained ACMV alone.

TRANSECT STUDY

Cassava plants in the transect plots were monitored for such variables as disease incidence and severity, and numbers of whitefly nymphs and adults, in order to track the passage of the epidemic in terms of vector populations, virus and symptom expression.

The study confirmed unequivocally that unusually high *B. tabaci* populations occurred at the CMD epidemic front, and that both the front and the high populations of whitefly moved southwards to occupy previously unaffected regions. The spread of the CMD epidemic is due to the immigration of *B. tabaci* carrying UgV into previously unaffected areas. These individuals infect new plants which results in a boost to the fecundity of the whitefly when they feed on them. The progeny of these individuals then migrate into new areas of susceptible cassava and the cycle recurs.

PROJECT WORKSHOP

The workshop *Cassava mosaic disease management in smallholder cropping systems* was held in Jinja, Uganda between 7 and 9 December 1998. Sixty-two delegates attended from Uganda, Rwanda, Kenya, Tanzania and South Africa, representing researchers, extensionists, national and international programmes, NGOs and farmers. The workshop was well received; workshop proceedings, recommendations and a video are being produced.

FUTURE

A new project (R7505) will carry out further adaptive research on the sustainable use of resistant varieties and maintenance of varietal diversity. The main focus will be participatory research on farmers' varietal choices and the options for utilization, processing and marketing; a study of reversion that considers the full range of varieties and takes into account the possible interactions between the different factors involved; quantitative information on disease incidence and severity and on yield losses; and the probable interactions between UgV, the whitefly *B. tabaci*, and the widely grown UgV-susceptible cassava varieties. Research aimed at incorporating *B. tabaci* resistance into the current CMD-resistant cassava varieties, for instance, could have the potential to prevent the genesis of future CMD epidemics.

Functional diversity of *Phaseolus* bean mixtures in East Africa

R6651

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April 1996–March 1998

Common bean (*Phaseolus vulgaris*) is the most important legume grown in East Africa, providing up to 40% of protein for many in the region. Pests and diseases are a major constraint to production, and subsistence farmers commonly grow mixtures of landraces with a wide diversity of seed colours, patterns, shapes and sizes, which provides some protection. Earlier work focused on the complex epidemiology of diseases within these mixtures, and began to identify the resistant components. This project has continued to characterize resistance to major bean diseases of components of traditional bean mixtures, and has contributed to improved strategies for the management of bean diseases, and to the maintenance of genetic diversity in traditional bean farming in East Africa.

ISSUES

Within-crop diversity, that is, planting a mixture of varieties of a crop, is often used as a means of stabilizing yields in variable environments where adequate inputs cannot be guaranteed and harvest uniformity is not a problem. In East Africa, particularly southern Tanzania, subsistence farmers tend to grow their beans as a mixture of landraces rather than as pure varieties.

In southern Tanzania bean mixtures provide a sustainable source of protein, vital in resource-poor households where meat is a rare luxury. Farmers select the components of their bean mixtures on the basis of a range of factors, including yield, disease resistance, growth habit, maturity, cooking time and taste. Beans have a range of seed coat colours, some of which are favoured more than others, and generally large beans are preferred to the small grain types. Several diseases have been identified which, along with soil fertility, are considered major constraints to bean production. There exists considerable natural resistance to the different diseases within the diversity of the mixture components. However, it would be just as impractical to try to breed resistance to all diseases into one type of bean as it would to produce one type of bean to satisfy all culinary requirements.

Previous research projects (R5530, R5532; see *IPM Research Highlights 1989–95*) have been analysing three farmers' bean mixtures in order to unravel the relationship between diversity, disease resistance and yield stability in traditional bean mixtures. This project continued the aim of understanding the genetic diversity of bean mixtures in terms of disease resistance, and providing a rational basis for their manipulation. It sought to characterize disease resistance in two major pathogens (three others having previously been studied), and to quantify the contribution of mixtures to disease control under field conditions.

ACHIEVEMENTS

Three representative mixtures had been selected for intensive study on the basis of the diversity present (seed size, shape and colour), comprising 300 subcomponents. Single seeds of each subcomponent were multiplied to produce genetically uniform stocks for disease evaluation. Isolates of key pathogens were collected and tested, so that representative, fully pathogenic isolates from appropriate geographical areas could be used for disease screening.

The previous projects had screened for disease reaction against nine races of halo blight (*Pseudomonas syringae* pv. *phaseolicola*); four isolates of anthracnose (*Colletotrichum lindemuthianum*); and several strains of bean common mosaic virus. The present project concentrated on angular leaf spot (*Phaeoisariopsis griseola*) and common bacterial blight (*Xanthomonas campestris* pv. *phaseoli*). The resistance screening has produced a volume of information that can be used to improve

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farmers' mixtures by modifying resistance gene frequencies according to the anticipated disease problems.

In an additional experiment, selected resistant mixture components were compared with examples of the world classes of beans to find out how they compared with the worldwide gene pool in terms of resistance gene frequency. Forty-one bean accessions were screened against 16 different isolates of five important pathogens sourced worldwide.

Field trials at three contrasting sites in Tanzania were conducted in both the 1996 and 1997 seasons, but the format and aims of the trials were very different. A variety trial format was used in 1996 to compare the performance of selected mixture components with standard sources of resistance and local commercial cultivars. In 1997 competition/compensation/density trials were conducted, both at the three Tanzanian sites (with disease inoculation) and in the UK under disease-free conditions. Data analysis showed that there is no competition between plants at the traditional spacing of 0.5 m, and maximum yield at this spacing could be achieved by one or two plants per planting hole. Increasing the plant density to 0.375 m spacing gave a reduced yield per planting hole, but yield per square metre was increased, especially in climbing beans. A combination of climbing and bush types produced the highest yields.

The completed disease screening provided a wealth of data from which resistant mixture components can be selected. Of special significance were the sub-components 5084/2 and 5084/5 of the variety 'small masusu', which were resistant to all nine known races of halo blight, and four strains of anthracnose. Such resistance to halo blight is very rare, particularly in combination with resistance to anthracnose. Studies showed that resistance to halo blight is controlled by a single recessive gene, and that to anthracnose is controlled by a different, dominant gene.

Components of bean mixtures grown by farmers in southern Tanzania

As well as identifying sources of resistance, discussions with farmers allowed those beans which are preferred by consumers for factors other than disease resistance to be identified, so that the two attributes can be matched.

FUTURE

The target institution for this research is the Tanzanian National Programme, and the beneficiaries are the smallholder farmers of Tanzania who grow bean mixtures. However, the results will be valuable globally to bean breeders, who will be able to use the characterized sources of resistance, especially the multi-disease resistance shown by 'small masusu', in breeding programmes. The Tanzanian National Programme is already using some of the disease mixture components in their breeding programme, but further input and resources are necessary to take the promotion further.

Further work on bean mixtures in the southern highlands of Tanzania has centred around biodiversity aspects. A recently completed project funded by the Environmental Research Programme of DFID (R6670; Dynamic conservation, enhancement and utilization of agrobiodiversity *in situ*: *Phaseolus vulgaris* beans in the southern highlands of Tanzania) conducted socio-economic studies in the form of interviews with farmers who grow bean mixtures, in order to find out what influences farmers in their decisions to select different bean types.

On the basis of the findings of both the 'Functional diversity' and '*In situ*' projects, a new 3-year project has recently begun (R7569; Participatory promotion of disease-resistant and farmer-acceptable *Phaseolus* beans in the southern highlands of Tanzania). This project combines the results and expertise of both scientists and farmers, working together in a participatory manner, to take forward the disease-resistant varieties that have been previously identified. Emphasis will be placed on varietal promotion in the resource-poor environment of the southern highlands of Tanzania, in the context of a clear understanding of local seed uptake pathways.

It is important that the resistant bean lines should be multiplied and made available, along with appropriate information, for selection and exploitation by both bean breeders and farmers. These materials need to be available locally, in adequate quantities, as good quality seed (several bean diseases are seed-transmitted), and at an affordable price.

Development of integrated management strategies for termites in maize-based smallholder cropping systems in Uganda

R6653

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April 1997–March 2000

Current termite control tactics for annual crops in sub-Saharan Africa are are too expensive for resource-poor farmers. This project investigated a range of cultural, biological and crop resistance strategies for the control of pest termites in maize-based smallholder cropping systems in Uganda. The choice of strategies resulted from biological and socio-economic surveys of resource-poor farmers in Uganda. The project has identified effective low-cost biological control agents for pest termites and quantified their effectiveness in farmers' fields; identified cultural practices (intercropping) that contribute to reduction in termite damage to maize; and identified local landraces of maize that show some tolerance to damage by pest termites.

ISSUES

Termites can cause severe losses to maize and associated legumes in Uganda and throughout East and southern Africa. In Malawi, smallholder farmers estimate crop losses to maize alone as up to 700 kg/ha. This project aimed to limit losses by developing appropriate and sustainable integrated pest management strategies for termites, in collaboration with smallholder farmers.

ACHIEVEMENTS

Trials demonstrated that intercropping maize with legumes can reduce damage caused by termites, but that the most consistent yield gains can be obtained from intercropping maize with sorghum at low densities. Since such combinations are already used by farmers, this approach could form part of a strategy for increasing maize yields.

Screening of maize cultivars for susceptibility to termite attack has shown that while local landraces appear to be less susceptible to attack by termite pests than modern hybrid cultivars, the latter still produce higher yields than local landraces in on-farm experiments. However, as there is some evidence that the lodging of hybrid maize by termites contributes to their relative unpopularity amongst poor farmers in the project area, consideration should be given to incorporating genetic characteristics which confer tolerance to termite attack into new maize hybrids in future.

Studies of on-farm crop loss due to pest termites indicate losses in crop yield of between 15 and 30% of that in a protected crop, equivalent to 0.2 to 0.5 t/ha. Losses from hybrid and open-pollinated, improved varieties were significantly higher than losses from a local landrace, but the hybrid varieties gave the highest mean yields overall. Such findings have clear implications for the adoption of new hybrid maize cultivars by poor farmers.

A survey of 150 farmers in the project area provided insights into farmers' knowledge of pest termites. Termites were categorized by a significant majority of farmers as serious pests, despite being used as human food. Indigenous crop protection methods and natural enemies were surveyed. In particular, a negative correlation between the abundance of ants' nests in maize fields and the damage to maize caused by termites was demonstrated. The importance of ants as control agents was confirmed by farmers, who have an extensive knowledge of this group.

A strain of the fungus *Metarhizium anisopliae*, provided by the International Centre for Insect Physiology and Ecology (ICIPE), was shown to be effective in controlling termites when applied to soil after planting in maize fields, giving yield gains of 50% over an untreated control.

Feedback and dissemination of results to farmers and scientists has ensured that the results of the work are now widely known in the region and elsewhere in Africa. This has led to proposed collaboration with the USAID-funded Investment in Developing Export Agriculture (IDEA) project and ICIPE in the development of a mycoinsecticide based on *M. anisoplae* for the control of pest termites.

Baits to attract ants into maize fields as a means of reducing termite damage were tested in both on-station and on-farm trials. Fish bones buried beneath mulch significantly reduced termite damage to maize, and gave yields 50% greater than in an untreated control, a yield gain of almost 900 kg/ha. As fish is widely available in southern Uganda, this could form the basis of an effective, low-cost method of termite control for poor farmers in the region.

A number of different botanical insecticides were tested against termites. Although all reduced termite damage to maize, none was as effective as *Metarhizium*.

FUTURE

The information obtained on the susceptibility of different maize cultivars to termite attack is now being applied through breeding strategies within the maize programme of NARO. Further work is proposed on cultural control (mulching and intercropping), and on attracting ants into maize fields as a means of natural termite control.

A video has been produced on the work of the project for training purposes within NARO.

Publications: see Bibliography on CD.

Development of management strategies for maize streak virus disease

R6642

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January 1996–March 1999

Maize streak virus disease (MSVD) occurs throughout sub-Saharan Africa, and can cause damaging yield losses. Earlier work has focused on the epidemiology of the disease and its leafhopper vectors; this second phase of the maize streak virus project concentrated on the development of management strategies for MSVD based on cultural control practices that are acceptable to farmers. These were developed through an understanding of the behaviour of the leafhopper (*Cicadulina*) vectors and their role in MSVD spread within maize plots and between maize plantings. Results demonstrate that various farming practices can affect the incidence of MSVD, and this can be explained by knowledge of vector behaviour. The project has confirmed that farmers can successfully select and produce their own maize seed. Farmers are keen to understand, and have proved able to benefit from knowledge on how to select and maintain open-pollinated varieties with preferred characteristics from season to season. The Ugandan Cereals Programme has benefited from the observations and experiments made during the course of the project, and has incorporated some of the techniques into its breeding programmes.

ISSUES

Maize streak virus disease (MSVD) is a serious constraint to maize production throughout sub-Saharan Africa. Yield losses in trials in East Africa have varied between 33 and 55% under natural infection conditions. In northern Nigeria, at the end of the growing season in epidemic years, 75-100% of maize plants can be infected. Studies on the epidemiology of MSVD have been limited to Zimbabwe, Mauritius, Nigeria and Zaire, but these areas represent only some of the agro-ecological zones in which the virus can be epidemic. This work aimed to study the disease in the mid-altitude agro-ecological zone, typified by maize production systems in Uganda. The first phase (R5246) focused on determining the role of the leafhopper vectors in the epidemiology of the disease. Data on the leafhoppers were incorporated into a geographic information system (developed through project R5360) to investigate the relationship between virus incidence, topography and meteorology in Uganda. Further research on MSVD was carried out under project R5237 on the identification and characterization of economically important strains of maize streak geminivirus.

Preliminary trials were previously undertaken on developing appropriate intercropping systems that minimize disease spread, yet are acceptable and profitable for the maize farmers in the region. This second phase of the project sought to develop these aspects of research and to integrate them with the use of MSV-tolerant varieties, as they become available through the Uganda Maize Programme, into an integrated management strategy for the disease.

ACHIEVEMENTS

Surveys within villages clearly indicated how little farmers and other stakeholders knew about MSVD. The surveys also showed that the lack of a reliable seed supply was a major problem. The project found that, due to cross-pollination by local susceptible landraces and farmers' seed selection strategies, MSVD resistance was probably being selected out from the only available resistant open-pollinated variety in Uganda, Longe1.

On-farm monitoring showed that the later maize was planted, the higher the incidence of MSVD, and that this appeared to explain why there was an indication that women's fields had a higher incidence of MSVD than men's fields, since the women tended to plant later in the season. The on-farm monitoring also showed that the incidence of MSVD was nearly three times higher in the shade of trees. Subsequent on-station experiments showed that the

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Joint preparation of training manual for farmers by researchers and collaborating farmers at Namulonge

majority of the principal MSVD vector species, *Cicadulina mbila*, were found in the shade, and the majority of the second most important vector, *C. storeyi*, were found outside the shade, effectively separating the two species by their behaviour.

Results from analysing the numbers of vectors and disease incidence within monitoring plots suggest that progress of MSVD is determined by conditions in the crop at an early stage in the epidemic. Thus plots that are characterized by a high initial rate of increase were those in which final incidence was also high. In addition, diseased stands were found to be highly clumped, but new foci were generated throughout the season. These findings are thought to be related to the mating behaviour of the vector, where the more mobile males locate the relatively sedentary females. In addition, females are thought to prefer maize plants of a favoured height, the distribution of which changes over the season.

Transmission studies showed that there was a large increase over time in the proportions of *C. mbila* carrying MSV in the field, and that they also had a much higher proportion of active transmitters than *C. storeyi*. This confirms that *C. mbila* is the most important vector of MSVD in Uganda.

Experiments have shown that, above a certain density, there was a significant attraction of wild male *C. mbila* to cages containing leafhoppers of the same species. In addition, the different sexes of *Cicadulina* locate each other by using vibrations transmitted through the material on which they are sitting, and the acoustic properties of the plants may be an important factor in the insects' selection of plants on which to settle. This may account for the vector's preference for plants of a certain height, which had been shown previously, and which would have a considerable effect on the distribution of MSVD within fields.

Intercropping maize with beans or millet results in a reduction in male *Cicadulina* activity within the intercropped host, but the catches of females are not reduced. Reductions in MSVD incidence and competition effects on yield in intercropped maize were too variable to produce any clear recommendation, but might merit further examination.

Taking into account the complexity of farmers' situations in the study areas, the project has improved farmers' knowledge of MSVD so that they can make informed decisions about managing the disease. This has been through the involvement of local extension staff, on-farm training, and the production of information leaflets.

It has been shown that various farming practices can affect the incidence of MSVD and this can be explained by the knowledge of vector behaviour. The most important are summarized below.

Intercropping. It was thought that if the spaces betwen the maize plants were filled with a dense, low crop then male activity would be hampered and the spread of MSVD reduced. Results showed clearly that the activity of male vectors was considerably reduced, but reduction in streak occurred only when the densities of the intercrops were particularly high, and to the detriment of the maize yield.

Time of planting. Maize fields planted later will have far more plants infected with MSVD because leafhopper numbers have already built up. In addition, because the leafhoppers appear to prefer maize at a height of 25–40 cm, a maize field planted later than others in an area will be at the preferred height, increasing the chances of heavy infection.

Gap filling. Replanting where seeds have not germinated will also increase the amount of MSVD because of the leafhoppers' preference for the younger plants in the field, and because the numbers of leafhoppers carrying the virus will be high by the time these new plants reach the preferred height. This does not necessarily mean that gap filling should be discouraged, as many of the plants may still produce a cob of some sort, which is better than none at all from empty stands.

Roguing. Removing diseased plants does not really help, because there are many leafhoppers with virus continuing to spread MSVD, and plants that are pulled out might have grown on to produce a small cob.

Spacing. Other workers have shown that the closer the spacing, the higher the incidence of streak. It is therefore important to understand the relationship of plant density, disease incidence, and agronomic characteristics with yield.

Shade. It is strongly recommended that maize is not grown in the shade, as a greater proportion of plants are likely to become infected, and at an earlier stage in growth.

Vector resistance. There are indications from experimental and on-farm work that *Cicadulina* show varying preferences for different varieties of maize. It is suggested that when maize breeders select for MSVD resistance, they should challenge plants with infected vectors confined in pots, and should not use a release method where the vectors have a chance of selecting plants on which to settle.

Growing MSVD-resistant varieties. Although MSVD-resistant varieties can be infected, they show a good tolerance to the disease, with very little leaf area lost to streaking. Thus little or no crop loss due to MSVD occurs. One problem that was found on-farm was a farmer-perceived 'breakdown' in resistance to MSVD in the Ugandan open-pollinated variety Longe1. On-farm, Longe1 is being grown amongst other, 'local', open-pollinated varieties of maize and is therefore being cross-pollinated. Investigations suggest that farmers may be selecting out MSVD resistance by selecting large seeds for replanting: because Longe1 seeds are smaller than those of many local varieties, selection of large seeds from cross-pollinated plants selects for the local variety and not Longe1. This was addressed by showing farmers how to isolate their Longe1 to avoid the risk of cross-pollination.

Maize plant infected with MSV showing systemic chlorotic streaking

FUTURE

The unreliability of available maize seed was a major constraint to farmers producing good yields from their maize crop. Through collaboration with village groups, extension officers and NGOs, it has been possible to train farmers as village trainers in their villages. The project began exploring the idea of empowering farmers to produce their own seed through selection and controlled pollination. The farmers have been very enthusiastic about taking up this technique, and a follow-up of this work has been agreed.

The on-farm studies, particularly those related to seed selection by farmers, have reached a point where they could become fully participatory. Suggested activities are the provision of appropriate training and information on seed production to farmers' groups in Namukubembe and Bugodi villages; monitoring of seed production activities in Namukubembe, Bugodi and selected sites; and evaluating the process and the output from both the farmer's and researcher's perspective. If evaluation indicates the approach is appropriate, activities should be scaled up to other villages through the FOSEM (Food Security and Marketing for Smallholder Farmers) network in Uganda.

The project has encouraged links between researchers, extensionists and NGOs operating in the project areas, and has established good rapport and collaboration with groups of farmers in key maize-growing areas which will continue, for example with the termite project (R6653) and a short project to continue the on-farm seed selection study (R7429). This will form a good basis from which to continue developing pest management and cropping strategies.

An investigation into the biology, epidemiology and management of finger millet blast in low-input farming systems in East Africa

R6733

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Finger millet is an important staple food in western Kenya, and a valuable source of nutrients. It is considered the domain of women, who also use it as a cash crop, generally managing the resulting income for the benefit of their household. Farmers cited labour and the cost of land preparation as factors limiting the cultivated area of this crop. High yield and early maturity are considered favourable variety characteristics, whereas disease susceptibility is an important negative attribute. Farmers recognize blast (caused by *Pyricularia grisea*) as a major disease which they correctly associate with high humidity and variety susceptibility. Progress towards sustainable control of blast on finger millet has been achieved through identification of cultural and field hygiene measures to reduce disease carry-over; documentation of the agronomic and socio-economic context into which control strategies will be placed; farmer participatory evaluation of the released resistant millet varieties P224 and Gulu E; and development of a laboratory-based bioassay to screen finger millet varieties for resistance and blast isolates for pathogenicity.

ISSUES

Finger millet is an important food crop within traditional low-input, cereal-based farming systems in Africa. It is of particular importance in upland areas of eastern Africa where it commands a high price in the market place, fetching three to five times the price of other cereals. This crop has particular relevance for food security as it is more drought-tolerant than maize, and less susceptible to bird damage than sorghum. In addition it can be stored for prolonged periods, and so may be the only cereal food source available at certain times of the year. Finger millet provides a valuable source of minerals and nutrients, and is recommended for pregnant or nursing mothers and infants. It is also a traditional crop and occupies a central role in ceremonies and other community activities.

Although a range of fungal and bacterial diseases have been reported on finger millet, the most important disease is blast, caused by the fungus *Pyricularia grisea*. The pathogen is highly destructive and economically important, causing in excess of 50% reductions in yield, particularly in wet years. Losses of up to 90% have been recorded in field studies in Uganda, 64% in Kenya, and near total losses in India.

Blast may affect finger millet at all stages of development from seedling to grain formation. Under suitable conditions (humid, wet and cloudy weather), initial brown specks on the leaves of seedlings develop into spindle-shaped lesions, then change colour, and an olive-grey overgrowth of the fungus can be seen over the central portions of the spots. Severe infection may lead to death in seedlings, whereas the disease tends to be less severe during the vegetative stages of the crop. Much greater damage is caused during the heading stage when grey-brown lesions are produced on the peduncle or 'neck' of the cereal. The tissue within these lesions turns black as it rots and, in severe cases, the neck may snap resulting in complete loss of the ear of grain.

Although blast was first recorded in 1933, there has been limited research on the biology and sources of *P. grisea* on finger millet. Seeds, crop debris and weed hosts have been implicated as potential disease sources. Preliminary work to assess variation was undertaken on a limited number of isolates of *P. grisea* from finger millet (R5349) and there appeared to be considerable variation. The existence of this potential variability within the blast population means that evaluation of control measures, for example the use of resistant cultivars or fungicides, should be conducted in those areas where the work is to be promoted and adapted.

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The purpose of this project was to contribute to improvement of yields of finger millet in low-input farming systems in East Africa by providing information on the biology and disease sources of finger millet blast. The investigation was based on constraints and potential control strategies identified by farmers themselves, and included consideration of the social and cultural significance of the crop, and evaluation of released finger millet varieties. This information can be used by breeders such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the national crop improvement programmes to assist in selecting resistant varieties, and towards the development of an integrated control strategy.

ACHIEVEMENTS

Twenty-two varieties of finger millet were found to be grown on the farms surveyed. This range reflects the numerous end uses of this crop, as well as farmers' recognition that different varieties perform better in different seasons. Farmers often grew more than one variety (either in separate plots or as variety mixtures), but one, Enaikuru, predominated.

The need for blast-resistant varieties was identified by farmers themselves. As a consequence, the suitability of the released varieties P224 (blast-tolerant) and Gulu E (moderately resistant) was investigated on-farm by participating farmers, and by a wider audience through community workshops and farmer days. A range of domestic and culinary attributes for the released varieties and farmers' existing varieties were evaluated. Overall, women ranked Enaikuru first, then Gulu E and P224. In contrast, men ranked Gulu E first, then P224, with the traditional cultivar Enaikuru third. However, traders and extension officers ranked Gulu E as first overall, with P224 best for traditional foods (*ugali* and *ugi*). Thus the released varieties showed a high degree of consumer acceptability.

The yields of released varieties P224 and Gulu E were similar to those of Enaikuru during on-farm evaluation under low disease pressure, although in the long rains yields were higher for the traditional cultivar than for either of the two released varieties. Gulu E demonstrated most resistance to blast. The observed yields were not correlated to disease scores in these experiments. Yield losses were related to time of onset of the disease: when crops were inoculated with the blast pathogen, maximum losses occurred in finger millet inoculated 90 days after sowing.

During interviews with farmers it was found that finger millet crop debris, including diseased heads, is usually incorporated into the soil at the end of the season. The blast fungus, *P. grisea*, was isolated from this material, and it was found that these isolates could infect healthy finger millet, indicating that crop debris is a potential source of finger millet blast.

Experiments were undertaken to determine the survival of *P. grisea* on crop debris. These studies showed that the fungus can survive on crop debris in the soil for up to 5 months (see Figure 1), although there is considerable reduction in inoculum potential 2 months after incorporation. Therefore although ploughing to a depth of 15 cm and a rotation period of >5 months would appear necessary for complete control of debris-borne inoculum, there is considerable benefit from ploughing and a rotation period of just 2 months between successive finger millet crops.

Blasted finger millet heads in the field

Twenty-one accessions of finger millet seed were screened for *P. grisea*, which was found to contaminate about 10% of the total seed tested, indicating that

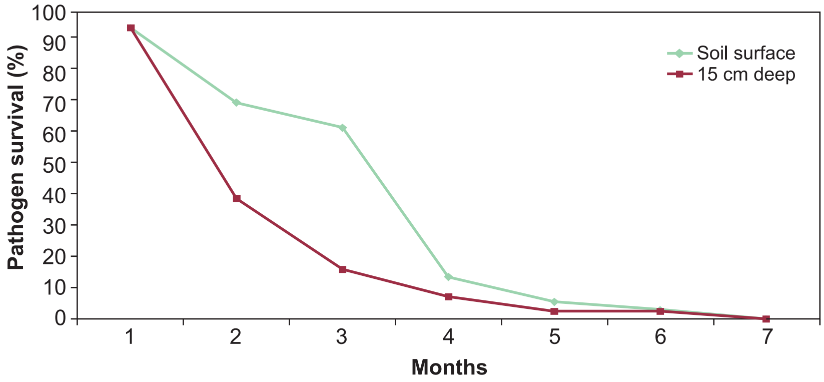

Figure 1. Survival of blast inoculum on crop debris on soil surface and buried at 15 cm

contaminated seed could potentially be a source of inoculum.

Data on finger millet blast collected during a final survey of 200 farms confirmed the correlation between incidence and severity of the disease. The highest average disease incidence and severity were 48 and 42%, respectively. Thus the disease resistance of Gulu E and tolerance of P224, along with their social acceptability, will be potentially valuable for smallholder millet growers, particularly if used in conjunction with cultural measures (including field hygiene) to limit or delay the onset of disease.

Project activities involved groups of farmers (participating and non-participating); finger millet traders (mostly women whose livelihoods depend on the income from this crop); and agricultural extension officers. In addition to the benefits to be gained through dissemination of information by agricultural extension officers to farmers, there will also be farmer–farmer and trader–consumer pathways of communication. The information conveyed via these routes will empower smallholder farmers to reduce potential losses due to finger millet blast through modification of cultural practices, particularly rotation and field hygiene and growing of improved varieties. The enhancement of production should improve food security at the family level and, if sufficient production is achieved, generate increased household income through the sale of grain to traders, resulting in availability of grain to those who may be otherwise unable to grow the crop, for example due to land shortages.

Farmer hand-harvesting finger millet

FUTURE

The work reported here has provided valuable information on the basic biology and ecology of the blast pathogen, and preliminary data on epidemiological factors such as inoculum survival and cultivar performance. The farmer participatory approach employed has highlighted the importance and value of this crop to the culture and livelihoods of smallholder farmers. In keeping with the agronomic and socio-economic context, further work in Kenya is required to:

- determine disease versus yield-loss relationships, taking into account compensatory growth;
- further evaluate the potential role of resistant varieties by screening farmers' varieties and other existing germplasm using the laboratory bioassay developed by this project;
- undertake farmer participatory evaluation of selected germplasm, along with sampling and molecular characterization of *P. grisea* populations at those sites.

Finger millet has also been identified as a key crop in the Teso Agricultural System in Uganda, and the following activities are suggested:

- evaluation of seedborne incidence and transmission of blast;
- investigation of management of blast through the use of seed treatments;
- identification and evaluation of blast-resistant finger millet cultivars in the context of variable pathogen populatons;
- socio-economic studies on farmers' perceptions of the disease and agronomic factors.

Groundnut rosette disease epidemiology

R6811

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December 1996–March 1999

Groundnut cultivation has a direct bearing on the nutritional and economic status of smallholder farmers in sub-Saharan Africa because it is an important source of protein and oil, and also provides cash income, contributing significantly to food security and poverty elimination. Rosette disease, caused by the groundnut rosette virus complex, is the most destructive virus disease of groundnut in the region. The International Crops Research Institute for the Semi-Arid Tropics has estimated that rosette disease causes greater yield loss to farmers in the region than any other virus disease affecting groundnut. Although chemical control and cultural practices are known to reduce risk of rosette, they are seldom adopted by smallholder farmers because of labour and capital constraints. Improved high-yielding lines with resistance to the disease and/or the vector may be the best low-input rosette disease management strategies. This project focused on understanding the interaction between the transmission of the three causal agents of rosette disease by the aphid vector in a range of virus- and vector-resistant genotypes, particularly short-duration lines which are less susceptible to drought and which can contribute to food security for smallholder farmers.

ISSUES

Groundnut rosette disease is endemic to sub-Saharan Africa and its offshore islands. Economists at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) have estimated that the value of the potential yield gain through rosette disease management is US$121 million per year. The 1996 Working Group on Groundnut Virus Diseases in Africa confirmed that rosette disease continues to be a severe constraint to groundnut production in sub-Saharan Africa, and recommended that host-plant resistance should be improved because it is regarded by many national programmes and NGOs as potentially the most effective disease management tool for smallholder farming systems. The Southern African Development Community (SADC)/ICRISAT Groundnut Project places major emphasis on the development of rosette-resistant lines, particularly short-duration varieties which are frequently preferred by farmers but which have not hitherto been available.

The Groundnut Project's breeding and screening programme has resulted in the identification of several high-yielding, agronomically acceptable short-, medium-, and long-duration lines with good levels of resistance to chlorotic rosette. In all rosette-resistant genotypes and germplasm lines which have been analysed to date, resistance has been found to the groundnut rosette virus component of the virus complex.

Earlier work at the Scottish Crop Research Institute, UK and ICRISAT (R5235) has shown that rosette disease is complex and involves three agents: groundnut rosette assistor luteovirus (GRAV), groundnut rosette umbravirus (GRV), and a satellite RNA (sat RNA) of GRV. The three agents are intricately dependent on each other and all play a crucial role in the biology and perpetuation of the disease. Variants of sat RNA cause different forms of the disease, whereas GRAV or GRV alone cause asymptomatic infections. GRAV acts as a helper virus in aphid transmission in that GRV RNA, which does not code for a coat protein, and sat RNA are packaged in the coat protein of GRAV to form virus particles that are aphid-transmissible. The sat RNA depends upon GRV for replication, and GRV depends upon sat RNA for aphid transmission.

The aim of this work was to improve understanding of groundnut rosette disease epidemiology, in order to contribute to the development of appropriate integrated management strategies based on host-plant resistance to the virus and/or vector.

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ACHIEVEMENTS

Aphis craccivora is the principal aphid vector of rosette disease agents. The source of virus-carrying aphids that initiate rosette disease is not known, and the factors associated with the development of disease epidemics are poorly understood. In this project, which interacted directly with the ICRISAT initiative to understand the epidemiology of the disease, detailed studies of the transmission characteristics of the three causal agents by the aphid vector have improved understanding of rosette disease spread.

Specific outputs include:

- the development of a new method to detect the three agents of the rosette disease complex in plants and aphid vectors by reverse transcription-polymerase chain reaction (RT-PCR)
- an improved understanding of the transmission efficiency of the three causal agents of rosette disease by the aphid vector on a range of groundnut genotypes, including rosette-resistant and vector-resistant lines, under field and laboratory conditions
- the identification of vector resistance in the short-duration line ICG 12991(Table 1)
- an assessment of yield loss due to the aphid-transmissible GRAV in a range of groundnut genotypes.

Table 1 Fecundity of *Aphis craccivora* on four groundnut genotypes with agronomically acceptable characteristics.

Cultivar	Age (days after sowing)	Mean days to reproduction	SE	*n*	Total offspring in first 5 days' reproduction	SE	*n*
JL24	7–22	6.00	0.09	23	49.20	1.41	22
	11–26	6.27	0.12	22	34.43	1.42	21
	28–43	6.62	0.16	21	37.80	0.98	20
CG7	7–22	6.47	0.10	21	44.43	1.60	21
	11–26	6.22	0.11	23	35.86	1.87	21
	28–43	6.45	0.18	20	36.33	1.98	21
ICG 90704	7–22	5.91	0.09	22	43.36	1.93	22
	11–26	6.24	0.10	21	35.45	1.34	21
	28–43	6.42	0.18	19	28.42	2.50	19
ICG 12991	**7–22**	**6.47**	**0.14**	**19**	**25.20**	**1.87**	**10**
	11–26	**7.67**	**0.17**	**9**	**14.70**	**1.35**	**6**
	28–43	**8.55**	**0.16**	**11**	**15.00**	**0.00**	**2**

The preliminary results of yield-loss experiments indicate that groundnut yield is reduced by between 25 and 60% due to rosette disease, depending on the cultivar. The lowest yield loss (23%) was recorded on ICG 90704, which is resistant to both GRV and sat RNA.

This has important implications for the release of 'resistant' groundnut genotypes such as ICG 90704 – in the event of high rosette disease pressure, as in an epidemic, there will still be significant yield loss on this genotype because it is susceptible to GRAV. Only low numbers of plants of genotype ICG 12991 were infected with GRAV, apparently because it could not be inoculated into the plants by the aphids. In the absence of any genotypes with GRAV resistance, further work on the nature of resistance in ICG 12991 and its inheritance is needed because it is proposed to develop durable resistance by combining vector resistance with GRV resistance.

Left, a farmer from Soroti town, Uganda, showing her groundnut crop destroyed by rosette disease (~80% incidence). Below, chlorotic rosette symptoms

FUTURE

The outputs of this project are being used by breeders at ICRISAT to develop improved groundnut genotypes with a range of resistance mechanisms to either the causal agents of rosette disease and/or the vector. A second phase involving a farmer participatory project using the promising rosette disease and vector resistance is being developed with ICRISAT in Uganda at the Serere Agricultural and Animal Production Research Institute based at Soroti (R7445).

Molecular and biochemical techniques for detection and identification of *Ralstonia solanacearum* and other plant-pathogenic bacteria

R6520

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Bacterial wilt is one of the major constraints on the production of a wide range of tropical and subtropical crops, including *Solanum* potato, banana and plantain, groundnut, tomato, eggplant and pepper. The disease is particularly difficult to control because it is soilborne and has such a wide host range. The use of resistant varieties is therefore an important component of control, but existing resistant varieties are often poorly adapted to local conditions, are often tolerant rather than truly resistant, and may carry latent infections. Improved techniques are needed for detection of this and other bacterial pathogens locally, to contribute to the development of better resistant varieties. Various diagnostic techniques have been developed in previous projects, including low-cost kit-based methods adapted for the particular conditions faced by tropical pathology laboratories; metabolic profiling; various molecular techniques including probes and the polymerase chain reaction; and enzyme-linked immunosorbent assays. In addition to field testing and further refining these methods under local conditions, valuable data have been gained on the importance of a range of bacterial diseases in cropping systems. Most significantly the approach of 'targeted seed pathology' has indicated the contribution that germplasm-borne inoculum of the bacterial pathogens studied makes to the spread and development of plant diseases in the field.

ISSUES

Bacterial diseases such as bacterial wilt are very serious in the subtropics and tropics, but most plant pathologists in these regions have had little exposure to bacteriology, compared to mycology or even virology. One reason for the comparative neglect of bacteriology in developing countries is the lack of techniques for identification and detection of plant pathogenic bacteria that are appropriate for the prevailing conditions, particularly the lack of financial resources for purchasing and storing the many different reagents and media required in classical bacteriology. The application of modern technologies, such as serological and molecular techniques, is also problematic because of frequent power cuts and other deficiencies in the infrastructure.

Various techniques for the diagnosis of bacterial wilt and the detection of the causal pathogen *Ralstonia solanacearum* have been developed, refined and field tested in previous projects (R5313, R5535, R5922, R5447; see *IPM Research Highlights, 1989–95*). These included the '*BACTID*' bacterial identification kit; metabolic profiling; various molecular techniques including probes and the polymerase chain reaction (PCR); and enzyme-linked immunosorbent assays (ELISA).

In this project the techniques were applied in Malawi and Tanzania, both to study the bacterial diseases and their spread in the field, and to evaluate the different techniques in developing country laboratories. The project focused on other diseases of vegetables in addition to bacterial wilt: vegetable cash cropping has intensified in response to growing urban markets in Tanzania and Kenya, but their bacterial diseases have not been studied in any detail. The research in Tanzania centred on PhD studies of the principal collaborator. The work in Malawi had to be curtailed due to the transfer of the chief collaborator to other duties.

ACHIEVEMENTS

Participatory appraisal of farmers' knowledge and perceptions established that seedborne and tuberborne bacterial pathogens are among the important disease causing agents that affect vegetable crops in Tanzania. Certain cultivation practices actually promote the

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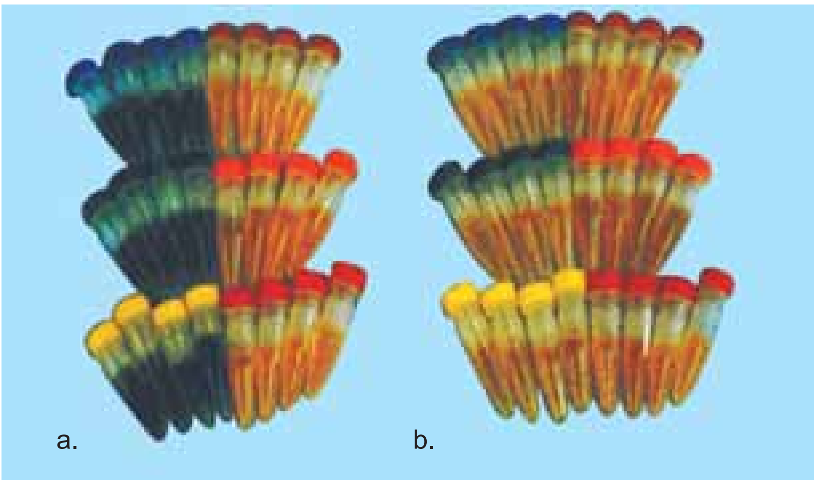
spread and development of the target pathogens. Most importantly, poor seed and potato seed tuber quality, including contamination with bacterial pathogens, should be addressed; this will require a combination of screening and quality control by Tanzanian suppliers to produce disease-free material and controls on imported seed. Unless the quality of vegetable seeds from commercial companies conforms to farmers' requirements, farmers will continue to produce and depend more on their own germplasm in order to satisfy their needs. Therefore it is worthwhile to support farmers' efforts by ensuring that reasonable quality germplasm is being used to sustain vegetable production.

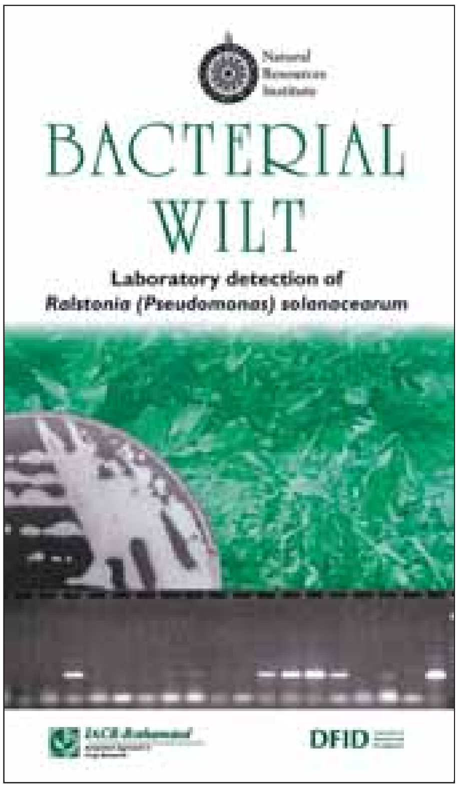
Among the project's major outputs were:

- the adaptation of a suite of diagnostic technologies for plant-pathogenic bacteria, including the production of manuals on *BACTID* and PCR/ELISA (right);
- evaluation of the various techniques in relation to the purpose of the diagnosis and prevailing conditions such as infrastructure and supply of electricity and water;
- data on the distribution and incidence of target pathogens, several pathogens being confirmed for the first time;
- data on the contribution of infection of germplasm within cropping systems;
- sources of variation in the bacteria *R. solanacearum* and *Xanthomonas campestris* pv. *campestris* (black rot) identified that will be important for disease control strategies;
- culture collection of reference isolates established;
- strategies for control identified – internal quarantine, seed quality, cultivation practices.



BACTID *biovar kit used to determine the biovars of isolates of* R. solanacearum *from tomato and potato: a. biovar 2 (potato isolate); b. biovar 3 (tomato isolate). A yellow colour indicates the metabolism of one of the differential substrates of the biovar test. Biovar 2 only metabolizes disaccharides (right-hand side of each set), biovar 3 metabolizes disaccharides and sugar alcohols (left-hand side of each set)*

Before this project started various assumptions were made about the causes of wilting in vegetables on the basis of symptoms observed in the field and, in general, little was known about bacterial diseases in Tanzania, even by plant protection specialists. Consequently, wilting was often attributed erroneously to the wrong cause without further investigative work. It is now confirmed that the bacteria *R. solanacearum* and *Clavibacter michiganensis* subsp. *michiganensis* are both significant causes of wilting in solanaceous crops, while the commonly observed necrosis of pith associated with wilting in tomato is not due to *Pseudomonas corrugata* as previously thought.



FUTURE

The *BACTID* bacterial identification system is being improved and expanded under a project originally funded by the Higher Education Funding Council for England. New *BACTID* software is being produced that will include an improved version of the core identification system (expert system); an encyclopaedia of media, tests and reagents used in the *BACTID* kit, taking advantage of practical experience gained from the project; and a learning module incorporating animated graphics of the tests taking place in the *BACTID* tubes.

Investigation of banana leaf speckle in Africa

R6794

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Leaf speckle disease of banana, a relatively little-studied disease, is causing significant damage in highland agroecosystems in Uganda. This project carried out an initial investigation into the variability and pathogenicity of the causal agent of the disease in Uganda, Kenya and Cameroon. Detailed examination of the material collected supports the recent transfer of the main pathogen from *Cladosporium* to *Periconiella*. It also reveals a more intricate picture of the banana leaf speckle complex than has been appreciated previously. Molecular studies suggest that variation exists across the geographic range of the fungus, which will be important in identifying and developing resistant varieties of banana.

ISSUES

Recent studies in Uganda have shown that cladosporium leaf speckle of banana is as damaging a disease as black Sigatoka in highland agroecosystems of East Africa. It is a major cause of leaf fall which, together with a number of other factors, results in a significant decline in yield. Although predominantly affecting highland bananas, it is also known to be a sporadic problem in lowland areas elsewhere in Africa. A key concern was whether the pathogen found in East Africa is the same as that found in West Africa. Knowledge about the genetic variability of the pathogen has been virtually non-existent, and is needed to formulate a disease management programme utilizing resistant varieties.

This study arose out of existing links with the Kawanda Agricultural Research Institute, particularly with an ongoing project (R6692) to develop techniques to detect the fungi causing fusarium wilt and Sigatoka leaf spots of banana. The aim of this work was to develop a method for pathogenicity testing of the fungus causing leaf speckle disease, in order to confirm the identity of the pathogen on highland bananas as a basis for future testing for host resistance.

ACHIEVEMENTS

Surveys were conducted in Uganda and Kenya, and samples were collected from these two countries plus Cameroon for isolation of the fungus. The isolates obtained were used for molecular studies of genetic variability and to develop pathogenicity tests.

Preliminary results indicate that banana leaf speckle is more complex than previously thought. Firstly, the actual identity of the causal organism has been questioned. Detailed examination by scanning electron microscope of isolates collected in East Africa confirmed that *Cladosporium musae* does not belong in *Cladosporium* but appears to be better placed in the genus *Periconiella*, and has been renamed *P. sapientumicola*. The fungus is of considerable scientific interest as it has two quite different spore-producing forms, something not previously observed in either *Cladosporium* or *Periconiella*. Secondly, *P. sapientumicola* was revealed to be genetically variable not only in East Africa, but also across the banana-growing regions of the tropics.

A firm conclusion from this preliminary work is that symptoms of banana leaf speckle are not sufficient for accurate diagnosis. It is essential that the fungus causing the disease is examined in detail to confirm its identity. This is critical as fungi in this complex appear to have developed a strikingly similar appearance. Meaningful studies of resistance to banana leaf speckle can be conducted only if the correct fungal species is isolated and used for inoculation.

The project also developed a repeatable method for infecting highland bananas with the fungus. This method can now be used to study the variation in pathogenicity of *P. sapientumicola*, and could also be used for assessing the pathogenicity of *Periconiella musae* and *Ramichloridium musae*, the other two leaf speckle fungi found on banana.

A brief study of molecular markers of genetic variability indicates that variability does exist in populations of *P. sapientumicola*, but this needs to be investigated further. The potential connection between genetic variability and pathogenicity needs to be explored in relation to environment and geography.

The findings of this project suggest that the banana leaf speckle complex has different fungal components according to host cultivar, region and climatic conditions. The Cameroon collections made at the end of the dry season comprised mainly *R. musae* and two undescribed species of *Cladosporium*: *P. sapientumicola* was not apparent. The Ugandan and Kenyan samples, collected from regions where rainfall is more evenly distributed, were predominantly *P. sapientumicola*, and *R. musae* was not found. These observations are the product of one set of samples, and this possible pattern needs to be tested further.

FUTURE

The results confirmed the main causal agent of the disease. The breeding programme can now target the pathogen when improving the resistance of highland bananas to diseases.
A study to identify sources of resistance for incorporation in highland bananas has already begun at Kawanda.

Adaptation of novel techniques for detection of fungi causing fusarium wilt and Sigatoka leaf spots of banana and plantain

R6006CB/R6007CB/R6692

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Bananas and plantains are a key staple food in many parts of the world, and are of vital importance to many subsistence and tenant farmers, and ultimately to the rural economy as a whole. Recent reports from East Africa have indicated that productivity has been declining. A number of pests and diseases, including black and yellow Sigatoka and Panama disease (fusarium wilt), have been identified as major factors in this decline. Cultural practices and the use of plant resistance are considered to be the two main components of any future disease management strategy, but their use has been limited by a lack of information on pathogen variability that exists in East Africa. Molecular biological and biochemical techniques for identifying and diagnosing the fungi (*Mycosphaerella* spp. and *Fusarium oxysporum* f.sp. *cubense*) which cause these diseases, have been developed under previous projects to monitor and characterize the pathogens in East Africa. This work has adapted and established these techniques in Uganda and Kenya through the installation of laboratory facilities and training of local scientists in their application, and through the development of research programmes employing the techniques to provide information on the geographic distribution, host range, variability and severity of the pathogen. The information obtained will be of benefit in developing improved disease control measures, initially through more accurate disease diagnosis, and ultimately by assisting in the selection of resistant cultivars and the development of ecologically based control strategies.

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ISSUES

Banana is the most important staple food crop in the Lake Victoria Basin area of East Africa, particularly in Uganda where it occupies approximately 40% of utilized arable land. However, the productivity of banana plantations in the area is decreasing. National programme surveys in Uganda and Kenya have identified the fungal diseases black and yellow Sigatoka leaf spots (*Mycosphaerella* spp.), and Panama disease (*Fusarium oxysporum* f.sp. *cubense*) as causing severe losses to smallholder crops of banana and plantain. The diseases are also of major concern in Tanzania.

Fusarium oxysporum causes major yield losses on a wide range of economically important crops, including banana. Host- and cultivar-specific pathogenic groups exist within the species, including a number of pathogenic races of *F.o cubense* that are of major economic importance on banana worldwide. The fungal species involved in the Sigatoka diseases, *M. fijiensis* (black leaf streak) and *M. musicola* (yellow Sigatoka), also appear very similar, and considerable difficulty has been experienced in identifying the individual pathogens from leaf symptoms alone. The difficulties in accurately diagnosing these diseases have contributed to a lack of basic biological and epidemiological information, and have been a major constraint to the development of sustainable control strategies, including the development and use of host-plant resistance, where knowledge of the nature of the pathogen being assessed is essential for success. Previous research projects completed at CABI Bioscience and NRI have resulted in the development of rapid and accurate biochemical and molecular techniques for characterizing and differentiating pathogenic forms of both diseases. The major aim of this project was to adapt these existing techniques for use in developing countries, and to integrate the technologies into the research programmes of national agricultural research services in Uganda and Kenya.

ACHIEVEMENTS

FUSARIUM WILT

Laboratory-based techniques for diagnosing fusarium wilt of banana and for characterizing *F. oxysporum*

Smallholder banana farm in Mukono, Uganda

were adapted for use by scientists in East Africa. A local capability for characterizing and identifying the pathogen was created in Uganda and Kenya through establishment of appropriate laboratory facilities and training of local counterparts in their use. As a result, a range of *in vitro* characterization techniques, including analyses of secondary metabolite production, extracellular isoenzyme production and vegetative compatibility testing, are now being used routinely in laboratories in these countries as part of national banana research programmes.

This work, coupled with comprehensive surveys and disease assessment trials undertaken, has provided extensive information on the incidence, severity and distribution of particular forms of the fusarium wilt pathogen in Uganda, Kenya and Tanzania. Fusarium wilt was found in all of the key banana growing regions in the three countries with a number of widely grown and economically important cultivars (Gros Michel, Bluggoe, Ney Poovan, Pisang Awak) being affected. Disease incidence was higher than 80% in some instances.

Reports have been produced on the feasibility and relative value of different pathogen characterization techniques in the East African context. These include preliminary information on the relative benefits, ease of application and potential for future use of DNA molecular techniques for determining the genetic diversity of *F. o. cubense* within East Africa and how it relates to other characters, including pathogenicity.

Results of the research have been disseminated to stakeholders, including NARS, extension services and farmers, in the form of up-to-date reports, disease distribution maps and advisory bulletins.

Plans have been developed, in collaboration with counterpart scientists in Uganda, Kenya and Tanzania, for adoption and incorporation of techniques for diagnosing fusarium wilts and characterizing *F. oxysporum* within integrated pest management programmes, in particular those involving screening for resistant banana cultivars. This has partly been achieved through a stakeholder workshop held in Nairobi in March 1997.

SIGATOKA

The previously developed PCR diagnostic test for *Mycosphaerella* spp. was adapted for use under local conditions, and a protocol developed. PCR equipment was set up in Nairobi, Kenya and Kampala, Uganda, and staff were trained in its use, resulting in further revisions to the draft protocol manual.

Disease surveys were carried out in Uganda and Kenya. A preliminary map of disease distribution in Uganda was produced, which revealed that the spread of black Sigatoka within Uganda has not been as rapid as anticipated. The disease was detected only at sites where mean annual minimum temperatures exceeded 13.8 C, which corresponded with sites below 1350 m above sea level. The incidence of black Sigatoka was always 100% where the disease occurred. In contrast, yellow Sigatoka was present at all the survey sites, but always with a very low incidence. The cultivar Kayinja supported more *M. musicola* than any other cultivar, and appears to be a good reference cultivar for monitoring the disease in areas where incidence of yellow Sigatoka is low. In Kenya, at present black Sigatoka is confined to the Coast

Examination of bananas exhibiting symptoms of fusarium wilt during survey in Mbeya, Tanzania

Sigatoka leaf spot symptoms on banana leaf, Mbeya, Tanzania

Province, and has not spread from its introduction here into the rest of the country. Neither has the disease spread into Western Kenya from Uganda, where it is present around Lake Victoria.

The reason for the absence of black Sigatoka in the other important banana growing areas has been assumed to be because it has not been introduced, rather than because it would not survive and flourish. The present findings have implications for transport of germplasm throughout the country. The rise in importance and popularity of the Cavendish banana types in many areas is also worth considering, as these are highly susceptible to black Sigatoka, and disease on these types could be severe if it spreads into the Western and Central Provinces. Although yellow Sigatoka is present in most areas in the country, it does not at this stage appear to be an economic problem except perhaps in Central Province in the commercial production areas near Maragua.

Through the establishment of appropriate laboratory facilities for utilizing previously developed identification techniques, local capability has been created in Uganda and Kenya for studying pathogenic variability of *F. oxysporum* and *Mycosphaerella* strains infecting banana and plantain in these countries. The use of these techniques as tools for rapid identification of host-specific strains of the fungus has, and will continue to, provide important information on the distribution and incidence of differing pathotypes within these two countries. An ability to generate this information locally will reduce the reliance of East African scientists on the expertise of overseas institutions, and will be of major benefit in the development and promotion of integrated pest management strategies appropriate to East African smallholder farming systems, in particular those concerned with the development and use of resistant banana cultivars. Ultimately, reductions in yield losses resulting from these diseases will lead to an increase in farm income, subsequent improvements in family welfare and gradual development/modernization of farming practices.

Typical symptoms of fusarium wilt on newly planted banana suckers, Murang'a, Kenya

In addition, the survey work in particular has led to important recommendations concerning issues such as the restriction of germplasm within the countries, and regarding the type of varieties that should be planted in certain areas and produced within national tissue culture programmes.

FUTURE

The depth of information acquired on the distribution and incidence of fusarium wilt and Sigatoka leaf spots in East Africa, the existence of differing pathotypes and the susceptibility of cultivars, will depend on the extent to which the established technologies are utilized in local research programmes. In order to maximize outputs, and ultimately the potential impact of the technologies, research efforts should be expanded to take account of possible pathogen variability across all banana production areas. However this will, for the most part, depend on prioritization of, and allocation of funding for, relevant activities by NARS. In Uganda and Kenya the diagnostic techniques developed in the UK will continue to be utilized through close links forged with national banana research programmes, and in particular through ongoing PhD research programmes initiated in 1995.

Knowledge gained to date and through future utilization of the newly adopted technologies and supporting research must be collated and disseminated in an approprate form to potential beneficiaries. These include NARS, plant disease clinics, plant breeders, extension services and farmers. Funding has already been obtained from CPP to initiate this process in Uganda under a new IPM project (R7567). Where not already available, efforts should be made to establish pathways to permit rapid and frequent dissemination of such outputs in order to maximize uptake and impact.

Epidemiology of rice yellow mottle virus disease in rice farming systems in Tanzania

R6763

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Rice is becoming an increasingly important food crop in Africa, including Tanzania where it is a staple food for 60% of the population and is particularly important in urban areas. Rice yellow mottle virus (RYMV) has become a severe constraint to rice production throughout sub-Saharan Africa, but little is known of the epidemiology of the disease in East Africa. This project has obtained information on farming practices and farmers' perceptions of RYMV in four main rice-growing regions of Tanzania; described the incidence and variability of the virus; carried out a preliminary investigation of transmission by beetles, leaf contact and seed husks; and assessed yield losses from farmer-preferred rice varieties and improved RYMV-tolerant lines, working towards appropriate integrated crop management strategies to reduce the risk of the disease.

ISSUES

Rice is the second cereal after maize in terms of production and preference in Tanzania, and per capita consumption of rice has increased from 15 kg/year in the 1970s to the current 35 kg/year. 74% of the rice is grown under rainfed lowland systems. Following increasing reports of rice yellow mottle virus (RYMV) outbreaks in major rice-growing regions of Tanzania in 1995, a preliminary survey (1995–97) reported that RYMV disease was present in all the major rice-growing areas of the country. First identified in Kenya, it has been found in many other countries throughout sub-Saharan Africa including Niger, Côte d'Ivoire and Madagascar. In general it is believed that changes in farming practices such as continuous cultivation, introduction of irrigation schemes, and use of improved varieties have aggravated the incidence and severity of the disease.

This project aimed to link Tanzanian scientists with initiatives of the West Africa Rice Development Association (WARDA), and European projects on the development of RYMV-resistant lines at John Innes Centre, UK (Plant Sciences Research Programme project R6355) and Laboratorie de Phytovirologie des Régions Chaude, France. Little work has been carried out on the epidemiology or impact of the disease in East Africa. Given the inevitable intensification of rice cultivation on the continent, an understanding of the epidemiology of this disease is essential in developing appropriate control measures to protect rice crops of smallholder farmers in Tanzania.

ACHIEVEMENTS

Information on farming practices was collected using participatory rural appraisal, through observations, interviews and ranking. Farmers provided information on the types of crops grown in the area, the importance of rice in relation to other crops, farming practices, and constraints to rice production. The most important constraints to rice production in the bunded systems of Mwanza/Shinyanga are water shortage and pests and diseases in general, whereas in shallow flooded areas of Morogoro and Kyela, pests and diseases were the first priority (see Table 1).

The distribution of RYMV in four major rice-growing regions of Tanzania has been mapped, and farmers' perceptions of this disease in their farming systems have been obtained. RYMV was confirmed in all the cropping systems surveyed, but is more prevalent in the shallow flooded system, where it can cause crop failure. In Kyela it has become a political problem, and District Agricultural Officers in this region are being pressurized by farmers and politicians to provide effective management options. Overall the disease is of economic significance to farmers in three of

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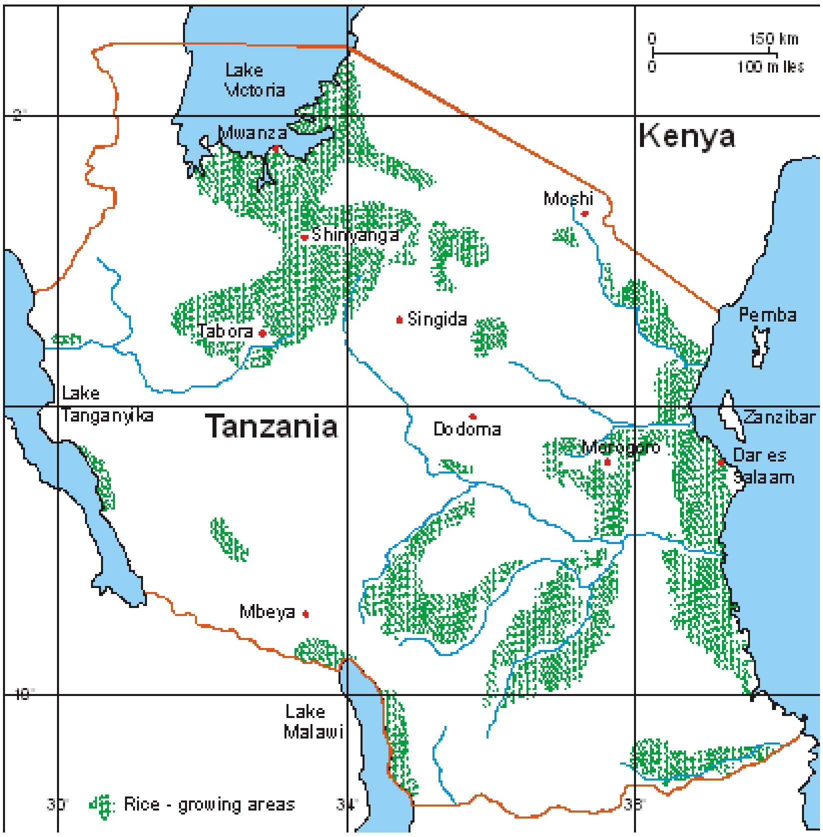

Figure 1. The major rice-growing areas (shaded) in Tanzania

Table 1. Pests and disease constraints to rice production mentioned by farmers in different regions

	Percentage of farmers			
Disease/insect	**Mwanza/ Shinyanga (*n*=55)**	**Ifakara/ Morogoro (*n*=109)***	**Kyela (*n*=22)**	**Pemba (*n*=107)**
Insects				
Stem borers	21.8	–	–	76.6
Leaf hoppers	10.9	–	–	–
Long–horned grasshopper	–	–	10.9	–
Armyworm	–	41.3	–	68.2
Trichispa sp.	–	–	–	100.0
Diopsis sp.	–	–	–	23.4
Diseases				
Yellowing[1]	14.5	–	–	–
Sheath rot[2]	7.3	–	–	–
Leaf spot diseases	1.8	22.0	–	–
RYMV[3]	8.2	100.0	50.0	100.0

[1]Symptom description by farmers.
[2]Based on field observations.
[3]Based on field observations and symptom description – samples removed from farmers' fields and confirmed by serological tests.

the four regions studied: Morogoro, Pemba and Kyela.

Location-specific factors are likely to be extremely important in the epidemiology of this disease in Tanzania; during the survey in Mwanza, RYMV-infected plants appeared in the same three sites between 1997 and 1999, and in Morogoro and Kyela farmers claimed that the disease appeared in their fields every year. An *Echinochloa* species was identified as a weed host of RYMV at one site in Mwanza, and it is possible that other alternative hosts are present.

The virus is known to be transmitted by Chrysomelid beetles. Beetle vectors (*Chaetocnema* and *Trichispa* spp.) were found in or at the edge of the rice fields around Mwanza, but many did not transmit RYMV; the low beetle populations found in the rice fields could explain the relatively low incidence and patchy distribution of the disease. No beetles were found in the large RYMV-infected plots in Morogoro. There is currently inadequate information on the populations of beetle vectors in the Morogoro and Kyela locations. Experiments suggested that leaf and root contact and seed are unlikely to be the major means of transmission of the virus.

Gel-diffusion and ELISA tests were carried out to determine differences among the samples of one region. The results suggest that there are at least two distinct RYMV strains that can be identified in Tanzania; the 'Mwanza' strain, and the 'Morogoro' strain which is similar serologically to strains from Pemba, Moshi and Mbeya. Using techniques developed by the project, different strains of the virus have been made available for resistance breeding work.

Experiments to collect data on the field spread of RYMV were unfortunately disrupted by drought in years 1 and 3, and by theft of field cages in year 2. However, despite the lack of information on field spread in the rainfed system, the project has provided the first detailed description of the virus disease in Tanzania.

FUTURE

Information on Tanzanian farming systems will be of use to WARDA and the Tanzanian national programme as they collaborate through the International Network for Genetic Evaluation of Rice (INGER-Africa). The second phase of this project will be developed in collaboration with WARDA. The data on varieties, constraints etc. gathered during the surveys will assist national agricultural research services in selecting suitable materials for specific locations. Information on the variability of RYMV in Tanzania has been passed to the the Plant Sciences Research Programme project on RYMV and used in screening trials of transgenic RYMV-tolerant materials.

RYMV-tolerant lines from WARDA have been field tested against the 'Mwanza' strain of RYMV, and at least one may have acceptable characteristics in terms of yield for farmers in these regions, but may lack the aromatic characteristics of the locally grown varieties.

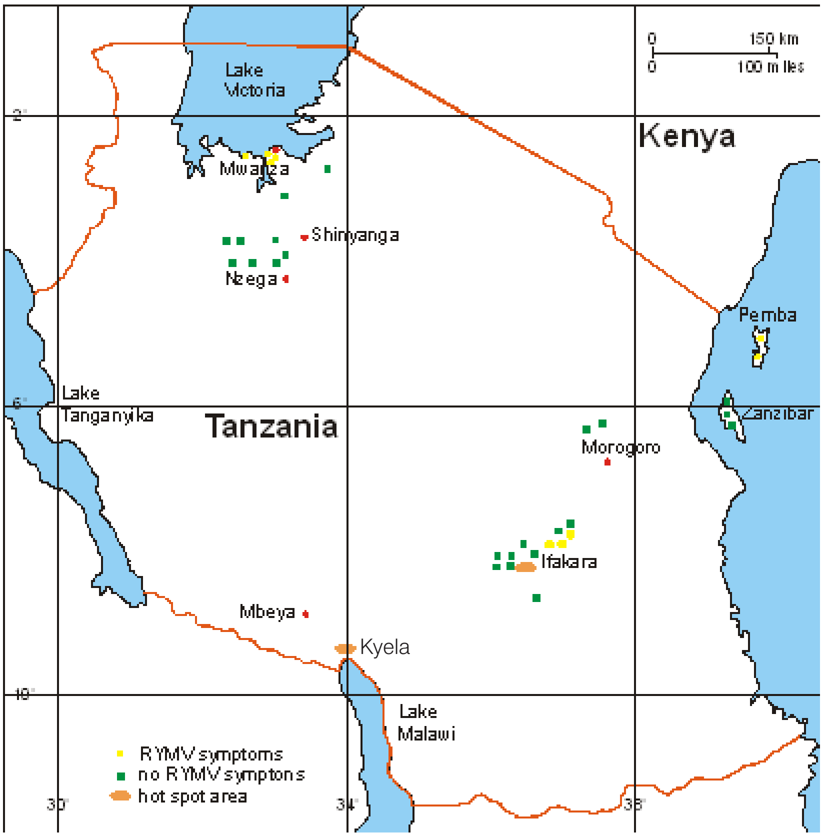

Figure 2. Sites surveyed for the presence of rice yellow mottle virus (RYMV) disease 1997–99

Farmer from Kyela discussing causes of RYMV disease in his rice crop

Future work should undertake farmer participatory trials with RYMV-tolerant materials developed by WARDA, who have 20 lines available for testing.

The mechanism of RYMV transmission is still poorly understood, and the principal means of spread within and between fields is still unresolved. It has been proposed that vector specificity for the beetle-transmitted sobemoviruses appears to be controlled by the interaction of the virus particles with the host plant following beetle feeding and delivery of the virus to the plant through regurgitation. The major transmission route for RYMV must be established to facilitate the development of cultural management.

Epidemiology and crop loss assessment of rice nematodes in West Africa

R6009, R6658

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Escalating demand for rice in West Africa is being met by imports rather than by increased production. The West Africa Rice Development Association (WARDA) is working to enable the region to become less reliant on imported rice. This project aimed to add to limited existing knowledge on rice nematode pests in the region. The research has clarified nematode pest distribution, both throughout West Africa, and on a more local scale. The contribution of individual nematode species to crop damage has been addressed, but the complex nature of interrelationships between nematode species and their environment has been challenging. As rice cropping practices change to meet the increased demand for rice and production systems become more intensive, nematode problems will become increasingly serious. This is already taking place in the savannah, but is also apparent in the forest zone. The project has identified very good sources of resistance to some important nematode pests which will enable the development and extension of practical and appropriate nematode management. These outputs are being adopted by WARDA as part of their selection process for improved rice lines.

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ISSUES

Rice is a major food staple in West Africa. Rice consumption in the region is rising at the rate of 45% a year, but currently this escalating demand is met by imports rather than by increased production. Imported, subsidized rice competes with local production and at the same time fuels demand, producing an acute need to increase rice production in the region. Traditional upland rice-farming systems in West Africa are built around forms of shifting cultivation in a mixed farming system. Population and production pressures have led to a decrease in the fallow periods between crops, and to more intensive cropping. The West Africa Rice Development Association (WARDA) is working to enable this intensification to proceed in a sustainable way.

In the context of shortening fallow and more intensive cropping, plant parasitic nematodes are likely to be an important production constraint. However, there is very little information available on nematodes in West African rice-based smallholder cropping systems, and WARDA has insufficient resources to rectify this. Understanding of the nematode communities and population dynamics within the diverse rice-growing environments is needed to assist in developing sound management strategies. This work aimed to provide the basic background knowledge, examining the pest status of nematodes in upland, hydromorphic and lowland swamp rice-growing environments of West Africa; examining the influence of shortening fallow on emergent pest species; and making a preliminary assessment of likely nematode management options.

ACHIEVEMENTS

Rice fields in West Africa are very variable in terms of water availability, which results in nematode communities of unusually diverse composition, species normally separated by stable ecological adaptation to lowland or upland rice occurring together. Nematode species have preferred environmental distributions, dictated by water conditions, although some species are less specific than others. Research results indicated the wide distribution of potential rice nematode pests within the region. The rice nematodes surveyed in the forest zone in the Ashanti region of Ghana are fairly typical of West African hydromorphic environments (Table 1). In northern Ghana, an undescribed species of *Ditylenchus* of unknown importance was highly prevalent on rice. Nematode communities tend

Table 1. Prevalence of plant parasitic nematodes in rice in the forest zone of Ashanti Region, Ghana

Nematode species	Prevalence*
Coslenchus franklinae	76
Helicotylenchus dihystera	47
Meloidogyne sp.	26
Pratylenchus zeae	26
Tylenchorhynchus annulatus	24
Heterodera sp.	12
Pratylenchus brachyurus	12
Xiphinema bergeri	12
Helicotylenchus cf. *mucronatus*	9
Longidorus laevicapitatus	6
Sakia	6
Aphelenchoides	3
Axodorylaimellus	3
Basiria	3
Chronogaster sp.	3
Dorylaimellus	3
Filenchus	3
Hemicriconemoides cf. *affinis*	3
Longidorus pisi	3
Rotylenchulus reniformis	3

*Percentage of farms with particular nematode spp.

to be complex, comprising a wide diversity of species. As a consequence, and due to the varied and often contiguous conditions present in rice-growing situations, assessment of yield losses caused by nematodes is complicated.

In field trials and on-farm studies, high populations of root lesion nematode, *Pratylenchus zeae*, were consistently associated with low grain yield in upland rice. Moreover, high nematode populations in farmers' upland rice fields at harvest were associated with low grain size. *Heterodera sacchari* was found to be highly pathogenic on susceptible rice cultivars under upland/hydromorphic conditions. It severely suppressed crop development, and in field trials caused complete crop losses in some cases. Losses were greatest in combination with drought stress.

In lowland rice, *Heterodera oryzae* populations at harvest were negatively associated with yield.

In the forest zone, current fallow periods appear sufficient to prevent nematode build-up, but pest species quickly predominate within a single rice crop, accompanied by over 50% reduction in nematode diversity in upland fields. In the savannah zone nematode prevalence increased markedly with intensification of rice production, particularly of *P. zeae*.

In mixed populations, *H. sacchari* replaces the widespread upland rice pest *Meloidogyne incognita* (root-knot nematode), and becomes dominant. The nematode is more prevalent in rainfed lowland/hydromorphic conditions where rice production is more intensive. It is less pathogenic under such conditions, but is nevertheless damaging. *Heterodera sacchari* appears less prevalent than *M. incognita* in the region, but the slow hatching of juveniles over several weeks means that its prevalence was underestimated using standard extraction techniques. It appears to have a low incidence in the first few years of rice following secondary forest, after which population levels increase rapidly. With intensification of rice production, improved weed management and widespread use of improved cultivars, it is likely that nematodes will be increasingly problematic, particularly *H. sacchari* which is not suppressed by improved crop rotations.

Resistance to both *H. sacchari* and *M. incognita* has been identified through screening trials, but not for *P. zeae* or *H. oryzae*. Weed infestation reduces *H. sacchari* population densities in upland fields, and *H. oryzae* in lowland fields. *Pratylenchus zeae* population densities on rice are higher under mixed cropping conditions with maize. Mineral fertilizer inputs affected nematode distribution, but inconsistent results indicate that many more variables need to be accounted for in further research.

A range of other avenues of nematode management have been researched, such as improved crop rotations, which will prove important elements of fully integrated pest management technologies in rice cropping systems. This project has also highlighted important issues concerning the interaction of nematodes and other constraints in rice production. In many cases nematodes have been overlooked, despite their importance, for example in determining the outcome of competition between rice and weeds. Also, drought stress is recognized as an important constraint to upland rice production, but is far less severe in the absence of particular nematodes.

The project also served to build a nematology capacity in West Africa through in-service training of technical and regional NARS staff, and specifically through an intensive one-week training workshop.

FUTURE

The research results will aid WARDA in assessing the impact of current cropping practices on nematode pests, and the implications of this for future production. Information on nematode-resistant cultivars will be used by WARDA in their selection procedure for improved cultivars.

Optimizing insecticide barriers for locust control

R7065

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January 1998–March 2000

Locust outbreaks have affected farmers on all continents since agriculture began, and often necessitate treating thousands of hectares with insecticidal sprays. Usually when treating locust hoppers the whole area is sprayed, but an alternative is to treat only narrow strips of vegetation. These strips or barriers are then encountered by gregarious hoppers as they roam around in search of food, and they consume a lethal dose of insecticide within the barrier. Although the barrier technique is not new, research support was required to analyse barrier spacing for different species of locusts, to identify suitable insecticides, and to determine effects on non-target species. The project's findings will allow hopper-infested areas, which can be extremely extensive, to be managed in a way which is effective, practical and potentially less damaging than either full coverage spraying or reliance on organochlorine insecticides. The sensitive non-target species which are at risk from locust control operations have been identified, and field assessments linked to a literature review on behaviour indicate that the combination of insect growth regulators with the barrier technique is relatively benign for the environment: insect growth regulators are innately less toxic than alternative pesticides, and the barriers are applied to only a fraction of the affected area.

ISSUES

When environmental conditions are favourable, locust numbers increase, sometimes producing devastating results. Historically this has required extensive control operations using insecticides which are usually applied as total coverage treatments, often over very large areas. Even in recession years some species of locusts and grasshoppers congregate in groups and threaten crops and grazing areas, so routine control operations using insecticides are necessary.

Many operational constraints to safe and efficient locust control exist. There are often deficiencies in the information, equipment and trained personnel needed to survey and control locusts by covering the whole area with sprays. The barrier technique involves spraying narrow strips of vegetation, termed barriers, with insecticide, rather than treating the whole area. As the barrier spraying technique is used as an alternative to full coverage or blanket spraying, the reduction in the area treated provides logistical advantages. Compared with the tactic of finding and spraying all hopper bands individually, which is almost impossible in practice, the barrier method is easier because it removes the need for high-intensity surveys. By laying down barriers the whole area is effectively 'treated', and although it is inappropriate for winged adults, the technique can successfully control many species of locusts and grasshoppers at the gregarious stage, which is induced by high population density. In this stage hopper behaviour and appearance change markedly, and they become much more of a threat to crops and grazing areas. Elegantly, it is this changed behaviour which enables the barrier technique to work, because hoppers roam around together in their search for grazing, and encounter the sprayed barriers. The efficacy of insecticide barriers relies on the movement and feeding behaviour of these gregarious groups or bands of hoppers so that they encounter the treated strips and consume a lethal dose of insecticide.

There has been uncertainty concerning the best spatial arrangement of insecticide barriers to achieve an effective compromise between high control efficacy, low control cost and low environmental impact. The objective is to use the maximum barrier separation and the minimum barrier width that provides effective control.

In this project four important locust species were considered: desert locust (*Schistocerca gregaria*), African migratory locust (*Locusta migratoria migratoriodes*), brown

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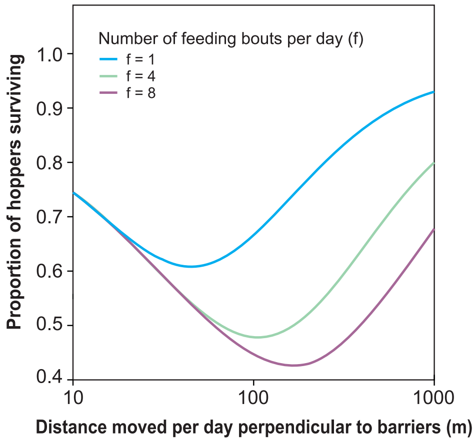

Figure 1. Effect of distance moved and feeding behaviour on the proportion of hoppers surviving barrier treatment

locust (*Locusta pardalina*) and red locust (*Nomadacris septem-fasciata*), although these are not the only species for which barriers are appropriate. Data on the four species were gathered from the locust archives held at NRI, and information on the behaviour of other locust species is not sufficiently complete to incorporate into the model.

Figure 2. Swarming hoppers in Madagascar

ACHIEVEMENTS

A mathematical model of the barrier technique was developed which encompasses the behaviour of different locust species, in order to rationalize the optimal barrier width and spacing for different species and growth stages. The model demonstrates that when the probability of feeding within a barrier is taken into account, there is an optimum rate of hopper movement which is a compromise between maximizing the probability of a hopper encountering the barrier during the period when the barrier remains biologically active, and the probability that a hopper will engage in feeding activity whilst inside the barrier. The optimum movement rate of the target was sensitive to the pattern of feeding activity, and a range of feeding patterns were explored. With a barrier width of 50 m, the optimum distance moved by a target hopper was approximately 160 m per day. The analysis suggests that species with intermediate rates of displacement form the best targets for barrier treatment.

Choice of insecticide is critical because barriers must remain active for several weeks. Dieldrin was previously the barrier insecticide of choice because of its persistence, but environmental accumulation, which was having an effect on non-target species such as birds, caused the organochlorine insecticides to be withdrawn. Now more modern replacement insecticides are required for barrier use which have suitable characteristics such as relative stability and acceptably low mammalian toxicity. In this work the insect growth regulators teflubenzuron, triflumuron and diflubenzuron were compared with fipronil, an insecticide with a more conventional mode of action. Sunlight is an important factor in degradation of insecticides and rapidly renders them inactive. Simulated solar degradation was used as a measure of the robustness of the molecules and relative field persistence. Survival under powerful artificial light was used as a means of comparing their suitability as barrier insecticides. The four candidate barrier insecticides were compared under simulated field conditions in order to recommend which might be appropriate for field use. All three insect growth regulators tested appeared to be sufficiently photostable to be suitable for barrier use, whereas the results were less clear for fipronil, which rapidly degraded into two main components in the presence of strong light.

In order to assess the non-target effects of barriers, behavioural information on a range of key non-target invertebrates was gathered, and an environmental monitoring exercise in Madagascar evaluated the impact of two of the pesticides on non-target organisms during emergency locust control operations during 1998. The most significant result was the negative impact of fipronil on termite populations, which appears to be very severe. Apart from this marked impact on termites, when applied in barriers, fipronil generally affects fewer non-target invertebrates than triflumuron, and has relatively minor adverse effects. Immature spiders, non-target grasshoppers and flies were the other terrestrial invertebrates that showed indications of adverse, short-term impacts. Work on triflumuron confirms evidence of some minor adverse impacts of barrier-sprayed insect growth regulators on the relative abundance of spiders, grasshoppers, crickets and caterpillars, with termites also being affected in the short term. The model, and other results obtained by the project, have produced a greater understanding of barriers, and will allow more rational decisions on insecticide choice.

FUTURE

Deployment of barriers for different species of locust hoppers will lead to environmental benefits over full coverage spraying. The agencies concerned with locust control will be working to validate the hypotheses developed in this project by carrying out field trials.

Field demonstration of vertical-looking radar as a cost-effective, automatic monitor of desert locust migration

R5445

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December 1992–March 1996

If conditions are favourable for breeding, solitary desert locusts can show enormous population growth over successive generations, leading to swarming and the major destruction of crops and livelihoods. To help in detecting early signs of population increase, a novel vertical-looking radar for monitoring the migratory flight of insects at high altitude was previously developed by NRI. This project involved a series of field trials in Mauritania, followed by an all-weather trial in the UK, which confirmed the system's capacity to acquire and store large amounts of data on insect migration. The method is inexpensive to run, and is well suited to monitoring desert locusts. Improvements in locust forecasting will enable targeting of control measures, and the control of swarms before they reach devastating proportions.

ISSUES

Once non-swarming, solitary desert locusts begin to breed there may be an enormous increase in numbers over successive generations, accompanied by a change into the swarming, gregarious phase. Monitoring these population upsurges would enable early prediction of swarms and targeted application of control, and thus the alleviation of huge crop damage and consequent poverty. However, desert locust solitaries migrate at night, and at altitudes of several hundred metres, so it has not been possible to monitor their movements effectively. The only method of observing the migration of solitary locusts has been with radar, but the use of conventional scanning entomological radars is very time-consuming and highly specialized, and it is not practical to use these systems routinely.

In the late 1980s work was carried out at NRI to design an inexpensive, automatic radar suitable for monitoring insect migration. This work resulted in the development of a novel form of vertical-looking radar (VLR). The aims of the present project were to evaluate prototype VLRs in overseas field trials, and to demonstrate the system's capacity to make long-term, automated measurements of insect migration in general.

ACHIEVEMENTS

Two radars were deployed: one VLR, and one scanning entomological radar of conventional design, to provide a control. Locust populations, and those of other large insect species (which could be confused with locusts by the radar), were monitored by ground surveys and light-trapping.

The 1993 field trials in Mauritania revealed errors in the processing routines which had not been revealed by previous trials with simulated data, so processing algorithms were rewritten for the 1994 trials and were then found to produce size distributions consistent with those estimated from the scanning radar. The processing algorithms were also modified to make them more robust when challenged by atypical signals, and to improve error handling.

Overall, the field trials confirmed the validity of the VLR concept. The results indicated that reliable differentiation between locusts and other flying insects was achieved, and that although the prototype VLR flight trajectory data did not exactly match that derived from the scanning radar, it was adequate to describe the speed and direction of locust migration. The trials also revealed that the prototype equipment needed re-engineering to make it suitable for long-term use by non-specialists. Thus in a 1-year extension to the original project, a new VLR antenna system suitable for long-term running was designed and built in the UK. The very satisfactory technical performance of this VLR has demonstrated that automatic, routine monitoring of insect aerial migration is now a feasible and economic proposition. The trial has yielded valuable information about the range of conditions over which the current configuration of the VLR can operate satisfactorily. The data set on insect movement incidentally constitutes the first systematic record of insect migration at high altitude over the UK.

FUTURE

There is great potential for the application of this practical and inexpensive technique in monitoring programmes for locusts and other insect migrants. Although there has not yet been any long-term VLR deployment in Africa, two remotely operated VLRs are now operational in Australia, deployed against the Australian plague locust, and two are also in continuous, routine use in the UK, monitoring the abundance and movement of insects over southern England. In this second programme the emphasis is on environmental issues rather than on pest control.

SELECTED PUBLICATIONS

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SMITH, A.D. and RILEY, J.R. (1996) Signal processing in a novel radar for monitoring insect migration. *Computers and Electronics in Agriculture* **15**: 267–278.

Identification of the factors which lead to changes in desert locust populations at the beginning and end of recession periods

R6822

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December 1996–November 1999

Smallholders in marginal, semi-arid areas are most vulnerable to desert locust attacks as they have fewer options for mitigating the impact of damage to staple crops, other than abandoning the land and moving to urban areas. Since locust outbreaks are often associated with major climatic fluctuations such as the occurrence of droughts, they pose a significant additional threat to food security in rural areas that are already vulnerable. This project has compiled and analysed basic data needed to improve the locust-forecasting capacity of the Emergency Centre for Locust Operations in Rome; assessed the processes leading to changes in desert locust populations; and laid the groundwork for using this improved knowledge to develop a decision-making tool to assist forecasters.

ISSUES

Plagues of the desert locust, *Schistocerca gregaria*, intermittently affect over 65 countries in Africa, the Middle East and south-west Asia. This pest poses a particular control problem since, unlike most species of locust, it has no permanent outbreak area but lives in relatively scattered populations in a generally arid environment known as the recession area, which stretches over 16 million km² from Mauritania to north-west India.

The current control strategy assumes that any locust population gathering in groups could lead to an upsurge and subsequently a plague. Successful control depends on the adequate flow of information on weather, locusts and vegetation between national and regional organizations and the FAO's Emergency Centre for Locust Operations (ECLO) in Rome. The aim of the project was to enhance ECLO's forecasting capacity by determining the processes leading to changes in desert locust populations, and using this knowledge to develop a decision-making tool to assist forecasters. Desert locust plagues begin and end relatively quickly, and the key to successfully sustaining survey and control capability in affected countries is the ability to efficiently increase and reduce survey and control capacity as plagues start and finish, through timely operational forecasts.

Publications: see Bibliography on CD.

ACHIEVEMENTS

The project has completed an analysis of changes in the distribution and numbers of desert locusts, particularly on a seasonal/annual basis. Key indicators of the relationships between environmental factors and locust population changes at the beginning and end of recession periods have been analysed, and will be incorporated in a decision-making tool for assisting ECLO forecasters.

FUTURE

The methodologies developed for deriving improved forecasts need to be tested operationally over at least 2 years to assess their appropriateness in real-time forecasting. A follow-on project to produce a validated decision-making tool should incorporate historical analogues of spatial and temporal patterns of rainfall and vegetation for different locust breeding seasons developed by this project (Figure 1), to be used in conjunction with information on locust population distribution, density and maturity, and synoptic weather data.

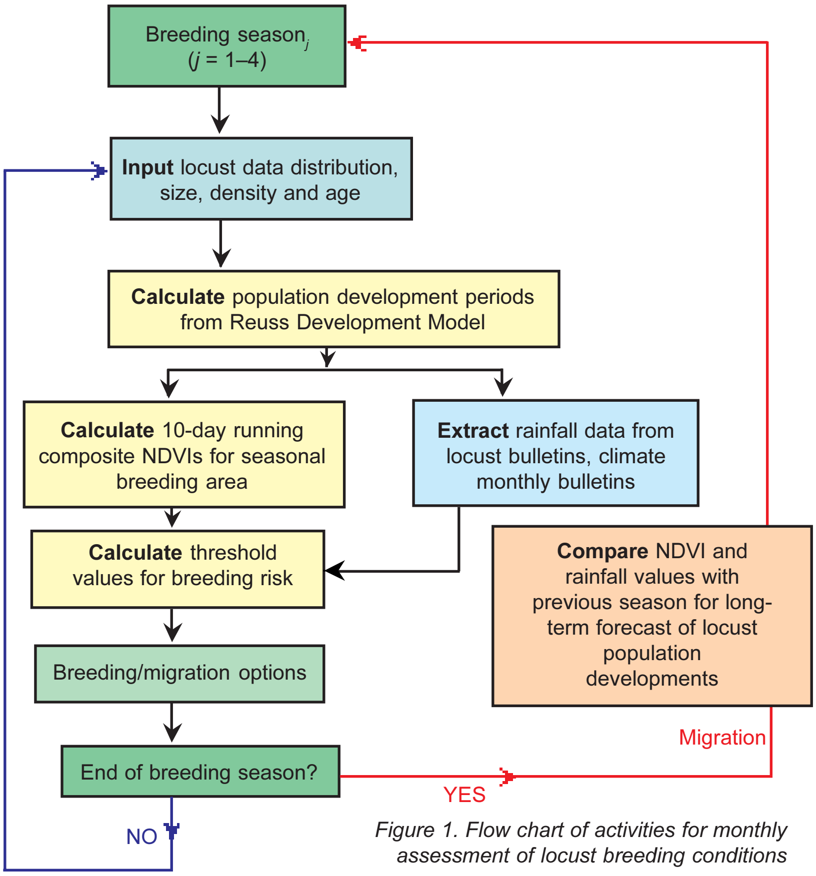

Figure 1. Flow chart of activities for monthly assessment of locust breeding conditions (NDVI = normalized difference vegetation index)

Statistical analyses of desert locust movements

R6809

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January 1997–May 1998

The extensive damage to crops that can be caused by locust plagues is well known. This project investigated the relationship between desert locust swarms and the weather systems that influence them. More detailed knowledge of these interactions is essential for more accurate forecasting and control. Through a detailed examination of the large-scale weather conditions in the Mediterranean Basin, North Africa and the Middle East for a 14-year period between 1958 and 1989, and of the behaviour of the desert locust population at the same time, relationships between locust movements and weather systems were investigated, and data extracted and incorporated into a geographical information system.

ISSUES

Plagues of desert locust (*Schistocerca gregaria*) start when rains occur close together in both time and space, prolonging breeding and allowing populations to build up. At times of plagues, locusts can spread to over 65 countries in Africa, the Middle East and South-West Asia, causing devastation to crops relied upon by large- and small-scale farmers alike.

Because locust breeding areas generally have scanty and erratic rainfall, a considerable degree of coincidence is required between adult locusts and rains in order to maintain populations. Downwind migration takes locusts towards areas of horizontal wind convergence and rainfall. Breeding areas are connected by seasonal migration circuits, although the detail of the circuits differs from year to year as they are dependent on sources of emigrants and locust trajectories in the windfields during migration flights.

Seasonal movements are influenced by the effects of large-scale (synoptic) weather systems and also by local winds, both of which can move populations to areas unsuitable for breeding and survival, as well as to new breeding areas – synoptic and local windfields are thus important in ending upsurges and plagues, as well as maintaining them. More detailed knowledge of such interactions is essential to enable the development of more accurate forecasting and control systems.

The aim of this project was to develop statistical analyses of locust movements in synoptic weather situations (in particular Mediterranean cyclones and desert depressions) in order to improve forecasting of movements in these systems and to promote improved survey and control strategies in locust-affected countries.

ACHIEVEMENTS

Locust movements for 14 years between 1958 and 1989 were examined and plotted. Weather data were also examined.

Six principal tracks of cyclones from west to east within the Mediterranean Basin have been identified, as has a general trend for disturbances to move eastward across North Africa. There are, however, some variations on these routes, with some northward movement both out of North Africa and across the Mediterranean Basin, depending on season, topography and weather conditions. No direct relationship between cyclone frequency and the movements of desert locusts has been found, but such movements that do occur affect swarming populations; there is no evidence of any relationship between cyclone movement and non-swarming populations. The movements of swarming populations lead to three important desert locust displacements:

- from summer breeding areas in West Africa to winter breeding areas in North-West Africa
- from winter to spring breeding areas in the Middle East
- from spring breeding areas in the Middle East to summer breeding sites in India and Pakistan (in association with movement on Persian Gulf cyclones).

A data capture, management and dissemination system (*SWARMS*: *Schistocerca* Warning Management System), based on a geographical information system, has been developed by NRI and the University of Edinburgh under UNDP funding, and was installed at FAO in 1996. This system permits improved analysis and forecasting of locust events. The weather and locust data generated during the current project are suitable for inclusion in *SWARMS*, as well as in national systems such as *RAMSES* (Reconnaissance and Management System of the Environment of *Schistocerca*), making them available to a wide audience of regional and country locust information officers.

FUTURE

This data analysis has increased our knowledge of the complex relationship between desert locusts and the weather systems that influence their movements, and has added to the data available for locust forecasting. In the long term, the analysis of such data will lead to the development of a forecasting rule which can be used to improve control measures against this devastating pest.

Models of *Quelea* movements and improved control strategies

R6823
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October 1996–March 1999

The Red-billed Quelea bird is a major pest of small-grain cereal crops throughout semi-arid areas of Africa, attacking millet seed heads, mature sorghum seeds and other crops. Annual losses in Africa have been estimated as US$45 million. This project has achieved a better understanding of the factors governing Quelea migrations in southern Africa and a framework with which to predict their movements, allowing control interventions to be planned in good time and more efficiently. Steps have also been taken to develop techniques to minimize the environmental damage that such control engenders by research on a detoxification mechanism, which shows much promise.

ISSUES

The Red-billed Quelea bird *Quelea quelea*, sometimes described as the 'feathered locust', is a major pest of small-grain cereal crops throughout semi-arid areas of Africa. US$45 million worth of grain loss was attributed to Quelea damage in Kenya and Tanzania in 1989. Quelea birds regularly migrate long-distance from one area or country to another. The routes and timing of movements of the different subspecies of *Q. quelea* in southern Africa, and the influence of environmental variables, are not fully understood. Quelea migrations are determined by weather patterns and vegetation as the birds feed on grass seeds which germinate following rain. The number of times they can breed depends on the prevailing conditions, with good rains tending to permit more breeding attempts. It is the young birds from successful colonies at the periods when millet or sorghum is about to be harvested that are responsible for most damage to subsistence agriculture.

Publications: see Bibliography on CD.

The aim was to develop a forecasting method for Quelea in southern Africa, to be used to improve the management strategies of national pest control authorities.

ACHIEVEMENTS

Methods of typing Quelea birds using microsatellite DNA have been developed in conjunction with known plumage polymorphisms, which will assist in establishing migratory routes of different subpopulations in southern Africa, and the extent to which these populations might remain geographically discrete.

The two subspecies involved in southern Africa are *Q. q. lathamii* and *Q. q. spoliator,* but the taxonomic validity of the latter is in doubt. *Q. q. lathamii* breeds in Angola, Botswana, Malawi, Mozambique, Namibia, South Africa and Zimbabwe. The subspecies *Q. q. spoliator*, thought by some to have a separate migration system from *Q. q. lathamii* and thus to need a separate control strategy, cannot be considered a valid taxon on the basis of morphological research conducted during this project. Thus control plans and forecasting do not need to assume the existence of two separate migration routes within the southern African system.

These results have improved the ability of the Problem Bird Control Unit of Zimbabwe, and similar organizations in southern Africa, to respond to Quelea attacks on crops by enhancing their understanding of Quelea ecology. In just one example, project personnel and target country collaborators noted extensive Quelea breeding in Botswana and Zimbabwe which led to the appearance of important colonies in Namibia. Immediate advice on appropriate measures was made available by e-mail, followed by on-site visits by project personnel.

A Quelea database compiled by the project has been distributed to national agricultural organizations, and provides information on Quelea breeding sites (some of which are traditional). These data, coupled with a prototype computer model driven by remote-sensed data on rainfall and vegetation conditions, will permit forecasting of zones where Quelea are expected to occur.

In addition, a promising method for cleaning up sites contaminated by fenthion, the pesticide used against Quelea birds, has been identified using the fungus *Phanerochaete chrysosporium*, which has been shown to break down fenthion in the laboratory.

Combined with more efficient control technologies, forecasts incorporating relevant climatic and ecological data should lead to substantial benefits in terms of increased crop yields, reductions in pesticide usage and improved control strategies.

FUTURE

Follow-up research to promote the findings of the project should include testing and refining of forecasts based on model outputs in relation to real-time events in southern Africa, and the development of the prototype model into a form for general dissemination. If these tests prove successful then the model could be adapted for use in other African countries.

Detection of phytoplasmas in putative insect vectors of Cape St Paul wilt disease of coconut in Ghana

R6521

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January 1996–March 1999

Diseases caused by phytoplasmas are causing considerable economic damage to coconut production in the Caribbean and Mexico, East and West Africa, and possibly in parts of South and South-East Asia. Identification of the vector(s) of the disease in specific areas is important , and may allow the development of protocols for screening of germplasm for resistance. However, conventional transmission tests are difficult to do for coconut and have so far been unsuccessful in Africa. This project focused on the detection of the Cape St Paul wilt disease phytoplasma in insect vectors and infected coconut palms; the improvement of procedures in the Molecular Biology Laboratory in the Department of Crop Science, University of Ghana; and the establishment of links with the Coconut Sector Rehabilitation Project under the French Development Agency and the Government of Ghana. Methods developed to detect the phytoplasma using a nested PCR protocol successfully amplified disease-specific products from both symptomatic and asymptomatic palms. This is the first time that a non-destructive sampling method has been successfully used in Africa to diagnose the coconut disease phytoplasmas.

ISSUES

Coconut is of unique value to coastal smallholder communities as a source of food, shelter and rural income, and the localized impact of phytoplasma diseases has been devastating, particularly in Ghana. Cape St Paul wilt was first observed in the Volta Region in 1932, where by the 1950s it had destroyed the coconut industry. It was first detected in the Western Region in the 1960s, and now affects 40% of the remaining 40 000 ha of palms in the western coastal belt.

Research in southern Florida has defined the main features of lethal yellowing disease in the New World, and identified a planthopper vector, *Myndus crudus*, in that region. A highly resistant variety, the Malayan dwarf variety, was identified and provided the basis for what has often been regarded as a model coconut rehabilitation programme. However, although the diseases in Africa show many symptomatological similarities to lethal yellowing, differences in varietal susceptibility and epidemiology suggest that different phytoplasmas have evolved in each region. Also, early experimental plantings of Malayan dwarf and other varieties in Ghana and Tanzania did not perform as well as expected.

An important part of these studies has been to identify insect vectors of Cape St Paul wilt in the different regions so as to monitor and control infectivity in vector populations and to develop a controlled resistance screening technique (infection can only take place by the vector route). This is difficult to achieve by conventional tra nsmission tests. The objective was to develop and apply specific, sensitive techniques to detect phytoplasmas in putative insect vectors, using the polymerase chain reaction (PCR) to amplify the DNA of this phytoplasma.

Publications: see Bibliography on CD.

ACHIEVEMENTS

This project built on work begun under R6160, and made two major improvements to the testing regimes. The first was to adopt a non-destructive method for sampling palms without having to cut them down. It involved the drilling of an 8-mm hole about 100 mm into the trunk of the palm, collecting the wood shavings produced and placing them in solution from which DNA was then extracted in the laboratory. The second improvement was the introduction of a nested PCR using commercially available dried-down PCR reagents. These are stable at room temperature and have a long shelf life, reducing the need for freezer storage of the DNA polymerase leading to fewer accidental losses due to power cuts. They also reduce pipetting errors by cutting the number of actions needed to perform PCR. Both techniques were transferred to the laboratory in Ghana where they immediately improved the results.

These improved techniques have enabled the detection of phytoplasma in all parts of infected palms, the highest concentration being in meristem and young frond tissues. Preliminary studies suggest that there could be more than one phytoplasma strain present in coconut palms in Ghana. Nested PCR has shown that *Myndus* spp. leafhoppers can carry a phytoplasma in Ghana, but further work is needed to establish its identity, then the role of the insect as a vector will have to be examined.

Contact with the coconut rehabilitation project funded by Agence Française de développement has been established. The diagnostic facilities established in Ghana, if maintained, will be invaluable to the project in screening potentially resistant/tolerant germplasm, and monitoring for disease in seedling nurseries and new coconut plantings.

FUTURE

A further project is being formulated with the goal of reducing losses due to phytoplasma diseases of coconut in Ghana and Tanzania through the standardization of molecular diagnostic techniques and their use to monitor coconut rehabilitation programmes.

Evaluation of the significance and potential for control of mistletoe in cocoa and citrus

R6656

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June 1996–March 1998

This project has determined the extent and significance of mistletoe infestations of citrus and cocoa. Demand for improved methods of mistletoe control was identified among cocoa farmers in Ghana. The study confirmed the macro- and micro-economic importance of cocoa and its fundamental role in rural livelihood systems in the cocoa-growing belt of Ghana. It also showed that mistletoes are a very significant and high-ranking constraint on the productivity of cocoa. There is institutional support in Ghana for work aimed at investigating the local manufacture and promotion of an inexpensive pruning tool. There does not appear to be the need for further work in commercial citrus, and no significant problem was identified which affects smallholder citrus growers.

ISSUES

Mistletoes, woody shoot parasites in the plant families Loranthaceae and Viscaceae, cause stunting, yield loss and, in severe cases, death of cocoa, citrus and many other tree-fruit and forest species throughout the humid tropics. Little up-to-date information was previously available on the current status of mistletoes as pests. The aim of this project was to assess the extent of parasitic mistletoe infestations of citrus and cocoa crops, and to report on the feasibility of developing appropriate control measures.

ACHIEVEMENTS

A full literature review of the distribution of mistletoes on cocoa and citrus in Latin America, Asia and Africa was carried out, along with consultations with local researchers.

In Central America, Mexico and the Caribbean, commercial citrus estates undertake regular pruning to control *Struthanthus*, *Phoradendron*, *Phthirusa* and other species. Mistletoe infestation of citrus is an important factor in orchard management in parts of Latin America and the Caribbean. The general practice is to pull the parasite by hand from the citrus canopy twice a year, which is said to cost in the region of 25 US cents per tree, representing a significant input for large estates.

In cocoa, relatively few problems are reported from South America, where the crop is native. In the humid forest zone of West Africa, however, cocoa is parasitized by a number of mistletoe species, 70% of infestations being by *Tapinanthus bangwensis*. Mistletoe infestation occurs in all types of cocoa farm, but is most prevalent in poorly maintained cocoa with little or no shade.

The infestation of cocoa by *Tapinanthus* and other mistletoe species in West Africa is the most widespread and economically significant pest mistletoe problem identified by this review. This study therefore focused on the current situation on smallholder cocoa farms in Ghana, where cocoa is by far the most important source of cash income for households. Since the 1960s productivity has been declining, with Ghanaian production now accounting for 10% of world cocoa output. This decline is attributable to a number of factors including the ageing cocoa tree stock; ageing landowners and associated land tenure issues; lack of control of key pests and diseases; the high cost of inputs; poor producer prices and the resulting poor returns. Cocoa plots are an important form of security, probably the only vehicle which many households can use to access loans. Farmers see the maintenance of the farms, albeit at a very low level of productivity, as an essential duty so that the trees can be passed on to future generations.

Farmers report that mistletoe infestation has increased during the past 20 years, largely due to the lack of availability of serviceable pruners (last sold in 1991). Mistletoe removal with a cutlass, while using a ladder or climbing the infested tree, is the only alternative to using a pruner but is perceived to be a dangerous, unpleasant task. In consequence labour hired for this purpose attracts a significant premium. A widespread demand for pruners was identified.

FUTURE

Future research should focus on developing an appropriate design for a locally manufactured long-handled pruner. The institutional arrangements for funding procurement and maintenance of pruners at the village level should be the focus of future work which could be implemented by local appropriate technology consultants with experience in small-scale agricultural engineering. In order to kick-start the supply of locally produced pruners, a pilot project should be established to stimulate their manufacture.

SELECTED PUBLICATIONS

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Development and evaluation of a pilot field handbook on natural enemies of vegetable pests in Kenya and Zimbabwe

R7266

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Surveys of farmers in Zimbabwe and Kenya found that, despite moderate or high awareness of the existence of natural enemies, the majority were unable to distinguish between natural enemies and pests on their crops. Most admitted to spraying crops regularly, in part to help eliminate arthropods that were not recognized as natural enemies. This project developed training materials to encourage farmers to identify natural enemies and to modify their control practices accordingly. A draft field guide was produced for use by extension workers and trainers, and multilingual (Swahili, Shona and English) posters and flip-cards for use by farmers and trainers were developed. Workshops were conducted in both countries to evaluate the materials produced by the project, and farmers' recognition abilities were seen to increase dramatically following exposure to the training materials.

ISSUES

There are numerous programmes in sub-Saharan Africa that aim to help farmers improve pest management and sustainability of production, while reducing unnecessary pesticide inputs and minimizing the human health and environmental problems associated with pesticides. Organizations working in the region have identified the need to improve smallholder farmers' knowledge of natural enemies and their use in pest management, and point to a lack of suitable training materials for smallholder farmers. This project represents the first effort to compile a field guide and associated materials to be used specifically within 'Training of Trainers' and 'Farmer Field School' programmes on biological and IPM.

Most published work in this field relates to the introduction of exotic natural enemies, an approach favoured by many large-scale commercial farmers. The surveys conducted here reveal a range of indigenous (as well as previously imported/established) natural enemies, and it is likely that conservation of these will be more relevant to smallholder farmers than the introduction of exotics.

ACHIEVEMENTS

This short project operated in close collaboration with DFID-funded projects in Zimbabwe and Kenya, and built on improvements in understanding of the current and potential role of natural enemies in vegetable production systems.

An important aspect of the initial field surveys was the photographic recording of natural enemies on farmers' fields. Generally, photographs of natural enemies are much less readily available than those of pests – pest species have received more emphasis in educational and training materials and, as natural enemies tend to be smaller and more mobile, they are more difficult to photograph. The field-based photographs were an indispensable medium used in the training materials to help farmers recognize specific groups of natural enemies.

The primary outputs were the training materials, produced as drafts for distribution during and after the workshops for evaluation and comment. These are being published under a current project which is also sponsoring further workshops in Zimbabwe. The main publication is a pilot field guide on natural enemies for use by trainers and smallholder vegetable farmers (see Selected publications).
In addition, multilingual posters and flip-cards were produced to complement the English language field guide. The flip-cards comprise sets of 36 photographs of key natural enemies, each with a blank card to allow farmers to include their own notes. This suite of three complementary materials is thought to be the first of its kind worldwide for use in pest management or natural enemy training programmes.

Feedback from the workshops has been incorporated into the final drafts, and the training materials have already been exposed to farmers working with Crop Protection Programme projects in Zimbabwe (R6764) and Kenya (R6616). Local scientists from counterpart institutions all indicated that they had learned a great deal about natural enemies during the course of the project and this information will, in due course, filter through to farmers.

FUTURE

Large-scale production of the training materials, with possible (mainly linguistic) adaptation for neighbouring eastern and southern African countries, will assist substantially in developing sustainable pest management systems for smallholder farmers and improving compatibility between biological and chemical pest management systems. Strategically planned dissemination, preferably coupled with farmer participatory research and training on the integration of chemical and biological pest management in smallholder systems, will be critically important to help translate progress in natural enemy recognition into improvements in biological control, IPM and sustainability.

SELECTED PUBLICATIONS

VERKERK, R.H.J. *et al.* (1999) *Important Natural Enemies of Vegetable Pests in Kenya and Zimbabwe: Recognition and Conservation*. London: Imperial College.

IPM of vegetables in Ghana

R6657

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Over-intensive agricultural production, particularly of vegetable crops, has led to increased pest and disease problems. Farmers tend to respond by over-using chemical pesticides. Work with farmers in the Brong Ahafo region of Ghana highlighted their need for accessible information, particularly on problems that are not easily visible such as plant diseases and nematodes. A pest identification manual for use by extension workers has been compiled with this in mind, published and distributed. Two potential biocontrol agents for the specific problem of root-knot nematodes were evaluated, and practical methods of production and application developed. Initial results suggest that both organisms (the bacterium *Pasteuria penetrans* and the fungus *Verticillium chlamydosporium*) could be useful components of an integrated system for vegetable pest management in Ghana, particularly in cabbage.

ISSUES

In peri-urban farming situations land has a high value for alternative uses, such as housing, and there is constant pressure on farmers to increase productivity. In the Brong Ahafo region of Ghana this has encouraged farmers to cultivate their land continuously and to use high levels of chemical pesticides. As a result a single crop such as tomato may be grown almost continuously on the same land for 15 or more years. This intensity of production has led to the development of intractable and costly pest and disease problems including whitefly, nematodes and virus diseases.

The project's aims were to improve methods for the control of weeds, insect pests, diseases and nematodes in market gardening and commercial horticulture, and to develop and promote environmentally friendly pest management packages.

ACHIEVEMENTS

Socio-economic studies concentrated on farmers' perceptions of pests in two of the five major vegetable crops grown in the region: tomato and eggplant. Farmers identified 15 groups they perceived as pests. These included grasshoppers, caterpillars, ants, termites, millipedes, beetles (found on leaves), maggots, aphids, crickets, butterflies, spiders, bees, mice, frogs and nematodes. By far the most commonly mentioned were caterpillars and grasshoppers. However, despite their effects on yield, only one farmer mentioned nematodes as a problem. The majority of farmers were not aware of insect life stages or of the process of metamorphosis, although a few did have some knowledge. Plant diseases were far less easily recognized by farmers, symptoms often being attributed to natural processes such as 'hotness of the sun' or 'dampness in the soil'; some felt that leaf spots were caused by insects. Weeds were generally well recognized by farmers, who were mainly concerned about grassy weeds.

A pocket pest manual has been published, containing simple descriptions and clear illustrations of pests and/or damage for use by extension officers who advise the mostly illiterate vegetable producers in peri-urban communities. Free copies have been distributed to government extension services, universities, relevant NGOs and other national agricultural research institutions in Ghana.

Root-knot nematodes (*Meloidogyne* spp.) cause severe galling and root damage on many food crops. Biological control organisms evaluated against these nematodes were a bacterium, *Pasteuria penetrans*, and a fungus, *Verticillium chlamydosporium*, combined with either poultry manure or mulch. A series of pot experiments showed that pepper and cabbage supported the greatest amounts of the fungus *V. chlamydosporium* in their rhizosphere, and led to the highest infection rates in *Meloidogyne* eggs. Both the fungal and bacterial biological control agents were more effective when used in conjunction with organic mulches and amendments such as *Panicum maximum* mulch and poultry manure amendments.

Work was also conducted on culture media for producing *V. chlamydosporium*: the best media were based on milled maize mixed with sand. Field trials showed that *P. penetrans* will establish in nematode-infested soil without the need for further applications; *V. chlamydosporium* did decline and re-application of this fungus will be necessary, but as it is easy to culture this is not a major drawback.

FUTURE

The latter phase of this project formed links with studies by CABI Bioscience on composting urban waste (R6941), with the objectives of increasing vegetable production and controlling pests and pathogens in peri-urban agriculture.

The results obtained here are now being taken forward in Kenya under projects R7403 and R7449.

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Pest management in horticultural crops: integrating sustainable pesticide use into biocontrol-based peri-urban production systems in Kenya

R6616

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Smallholder, peri-urban vegetable farmers in Kenya rely heavily on the use of chemical pesticides to control pests and diseases. This has led to increasing concern about pesticide residues in produce, operator exposure, and the development of resistance and environmental damage, especially to beneficial natural enemies. The cost of pesticides absorbs a significant proportion of farmers' income, but currently they have few alternatives. This project has identified the key vegetable pests and diseases and their potential natural enemies, assessed which natural enemies could be useful in integrated pest management systems, investigated how pesticide use could be improved, and recommended alternative pest management strategies.

ISSUES

Smallholder vegetable production provides an important source of employment, income generation and poverty alleviation for more than 200,000 households in rural areas around Nairobi. Peri-urban production systems are characterized by intensive land use, and typically produce high-value crops such as vegetables. A dependable supply of safe and affordable vegetables is an important requirement for the general health of the urban population, especially low-income households, as fresh vegetables provide vitamins and energy to supplement the staple maize diet.

The major constraints in peri-urban production systems are pests and diseases, and to control these smallholder farmers still rely heavily on pesticides. This can be hazardous to the health of both suppliers (through contamination while applying pesticides) and consumers (through pesticide residues in produce). Over-use of pesticides is also damaging to the environment, leading to pesticide resistance among insect pests and diseases, and reducing the numbers of beneficial natural enemies. By developing an integrated pest management strategy for vegetable production which reduces reliance on pesticides, the volume and quality of vegetable production will be increased in a sustainable way in order to meet the requirements of an expanding urban population.

The aims of the project were to develop and promote improved methods for the control of pests and diseases affecting the quality and production levels of vegetables in peri-urban areas in Kenya, and specifically to improve pest management methods used by smallholder vegetable growers in the vicinity of Nairobi, who supply the urban population with fresh produce.

This project followed on from initial work in Kenya under R6146 (see *Research Highlights 1989–95*), and benefited from data on environmental effects of pesticides and methods for ecological hazard assessment compiled under projects R5368 and R6764.

ACHIEVEMENTS

A participatory rural appraisal was undertaken to gather information on pest management practices and identify potential farmer collaborators. From this appraisal it emerged that four main crops (kale, cabbage, tomato and spinach) accounted for over 95% of peri-urban vegetable production, and these crops became the major focus of subsequent research activities.

PEST AND DISEASE SURVEYS

A series of season-long, on-farm surveys of the four crops grown in two contrasting agro-ecological zones and under different management practices, i.e. organic and high pesticide use (intensive),

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ODUOR, G., ONGARO, J., PETE, S., KARANJA, P., COOPER, J., MWANIKI, S., KIBATA, G. and SIMONS, S. (1998) Pests of horticultural crops on small-scale peri-urban farms in Nyathuna, Kiambu: Influence of pesticide regimes on pests and natural enemies. In: *Proceedings of the Second Biennial Conference on KARI/DFID NARP II Crop Protection Programme, 16–17 September 1998*. pp.18–29.

Table 1. Summary of importance of pests, natural enemies and diseases

Factor	Cabbage	Kale	Spinach	Tomato
Most abundant pests	Diamond-back moth Aphids *Trichoplusia*	Diamond-back moth Aphids Whitefly	Aphids *Trichoplusia* Leaf miner	Leaf miner Thrips Aphids
Most damaging pests	Diamond-back moth Aphids *Trishoplusia*	Diamond-back moth Aphids *Trichoplusia*	*Trichoplusia* Leafminer Aphids	Bollworm Leafminer Thrips
Most abundant natural enemies	Syrphids Spiders Ants	Syrphids Spiders Ants	Spiders Ants Coccinellids	Ants Spiders Coccinellids
Most damaging diseases	Black rot Ring spot Downy mildew	Black rot Downy mildew Virus	*Cercospora* Virus	Early blight Late blight Virus

identified the major pest and disease problems and areas of pest management which required improvement (Table 1). The diversity and severity of pests was substantially higher in the lower, warmer locations, whereas in higher, cooler places diseases were the greater problem. Extensive surveys of natural enemies, particularly of the major brassica pests (diamond-back moth and aphids), revealed a rich diversity of arthropod natural enemies, both predators and parasitoids (a parasitoid is a parasite that actually kills its host). But at both locations natural enemy numbers were far lower than expected, probably due to the long history of pesticide use. Natural enemies were found to be more abundant on organic farms, although this could not be correlated with the severity of damage caused by pests and diseases; pests often caused damage in the presence of natural enemies.

However, from the taxonomic identifications it emerged that a number of the natural enemies identified were, in fact, hyperparasitoids (hyperparasitoids attack other parasites within a host organism). Further studies are needed to understand these complex interactions in order to quantify the impact of natural enemies on pest management. The potential benefits of using natural enemies in conjunction with more benign pesticides also need to be explored.

Following the results from the baseline survey, where unexpectedly low numbers of natural enemies were observed, a more detailed comparison was made in which the effects of conventional pesticide regimes were studied and compared with a control (organic) in the same agro-ecological zone for their effect on natural enemy abundance. Farmers who grew their vegetables organically had all undergone training with the Kenya Institute of Organic Farming (KIOF), and were selected in collaboration with KIOF. The four most commonly grown crops were monitored for pest, disease and natural enemy populations on 20 farms (10 high-pesticide and 10 organic) just prior to harvesting (spatial experiment); and on three farms (high-pesticide, intermediate pesticide and organic) at weekly intervals throughout an entire cropping season (temporal experiment). Figure 1 shows the effect of pesticide regime on natural enemies (spinach differed from the other vegetables in receiving few pesticide treatments).

PESTICIDE USE

Pesticide use by farmers was studied in terms of the choice of active ingredient, quality of application and its effectiveness. It was clear that the majority of vegetable crops were receiving an incorrect pesticide dose. Only 22% of the applications observed were within 25% of the recommended dose rate. Although manufacturers indicate on the pesticide label how much spray should be applied to crops, the way the information is expressed varies from product to product and it is easy for farmers to be confused about how much to use, even when they measure carefully. Ambiguous or incomplete label information resulted in under-dosing or over-dosing (up to six times the volume rate required). Both are undesirable – the former risks crop failure and leaves surviving pests to breed, which encourages development of pesticide resistance; on the other hand, too much pesticide is uneconomic and leads to excessive residues on harvested crops.

On most farms, spray distribution was poor (<5% coverage), highly variable and gave minimal coverage on the lower surface of leaves where many pests and pathogens are found. A modified spray lance (the V lance), which releases spray upwards from within the crop rather than downwards from above, was developed. Whereas the conventional lance achieved <50% reduction in pests and natural enemies, with the modified lance there was almost complete control. However, it also had a negative impact on natural enemy populations. Further work is now required to test the lance on more benign or target-specific formulations such as *Plutella xylostella* granulosis virus (PxGV) which infects diamond-back moth, and to determine whether, with improved application efficiency, it would be possible to reduce dose rates.

Operator exposure was assessed qualitatively using a fluorescent tracer technique. A significant quantity of pesticide was found on the protective suits used in the trials, which indicates that farmers—who often wear little or no protective clothing – are being heavily exposed to the pesticides they are using.

CONTROL METHODS

The influence of pesticide regime (conventional and non-conventional) was studied in a series of large, multifactorial experiments conducted either on-station or on-farm in contrasting agro-ecological zones over consecutive growing seasons. Non-conventional pesticides included a botanical concoction developed by KIOF, PxGV, *Bacillus thuringiensis* (Bt), neem, Mexican marigold, burnt trash, chillies, hot water and milk. On brassicas, both PxGV and Bt were promising against diamond-back moth with only slight or zero impact on natural enemies, but none of the non-conventional pesticides was particularly effective against aphids. The standard conventional pesticide Karate (lambda-cyhalothrin) gave poor control of diamond-back moth, which is attributed to insecticide resistance, but gave good control of aphids; however, it also had a negative impact on natural enemies. The biopesticides Bt and, to a lesser extent, PxGV were promising against diamond-back moth, with only a slight (or no) negative impact on natural enemies. As expected, the specific virus PxGV had no effect on anything but diamond-back moth. It was particularly disappointing to observe the poor performance of the KIOF 'concoction', a botanical formulation which is widely used by organic, peri-urban vegetable farmers, although it would be useful to compare the farmer-prepared KIOF mixture used in these experiments with others – the recipe promoted by KIOF does not specify the quantities of individual ingredients. None of the non-conventional pesticides was particularly effective against the aphid *Brevicoryne*, which is the second most important pest of brassicas.

For root-knot nematodes on tomato seedlings in the nursery, the treatments applied had a limited effect on nematode populations, with only fresh marigold and hot water showing a relatively small reduction in nematode populations. The standard conventional pesticide, Furadan (carbofuran), was found to be ineffective. Biological control using Kenyan isolates of the nematode pathogens *Verticillium* and/or *Pasteuria* may be the answer. Having been proven in the laboratory, these organisms now need to be assessed on-farm.

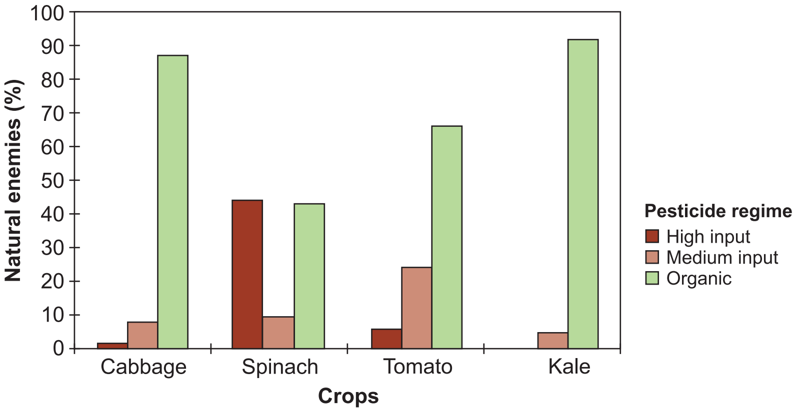

Figure 1. Percentage of natural enemies in insect populations found on four crops under three different pesticides input regimes

Control of tomato blight (early and late), the major constraint to tomato production, was investigated in a series of experiments on the epidemiology of blight, the extent of tolerance or resistance in different varieties, and a comparison of conventional and non-conventional control methods. Late blight was found to be the dominant of the two diseases and frequently masked the symptoms of early blight. None of the tomato varieties currently available in Kenya showed a consistent tolerance or resistance to blight, and there was no clear difference between the control treatments, although the application of milk did suppress the disease on one of the farms. These experiments need to be repeated before definite conclusions can be drawn.

Plant virus diseases were found in samples taken from almost all brassicas and peppers collected from farms. It is likely that yields are being significantly reduced. The extent of this viral infection and the source of the infection (whether largely seedborne or spread by insect vectors) remains to be determined.

Active farmer participation has been a key feature of this project, from the initial stakeholders' meeting through to the pest risk assessment and conducting of collaborative on-farm experiments, and several farmer participatory workshops and in-field demonstrations. The farmers themselves have played a significant role in directing the research.

FUTURE

The complexity of the cropping system and the two types of production constraints (insects and diseases) require a longer-term approach than for a specific pest–crop interaction.

The first phase of the peri-urban vegetable IPM project has laid a good foundation for developing a 'basket of pest management options' for the production of peri-urban vegetables. It is now necessary to develop practical and appropriate IPM strategies which will be adopted by smallholder peri-urban farmers. Other areas include work with benign pesticides, and an exploration of the potential role of clean and improved planting materials.

Existing routes for uptake include farmer field schools in the peri-urban area, and collaboration with NGOs (including KIOF) and with more traditional extension services (Ministry of Agriculture and KARI). In the second phase of this project (R7403), farmer-friendly publications will be produced and disseminated through a series of farmer participatory meetings.

Investigation of biorational methods for control of insect pests of vegetables in Kenya

R6615

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The diamondback moth (*Plutella xylostella*) is one of the most serious pests of cruciferous crops worldwide. In recent years it has become increasingly difficult to control by conventional means because of the widespread development of resistance to chemical insecticides (including the newer pyrethroid insecticides), to insect growth regulators, and even to the bacterial biocontrol agent *Bacillus thuringiensis* (Bt). There is a need to develop new control technologies that could be used as an alternative to Bt, or as part of an integrated pest management system to prevent Bt resistance building up to uncontrollable levels. This project, based in Kenya, has developed and refined methods for the management of vegetable insect pests based on new biorational alternatives to chemical insecticides. Research focused on a number of promising approaches, including the use of other microbial pathogenic agents such as insect viruses; mating disruption with synthetic pheromones; and the use of fungal pathogens.

ISSUES

Kale and cabbage are typically the most important vegetable crops grown by smallholders in Kenya, with pests rated as the most important constraints to production. Diamondback moth has been identified by a number of agencies as the key pest on crucifers and brassicas throughout East and Southern Africa.

Damage by diamondback moth in Kenyan vegetable production was significantly reduced in the 1970s as smallholders' use of organochlorine insecticides spread. This situation was maintained through the 1980s with the introduction of synthetic pyrethroids. However, by the mid 1990s control was faltering due to the decreased effectiveness of chemical control. Trials of standard insecticide (R6616; see page 50) have confirmed the high level of resistance to chemical insecticides in Kenyan diamondback moth.

Failure of chemical control in several countries in the late 1980s led to the widespread adoption of the microbial pesticide *Bacillus thuringiensis* (Bt) in the early 1990s, and for several years Bt-based integrated pest management (IPM) systems were successful. However, experience in the USA, Central America, Hawaii and Malaysia has shown that diamondback moth rapidly develops resistance to Bt when it is used repeatedly and extensively. The aim of this project was therefore to develop improved methods for the management of Kenyan vegetable insect pests based on new biorational alternatives to chemical insecticides.

ACHIEVEMENTS

VIRAL CONTROL OF DIAMONDBACK MOTH

A granulosis virus (PxGV) of diamondback moth was first recorded in Japan in 1970. Although since then PxGV has been extensively studied, little progress has been made towards its application for diamondback moth control.

Previous work in Asia had identified non-Kenyan strains of insect viruses as potential control agents. However, there were difficulties in obtaining clearance to work on exotic viruses in Kenya, so this work focused on the study of native diamondback moth viruses. New African strains of PxGV have been discovered that are highly infectious to diamond-back moth, and have been shown in field trials to be more effective than insecticides at controlling damage (see Figure 1). Field trial results with the new strains were better than those reported previously using Asian virus strains.

MATING DISRUPTION WITH SEX PHEROMONES

Mating disruption with pheromones has been developed

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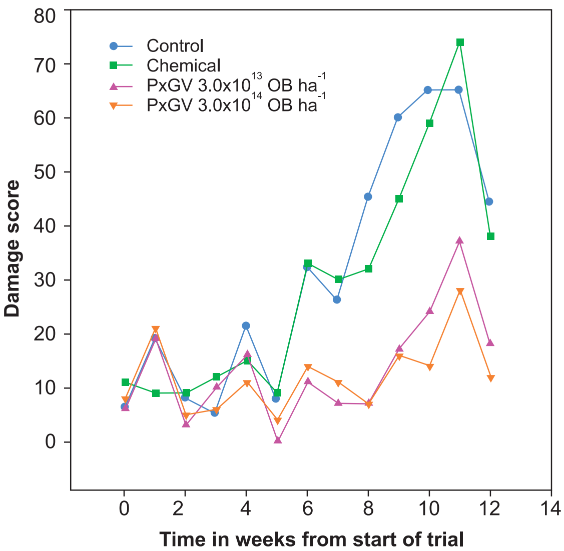


Figure 1. Effect of virus treatments on damage to kale (OB = occlusion bodies)

for a number of economically important lepidopterous pests (see pp. 56, 71, 95). By permeating the air with a synthetic blend of female pheromone components, male moths are prevented from following odour trails of pheromone released by females, resulting in a reduced level of mating and a significant reduction in the larval population of the next generation. This project has identified a combination of pheromone blend and dispenser formulation that shows promise as a component of diamondback moth control. The formulation consists of poly vinyl chloride (PVC) dispensers (originally developed by NRI and now manufactured commercially by Agrisense-BCS), produced in a 'string' form for easy manual application to the crop. Field trials in Kenya have demonstrated that this can be used for successful mating disruption. In trials the formulation was more effective than chemical insecticides in controlling diamondback moth, reducing yield losses by 50% compared to control plots. Although there have been a few reports of the successful use of diamondback moth pheromone for control over large areas (>5 ha) in the USA and South-East Asia, importantly, this is the first time the technology has been demonstrated to be effective in small plots (0.1 ha) typical of small-scale vegetable producers in Kenya.

PHEROMONE TRAPS TO SPREAD *ZOOPHTHORA RADICANS*

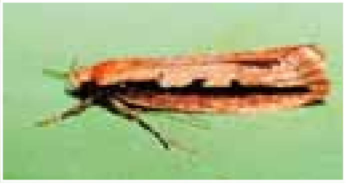
The fungus *Zoophthora radicans* commonly infects diamondback moth in the field and is therefore of interest as a biological control agent. However, applications of *Z. radicans* direct to field crops against a number of pest targets, including diamondback moth, have provided variable levels of control because of the need to apply the fungus to saturation point for germination and infection to take place. Also, it is necessary for microbial insecticides to be stored for long periods, and stabilizing fungal spores in a viable form poses a significant technical problem.

At IACR-Rothamsted a novel system involving specially designed pheromone traps for the spread of *Z. radicans* by diamondback moth adults was developed to overcome these problems. The strategy was that male moths attracted to the pheromone in the trap would enter and be inoculated with a lethal dose of the fungus. The moths would then leave the trap and disperse to the crop, carrying the inoculum to susceptible larvae and thus spreading the fungal infection. Moths succumbing to infection would also be a source of inoculum in the crop. The advantages of this system over the conventional spraying of mycoinsecticides are that:

- only small quantities of fungus and pheromone are required
- the trap can be designed to protect the fungus from harmful effects of UV radiation and to provide a suitably moist environment to promote the activity of the fungus
- only male diamondback moths are attracted by the pheromone, so the fungus specifically targets this pest with minimal effects on other organisms and the environment.

A prototype pathogen-dispensing pheromone trap has been field tested in Malaysia (Figure 2). The preliminary field work in Malaysia was restricted to small-scale trials with the single pathogen *Z. radicans*; the current project provided an opportunity to conduct larger trials, to integrate other fungal pathogens into the

Figure 2. PVC trap for dispensing pheromone and insect fungal pathogens in the field



Damage caused by Plutella xylostella *on cabbage in Kenya; inset, adult diamondback moth.*

system, and to determine the suitability of this strategy for integration into diamondback moth management strategies for subsistence farmers.

Following on from the work with a Malaysian isolate, this study carried out field work in Kenya with a local isolate of *Z. radicans*. Cage trials confirmed that using these autodissemination traps 10% of diamondback moth males could be infected with a fungal pathogen, showing that the technique is feasible. Further research suggested that the efficiency of the system could be improved further if a second insect pathogenic fungus, *Beauveria bassiana*, was used in the pathogen dispensers alongside *Z. radicans*.

COMBINED FORMULATION OF VIRAL AND FUNGAL INSECT PATHOGENS

A combined formulation of viral and fungal insect pathogens will offer benefits by creating a cocktail of specific agents to provide a practical means of managing a pest complex. A multiple mode of action will be advantageous for resistance management and may show synergistic effects. In this study, methods for producing a co-formulation of a granulosis virus and *B. bassiana* were investigated, including aspects of storage, formulation and application, and scanning electron microscopy for identification and distribution studies.

The results established that it is possible to co-formulate viruses and fungi and retain their viability. The development of dual-action biological pesticides using PxGV and fungus for control of diamondback moth and other important species in the brassica pest complex is therefore feasible.

The project has successfully developed and tested several new approaches to the control of a key pest of vegetable production in Kenya. Two technologies, insect virus and pheromone mating disruption, have been successfully field tested in Kenya. The two other technologies, autodissemination and co-formulation, have been shown to be technically feasible, although further research is needed before they can be evaluated in the field.

Currently used chemical insecticides do not control diamondback moth effectively, and these new biorational technologies can produce very significant increases in yield (up to 100%) through reduced losses. The impact on peri-urban farmers of the introduction of new methods of control is likely to be both positive and significant in scale. Reduced crop losses would directly improve the cash income of these farmers and improve both the quality and quantity of the urban food supply.

The results obtained, while focused on Kenya, have potential world-wide significance, as the same pest complex is a major constraint to brassica production throughout the tropics. These technologies could have applications in a wide range of peri-urban vegetable production centres throughout Africa and South Asia. Given the simplicity of the technologies developed, and the possibility of one application where previously several had been necessary, there is a strong likelihood of adoption, resulting in increased food production and quality, and reductions in the costly and risky use of chemical pesticides.

FUTURE

The next stage of the project (R7449) will involve the development of these promising technologies to the point where they can be evaluated on farm and, if appropriate, transferred and promoted to farmers. As evaluation, uptake and promotion become increasingly important Kenyan-based partners should become more diversified. It will be important to involve potential commercial producers of the new technologies. Market studies should be carried out in Kenya to determine the likely commercial market for the technologies developed so that commercial involvement in their production can be facilitated.

Development of pheromone traps for monitoring the legume podborer *Maruca testulalis* (*M. vitrata*)

R6659

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1 April 1996–31 March 1999

The legume podborer, *Maruca testulalis,* is a major, pan-tropical pest of legume crops. In a previous project a major and two putative minor components of the female sex pheromone of *M. testulalis* were identified. The project described here aimed to complete identification of the pheromone, optimize traps baited with the synthetic pheromone, and investigate their use to study the ecology of the pest. Pheromone traps will assist researchers in developing integrated pest management strategies to control the podborer by providing information concerning its behaviour and activity in the field. Traps will also provide farmers with a simpler alternative to pest scouting so that they can better time the application of control measures, reducing both the cost inputs and the environmental and resistance problems experienced with less specific pesticide application.

ISSUES

The legume podborer, *Maruca testulalis* (now called *Maruca vitrata*), is a pest of legumes throughout the tropics – it is a major pest of cowpea in Africa and Asia, and is of sporadic importance in South America, causing yield losses of 20–80%. It is a particularly serious pest of early-maturing varieties of pigeonpea, and development of these varieties is leading to an increase in the area of pigeonpea grown in India and other countries in South-East Asia. It is also an important post-flowering pest affecting beans in Africa and Asia, and an occasional pest of soyabean.

The larvae are highly mobile, feeding continuously on flowers and newly formed pods and causing severe damage throughout the reproductive cycle of the crop. The use of insecticides to control insect pests in cowpea does result in several-fold increases in yield and crop value; however, studies with Nigerian farmers show that only a minority apply insecticides due to their high cost and lack of availability. Where insecticides are used, webs protect *M. testulalis* larvae, so careful and timely application is required.

Some cowpea varieties have been shown to possess modest levels of host resistance, based on plant architecture, but wild species of *Vigna* (cowpea) show much greater resistance through antibiosis effects. However, it has proved difficult to transfer this to cultivated varieties. No screening of resistance to *M. testulalis* in beans has yet been reported, but there are considerable differences in susceptibility among pigeonpea varieties.

There is a lack of information on the behaviour and activity of adult *M. testulalis* in the field, particularly in relation to possible migration patterns and off-season occurrence. This has hindered the development of integrated pest management strategies. There is a need for ecological studies to enable the successful implementation of strategies involving manipulation of cowpea planting dates and use of short-season varieties or companion crops to reduce *M. testulalis* damage. To achieve this, pheromone-baited traps for *M. testulalis* could provide simpler alternatives to pest scouting by farmers, to help them time the application of control measures more effectively and reduce the number of sprays necessary. Such an approach has been developed as part of an IPM package against *Spodoptera litura* on groundnuts in India, and pheromone traps are being used by farmers to monitor for cotton pests in India, Pakistan and Egypt, and for pests of rice in India.

In a previous project (R5292), methods for rearing *M. testulalis* were developed in the UK,

Publications: see Bibliography on CD.

Left: a white, plastic jerry-can is being adapted for on-farm use – it attracts most moths and is practical and robust. Right: moths caught inside the trap

as was a convenient wind-tunnel bioassay in which male moths responded well to both live virgin female moths and extracts of female pheromone glands. These studies showed the behaviour of this species is unusual in many respects, particularly in terms of delayed sexual maturity and mating. The major active component in extracts of pheromone glands from virgin female *M. testulalis* was identified as (*E,E*)-10,12-hexadecadienal (EE10,12-16:Ald). The corresponding alcohol, (*E,E*)-10,12-hexadecadienol (EE10,12-16:OH), was also shown to be present, but these compounds, singly or in combination, were only weakly attractive to male *M. testulalis* moths in laboratory bioassays. Thirty-two synthetic blends were tested in traps: no *M. testulalis* males were caught, but night observations showed that approaches to lures by male *M. testulalis* moths were increased by the presence of (*E*)-10-hexadecenal (E10-16:Ald) and EE10,12-16:OH.

The work was originally requested by scientists at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India. Subsequently, scientists at Tamil Nadu Agricultural University (TNAU), India; the International Institute of Tropical Agriculture (IITA), Nigeria and the IITA Plant Health Management Division at Cotonou, Benin; the Asian Vegetable Research and Development Center (AVRDC), Taiwan; and the Food Crops Research and Development Institute (FCRDI) of the Department of Agriculture in Sri Lanka have all expressed interest in the project and carried out testing of experimental lures.

The project described here aimed to develop and promote improved methods for control of pod-boring caterpillars on food legumes by completing identification of the pheromone of the legume podborer, optimizing traps baited with the synthetic pheromone, and investigating the use of these to study the ecology of this pest.

ACHIEVEMENTS

SYNTHETIC LURE DEVELOPED

In laboratory wind-tunnel studies In the UK, male responses were optimal when both putative minor components were present in small proportions relative to the major component; a significant effect of lure dose was also demonstrated.

In trapping experiments in cowpea fields at the IITA station near Cotonou, Benin, lures containing the synthetic three-component blend produced significantly more moth captures than with one-or two-component blends, live females or unbaited controls. The proportion of the two minor components, relative to the major component, was not critical over the range tested. Polythene vials containing 0.1 mg of pheromone attracted more males than other combinations of dose or dispenser, but differences were not statistically significant. A locally constructed water trap was shown to be as effective as a commercial funnel trap and superior to a commercial sticky, delta-trap design. Evidence indicated that lures suffered no loss of attractiveness over a period of up to 4 weeks under field conditions. An unexpected finding was that females comprised 20–50% of total catches with synthetic lures, although almost none were attracted to live females or unbaited controls.

OPTIMIZED TRAPPING SYSTEM

Experiments were carried out to relate catches of *M. testulalis* moths in pheromone trap catches to those in a light trap situated away from cowpea fields at the IITA station, and to larval infestations in cowpea fields. The temporal patterns of catches in the light trap and in pheromone traps within fields were different, but there was better correspondence between catches in the light trap and in pheromone traps placed outside fields, and these preceded the appearance of eggs and larvae in nearby fields by a few days. Thus pheromone traps placed outside fields could be used to predict larval infestations. Catches in pheromone traps in the fields appeared to be of moths which originated from larval infestations within those fields, and these were not detected in the light trap. Catches in the light trap were greater than in individual pheromone traps, but, within each type of trap catches of one sex accurately reflected the presence of the other.

Thus from a practical trapping standpoint the development of an effective synthetic lure is considered complete, at least for West Africa: it consists of a polythene vial containing 0.1 mg of the three-component blend, in a 100:5:5 ratio. For the first time a synthetic pheromone blend has been identified that is more attractive to male *M. testulalis* than virgin female moths under field conditions.

However, the lack of effect of varying the relative amounts of minor blend components, and the attraction of female moths to synthetic lures, were both unusual and unexpected findings in the context of previous research on female-produced sex pheromones. It is unlikely that other pheromone components remain to be identified, although there may be scope for further optimization of the ratio of the three components, and other aspects of the species' reproductive behaviour remain to be understood. Regardless of explanation, catches of females may actually improve the predictive power of traps, since catches of both sexes should more accurately reflect population events.

ECOLOGY AND BEHAVIOUR

The data obtained show that the ecology and behaviour of *M. testulalis* in relation to pheromone trap catches are unusual, and without further studies interpretation is uncertain. It is likely that infestations in cowpea crops at the IITA station arose principally through immigration of moths into the vicinity around the start of a cropping season. Immigrants were only well detected by the light trap and perimeter pheromone traps (in the second season). Immigrating moths gave rise to larval infestations some days later, and only after this did pheromone traps within fields catch moths which were presumably either the progeny of the original immigrants, or, possibly, late immigrants. These moths emerging from field infestations were detected well by the within-field pheromone traps, but not by the distant light trap. The most important conclusion is that pheromone traps placed outside cowpea fields can be used to predict larval infestations beginning a few days later.

Within fields, moths were trapped in generally low numbers, intermittently or for short periods, particularly in the second season. This may go some way to explaining the absence of catches in Sri Lanka and Kenya, in that traps may not have been used over periods coinciding with the presence of adult moths in fields. The use of what is now known to be an inferior trap design may also have contributed to these results.

FUTURE

The project has produced effective pheromone lures and working traps for the first time. A follow-on project (R7441) based in Ghana and Benin, in collaboration with IITA-Benin and with cowpea as the commodity base, will complete optimization of the design and operation of pheromone traps for *M. testulalis* and integrate their use with other novel IPM technologies to provide improved methods for control by smallholder cowpea farmers. Specifically, it will attempt to develop trap-catch thresholds to allow optimal timing of conventional insecticide applications, or of novel botanical or microbial control agents, manipulation of planting dates or resistant varieties. The project will also aim to provide a better understanding of the population dynamics, ecology and behaviour of *M. testulalis*, based on long-term monitoring through networks of pheromone traps within crops, alternative host areas and elsewhere; information gained will aid the further development of sustainable control methods.

IITA, through the Swiss Development Corporation-funded PEDUNE (Protection ecologiquement durable du niébé) project in West Africa, has already collected baseline socio-economic data to facilitate future impact assessment of IPM technologies. PEDUNE was instituted to promote the transfer and implementation of research on cowpeas to smallholder farmers through the farmer field school approach. It consists of collaborating research, extension and NGO organizations in nine West African countries. This needs to continue, and the follow-on project will conduct surveys to determine farmers' attitudes to traps and their potential for use in the development of new IPM strategies against *M. testulalis*. It will also evaluate the impact of the technologies developed. A further long-term objective is the development of a formal predicative model for outbreaks of *M. testulalis.*

Outside West Africa, links developed under the previous project with the FCRDI, Sri Lanka, TNAU, India and the Japan Society for the Promotion of Science's Nairobi Research Station will be maintained informally. Experimental results will be exchanged in respect of *M. testulalis* pheromone trapping; if results are promising more formal collaboration may be attempted, for example in Sri Lanka with pigeonpea as the commodity base.

Development of coffee IPM components in Kenya

R6782

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Coffee is an important source of income for an estimated 300 000 smallholder farmers in Kenya, who produce over 60% of the export crop. Recommended pest control measures for coffee rely heavily on the use of pesticides, which are costly to the farmer (fungicides can account for over 30% of total production costs), and potentially harmful to the environment and natural enemies. This project has begun to identify safe biological and cultural control methods, together with host plant resistance, which could be incorporated into an integrated pest management strategy for smallholder, coffee-based cropping systems in Kenya, thus reducing reliance on inorganic pesticides.

ISSUES

Coffee, a major source of income for smallholder farmers in Kenya, is susceptible to a wide range of pests and diseases which are responsible for significant yield losses, as well as affecting the cup quality. Coffee berry disease (*Colletotrichum kahawae*) alone can cause up to 30% yield loss, whilst infestations by antestia bugs (*Antestiopsis* spp.) and coffee berry borer (*Hypothenemus hampei*) directly affect the bean and liquor qualities of coffee.

Recommended pest control measures currently rely heavily on the use of inorganic pesticides – it has been estimated that fungicides account for 30% of the total cost of production. Increasing reliance on broad-spectrum chemical pesticides has led to concerns about health and environmental risks, detrimental effects on natural enemies of pests, pesticide resistance, and cost, particularly for smallholder farmers. Despite such concerns, inorganic pesticides continue to be the control method preferred by smallholder coffee farmers themselves.

Using a combination of natural enemies, cultural practices and resistant varieties, and by raising awareness of such strategies, the aim of this project was to reduce the current reliance on inorganic pesticides in coffee production.

ACHIEVEMENTS

Participatory rural appraisals, together with an extensive socio-economic survey of about 200 smallholder coffee farmers, were conducted at the start of the project and revealed that pests and diseases were perceived by farmers to be major constraints to coffee production. The survey identified measures taken by farmers in order to try and reduce losses. Subsequently, a year-long biological survey of farms in different agroecological zones confirmed that pests and diseases (especially coffee berry disease, coffee leaf rust and antestia bugs) were economically important, and also established the distribution of pests, diseases and their natural enemies in central Kenya.

On-farm experiments on the effects of farmers' practices (intercropping with banana; pesticide use; use of improved coffee varieties) revealed that they generally had little or no effect on the incidence of pests, diseases or natural enemies, with the exception of fungicides for control of coffee leaf rust. However, the coffee variety Ruiru 11, bred by the Coffee Research Foundation (CRF), was found to be highly resistant to coffee berry disease, coffee leaf rust and also possibly root-knot nematode. Currently, the main drawback with this variety is the limited availability of seeds/seedlings. CRF is addressing this shortage through a separately funded coffee variety multiplication project.

Sixty potential biocontrol agents (pathogens, parasitoids and predators) of key insect pests and diseases of coffee were collected, identified and characterized. Some of the more promising natural enemies were subsequently evaluated in the laboratory and field. Egg parasitoids (*Telenomus seychellensis*) of antestia bug were reared successfully *in vivo* in the laboratory and initial field releases made at CRF in order to establish correct procedures for rearing and field release. Additional field releases and detailed follow up studies are now required to quantify the impact of these parasitoids on the population of antestia bugs. Other natural enemies which were reared and are being maintained at the laboratories at CRF include predators of the giant looper, *Ascotis selenaria* (e.g. *Rhinocoris* sp. and *Macrorhaphis acuta*), and predators and parasitoids of green scale, *Coccus viridis* (e.g. *Chilocorus* spp. and *Metaphycus* spp.).

Field trials were conducted on farmers' fields, thus transferring new technologies directly to the contact farmers. Recommended IPM components were also passed on through farmer participatory meetings and farmer field schools established under a separately funded FAO project. The research liaison section of CRF also served as an important adoption pathway.

FUTURE

Under the guidance of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), in the light of these results a proposal for a Regional Coffee IPM project was revised and expanded into a regional Coffee Research Network (CORNET), to include all aspects of coffee production, processing and marketing. The proposal was endorsed by ASARECA in 1999 and is currently under review.

Publications: see Bibliography on CD.

Integrated management of the fusarium wilt/root-knot nematode complex on cotton

R6761

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Fusarium wilt has long been the major disease of cotton in Tanzania, and phytosanitary measures and the use of resistant varieties have been practised with some success for many years. However, the impact of root-knot nematode which increases plants' susceptibility to the disease, in addition to changes in the cotton sector leading to less regulation, have led to the disease increasing and threatening the hitherto unaffected southern zone of Tanzania's cotton-growing area. This project conducted surveys and analysed existing survey data in order to update the current status of fusarium wilt in Tanzania and Uganda, and also surveyed farmers to obtain an idea of their perceptions of the disease. Farmers' difficulty in recognizing the *Fusarium* fungus as the cause of cotton wilt means that control measures should realistically be taken at the national level. There are two main aspects to the management of fusarium wilt: to prevent its spread on planting seed by organizing a certified seed multiplication system; and to reduce losses experienced by farmers whose land is already infested. In Tanzania the wilt-resistant variety UK 77 performs well in the absence of root-knot nematode; where the nematode is also present, improved resistance to root-knot nematode is required.

ISSUES

Cotton is one of Tanzania's major export commodities and, together with coffee, is foremost amongst the country's export crops. 95% of national production comes from the area south of Lake Victoria, bounded on the east by the Serengeti National Park and in the west by the highlands on the borders with Rwanda and Burundi, known as the western cotton-growing area (WCGA). Cotton is the main source of income for many rural families in the WCGA. Fusarium wilt (caused by *Fusarium oxysporum* f.sp. *vasinfectum*) was first noted in Tanzania in 1954. It is the most important disease of cotton in Tanzania, and is now widely distributed in the WCGA. Since the 1960s attempts have been made to control and contain the spread of the disease through the use of resistant varieties and phytosanitary measures to reduce the risk of distributing infected seed for planting. Resistance to wilt has been an important selection criterion for varieties intended for the northern zone, but has not been required for the unaffected southern zone. The wilt-resistant varieties carry codes with odd numbers, currently UK77 and UK91, whereas wilt-susceptible varieties carry codes with even numbers, currently UK74 and UK82. Both UK77 and UK91 have good levels of resistance to fusarium wilt and although some infection still occurs, it is much less than would occur with the wilt-susceptible varieties. However, many of the sandy soils of the WCGA are infested with root-knot nematode (*Meloidogyne incognita*), and where this parasite occurs together with the wilt pathogen, susceptibility to fusarium wilt is increased.

Following the liberalization of the Tanzanian cotton sector in 1993, restriction of the movement of seed cotton across ginnery zone and breeding zone boundaries has ceased, and phytosanitary control measures against the spread of fusarium wilt have become difficult to apply.

The last fusarium wilt survey was conducted in 1988, when it appeared that the disease was continuing to spread. The aim of the project described here was to improve understanding of the effects of liberalization on cotton production in general and, more specifically, on the potential for spread of fusarium wilt, and to improve knowledge of farmers' perceptions of the disease, thus contributing to the design of a management system for fusarium wilt which takes account of the new realities in a deregulated industry.

SELECTED PUBLICATIONS

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KATSANDONIS, D. (1999) The nematode-enhanced susceptibility to fusarium and verticillium wilt of cotton. PhD thesis, Department of Agriculture, University of Reading, UK.

Table 1. Fusarium wilt incidence recorded on different soil types

Soil type	Fields with fusarium wilt (%)
Lusenje (grey sand – sandy loam)	69
Nduha (brown sandy loam)	67
Itogolo (grey sandy clay)	50
Ibushi (grey – brown calcareous clay loam)	33
Mbuga (black cracking clay)	0

ACHIEVEMENTS

Surveys confirmed that fusarium wilt is widespread in the northern zone of Tanzania's WCGA. With the exception of parts of Sengerema District, where the grey sandy soils are particularly conducive to wilt, disease incidence was generally below 5%. This reflects the success of the resistant variety UK 77. Where disease incidence was 10% or above, the wilt was associated with root-knot nematode. This suggests that fusarium wilt management in the areas already infested with the wilt pathogen and root-knot nematode will require selection for nematode resistance.

The main factors influencing the spread of fusarium wilt were identified. The pathogen is seedborne and, at present, planting seed is derived from farmers' crops. Previous phytosanitation measures are now ineffective as a result of deregulation: the cotton buying posts were identified as the point at which potentially infected seed cotton is mixed with non-infected seed cotton, and also where wilt-resistant and wilt-susceptible varieties were being mixed.

Fusarium wilt is confined to the sandy soils in the WCGA (Table 1). Much of the cotton-growing land in the northern sector of the WCGA, closest to Lake Victoria, is already infested with both the fusarium wilt fungus and root-knot nematode. Although fusarium wilt has been reported from a limited number of sites in the southern zone of the WCGA, cotton is grown on clay and calcareous soils in much of this zone. It was confirmed in pot experiments that the ibushi soils (calcareous) are particularly non-conducive to fusarium wilt, but are still fertile. If further spread of fusarium wilt is to be prevented, a seed multiplication system is required where the seed crop is grown only on ibushi soils.

Figure 1. Sketch map showing the western cotton-growing area (WCGA) in western Tanzania and the boundary between the northern zone (closest to Lake Victoria) where fusarium wilt is prevalent and the southern zone where it is mainly absent.

The project also conducted extensive surveys in the cotton seed multiplication areas around Lake Kyoga in Uganda. Both verticillium wilt and the fusarium wilt/root-knot nematode complex were found. Verticillium wilt was found on the clay soils in Apac district, while fusarium wilt/root-knot nematode was found on the sandy soils, mainly in Pallisa and Kamuli. There is a need in Uganda to begin screening for resistance to root-knot nematode, as it was rare to find fusarium wilt in the absence of the nematode.

In Tanzania, the project originally planned to conduct a survey for fusarium wilt across the whole of the WCGA, relying partly on questionnaires administered by extension staff. This was abandoned for two reasons: earlier surveys show that fusarium wilt is so widespread in the northern zone that the whole area should now be regarded as unsuitable for seed multiplication; and owing to the large number of villages that each extension worker has to cover, it is doubtful that negative records could be relied upon. Instead, an indication of the rate of spread was obtained from the records of previous surveys which were conducted in 1969, 1979 and 1988. The number of villages with fusarium wilt increased by 30 between 1969 and 1979, and by 59 between then and 1988. In 1979 there were no records of wilt in the southern zone of the WCGA; even in 1988 there were only a few localized incidences. However, any presence of fusarium wilt in the southern zone has serious implications, as varieties grown in the zone are not selected for resistance to wilt.

Table 2. Farmer recognition of fusarium wilt symptoms

Location	Number of respondents	%
Own fields	70	78
Other fields	12	13
Neither	8	9
Total	*90*	*100*

The information from these surveys was combined with information provided by the Tanzania Cotton Lint and Seed Board in order to tabulate wilt distribution according to District boundaries. Previously, the information on wilt distribution was collected by ginnery zone. This made sense prior to market liberalization, when there was only one ginnery per zone and restrictions were in place on the movement of seed cotton across ginnery zone boundaries. Now that the private sector has constructed new ginneries, there are several ginnery zones with more than one ginnery, and seed cotton is marketed across both ginnery and zonal boundaries. The cotton buying posts are now situated according to District boundaries.

Variety mixing could be avoided by converting to a single-variety system and growing only the latest fusarium wilt-resistant variety in both northern and southern zones of the WCGA. If it is deemed necessary to retain a two-variety system, then the problem could still be circumvented if planting seed is not derived from the main crop.

While recognizing the problem, farmers and other stakeholders surveyed had a poor understanding of the causes of fusarium wilt (Tables 2 and 3), and none at all of nematodes. Farmers therefore cannot be expected to implement control measures. Likewise, cotton buyers and ginning companies in the deregulated cotton industry cannot be expected to implement phytosanitary measures. The spread of fusarium wilt on seed can only be controlled by having a scheme for the production of certified seed in which seed production is separated from crop production as a whole. The project has shown that the ibushi soils are non-conducive to fusarium wilt, and seed multiplication schemes should be sited on these soils. The one proviso is that a disease known as ‘Lubaga wilt’ appears to be prevalent on ibushi soils – more work is required on the (as yet unknown) cause of this disease, and whether or not it may be seedborne.

Table 3. Farmer perceptions of causes of fusarium wilt symptoms

Cause	Number of respondents	%
Insect pests	16	15
Pest problems	13	12
Termites	6	6
Drought	16	15
Rain related	8	7
Fertilizer/ excessive rainfall	1	1
Low fertility	1	1
Not known	47	44
Total	*108*	*100*

However, a separate, certified seed-production system will not be without a cost: farmers will need to be paid a premium to produce a seed crop, and ginning companies will need to be compensated for the revenue lost from not being able to use the seed for oil extraction.

Similar problems with the risk of spreading fusarium wilt on planting seed were identified in Uganda, but to a lesser extent: in this country the problem could be addressed by ceasing to use the areas of sandy soil for seed multiplication. But selection for resistance to fusarium wilt is not practised in Uganda, and the best approach to control of the fusarium wilt/root-knot nematode complex would be to begin selection for resistance to root-knot nematode from the stage of single plant selection, followed by testing in the later generations in a sick plot infested with the wilt fungus and root-knot nematode.

An IPM system for fusarium wilt management would have the following components.

- Certified seed production system to prevent disease spread through infected seed.
- Consider moving to a single-variety breeding programme. The single variety should be wilt resistant. The only justification for continuing the two-variety system would be that the fusarium wilt-susceptible alternative was consistently higher yielding in the southern zone and had a significantly higher ginning out-turn.
- Varietal resistance: UK77 has good wilt resistance but requires improved resistance to root-knot in order to maintain resistance levels on soils heavily infested with the nematode.

FUTURE

Further work is required in two areas:

- The outputs from the present project with respect to seed transmission of fusarium wilt should be developed further by assisting the Tanzania Cotton Lint and Seed Board to prepare a plan for a seed multiplication system that can provide high-quality seed free of seedborne diseases.
- Management of fusarium wilt in areas infested with both the wilt pathogen and root-knot nematode requires the wilt-resistant varieties to have improved resistance to the nematode. The cotton research stations at Ukiriguru in Tanzania and Serere in Uganda require assistance to develop screening methods to produce varieties resistant to root-knot nematode.

Assessment of major soilborne pests of the multi-purpose agroforestry tree *Sesbania sesban*, and the development of IPM strategies

R6736

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Sesbania sesban is one of the main agroforestry tree crops being promoted in Africa to improve soil fertility by nitrogen fixation, and to provide fodder for livestock. However, the species is subject to pests and diseases, and has been little studied in the past. This project has identified the main soilborne (and other) pests of *Sesbania* in eastern and southern Africa, and developed and promoted practical pest management strategies. Farm surveys identified three leaf beetles, *Mesoplatys ochroptera*, *Exosoma* sp. and *Ootheca* sp., as major insect pests, and two root-knot nematode species, *Meloidogyne incognita* and *M. javanica*, as major nematode pests of *Sesbania* in Africa. *Sesbania* nursery beds in farms and research stations were found to be commonly infested with root-knot nematodes. The root-knot nematodes are particularly damaging in loamy sand soils in Zambia, Malawi and Tanzania, especially where nematode-susceptible crops such as tobacco or solanaceous vegetables are also grown. Recommendations have been produced for the integrated and practical management of the major pests to assist in the more sustainable and productive use of *Sesbania* by smallholders in agroforestry systems.

ISSUES

The increased use of nitrogen-fixing leguminous species of trees to improve soil quality is a major component of the development and promotion of agroforestry systems in Africa, particularly by the International Centre for Research in Agroforestry (ICRAF). One of the main agroforestry tree crops being promoted in Africa is *Sesbania sesban*, a fast-growing, nitrogen-fixing tree with good quality leaf biomass which is traditionally grown in Africa and is acceptable to farmers for improving soil fertility and providing fodder for livestock. *Sesbania* is being recommended as a short-duration improved fallow crop to replenish soil nutrients and thus improve yields of sequentially grown food crops, particularly maize.

The promotion of *Sesbania* as an improved fallow has been restricted partly because the tree is susceptible to soilborne pests, in particular to the root-knot nematodes, *Meloidogyne* spp. Problems had arisen concerning the establishment and subsequent growth of *Sesbania*, and ICRAF has reported a complete failure of *Sesbania* (thought to be due to nematode attack) in Rwanda and Malawi. Until the beginning of this project there had been no concerted programme directed at the identification and management of pests of *Sesbania*.

ACHIEVEMENTS

INSECTS

Surveys showed that soil insects were less important than previously thought. Whitegrubs (Scarabaeidae) may occasionally cause some damage to the rooting system in some regions (such as Kenya), but were rarely found in Zambia. Termites are often cited by farmers as a major problem in legume fallows, including *Sesbania*, but in most cases they were found attacking dead or dying trees.

In contrast, three leaf beetles appeared to be major pests of *Sesbania* fallows: *Mesoplatys ochroptera*, *Exosoma* sp. and *Ootheca* sp. The three species are particularly damaging to young seedlings and, when the attack occurs early in the year, can seriously hamper their establishment. *Exosoma* and *Ootheca* occur sporadically, particularly in Zambia and Malawi, whereas *M. ochroptera* is a very abundant and frequent pest of *Sesbania* throughout eastern and southern Africa. Therefore work focused on *M. ochroptera* and its control in improved fallows.

The following aspects of *M. ochroptera* were investigated through farm surveys, laboratory experiments and field trials: general biology and ecology of the beetle;

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Table 1. Main insect species observed on *S. sesban* in improved fallows in Kenya (K), Malawi (M), Tanzania (T) and Zambia (Z)

Species	Importance*	Country
Root feeders		
Schizonycha sp. (Col.: Scarabaeidae)	1	K
Trochalus sp. (Col.: Scarabaeidae)	1	K
Trunk/root feeders		
Amitermes evuncifer Silvestri (Iso: Termitidae)	1	T
Ancistrotermes latinotus Holmgren (Iso: Termitidae)	1	T
Macrotermes spp. (Iso: Termitidae)	1	K
Microtermes luteus Harris (Iso: Termitidae)	1	T
M. subhylinus Silverstri (Iso: Termitidae)	1	K
Odentotermes badius (Haviland) (Iso: Termitidae)	1	K
Pseudacanthotermes spp. (Iso: Termitidae)	1	K
Defoliators		
Exosoma sp. (Col.: Chrysomelidae)	2	M, Z
Mesoplatys ochroptera Stal (Col.: Chrysomelidae)	3	K, M, T, Z
Ootheca sp. (Col.: Chrysomelidae)	2	M, Z
Euproctis rubricosta Fawc. (Lep.: Lymantriidae)	1	M, Z
Undetermined tortricid (Lep. Tortricidae)	1	
Sap suckers		
Anoplocnemis curvipes (F.) (Het.: Coreidae)	1	T, M, Z
Brachyplatys testudonigra F. (Het.: Plataspidae)	1	M, Z
Hylda patruelis Stal (Het.: Tettigometridae)	1	M, Z
Nezara viridula L. (Het.: Pentatomidae)	1	M, Z
Aphis fabae Scopoli (Hom. :Aphididae)	1	M, Z
Lipaleyrodes sp. (Hom.: Aleyrodidae)	1	M, Z
Flower feeders		
Haplothrips gowdeyi Franklin (Thys.: Thripidae)	1	K
Megalurothrips sjostedti (Tryboom) (Thys.: Thripidae)	1	K, T, M, Z
Mylabris dicincta Gerst. (Col.: Meliodae)	1	M, Z
Seed feeders		
Acanthoscelides obtecus (Say) (Col.: Bruchidae)	1	M, Z
Callobruchus sp. (Col.: Bruchidae)	1	K
Undetermined eurytomid (Hym.: Eurytomidae)	1	M, Z

*Importance: 3 = serious damage frequently observed; 2 = serious damage occasionally observed; 1 = frequently found species not presently considered as a serious pest of *Sesbania.*
Only insects for which damage has been observed are listed.

natural control in fallows and natural habitats; influence of cultural practices on beetle populations; resistance/tolerance of *S. sesban* to *M. ochroptera*; and possibilities of using plant extracts as repellents or biopesticides. Future work should focus on the two other beetle species, *Exosoma* sp. and *Ootheca* sp., of which very little is known.

NEMATODES

Both root-knot nematode species, *M. incognita* and *M. javanica*, were pathogenic to *S. sesban* but variations occurred between different country isolates and species. *Sesbania* was relatively tolerant of low numbers of nematodes, and was only seriously damaged when high soil populations were present. Growth of *Sesbania* was correlated with the extent of root galling.

None of the *Sesbania* lines was resistant to the nematodes, including one from Tanzania which was reported to have resistance ('Tabora 026').

Nematodes could be eliminated from nursery beds to produce healthy seedlings, and greater attention to nursery beds earlier in the season is a simple, practical and effective means of producing clean seedlings. Older seedlings than previously recommended were significantly better at establishment and had a greater ability to withstand pest attack.

A range of other insect and nematode pests occurred with *Sesbania* but were not of major significance (see Tables 1 and 2), including an important nematode pest of maize, *Pratylenchus zeae*. Other potential pests of *Sesbania* recorded included fungal pathogens of the genus *Fusarium*.

RECOMMENDATIONS

Information from field trials in Zambia and experiments in the UK with the insect and nematode pests enabled practical recommendations to be made. Although nematodes are important pests of *Sesbania*, they can be managed by farmers by relatively simple and practical means.

- Maize can be successfully grown in rotation as *Sesbania* does not support the nematode pest of maize and, conversely, maize is a non- or poor host of root-knot nematodes.
- Resistance to nematodes and insects was not found and therefore was not an option, but avoiding nematodes and insects are appropriate measures: avoiding crops in rotations which are highly susceptible to root-knot nematodes and using nematode-free seedlings are the most effective management measures that can be taken.
- Greater attention to nursery beds earlier in the season is a simple, practical and effective means of producing seedlings free of nematodes. *Mesoplatys* could also be a problem starting in the nurseries. Insect adults, egg masses and larvae can be hand picked and destroyed on seedlings before transplanting from nurseries to the field.
- When *Sesbania* fallows are cleared, this should be done before the onset of the rain to prevent the overwintering beetles from breeding.

Table 2. Plant parasitic nematodes associated with *S. sesban* in eastern and southern Africa

Species	Status
Criconemella curvata	
Criconemella sphaerocephala	
Helicotylenchus pseudorobustus	
Hemicriconemoides cocophillus	
Hemicycliophora sp.	
Meloidogyne incognita	
Meloidogyne javanica	*
Paratrichodorus sp.	
Pratylenchus zeae	*
Rotylenchulus parvus	*
Rotylenchulus variabilis	*
Scutellonema brachyurus	
Scutellonema clathricaudatum	
Scutellonema magniphasmum	
Scutellonema unum	
Tylenchorhynchus spp.	
Xiphinema sp.	

*Major parasitic species

- As most insects overwinter in or around adjacent older *Sesbania* fallows, with heavy infestations of *Mesoplatys* beetles it is recommended not to plant *Sesbania* in the following year, especially on adjacent fields. Instead, farmers may plant another non-host fallow tree such as *Tephrosia vogelii*. One year without *Sesbania* on-farm should be enough to reduce local populations to an acceptable level.
- In the absence of *S. sesban*, *Mesoplatys* breeds on other wild *Sesbania* species. Weeding out these species will reduce insect numbers, but must be done before flowering and seed dispersal.

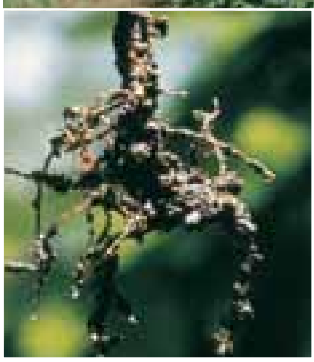
These measures for farmers to manage the nematode and insect pests of *Sesbania* and to increase nitrogen fixation and subsequent maize growth were recommended through ICRAF, and information to produce advisory leaflets was provided.

FUTURE

Following reports that other agroforestry tree crops, including *Tephrosia vogelli* and *Acacia* spp., are also susceptible to root-knot nematodes, there is a need to investigate the nematode damage to these other tree crops with the aim of developing and promoting acceptable management methods. Growing a number of different nitrogen-fixing trees as mixed fallows is a developing trend being introduced to farmers, and the effects of these mixtures of plants on pests and diseases require investigation.

A possible new disease, which we refer to as 'drying disease', was seen on *Sesbania* and *Tephrosia* in Zambia. The diseased material collected from the trees yielded two separate species of *Fusarium*; the nature and cause of this disease needs to be verified and management methods developed. More widely, fungal pathogens are largely unknown or neglected on agroforestry crops, and need to be investigated and their relative importance determined.

Several ecological aspects of *M. ochroptera* remain unknown, in particular the natural control of the beetle on wild *S. sesban*. The two other major defoliators, *Exosoma* and *Ootheca*, are still very poorly understood, and several aspects of their biology need to be studied before developing control measures. The possible insecticidal or repellent properties of *Tephrosia vogelii* and *Gliricidia sepium* merit further investigation.



Left, a 2-year-old healthy experimental plot of Sesbania sesban, *Msekera, Zambia; below,* Sesbania *fallow with severe root knot, Tanzania. Inset: severe root knot galls on* Sesbania

Development of appropriate management systems for hymenomycete disease of perennial crops

R6628

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April 1995–August 1999

Diseases caused by *Ganoderma* and related pathogens cause significant losses of oil palm and other perennial crops, including coconut and tea, in Asia. Development of appropriate integrated management systems in successive plantings of crop monocultures is currently hampered by a limited knowledge of the different hosts, the mechanisms of disease establishment, and the influence of environmental factors. Techniques developed through a previous project were used to determine the extent and variability of populations of *Ganoderma* in oil palm and coconut cropping systems in Malaysia and Indonesia, as well as in coconut crops in Sri Lanka and India. Limited studies of a tea cropping system were also conducted. The project sought to determine how the fungus survives between crops; to use biodegradation to eliminate infective inoculum in crop debris; to study the influence of environmental factors on disease development, including the effect of soil amendments on root colonization and pathogen survival; and to produce an Asian research network to facilitate the exchange of new knowledge and appropriate management strategies.

ISSUES

Palm-oil production is a major source of export revenue for several countries in South-East Asia. The palm-oil industry employs thousands of people, and the crop is also an important source of income for smallholder farmers – independent smallholders represent about 10% of the area under cultivation in Malaysia, with a further 40% of the land area being cultivated by smallholders within Federal and State Land Schemes. Particularly in Indonesia, oil-palm production has created cash economies in areas that would otherwise have little prospect of income for the rural poor. The fungal disease basal stem rot (*Ganoderma*) can be very damaging, with a greatly shortened economic life to the planting which will then entail costly replanting. In Malaysia, the expected economic life of an oil palm planting is 25 years, but losses to *Ganoderma* basal stem rot of up to 85% of the stand have been recorded within 15 years of planting. In Sumatra, losses of up to 50% of the oil palm stand are often seen by the time the palms are only half-way through their normal economic life. Smallholders are particularly vulnerable to the high cost of replanting. Also, with each replanting the disease becomes progressively worse, so replanting needs to be done more frequently. This is likely to have a very significant impact in Indonesia as this country moves from first planting to successive replantings. Linked with replanting is the issue of environmental sustainability – if replanting becomes uneconomic then further areas of primary forest will be cleared for first plantings. Thus the management of *Ganoderma* is a key issue for environmental sustainability. In addition, other smallholder perennial crops, notably coconut, are also affected by *Ganoderma* diseases: in India and Sri Lanka coconuts are affected by a stem bleeding disease caused by *Ganoderma*, and some losses of tea plantings also occur in Malaysia.

Techniques developed through a previous project (R5325) were used here to determine the extent and variability of *Ganoderma* populations in oil palm and coconut cropping systems in Malaysia and Indonesia, as well as in coconut crops in Sri Lanka and India, to determine the means of spreading. Limited studies of a tea cropping system were also conducted.

ACHIEVEMENTS

In oil palm, debris from previous plantings was shown to be a significant source of fungal inoculum. Previously this debris was burned, but management practices now commonly involve excavation of the stumps and trunks, which is

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Fungal brackets of Ganoderma

very costly and is usually beyond the means of smallholders. Cheaper, easier management of the debris is required. One possible approach is by biodegradation of the debris using microorganisms. A survey of potential antagonists was conducted in South-East Asia and the biodegradative ability of isolates tested, demonstrating the feasibility of this approach; further work is required on this, particularly in the field. Another approach takes advantage of the fact that diseased palm stumps appear to lose their infectivity over time: smallholders may be able to practise a short fallow system to reduce the inoculum between oil palm crops. Coconut stumps also represent a hazard to new plantings of oil palms, and their removal also represents considerable outlay for smallholders (and estates). Further investigation of the biodegradation of coconut debris is also needed. These studies would also be useful to smallholders throughout Asia.

Soil amendments, notably calcium nitrate, organic matter and antagonistic microorganisms such as *Trichoderma*, have resulted in reduced disease in glasshouse trials. Field testing is in progress and continues to demonstrate some benefit of amendments. The use of organic amendments to encourage antagonists to reduce the inoculum could be coupled with the short fallow system as recommendations to smallholders.

Understanding the pathogen's biology using biochemical and molecular methods is essential to exploring the disease in the field. Variability studies indicate that the *Ganoderma* associated with Thanjavur wilt in India is different from that isolated from oil palms and coconuts in Malaysia and Indonesia. In Sri Lanka, the level of variability in the pathogen population was much lower than in South-East Asia, with the same genotype being found several kilometres apart and in several species of palms, whilst in Malaysia each palm contained an individual genotype. Early indications suggest two types of *Ganoderma* may be present in coconuts in Sri Lanka.

Fallen palm due to basal stem rot

The enhancement of skills among scientists from a number of countries in the region has been a key feature of the project. Training attachments were provided at CABI Biosciences for counterpart scientists from the three countries under study. Informal networking has facilitated exchange of ideas throughout the project, while the Second International Workshop on *Ganoderma* Diseases of Perennial Crops in 1998 enabled the transfer of technologies to those best placed to use them within the region.

A research network, instigated by the First International Workshop (1994) and promoted by the project, has progressed well, with positive feedback from the collaborating institutions.

FUTURE

It was concluded at the 1998 Workshop that much basic science still needs to be done, including investigation of host responses and the mechanisms of pathogenicity and associated enzymatic degradation (these aspects would be useful both to plant breeding and to biodegradation). Breeding for resistance and the development of robust techniques of screening, including a sound method of artificial inoculation which would allow the mass screening of germplasm, was considered a high priority. Enzymatic degradation studies are also a top priority. Individual organisms have been shown to be capable of degrading components of the oil palm debris, but combinations should be studied to produce a compatible cocktail of degraders, as is seen with the natural successions on trunks and stumps in the field. Enzymatic breakdown also has enormous scope for useful by-products such as ruminant feeds and materials for the building industry.

As well as coconut and oil palm cropping systems, future studies should include other systems such as tea and forest systems. *Ganoderma* and related species are likely to affect forestry species in the region, particularly some timber species such as *Acacia*, as successive replants progress. The interrelationships between isolates from forestry species and palms should be investigated. Some of these aspects are currently being studied in Papua New Guinea under a European Community (EC) - funded project.

The success of the regional network should be continued, following a research framework developed at the 1998 Workshop. A programme of adaptive research on the management of *Ganoderma* disease of oil palm to operate as a regional programme in South-East Asia, building on the outputs of the current DFID-funded project, is under development with collaborators from the region.

Coconut diseases of uncertain etiology

R6604

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April 1996–September 1998

Yellowing, wilting and decline diseases of coconuts in South-East Asia have been increasing in incidence over recent decades. In many cases the cause of these diseases remains undefined. Because coconut production is central to the rural economy in many areas of South-East Asia, it is becoming increasingly important to identify the causes of these diseases as a first step towards developing appropriate crop protection practices for small-scale growers. The effect of these coconut wilt diseases is to seriously reduce the income of smallholder families. There appears to be a lack of coordinated coping strategies, and little incentive for the introduction of alternative crops. Activities under this project focused on monitoring the spread and attempting to identify the causal organisms of the coconut diseases in Indonesia known as Natuna wilt or Kalimantan wilt; the Indian disease coconut (root) wilt or Kerala wilt; and that in Sri Lanka commonly called leaf scorch decline. Preliminary results indicate that the Indonesian diseases are caused by the same phytoplasma.

ISSUES

In various regions of South-East Asia there is an increasing incidence of failure in coconut for unexplained reasons. For example, in a village in central Kalimantan, Indonesia, it was reported that in 1990 an unidentified disease affected ~1% of coconut palms; by 1996 this had reached 10%, and production had probably fallen by 30% as the best-producing trees were affected.

In both Natuna and parts of Kalimantan, Indonesia, the economy is completely geared to the production of copra: farm families depend almost entirely for their cash needs on coconut, which also provides employment to the landless and land-poor population. In Sri Lanka, following land reforms, coconut production is predominantly in the hands of smallholders, and there are well developed markets not only for copra, but for fibres, charcoal, activated carbon and increasingly, desiccated coconut. Small-scale farmers have no effective coping strategies to deal with these diseases, and few see an alternative to growing coconut.

Since 1972, lethal yellowing disease of coconut in the Caribbean and the Americas has been associated with a phytoplasma (microscopic organisms formerly known as mycoplasma-like organisms or MLOs), and related diseases in Africa (Cape St Paul wilt in Ghana, and coconut lethal decline in Tanzania) have also been associated with phytoplasma pathogens. At least three diseases in India and South-East Asia have been attributed to phytoplasmas despite some symptom differences from lethal yellowing.

NATUNA WILT/KALIMANTAN WILT

In Indonesia, a lethal disease of coconuts has been known for some years on Natuna Island in the south China Sea, and recently an outbreak was reported to have destroyed over 2000 ha of mature coconut palms in central Kalimantan. In central Sulawesi, a yellowing disorder of coconut palms has also been reported, and the symptomatological and epidemiological similarities between these disease outbreaks suggest that they may be caused by the same or similar groups of pathogens.

KERALA WILT (COCONUT ROOT WILT)

In India, at least two diseases of uncertain etiology have been tentatively associated with phytoplasmas: tatipaka disease in Andhra Pradesh, and coconut root wilt or Kerala wilt in the southern parts of Kerala and Tamil Nadu states. Kerala wilt causes significant losses and has been the subject of extensive investigation; electron

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In Indonesia, Natuna wilt (above) and Kalimantan wilt (right) tend to affect palms >10 years old, but symptoms have been observed on palms as young as 7 years. Palms that are not in bearing are not affected by the disease. Symptoms include wilting and drooping of lower fronds, progressing from the oldest to the youngest leaves. Affected leaves lose their sheen before changing colour from green to brown. There is no pronounced yellowing stage on Natuna Island (although this is seen in Kalimantan wilt, possibly being a genetic trait rather than a response to infection), and there is no necrosis/blackening of unopened or immature inflorescences. Nut production ceases with the appearance of symptoms

Coconut root wilt disease in India (above) is initially seen in flaccid leaflets which curve downwards, giving a rib-like appearance to the frond. There may be yellowing of the crown. There may be some nut fall, but a reduction in the number and size of nuts is more usual. The palm does not die, but examination of the roots shows that there can be extensive rotting of the root system and a lack of new growth

Leaf scorch decline (Sri Lanka) is seen in palms >20 years old, and the course of the disease can take up to 6 years before the palm dies. It first appears as a scorching of the tips of lower fronds. It then progresses along the pinnae to the mid-rib and from the lower to the upper fronds. There may be curling of the frond. The youngest fronds often remain green, even in advanced stages of disease, but they are shorter and thinner in appearance than those of healthy trees. Affected fronds remain attached to the trunk for longer than normal. There is a rapid tapering of the trunk, affected palms produce fewer and smaller inflorescences, and nuts are elongated. Eventually the crown diminishes and falls off. The root system decays giving a fibrous appearance; fewer secondary roots are seen, but laterals proliferate and then decay rapidly microscopy evidence associates a phytoplasma with Kerala wilt-infected coconut and arecanut palms, and there are claims for the remission of symptoms following the application of tetracycline antibiotics. The symptoms of Kerala wilt, however, are quite different from those of lethal yellowing. Palms decline in production over many years, and the disease is not regarded as lethal. Unlike lethal yellowing, root wilt disease spreads rather slowly and reports of its transmission by a lace bug are at odds with the confirmed vectors of all other phytoplasma diseases.

LEAF SCORCH DECLINE

In Sri Lanka, leaf scorch decline is a sporadic problem and causes losses in coconut production. Again, palms usually decline over a long period, but unlike root wilt disease, they eventually die. A more rapid, premature decline condition has been observed since 1994 in which palms die within 2 years of the onset of symptoms. The present status of leaf scorch decline is not well documented and few investigations into possible pathogens have been made.

Identification of the pathogen is an essential first step in the development of scientifically based sustainable crop protection measures. The project therefore aimed to identify the pathogens associated with these coconut diseases of uncertain etiology or origin in Indonesia, India and Sri Lanka.

ACHIEVEMENTS

PATHOGEN STUDIES

Surveys in Indonesia (Natuna Island and central Kalimantan), India and Sri Lanka collected and compared symptom information (see illustrations), and obtained samples for molecular analysis.

The disease symptoms of Natuna wilt and Kalimantan wilt are very similar, if not identical. In central Kalimantan a variant of Kalimantan wilt, which exhibited a yellowing of the foliage as well as a wilt, was observed. Experimental plots were established to study the spread of Kalimantan wilt, and the extent of the current outbreak was mapped.

There are no symptom similarities between the wilt diseases in Indonesia and Kerala wilt (India) and leaf scorch decline (Sri Lanka). However, there are some similarities between the Indian and Sri Lankan diseases. The main difference is that Kerala wilt does not kill the palms, while leaf scorch decline kills the palm but is more sporadic than any of the other diseases studied. A study was instigated at the Coconut Research Institute, Sri Lanka to chart the spread of leaf scorch decline as previous records were sparse. Tetracycline antibiotic therapy trials were set up in central Kalimantan and Sri Lanka to obtain more evidence on whether the diseases are caused by phytoplasmas.

Phytoplasma DNA was successfully amplified from diseased coconut palms with Natuna wilt, Kalimantan wilt and Sulawesi yellows. Amplified phytoplasma DNA was compared by digestion with restriction endonucleases. Restriction fragment-length polymorphism (RFLP) profiles suggested that two different phytoplasmas were present.

The phytoplasma origin of the products was further confirmed by DNA sequencing. No phytoplasma DNA was amplified from Kerala wilt, leaf scorch decline or premature decline-affected coconuts, and no pathogens of a virus-like or viroid-like nature could be found.

Scientists from all three national institutes (Research Institute for Coconut and Palmae, Indonesia; Coconut Research Institute, CRI, Sri Lanka; and Central Plantation Crops Research Institute, CPCRI, India) were trained at Rothamsted, UK in molecular detection technologies.

Results from the project were discussed at the International Coconut Biotechnology Symposium, Merida, Mexico, 1997 and publicized through an international workshop held in Manado, Indonesia in February 1998. If losses on the scale of those experienced in Africa and the Caribbean are to be avoided in Indonesia, then the initial results from this project will need to be applied in a more comprehensive action.

SPREAD

A study was carried out on the epidemiology of Kalimantan wilt. Over one year of study the percentages of trees showing symptoms approximately doubled. The greatest number of new symptom appearances occurred in a fairly narrow time window (August–October), suggesting that infection of the palms may have taken place in a similarly narrow time frame. This should help with future studies on potential vectors of the disease.

FUTURE

Priorities for follow-up in Indonesia include:

- confirm the phytoplasma etiology by continuing epidemiology and therapy trials; obtain corroborating evidence of phytoplasma infection by electron microscopy
- use molecular techniques to refine a diagnostic test for the three diseases, and use in conjunction with epidemiological data to identify a possible vector
- look for local resistance to diseases by following up seed-garden experiments in Natuna Island
- develop farmer coping strategies that are sustainable.

In India, molecular biology capabilities are being introduced at CPCRI. These should be used to provide corroborating evidence for the transmission trials.

In Sri Lanka, the Coconut Research Institute should continue to monitor the spread of leaf scorch decline and premature decline, and continue with the antibiotic therapy trials, with penicillin included as an additional antibiotic.

Development of pheromones for management of coconut pests in Sri Lanka

R6929

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The red palm weevil (*Rhynchophorus ferrugineus*) and the rhinoceros beetle (*Oryctes rhinoceros*) are the two most important pests of coconuts in Sri Lanka and most of South-East Asia. Current methods of control are only partially satisfactory, and there are fears that infestation levels will increase dramatically following the recent banning of the insecticide monocrotophos. This project provided the basis for development of mass trapping with pheromone-baited traps for control of these pests, as has been successful with a related species in Central America. This technology will be environmentally acceptable and appropriate for use in developing countries.

ISSUES

Coconut palms and their many products contribute 19% of agricultural GNP in Sri Lanka, the majority being for domestic consumption but also contributing 3.6% of total exports. It is estimated that the industry also provides employment for more than 135,000 persons. The two most important chronic insect pests are red palm weevil, *Rhynchophorus ferrugineus,* and rhinoceros beetle, *Oryctes rhinoceros*, with infestation levels often 10% or greater. The larvae of the palm weevil bore into the crown and trunk causing death of the tree. Rhinoceros beetle attacks the growing point and leaves, causing reduction in yield and secondary infections by fungal rots.

Current methods of control involving application of tar or oil to stems to prevent egg-laying, injection of stems with insecticide, and removal of infested palms are only partially satisfactory, and there are fears that infestation levels will increase dramatically following the recent ban in Sri Lanka of the commonly used organophosphate insecticide monocrotophos.

The aim of this project was to develop and promote methods for control of rhinoceros beetles and weevils by developing pheromone trapping systems for *R. ferrugineus* and *O. rhinoceros* appropriate for use in Sri Lanka. These will provide a basis for environmentally benign, appropriate methods for control of these pests.

ACHIEVEMENTS

Male-produced aggregation pheromones have been reported for both these species. The current project has established the pheromone blend produced by *R. ferrugineus* from Sri Lanka. A new minor component has been identified, and the roles of the minor components are being investigated in the field.

The major component was confirmed to be (4*S**,5*S**)-4-methyl-5-nonanol (ferrugineol), as reported previously.

One of the minor components was identified as the corresponding ketone, 4-methyl-5-nonanone (ferrugineone), but it was present at <1% of the major component, much less than the 5–10% reported previously.

A new minor component was identified as (3*S**,4*S**)-3-methyl-4-octanol, which has not been reported previously for this species.

A fourth EAG-active component was identified as 2-hydroxy-3-butanone (acetoin), a fermentation product of sugarcane. Production of this coincided with the period during which sugarcane is reported to be attractive to the weevils.

Production of the pheromone of *R. ferrugineus* at the Coconut Research Institute (CRI) in Sri Lanka has been initiated, and four members of the CRI have been trained in aspects of pheromone research.

Improved slow-release dispensers for the pheromones of both *R. ferrugineus* and *O. rhinoceros* have been developed and proven in the field.

FUTURE

Coconut growers in Sri Lanka are already aware of the possibilities of pheromone trapping as a result of the CRI's extension work, and the CRI cannot meet demand for the traps.

Work is in progress at CRI to complete optimization of the pheromone blend for *R. ferrugineus* and investigate the importance of natural and synthetic food attractants.

Further assistance is required:

- to secure supply of the synthetic pheromone for *R. ferrugineus* locally in Sri Lanka;
- to develop a cheaper synthesis for the pheromone of *O. rhinoceros*;
- to demonstrate that the pheromone traps can be used to control *R. ferrugineus* and *O. rhinoceros* and establish the necessary parameters.

Nematode resistance in bananas

R6391

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October 1995–December 1999

All types of banana (*Musa*) are susceptible to damage caused by plant parasitic nematodes, the most important of which are the banana burrowing nematode *Radopholus similis* and the root lesion nematodes, *Pratylenchus* spp. Nematode resistance in bananas is not common, and this project set out to identify sources of resistance (or tolerance) in the wider *Musa* germplasm. The results obtained show that there is resistance to both nematode species in some cultivars, but not in any that are widely grown commercially. Cultivars showing resistance have less lesioning on their roots, and nematode populations are significantly lower than on susceptible plants. Immunity to infection is not known. The rate at which nematodes multiply is lower on the 'resistant' cultivars. A new result was the discovery that *R. similis* is more damaging nematode-for-nematode than *P. coffeae*; when inoculated with similar numbers, the former caused greater loss of fresh root and shoot weight. Biochemical analyses have shown that the resistant cultivars have higher concentrations of phenolic compounds such as tannins, or that greater quantities of phenolics develop following infection. These contributions towards understanding the mechanisms of resistance (or decreased susceptibility) will assist banana improvement programmes to select for these attributes in cultivars and synthetic hybrids.

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ISSUES

Nematodes were recognized as major pests of banana in relatively recent times. In the 1950s severe crop losses (over 50%) were experienced in commercial plantations in the Caribbean and Latin America resulting from nematode root damage, which predisposes banana plants to topple. It is likely that this coincided with the change of cultivar made necessary by the epidemic of fusarium wilt known as Panama disease which destroyed the hitherto principal export clone Gros Michel. The replacement Cavendish clones were used for their immunity to the disease. It can be hypothesized that during the period of rapid multiplication and distribution of the Cavendish clones, the burrowing nematode *Radopholus similis* was also distributed on infested planting material.

There is a long history of banana breeding, but success in terms of new varieties being adopted for widespread cultivation has been slow to happen. This is largely due to the problem of incorporating essential qualities into varieties that meet the criteria for grower/consumer acceptability concerning flavour and cooking quality. The challenges are easier now that banana breeders are selecting for uses other than the international trade in dessert fruit.

This project was set up to seek sources of resistance to nematodes in the *Musa* germplasm that had not hitherto been tested. The information gained can be used by the international and national banana improvement programmes, for example in India, Honduras, Cameroon and Brazil, and the International Institute of Tropical Agricultural (IITA) programmes in Nigeria and Uganda. All of these programmes seek to improve yields and sustainability of bananas for the smaller banana producers by developing new cultivars with pest and disease resistance and good agronomic and culinary qualities.

ACHIEVEMENTS

A diverse selection of cultivars, diploids, triploids and tetraploids, some inedible wild seed-forming types (*Musa acuminata* and *M. balbisiana*), and some grown for cooking rather than as sweet dessert fruit have been evaluated. The principal research activity has been to compare the reaction to nematode attack measured in terms of lesion development, nematode abundance and plant growth response. Other features that contributed to the assessment included the growth of the root system, the anatomy of the roots, and biochemical differences in roots between cultivars. It has been found that resistance/decreased susceptibility to nematodes is

The diversity of fruit within Musa.

present in the *Musa* germplasm. When challenged with nematodes, some cultivars contained the development of the nematode population when compared to some susceptible cultivars. None was immune to attack, but root lesions were fewer or contained fewer nematodes.

This feature was found in some diploid cultivars, and these can be used in banana improvement schemes. The genetic basis for this resistance (or resistance to other diseases) has not been determined, mainly because of the practical difficulties in banana breeding. The heritability of these traits is still unknown.

Differences in root anatomy could be associated with the decreased rate of nematode reproduction in some cultivars. The amounts of aerenchyma or respiratory tissue with air spaces in the root cortex differ between cultivars: those that are less susceptible to nematodes have less aerenchyma. Similarly, the amounts of phenolic compounds, such as tannins and flavonols, were found to be different. In resistant cultivars higher levels were encountered, particularly after challenge by nematodes.

Root vigour can account for tolerance to nematodes, allowing bananas grown under field conditions to withstand nematode attack and produce acceptable yields of fruit. The root health of bananas is critical because, in extreme cases, the crop losses result from plants falling over, with consequent total loss of fruit. Some cultivars have a proportionally larger root system than others, which may explain the field tolerance, but from a crop improvement standpoint may be less attractive if such varieties are intrinsically less productive in terms of size of fruit and exportable yield.

R. similis*, the banana burrowing nematode (~0.7 mm long, 0.03 mm wide).*

FUTURE

The results from this project have demonstrated that there are *Musa* cultivars that are less susceptible to nematodes than the standard cultivars currently grown widely for subsistence and local markets.

Some of the many cultivars grown in southern India may be less susceptible to nematodes but their use and distribution is quite limited. The inclusion of some of these cultivars in banana improvement programmes is desirable, but the beneficial effects of including any resistance traits in new varieties will be a medium-term (10-year) objective.

There is a diversity of germplasm in India, much of which has not yet been fully evaluated. However, the major constraint is the high incidence of virus infection in the wild (and synthetically produced) varieties. Until advances can be made in virus elimination, the widespread exchange of these under-exploited materials will be restricted. This situation underlines the serious nature of the banana viruses and the priority that should be given to their elimination from plants as well as their epidemiology.

Contemporaneous research (R6583) suggests that there is quite wide genetic (pathogenic) variability between nematode populations, even from within one country. If such variability is normal, it may require that more in-country evaluations be made with selected cultivars. Future work with the same cultivars at different sites in Uganda may help to disclose if such variability has field significance.

Identification, vector relationships, epidemiology and control of virus and bacterial diseases of banana

R6579

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April 1996–February 1998

The Asia–Pacific region, including the Philippines, is the centre of diversity for bananas and plantains, and is therefore also a centre of diversity for many of the pathogens attacking this family. Banana viral and bacterial diseases, particularly banana bunchy top virus and the bacterial diseases Moko and Bugtok, are major constraints to banana production by both commercial and small-scale growers throughout the region. This project built on earlier efforts to obtain information on the insect vectors of these diseases and their movements, and hence on the pattern and rate of spread of the diseases. An improved understanding of disease increase and spread has allowed the formulation of more relevant control strategies. Project findings have been disseminated to local small-scale growers and extension agents in the southern Philippines, and other promotional pathways (such as a comic strip publication) are being pursued.

ISSUES

Banana is the most important fruit species in South-East Asia, ranking first in the Philippines, Indonesia and Thailand in both area planted and production. As well as being locally important to smallholders, banana is one of the most important export crops in the Philippines. As a vegetatively propagated crop, banana is particularly susceptible to accumulation of virus diseases. Banana bunchy top virus (BBTV) was ranked by the International Network for the Improvement of Banana and Plantain (INIBAP) as the most important virus disease of banana in the region, and has the potential to cause major losses, as occurred in the 1920s in Australia, and more recently in the early 1990s in Pakistan. Banana bract mosaic virus is also becoming increasingly important in the Philippines and on the Indian subcontinent. In addition, diseases caused by the bacterial pathogen *Ralstonia* (*Pseudomonas*) *solanacearum* (Moko and Bugtok) can devastate crops, sometimes causing total collapse of young, fast-growing plants within one week.

The aim of this project was to build on the findings of a previous project (R5234; see *Research Highlights, 1989/95*) to obtain more information on the epidemiology of these diseases in the Philippines, and on the factors influencing their pattern and rate of spread.

ACHIEVEMENTS

BANANA BUNCHY TOP VIRUS

A study of smallholder banana growers' perceptions of banana diseases and their knowledge and understanding of currently recommended control practices was continued. Most farmers had heard of bunchy top virus but did not recognize it until the disease was at an advanced stage; young infected suckers were completely overlooked. Other less damaging viruses (banana bract mosaic virus and cucumber mosaic virus) generally were not recognized. Farmers were confused over the different control measures used for different diseases, and there was no clear extension message. The recommended control measures of roguing bunchy top-infected plants were not followed adequately, even when farmers were aware of them, as they tended to leave part of the infected root mats and young suckers in the ground after the infected mother plant had been removed. Farmers were unaware that this provided a source of disease inoculum which could then be spread to other plants. Even the farmers who knew that bunchy top was a virus spread by aphids, and

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Left, local banana growers during field demonstrations at the project workshop

Right, a young banana plant already severely affected by BBTV

who had good contact with extension staff, did not appear to be aware of the risks of leaving infected suckers in the farm. New planting material usually came from the farmer's existing plants, or was bought from neighbouring farms. Tissue-cultured material generally was not available to individual farmers. Where it was available it was often planted in amongst infected plants, and most of the benefits of clean planting material were soon lost.

During the preceding project (R5234) three trial sites, each consisting of at least 600 virus-indexed banana plants, were established. This project continued to monitor the trial sites, both visually and by enzyme-linked immunosorbent assay (ELISA), for infection and spread of bunchy top virus. Climatic records were kept for each site, and the number and type of aphids caught in yellow pan traps at each site were also recorded. Despite following the routine management practice of digging out infected plants and replacing them with healthy ones, the incidence of bunchy top virus gradually increased at all three sites. However, only at one site was the incidence sufficiently high to readily observe aggregation of bunchy top virus infections, indicating that some secondary spread of the disease was occurring. Alate (winged) banana aphids (*Pentalonia nigronervosa*), the vectors of bunchy top virus, were caught most frequently on yellow sticky traps between ground level and 1 m above ground level in the experimental plots of banana. However, BBTV incidence and rate of spread were not readily associated or correlated to aphid abundance.

Preliminary results suggested that the 'vampire' method – whereby infected banana mats were destroyed by driving split bamboo skewers soaked in the herbicide glyphosate into the base of the pseudostems of the mother plant and suckers – was a more efficient means of eradication than the common practice of roguing.

Information on the epidemiology of bunchy top virus was obtained by compiling disease incidence data from commercial banana farms in the Davao city region. From these data, models of a bunchy top virus disease epidemic were developed, incorporating the two key features of an epidemic in a plantation in the Philippines: an exponential increase in disease incidence over 10 years (Fig. 1), and a declining gradient of incidence from the outside edge of the plantation to the centre. A non-

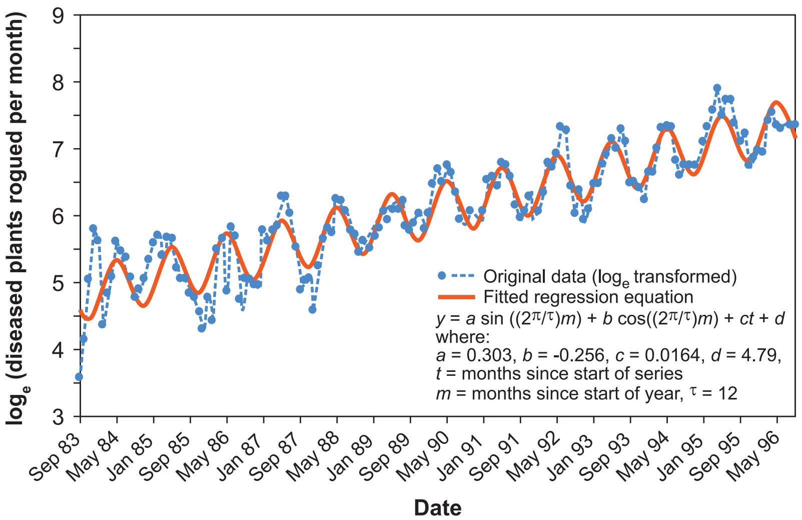


Figure 1. Original data and fitted regression of the number of banana bunchy top-diseased plants (natural log transformed) removed each month from a banana plantation in the southern Philippines

BBTV-infected suckers emerging from the mat of a banana plant that has not been properly destroyed: a potent source of virus for infecting neighbouring plants

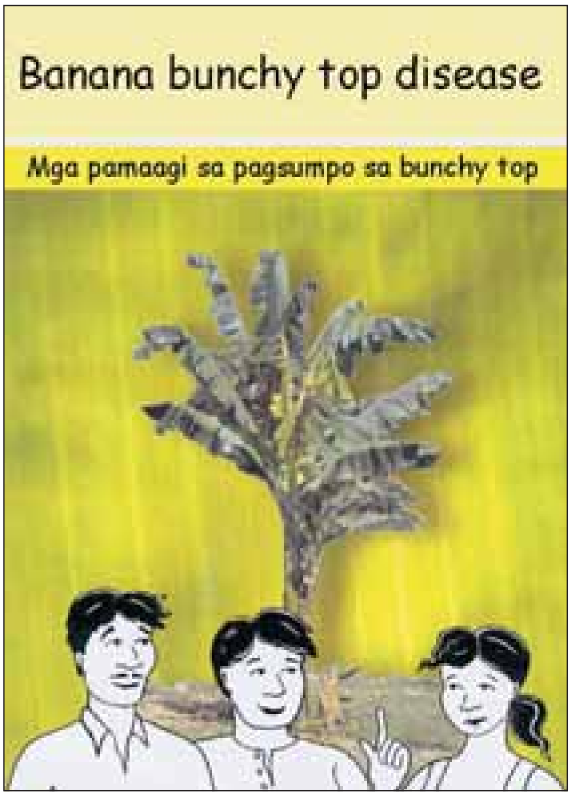
spatial and a spatial model were developed; analysis of the two models showed that for disease incidence to increase exponentially over time, the rate of disease progress could be dependent either on internal spread and roguing rate (proportion of diseased plants removed and replaced per unit time), or on the rate of increase of external inoculum pressure. The spatial model was also used to explore a variable roguing rate across blocks. Simulations indicated that this may produce small gains over the adoption of a constant roguing rate over all blocks, but would be risky because a slight shift in roguing emphasis can result in a dramatic increase in disease.

BANANA BRACT MOSAIC VIRUS

The incidence of banana bract mosaic also appeared to be on the increase in the Philippines. Transmission studies (in association with a UNDP-funded project) showed that banana bract mosaic virus is most efficiently transmitted by the banana aphid *Pentalonia nigronervosa,* but can also be transmitted by the aphids *Aphis gossipii* and *Rhopalosiphum maidis.* Banana bract mosaic virus is only distantly related to abaca mosaic potyvirus.

MOKO

During experiments to try to identify the putative insect vectors of *Ralstonia solanacearum,* banana-infecting strains of the bacterium were isolated from individuals of the banana thrips (*Thrips hawaiiensis*) and of an unidentified dipteran fly caught on Bugtok-infected bunches of cooking banana. So far no consistent differences between the Bugtok and Moko strains of *R. solanacearum* have been identified at the nucleic acid level; however this is still under investigation.



The comic-strip publication, written in the local dialect, on the control of banana bunchy top disease

SUMMARY

Shortfalls have been identified in the current control practices for bunchy top virus and in farmers' understanding of the disease process, and methods to improve these have been devised. A comic-strip publication in the local dialect on the control of banana bunchy top disease has been produced, and an end-of-project workshop, held at the Bureau of Plant Industries Davao station in August 1997, was attended by over 50 small-scale banana growers and field workers from the Davao region. In addition, the capability of the Philippine Bureau of Plant Industry for research on the detection and identification, vectors and control practices for virus and bacterial diseases of banana (and other crop plants) has been strengthened, and diagnostic tests for identification of banana diseases transferred.

FUTURE

Further research is required to determine if the findings of this project are applicable to other banana-growing regions of South-East Asia. Further work is also needed to evaluate the alternative control practices resulting from this project.

A similar study has recently been initiated on the epidemiology of banana streak badnavirus in Uganda (R7529), and there is a further need for such a study on banana bract mosaic potyvirus in India.

Investigation of the *Rhizoctonia* sheath disease complex in rice

R6643

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Rhizoctonia sheath disease, caused by a complex of three related fungi, is one of the most significant constraints to rice production in Asia. Development of effective and sustainable control measures has been hampered by a poor understanding of the pathogens involved, and of the effects of environmental and management factors on these pathogens and how they interact. The specific and sub-specific diagnostic tools developed through this project should provide the key to resolving these uncertainties and developing optimal sustainable methods for disease control in the future.

ISSUES

Sheath blight is a disease of rice caused by the fungal pathogen *Rhizoctonia solani* which affects the lower part of the leaf. It causes significant crop losses in many rice-growing areas of South and South-East Asia, and its impact on rice production in the region is increasing due to wider use of high-yielding varieties and increased fertilizer application. It is now ranked as one of the two major rice disease problems in many countries.

Earlier work on characterizing and developing appropriate disease management strategies for sheath blight (R5535 and R5922; see *Research Highlights 1989–95*) demonstrated the need for diagnostic methods to detect and discriminate between *R. solani* and two other *Rhizoctonia* species, *R. oryzae* and *R. oryzae-sativae*, which also cause sheath blight-like lesions on the rice crop. The three species produce very similar symptoms on the rice sheath, may coexist as a disease complex, and collectively cause considerable yield losses in rice in Asia.

Sheath spot, caused by *R. oryzae*, and aggregated sheath spot (*R. oryzae-sativae*), are generally not considered to be as widespread or economically important as sheath blight, but the three related diseases have been incorrectly diagnosed in many cases. A lack of techniques for detecting and differentiating the individual pathogens has impeded the development and specific targeting of sustainable and appropriate disease management practices. These include mapping of species distributions, which would help in planning how and where to plant different resistant rice lines, and assessment of different rice varieties' resistance to the three *Rhizoctonia* species individually and in combination, thereby improving the productivity: investment ratio for small-scale farmers and contributing to a reduction in rural poverty.

The aim of this project was to characterize the nature of the *Rhizoctonia* disease complex (*R. solani, R. oryzae* and *R. oryzae-sativae*) in rice-based cropping systems, and to use this information as a basis for developing morphological, biochemical and molecular techniques for identifying the causal agents at an early stage of disease development, leading to improved disease diagnosis and management.

ACHIEVEMENTS

Comprehensive culture collections of strains of *R. solani, R. oryzae* and *R. oryzae-sativae* collected from specific cropping systems in South and South-East Asia have been established in the UK and India.

A number of approaches were developed in the UK to assess variation within and between *Rhizoctonia* species at the genetic level (Table 1). These methods included analyses of genetic variation in ribosomal DNA (rDNA) and the subsequent development of species-specific PCR primers targeting this region, and analyses of variation in mitochondrial DNA (mtDNA)

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with subsequent development of DNA probes for use in Southern blots.

From the above work a range of tools has been developed that can rapidly identify the *Rhizoctonia* species present in diseased rice sheaths. These will permit the tracking of sub-specific populations of these pathogens through the development and spread of sheath disease epidemics in the field. Preliminary application of these tools during the project has provided greatly improved insight into the components of the sheath disease complex of rice in South and South-East Asia. It has, for example, reinforced suspicions that *R. solani* is a causal agent of rice sheath blight throughout India. It has also revealed the presence of *R. oryzae* as a rice pathogen in India for the first time. The three species exhibited geographic and ecological specificity, differed in growth response to temperature in culture, showed differential virulence on rice and differed in their tolerance to the fungicide carbendazim, which is widely used in India to control sheath blight.

The findings strongly suggest that our understanding of the relative importance of *R. solani, R. oryzae-sativae* and *R. oryzae* in the region, of their interactions with each other and with climatic factors, and of their responses to cropping practices, is more limited than previously assumed. More importantly, measures currently applied to control sheath diseases of rice may be inappropriate.

The effect of temperature on growth of the three species observed in this work suggests that they may be adapted to quite

Table 1. Summary of suitability of techniques for differentiation and diagnosis of *R. solani*, *R. oryzae-sativae* and *R. oryzae* at species and sub-species level

	Suitable for diagnosis of:			
Technique	**Species groups**	**Species**	**Sub-species**	**Notes (+ benefit; – limitation)**
Morphological characterization		√	√	+ Can be conducted with minimal technological input – Requires isolation of the pathogen(s), (time-consuming, plus a risk of preferential isolation) – Requires experienced personnel for reliable identification
Species-specific PCR primers		√		+ No fungal isolation required + Identification achieved within 48 h
Restriction fingerprinting of rDNA		√	√	+ Differentiation of *Rhizoctonia* species possible in most cases + Permits tracking of individual strains – Requires isolation of the pathogen – Species designation not 100% reliable
mtDNA analysis			√	+ Permits tracking of individual strains – Pathogen isolation required
Immunological detection	√			+ Rapid confirmation of *Rhizoctonia* infection without pathogen isolation – Differentiation between *Rhizoctonia* species not reliable – commercially available 'Agri-screen' also give a positive reading for *S. hydrophilum* infections
Biochemical characterization	√		√	+ Permits differentiation of intraspecific groups of strains and possibly individual strains + Many techniques relatively simple to perform – Pathogen isolation and prior identification to genus is required
Fungicide resistance		√		+ Differentiation of *Rhizoctonia* species possible – Pathogen isolation and prior identification to genus is required
Temperature tolerance		√		+ Differentiation of *Rhizoctonia* species possible – Pathogen isolation and prior identification to genus is required
Pathogenicity testing	√			+ Lesion appearance is easily identifiable for the *Rhizoctonia* group – Requires isolation of the pathogen

different ecological conditions. The more rapid growth of *R. oryzae-sativae* and *R. oryzae* at two temperature extremes (10 and 35ºC, respectively) may indicate species-based differences in optimal climatic conditions for inoculum persistence and epidemic development. The ability of *R. oryzae* to maintain growth across a wide range of temperatures, its less aggressive nature on the rice plant and its resistance to the fungicide carbendazim suggest that, of the three species, it is best adapted ecologically. The current perception of *R. oryzae* as a 'less significant' rice pathogen may be due to a lack of awareness, or the fact that it is an emerging pathogen under the current intensification of rice production. In either case, it appears to have the greatest potential as a future major constraint to rice production.

Sheath blight, caused by Rhizoctonia solani*, on paddy rice in Asia*

The tools developed through this project now make it possible to obtain a better understanding of these problems and to provide key information for the development of control measures. Areas where these tools should prove invaluable include:

- identification of the predominant sources of pathogen inoculum in the field (e.g. detection in soil, circumventing the need for isolation);
- mapping of species distributions to facilitate optimal deployment of resistant rice lines;
- assessment of rice germplasm in terms of resistance to the three *Rhizoctonia* species, both individually and in combination;
- identification of environmental factors determining the relative significance of the three species under various agro-ecological conditions;
- determining effects of cultural crop management practices on pathogen prevalence and disease development.

Broader use of the technologies developed by the project will enhance our understanding of the diseases so that more appropriate management practices can be developed and effectively applied. In the longer term this will lead to cost-effective reductions in losses resulting from these diseases, an improvement in rice yields and enhanced sustainability for smallholder farmers in Asia.

FUTURE

A proposed further study will determine sources of inoculum and mode of transmission of *Rhizoctonia* diseases within local rice-cropping systems, and investigate the effects of farm management practices on pathogen inoculum sources, levels and transmission, and disease development. The study will provide an accurate assessment, under specific cropping conditions, of the population dynamics during the course of disease establishment and spread, and will clarify the potential importance of primary and secondary sources of inoculum. Outputs will permit the identification of conditions and cropping practices that most effectively restrict disease development and spread, by reducing or eliminating potential sources of inoculum and restricting subsequent pathogen dissemination. Final results of the study will aid the formulation of clear recommendations for crop management which will minimize losses due to *Rhizoctonia* diseases in rice cropping systems.

A number of centres – the Central Rice Research Institute, the Directorate of Rice Research, Govind Ballabh Pant University of Agriculture and Technology, Haryana Agricultural University and Tamil Nadu Rice Research Institute (India); National Institute of Plant Protection (Vietnam); China Rice Research Institute; Crop Diseases Research Institute (Pakistan); and the Institute of Agriculture and Animal Science (Nepal) – have expressed significant interest in using these technologies to support ongoing studies of rice sheath diseases in their respective countries.

Epidemiology and management of rice tungro virus disease

R6519

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Rice tungro disease is one of the most important constraints to rice production in intensively cultivated, irrigated areas in South and South-East Asia. It is a highly destructive disease, and resource-poor farmers can suffer serious loss of income if their crops are affected. Tungro, a virus disease with an insect vector, is difficult to control, and management strategies have traditionally relied on heavy insecticide usage, with adverse effects on human health and the environment. This project aimed to reduce yield losses and to protect farmers' income in intensive rice-cropping systems by developing and promoting sustainable strategies for management of tungro disease. The project has identified appropriate methodologies to reduce yield losses due to tungro in endemic areas, and to protect farmers' incomes from the drastic loss of income that results from a serious attack of the disease. The key management option is the deployment of new disease-resistant varieties. This offers the most practical and sustainable approach in endemic areas. Two tungro-resistant varieties identified through the project were released in 1999 in Indonesia. One of these varieties, Tukad Unda, was quickly adopted by farmers and was grown on 10 000 ha. One tungro-resistant variety has been approved for regional release in the Philippines and others are being used in resistance breeding programmes in India.

ISSUES

Rice tungro disease emerged as a serious problem for rice farmers in the 1960s, as a result of the intensification of rice production during the Green Revolution. Major outbreaks occurred throughout South and South-East Asia, causing serious production losses over wide areas. Large-scale epidemics have become less frequent but still occur: in 1995, for example, a tungro outbreak occurred in central Java, Indonesia, affecting an estimated 18 000 ha of rice and resulting in major economic losses for resource-poor farmers and for the country as a whole.

The dynamics of tungro disease are extremely complex and, until recently, remained poorly understood. Consequently there was no clear strategy to manage the disease, and many of the control measures implemented were inappropriate and ineffective. The use of varieties with resistance to the leafhopper vector has been successful in reducing tungro incidence, but this resistance has not proved to be durable. Farmers have been forced into relying on insecticides, even though they know that this approach had limited efficacy. Many rice farmers depend on credit to purchase inputs; as a result of the lack of effective control measures and high yield losses, farmers have been caught in a debt cycle from which they cannot easily escape.

Results of a previous project (R5243) showed that tungro incidence is not directly related to insect abundance, and that the widely used threshold-based recommendations for control by insecticides could not be justified. Research on disease dynamics revealed that secondary plant-to-plant spread by leafhopper vectors plays an important role in tungro epidemiology.

Developing rice varieties with resistance to the rice tungro spherical virus, rather than to the insect vector, has the potential to dramatically reduce tungro incidence by preventing secondary spread. The most effective way to control tungro was found to be not through tactical measures such as applying insecticides or removing infected rice plants, but rather using a strategic approach involving the use of virus-resistant varieties and the manipulation of planting dates.

This project has built on the previous findings, with the aim of developing and promoting sustainable tungro disease management strategies.

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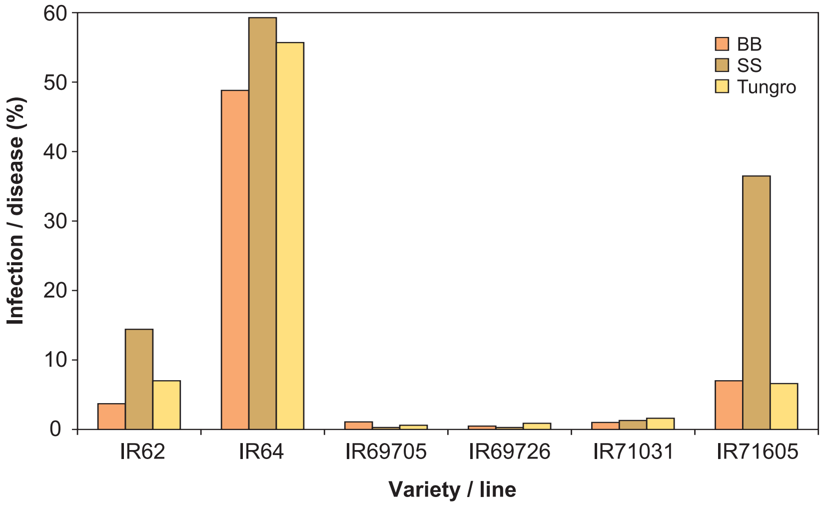

Figure 1. Mean tungro incidence and infection with rice tungro bacilliform (BB) and spherical (SS) viruses in advanced breeding lines and varieties at two sites in the Philippines and one in Indonesia in replicated field trials (1998)

ACHIEVEMENTS

DURABLE RESISTANCE

Advanced breeding lines with resistance to rice tungro viruses developed at the International Rice Research Institute (IRRI) were selected and evaluated in the greenhouse and in multilocation field trials in India, Indonesia and the Philippines. Figure 1 illustrates the performance of four advanced breeding lines at sites in the Philippines and Indonesia in relation to leafhopper-resistant (IR62) and tungro-susceptible (IR64) check varieties. Lines IR69705-1-1-3-2-1 and IR69726-116-1-3 have virus resistance derived from a traditional Indonesian variety, Utri Merah. These lines consistently showed strong resistance to tungro disease at all trial sites. Moreover, IR69726-116-1-3 has an excellent plant type, which is attractive to rice farmers in Indonesia and the Philippines, and has good eating quality and high yield potential. Some of the advanced breeding lines tested showed good resistance at some sites, but only moderate resistance at others. This shows the value of multilocation testing, which is essential for the development of successful resistance deployment strategies.

On-farm trials were conducted in North Cotabato, Philippines and Tamil Nadu, India to assess the performance of promising virus-resistant lines in farmers' fields. Replicated field plots were planted with a virus-resistant or virus-tolerant line, a leafhopper vector-resistant line, and a variety chosen by the farmer and grown in the rest of his or her field. Leafhopper vector numbers, tungro disease incidence and grain yield were recorded. The trials enabled farmers to discover for themselves the value of virus-resistant varieties and to appreciate that insecticide sprays were not needed, even when large numbers of leafhoppers were present in the crop. In one trial in the Philippines, the collaborating farmer bulked up seed of the virus-resistant line IR69705-1-1-3-2-1, and renamed it Line 386. Through a process of exchange and sale among farmers and traders, Line 386 became widely adopted in North Cotabato and the neighbouring province of Maguindanao. In view of the spontaneous uptake of Line 386, the Philippine Rice Research Institute decided to give it their official blessing and distributed seeds to farmers under the name Matatag 3. This informal process of seed dissemination also occurred in Tamil Nadu with IR68305-18-1 which was taken up by farmers and subsequently entered in the State multilocation yield trials.

A simple, reliable and relatively low-cost prototype diagnostic kit for rice tungro bacilliform virus was developed. This should greatly facilitate the resistance breeding work undertaken by researchers in national agricultural research programmes. Previously, researchers had to rely on symptom expression alone and this did not allow them to identify resistance to the individual viruses. The kits will also be useful to agricultural extension staff for early and rapid identification of tungro outbreaks. Test kits were evaluated by selected participants at an international workshop on tungro management conducted in November 1998. The method was then refined and further field evaluation was done in Bangladesh and the Philippines.

On-farm trial in North Cotabato, Philippines: yellow areas, 'farmer choice' (tungro-susceptible) variety showing almost 100% tungro incidence; green areas, leafhopper- and virus-resistant lines showing very low tungro levels

MODELLING STUDIES

Modelling studies were carried out to investigate the dynamics of disease spread between rice fields. A lattice model was developed to examine how the spatio-temporal deployment of resistant varieties could reduce the incidence of rice tungro disease. The model was also used to assess how changes in the synchrony of planting dates affected the incidence of tungro. Figure 2 shows that where planting dates are highly staggered, it is extremely difficult to reduce tungro incidence through cultural measures. However, in situations where the variation in planting dates is not so great, a relatively small move towards synchrony results in a big reduction in tungro disease.

EXTENSION

Surveys of farmers' perceptions of tungro disease and their current control practices were used to develop extension methodologies for improved tungro management.

Two training courses in the identification and management of rice tungro disease were devised for agricultural extension officers and for rice farmers. Courses were conducted in North Cotabato and Tamil Nadu. Selected agricultural extension officers subsequently trained groups of about 30 rice farmers in three villages in North Cotabato and two villages in Tamil Nadu. On-farm trials were used in the training to demonstrate the advantages of resistant varieties and to enable farmers to identify tungro disease, tungro vectors and their natural enemies.

Information obtained from focus group surveys conducted 2 years after the training showed that farmers retained the main messages promoted during the courses. The spontaneous adoption of virus-resistant lines by farmers before clearance for varietal release indicates the potential for their widespread uptake. Farmers understood the importance of synchronizing planting dates to reduce tungro incidence, but were constrained by insufficient and irregular water supplies. However, at a workshop held in Midsayap, Philippines in December 1998, a commitment was made by farmers, agricultural extension officers, local government units and the National Irrigation Authority to improve the scheduling of irrigation water in the municipality. If successful, this would serve as a model for other areas. Reports from Midsayap in the 1999 wet season indicate that a tighter scheduling of irrigation water was achieved, resulting in more synchronous planting and low tungro incidence.

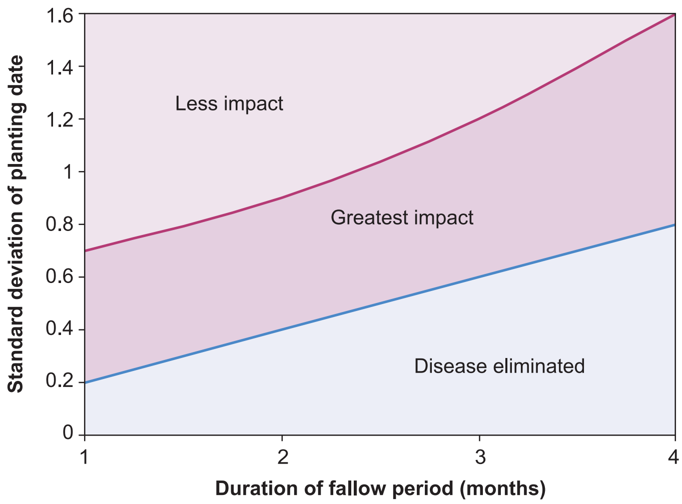

Figure 2. The impact of changes in planting date synchrony depends on the current level of planting synchrony (standard deviation of planting) and the fallow period between successive rice crops. The appropriateness of recommending synchrony changes can thus be evaluated for specific cases

The success of the training led to the production of two training manuals in tungro identification and management aimed at rice farmers and extension workers, respectively. These manuals were used in a training programme conducted by IRRI in June 2000 in Iloilo, Philippines, where a serious tungro outbreak was recorded.

FUTURE

Durable resistance to rice tungro disease offers the most practical, cost-effective and environmentally sound way to stabilize yields and protect farmers' income in intensive production systems where the disease is a major problem. By identifying virus-resistant advanced breeding lines appropriate for particular geographical locations the project has laid the basis for this approach to be implemented. Two lines, IR68305-18-1 (Tukad Unda) and IR69726-116-1-3 (Tukad Petanu) were released in 1999 as approved varieties by the Indonesian government. Tukad Unda was grown on 10 000 ha in Bali and showed good resistance to tungro disease. Line IR69726-29-1-2-2-2 was approved for regional release by the Philippine Seedboard in April 2000, and IR68305-18-1 has been entered in the cooperative yield trials in Tamil Nadu, India. The development of a simple and reliable diagnostic kit has provided rice breeders with a valuable tool to utilize this resistant material in their own breeding programmes. There is strong demand for the kit, and researchers and agricultural extension officers from Bangladesh, India, Indonesia and the Philippines have been trained to use it. The project has contributed to a new emphasis on strategic measures for tungro management in recommendations promoted by national agricultural extension agencies. This has led to a reduced emphasis on insecticide-based tungro control strategies, with consequent benefits for human health and the environment.

Application of mating disruption to control yellow rice stem borer in India

R6739

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Demand for rice production in developing countries is expected to increase by 1.8% per year – this demand can be satisfied only by increased productivity. In many of the rice-growing regions of Asia, and particularly in India, the most economically important insect pest is the yellow stem borer, *Scirpophaga incertulas*. Where yellow stem borer is a perennial pest of economic importance, even with the use of cultural practices and tolerant varieties to suppress pest populations, expensive and environmentally damaging chemical control may be the only course presently available to rice producers. Control of lepidopterous pests by the mating disruption technique, in which mating is suppressed by permeating the air around a crop with female sex pheromone, is now well established in a wide range of crops. A controlled-release formulation has previously been developed and successfully field-tested in India for use in controlling yellow stem borer by mating disruption. A second control technology, mass trapping, was subsequently developed independently by the Directorate of Rice Research. The project described here worked closely with smallholder rice cultivators to investigate whether these technologies could provide a practical and viable crop protection strategy.

ISSUES

The demand for rice production in developing countries is expected to increase by 1.8% per annum. There is little land left to develop in South Asia – in fact the amount of land available for agricultural use is likely to fall because of increased urbanization. To consolidate recent gains in productivity, many Asian countries have recognized the importance of encouraging sustainable production that puts a value on the environmental, social and economic costs of current rice cultivation practices. Excessive use of fertilizers and pesticides could be reduced by adopting need-based use of these inputs, yielding an estimated saving of up to US$2.5 bn.

The yellow stem borer, *Scirpophaga incertulas*, is a major insect pest of rice in Asia, and chemical control is generally regarded as being the only option. The systemic insecticides available to smallholders in India, such as phorate and carbofuran, are relatively cheap and readily available but are invariably toxic to a wide range of organisms apart from the target pests. The indiscriminate use of such insecticides exposes people and domestic animals to these compounds, both during application and through subsequent groundwater contamination. Insecticides can also cause a resurgence of secondary pests by killing predators and parasites that would normally control them. During the rainy season insecticides are generally ineffective as water levels cannot be controlled and pesticides are leached out into the groundwater.

In contrast, pheromones (chemicals secreted by insects that affect members of the same species) are species-specific, have no adverse effects on the environment, are unaffected by rainfall, and would be fully compatible with an integrated pest management (IPM) approach to controlling rice pests in both dry- and wet-season crops. By permeating the air with a synthetic blend of female pheromone components, male moths are prevented from following odour trails of pheromone released by females. This results in a reduced level of mating, or mating disruption, that can lead to a significant reduction in the larval population of the next generation and hence a reduction in the damage sustained by a crop.

A pheromone has been developed for yellow stem borer (R5297; see *Research Highlights 1989–95*). On-farm development trials, conducted

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CORK, A. (1998) Pheromones for control of yellow stem borer in India: does mating disruption meet the needs of the rice cultivator? In *Proceedings of the Sixth Australasian Applied Entomological Research Conference*, September/October 1998, Brisbane, pp. 304–313.

CORK, A. and HALL, D. (1998) Application of pheromones for crop pest management in the Indian sub-continent. *Journal of Asia–Pacific Entomology*, 35–49.

by researchers using prescribed protocols and teams of labourers, have demonstrated that yellow stem borer can be effectively controlled by mating disruption with synthetic sex pheromones (R5747). Mating disruption can provide control in areas as small as 1 ha on smallholder rice cultivators' fields in a range of agro-climatic zones of India, but is effective on a larger scale. Yields may be increased by 50–75% compared to untreated controls, and by 10% compared to plots treated with insecticides. In separate trials the Directorate of Rice Research (DRR) demonstrated that mass trapping with synthetic pheromone was also efficacious. Mass trapping involves catching male moths in pheromone-baited traps to reduce the ability of female moths to mate and lay fertile eggs. The aim of the current project was to validate these technologies as a viable crop protection strategy amongst smallholder rice cultivators.

Farmers engaged in attaching Selibate® YSB pheromone dispensers to bamboo sticks

ACHIEVEMENTS

The challenge facing this project was the validation of yellow stem borer pheromone technology by means of voluntary on-farm trials with a group which constitutes the dominant rice farming community in India – small-scale subsistence farmers. A prerequisite for the successful application of mating disruption and mass trapping was the use of large areas of rice, and since most of the rice grown in India is cultivated in small plots of approximately 0.4 ha or less, this required effective community participation to be fully successful.

Validation is a fundamental step before a science-led technology can be released and promoted on a wider scale. Ideally, validation should take place in the context of currently used farmers' practice, with no financial or other inputs that might influence the outcome of the process. In an attempt to conform to this strategy the project worked closely with farmers in establishing mutually suitable conditions for field trials. Farmers were encouraged to continue with their existing farming practices, the only exception being that farmers participating in the trials would not spray pesticides in trial fields, a condition to which they initially agreed.

Four villages were selected for on-farm trials. The farmers in these villages identified the damage caused by stem borers as a major problem affecting their rice, and were prepared to participate in trials to test the new technologies under offer. Villagers selected groups of farmers who would provide blocks of land for the trials and they applied the pheromone under the direction of participating NGOs. Farmers later indicated that the application of pheromone traps and dispensers was not a burden for them.

NGO staff and labourers recruited from participating villages were trained to collect field data and assist social anthropologists in interviews with farmers, with varying levels of success. Interviews with farmers generated important background information on farmers' understanding of pests and existing pest control strategies. There was little local understanding of the concept of natural predators. Farmers generally sprayed a range of pesticides when they saw any insects in the rice field. All insects were assumed to be harmful, and no distinction was made between the damage caused by fungi, bacteria, or viruses, or that caused by insects.

Farmers applied between one and seven applications of pesticide per season depending on the season and village sampled. The average cost of one pesticide application was comparable to the cost of applying mass trapping to control yellow stem borer for the whole season. Thus if yellow stem borer was perceived as a potential threat to a crop, mass trapping would represent a cost-effective means of control. However, these low costs were only possible because of indigenous production of traps and lures; the formulation used for mating disruption is currently manufactured in the UK and is subject to an import tax of 50% that makes its use in India prohibitively expensive.

For a range of reasons most farmers were unwilling to refrain from using pesticides in trial areas. The constant use of pesticides by most farmers compromised their ability to test the technology on offer effectively. In no field trial

A farmer and children walking to fields to 'plant' the pheromone dispensers

was pesticide use sufficiently restricted to allow farmers to fully appreciate the impact of the new control technologies on stem borer damage. While it would seem desirable to have initially developed the pheromone technology under tests with the same level of farmer participation, it was evident from these trials that this would not have been possible without of some form of compensation package being agreed.

A range of factors appear to have influenced the farmers' behaviour in the context of this project and should be taken into account in future projects. These include indigenous beliefs about pests; aversion to risk; lack of understanding of the new technology; and poor communication of the project aims and approach by intermediaries. Other constraints were also found to affect farmers' adoption of new practices, for example, farmers in Kakinada were well aware that they were applying too much pesticide, and this was borne out by the low incidence of almost all arthropod species in field samples. The resulting loss of predators from the rice fields subsequently resulted in high planthopper populations. The farmers had been instructed on how best to spray the planthoppers to achieve control, but as this was more labour-intensive than their conventional practice they did not act on the advice.

Pheromone technology presents an interesting case concerning gender and pest management practices. It is not exactly clear why although the concept of pheromone technology was introduced to both men and women, only men took responsibility for its practical application. If men are conventionally responsible for applying pesticides because of the health risks to women, then pheromone technology offers an opportunity for increasing women's involvement in pest management strategies as it does not pose a threat to human health. If other factors were influencing men's control over pest management technologies, then involving women in the decision-making process on the choices of and need for pest control interventions becomes a more complex task.

The project raised important issues concerning farmer participatory validation methods. Providing farmers with demonstration trials would have helped them to see how the technology would benefit them. Alternatively, farmers using their own land for the trials could have been compensated for any loss to their yield caused by using pheromones instead of pesticides.

Other lessons learned included:

- a need for effective and rapid communication among stakeholders in order to build an effective partnership in farmer participatory projects
- researchers should be sensitive to farmers' comments and respond to their suggestions
- despite farmers' assurances, they are not necessarily prepared to risk their livelihoods to test new technologies
- IPM component technologies can be tested by farmers only if adequate provision is made to address other crop protection issues
- intermediaries need to have the capability of providing participating farmers with training in crop protection and other IPM-related issues
- the problem to be addressed in the project has to be of sufficient importance to farmers for them to fully participate in the evaluations.

FUTURE

During the course of the project, efforts were made to encourage companies known to be involved in the production of biorational control technologies to consider producing and marketing pheromone products for control of yellow stem borer, and representatives from two such companies attended the project workshop. Given the high level of interest in the Indian Council of Agricultural Research (ICAR) and associated institutes, and a positive response from industry, it is conceivable that a major effort will be launched through the Government system to promote mass trapping of yellow stem borer as part of an IPM package of technologies for controlling rice pests.

The Pakistan–UK fruit fly project

R6924, R7447

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September 1997–February 2000

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STONEHOUSE, J.M., MUMFORD, J.D. and MUSTAFA, G. (1998) Economic losses to Tephritid fruit flies (Diptera: Tephritidae) in Pakistan. *Crop Protection* **17**: 159–164.

AFZAL, M., MAHMOOD, R. and STONEHOUSE, J.M. (2001) Soaked-wood killer blocks for MAT fruit fly control in Pakistan. In: Price, N. (ed.) *Proceedings of the Symposium on The Fruit Flies of the Indian Ocean Region*, Mauritius, June 2000. Port Louis, Mauritius: Ministry of Agriculture, Food Technology & Natural Resources/Indian Ocean Commission/EU Indian Ocean Regional Applied Fruit Fly Research Programme (in press).

HAI, M.A., MAHMOOD, R. and STONEHOUSE, J.M. (2001) Fruit flies in plums in North-West Frontier Province: development, attack and drop. In: Price, N. (ed.) *ibid.* (in press).

MAHMOOD, R., BALOCH, K.N., MAKHDUM, A.H., CHAUDHARY, Z.M., MUSTAFA, G. and STONEHOUSE, J.M. (2001) Fruit flies in Pakistan: damage and control in farmers' fields. In: Price, N. (ed.) *ibid.* (in press).

ZIA, Q., MAHMOOD, R. and STONEHOUSE, J.M. (2001) Laboratory and field tests of home-made baits of animal protein. In: Price, N. (ed.) *ibid.* (in press).

Fruit flies, principally *Bactrocera* spp., are serious pests of fruit and vegetables in Pakistan, causing annual losses of nearly US$200 million. The aim of this research was to develop cost-effective and accessible technologies for the assessment and control of fruit fly damage in Pakistan. Two control methods, the bait application technique and the male annihilation technique, were assessed: overall average reductions in infestation losses ranged from 75 to 100%, and these methods were as good as, if not better than, cover sprays, to which they are decidedly preferable for reasons of cost, safety and environmental contamination. As well as reductions in fruit infestation, the trial data show increases in the overall density of fruit production, suggesting that percentage infestation data of sampled fruit have underestimated true economic losses.The findings of this research will improve the volume and quality of fruit production, and thus incomes and nutrition, in ways that are cost-effective, accessible and environmentally benign.

ISSUES

Pakistan is a predominantly agricultural country. Its population is growing at the fastest rate of any major Asian nation, and is projected to become the world's third largest by 2050. It will therefore be necessary to maximize farm yields per unit area, and to develop high-value crops such as fruit. Tephritid fruit flies, principally *Bactrocera* spp. (previously called *Dacus* spp.), are estimated to cause annual losses of nearly US$200 million at farm level, including 15% of mangoes (annually $40 million), 35% of guavas ($46 million) and 35% of melons ($46 million). Fly attacks have led to the virtual abandonment of guava cultivation in Sind and, together with apricot, in the Islamabad/Rawalpindi area.

The principal pests are in the species or species complexes of the oriental fruit fly *B. dorsalis*, the peach fruit fly *B. zonata*, and the melon fly *B. cucurbitae*. There is a need for more complete information on which flies are found where: in general the distribution of fly species, and their movements within Pakistan with seasonal changes in weather and vegetation fruiting, are incompletely mapped. This research aimed to quantify levels and patterns of damage, and to assess the prospects for two control methods, the bait application technique (BAT) and male annihilation technique (MAT), which use less than 10% of the pesticide in the cover sprays currently in widespread use.

ACHIEVEMENTS

Fruit fly losses were assessed in farmers' fields of guava, melon, jujube and mango in four areas under different control regimes, by the percentage season-end fly infestation of sampled fruit, and the density of fruit on trees relative to those fallen to the ground.
In guava, infestation was 80% in unprotected orchards, 40% in an orchard protected by cover sprays, and 17% in orchards protected by BAT; fruit on trees per unit volume of tree canopy were 51.5% of the total in unprotected and 59.7% in BAT orchards. In jujube, infestation was 43% in unprotected and 3% in BAT orchards, and 3.7% of unprotected and 12.7% of BAT-protected fruit remained on the tree. In melon, fly infestation was 26% in unprotected and 3% in BAT fields. Fifteen farmer-managed trials found BAT-treated melon fields yielded 36% more than unprotected. In all trials, farmers gave very favourable reports of BAT. Smaller-scale trials on luffa and persimmon were inconclusive, probably due to late starts. MAT by wood blocks soaked in lure mixed with insecticide is less expensive, cumbersome and time-consuming than the plastic traps in current use. In late-season mango, percentage

A ber (jujube) orchard in Khanpur, Punjab, March 1999, the site of an informal, farmer-managed trial of protein bait sprays against fruit flies. This farmer tried a single BAT spray instead of his usual three cover insecticide sprays; the first cover spray was ineffective (it may have washed off in rain), and the bait spray was so successful that the other insecticide sprays were abandoned. The fruit yield was so high that the tree branches were bowed and even broken by the weight

infestation before harvest was 20% in an unprotected plot and 0% in one protected by soaked blocks; 43.8% of fruit were on the tree in unprotected orchards, and 46.7% in MAT orchards. Attacks by fruit flies in early-season mango were limited, but also reduced.

The overall average reductions in infestation losses implied by these trials were 75% for guava by BAT, 93% for jujube by BAT, 86% for melon by BAT, and 100% for mango by MAT. If the estimated savings obtained by these experiments are applied to the loss estimates above, the resulting annual gross savings (excluding costs) at farm level for the whole of Pakistan would be $40 million in mangoes, $35 million in guavas and $40 million in melons, or $115 million annually for these three crops.

The distribution of attacks was also assessed in these trials. Fly maggots were not evenly distributed among fruit, but clustered in relatively few heavily infested fruits, differing significantly from a Poisson (random) distribution. But the number of maggots per infested fruit remained relatively constant, so that the frequency of fruit infested was a direct function of the total number of maggots present, suggesting a constant economic return from control measures regardless of the intensity of fly attack.

In a separate experiment monitoring the development of infestation in plum orchards, attack was predominantly during early ripening of fruit, and tended to the west-facing parts of trees, possibly because they are sunlit when flies are active at dusk. Fly attacks were on 23% of fruit in unprotected plots and 13% in protected plots, and additionally fruit in unprotected plots were significantly likelier to fall from the tree prematurely, even though not visibly attacked, and these falls took place before the main period of fly oviposition. Attacked fruit developed to the point of disintegration slightly more quickly than unattacked fruit. More mature, developed fruit were not more likely to be attacked by flies.

Modifications of BAT and MAT were evaluated in laboratory and field studies on the effectiveness of individual 'killing points' of bait or lure by recovering flies attracted and killed. Laboratory studies were in choice chambers specially developed by this project for assessment of the relative attraction and killing power of BAT mixtures. Field studies were by catching bags below killing points to record flies killed, calibrated to total kill by a descending tier of increasingly wider bags to allow the fall of dead flies away from the killing point to be mathematically modelled. Assessed by both methods, BAT with a home-made meat broth had approximately 71% of the effectiveness per unit volume of commercial protein hydrolysate, and application by brushes was as effective as by a sprayer, although there may be a substantial health risk from the mixing of insecticide with a meat broth, which is prepared in a way similar to a food product. Soaked wood MAT blocks, on average, killed over three times more flies and lasted over twice as long as the plastic lure-baited traps currently recommended and used in Pakistan.

FUTURE

This work is still very much in progress, with Pakistani partners engaged in substantial research work, including further field trials, studies on the male annihilation technique, and an expansion of the programme of informal, farmer-managed trials. Information about the project's activities, findings and recommendations has been distributed to participating extension services, and to officials at senior levels in the Pakistan Agricultural Research Council.

Sustainable management of the whitefly, *Bemisia tabaci*, and tomato leaf curl virus (ToLCV) on tomato in India

R6627

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The whitefly *Bemisia tabaci* is currently the most serious pest of tomato in India, causing direct damage as well as transmitting tomato leaf curl virus. When populations of the whitefly are high, over 90% of plants can become infected, resulting in yield losses that may reach 100%. Farmers surveyed did not recognize the whitefly as the source of the virus disease, and responded by applying pesticides which are both costly and, in this case, ineffectual. A number of options for alternative pest management strategies were studied. New tomato lines resistant to the virus disease were developed, and show the most promise for sustainable control. This was the output in which tomato farmers expressed the greatest interest.

ISSUES

In the recent past, over-reliance on conventional insecticides in vegetable and cotton production has resulted in the evolution of several new, highly resistant biotypes of whitefly (*Bemisia tabaci*). These 'aggressive' strains outcompete the original biotypes, are highly mobile and, worldwide, cause hundreds of millions of pounds worth of damage annually. The development of alternative management practices is vitally important both to prevent the evolution of more aggressive biotypes, and to cope with those already in existence.

In India, tomato is both a high-value crop which is exported to the Middle East, and an important subsistence vegetable grown mainly by women. *Bemisia tabaci* is currently the most serious pest, causing direct damage as well as transmitting tomato leaf curl virus (ToLCV). When whitefly populations are high, over 90% of plants can become infected, resulting in a yield loss of 40–100%. Disease symptoms are particularly severe if the plants are infected at an early stage of development. With associated risks to both their health and the environment, farmers currently use large quantities of costly broad-spectrum insecticides in increasingly unsuccessful attempts to control *B. tabaci* and ToLCV.

In response to this potentially devastating problem, the University of Agricultural Sciences, Bangalore (UASB) initiated a research programme to introduce ToLCV resistance genes into edible tomatoes through conventional plant breeding techniques.

The aim of this project was to develop and promote sustainable and cost-effective management practices for the tomato pest *B. tabaci* and the virus disease ToLCV, thereby improving both the quantity and quality of Indian tomato production. The project builds on previous work on insecticide-resistant whitefly in Pakistan (R5699; see *Research Highlights 1989–95*).

ACHIEVEMENTS

RESISTANCE SCREENING

Resistance to ToLCV is an extremely important component of the IPM recommendations for tomato production.

Screening in both the glasshouse and field was carried out during five field seasons and several very promising lines are being developed. F_5 lines currently in the field have shown excellent resistance and will be rescreened in the next field season when they will experience the most intense disease pressure.

Seven genotypes which performed well with respect to fruit yield and other horticultural characters were selected for further field trials (see Table 1). The opinions of tomato growers were obtained during the

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RAMAPPA, H.K., MUNIYAPPA, V. and COLVIN, J. (1998) The contribution of tomato and alternative host plants to tomato leaf curl virus inoculum pressure in different areas of south India. *Annals of Applied Biology*, **133**: 187–198.

HOLT, J., COLVIN, J. and MUNIYAPPA, V. (1999) Identifying control strategies for tomato leaf curl virus disease using an epidemiological model. *Journal of Applied Ecology* **36**: 625–633.

Table 1. Fruit characteristics of selected ToLCV-resistant lines

TLB No.	Fruit characters
111	Round shaped, slightly less than medium sized fruits, good yielding
119	Round shaped, medium sized fruits (70–90 g), deep red, high yielding
122	Round shape, more than medium sized fruits, deep red colour, high yielding, more foliage
129	Oblong shape, light red, nipple at the basal end of the fruit, high yielding; good in other characters such as fruits / cluster, more foliage etc, except the shape of the fruits
130	Round shaped, medium sized fruits, high yielding
134	Oval shaped, medium sized fruits and deep red colour, high yielding and good taste
148	Oval shape, deep red above, medium sized fruits, good yielding

end-of-project farmer-field day/ workshop. The farmers evaluated F_5 lines by considering resistance to ToLCV, foliage of plants, fruit bearing, size of the fruit, shape of the fruit, transportability, marketability, firmness of fruit and thickness of the skin and taste of the fruits. At least two of the lines looked very promising and also fulfilled the farmers' horticultural requirements.

These seven ToLCV-resistant genotypes will go on to multilocation on-station trials in the Bangalore area. This work is planned for the next phase of the project. This is the first time systemic ToLCV resistance has been successfully introduced into tomato lines with acceptable horticultural characteristics in India, and the demand for these new varieties from all stakeholders is clearly evident.

The use of these genotypes will be a sustainable resource for poor farmers as, unlike hybrid varieties, they are true-breeding and seeds can be collected for use in the following season. Further benefits include cost savings from the reductions in pesticide use, improvements to farmers' health, and reductions in environmental pollution and pesticide residues in tomato-based products.

PARASITOIDS AND PREDATORS

Insects attacking *B. tabaci*, both parasitoids and predators, were collected in Karnataka, identified and mass-produced for field trials. The parasitoid species identified included *Encarsia transvena*, *E. adrianae* and *Eretmocerus mundus*. Among many predators found in tomato fields, *Axinoscymnus puttarudriahi* was very common. Colonies of several species were established and the insects were mass-reared. These were then used in a mass-release experiment to determine whether they could be used to control the *B. tabaci* population and influence ToLCV spread.

Unexpectedly, the numbers of immature *B. tabaci* developing on the tomato crop before release were relatively low. The beneficial insects which feed and develop on the immature stages of *B. tabaci* had a limited effect on the *B. tabaci* population within the tomato crop, and there was almost no effect on the spread of ToLCV. This was found to be because almost all the spread of ToLCV into a susceptible tomato crop is caused by virus-carrying adult *B. tabaci* coming into the crop from outside. This finding has both increased our understanding of the pathosystem, and aided the formulation of sustainable IPM recommendations.

The data showed that tomato yields and disease spread were similar in the treated and control plots. In plots where beneficial insects were released, the yield was just significantly higher, although this result is hard to explain in terms of disease progression within the crop. These results suggest that given the effort involved in the mass production of predators and parasitoids, the returns to be obtained in terms of increased tomato yield are neligible.

However, augmentation of beneficial insects did produce an increase in the final tomato yield which was achieved without applying any chemical sprays. This finding is important in that it demonstrates the value of at least preserving the complex of beneficial insects within the crop, as they also prevented any other major insect pests such as *Helicoverpa armigera* from causing damage. This work was carried out by Mr Venkatesh towards his PhD.

MYCOPESTICIDES

Fungal isolates were collected both from the field and from the Institute of Mycology, Chandigargh, India, and mass-produced for field trials. The pathogens *Beauveria bassiana* and *Verticillium lecanii* performed well, and *B. bassiana* gave similar yield results to the currently recommended conventional insecticide Hostathion (triazophos). The *B. bassiana* treatment using material that was mass-produced at UASB gave better results than the commercially available mycopesticide Biorin.

In the laboratory, bioassays showed that both *B. bassiana* and *V. lecanii* were very effective against all stages of *B. tabaci* except the egg. A major limitation was that they also attacked parasitized *B. tabaci* nymphs and the adult stages of beneficial insects; in this regard their effect was not unlike a broad-spectrum conventional insecticide, and widespread use would probably affect the local silk industry. Other limitations were that efficacy would be reduced by fungicides which are often sprayed by farmers, and control is currently not noticably better than achieved with a conventional insecticide, which may impede its adoption by local farmers. This work was carried out by Dr Anita Cherian towards her PhD.

SIMULATION MODEL

Epidemiological data were collected and incorporated into a mathematical model that was used to assess and identify potential novel control techniques. Those that increased and decreased the vector emigration and immigration rate, respectively, had the greatest potential for reducing the spread of the disease (see Selected publications).

FARMERS' PERCEPTIONS AND MANAGEMENT PRACTICES

A large survey was carried out of farmers' perceptions and management practices related to *B. tabaci* and ToLCV, and the socio-economic factors affecting the adoption of new varieties and IPM management strategies. The study consisted of group and individual discussions with farmers, plus a structured questionnaire survey of 174 farmers in 15 locations. ToLCV was known by a variety of local names. Approximately 97% rated ToLCV as their most important tomato disease, but they were largely unaware that it was transmitted by *B. tabaci*. Most associated the disease with hot weather, and thought that high temperature was the cause. 11.5% of farmers did think that insects were involved in causing or spreading the disease, but only four farmers knew that whiteflies were the disease vector.

Farmers' stated methods of controlling ToLCV were based on using chemicals. However, many were aware that infected tomato plants did not recover after spraying. Other diseases reported included leaf spots, wilt, blight, various forms of rots, powdery mildew and damping off. Fruit borers and leaf miners were also important pests.

Questions on general pesticide use revealed that the application of chemicals was the most commonly reported pest management practice, and farmers sprayed up to 25 times in a season with a mixture of chemicals. Only one farmer said he did not apply chemicals. Over 75% of farmers knew the brand names of the chemicals they were using but it was not clear how many knew much about the active ingredients; for example, a few were using mixtures of very similar chemicals. Few non-chemical pest management methods were reported by farmers.

Other farmers were said to be the main source of information on farming; over half the farmers obtained information from pesticide dealers, particularly on which chemicals to buy. The media was another important resource. Extension staff were not seen as the main source of information by most farmers.

Farmer field trials were carried out looking at the effect of netting-covered nurseries. All the farmers experienced increased yield due to the netting and felt that it was a good technique. They were also very keen to obtain ToLCV-resistant varieties.

RECOMMENDATIONS

Recommendations for pest management practices were formulated in the light of the project's experimental results and farmers' views. An information leaflet containing the IPM recommendations has been published in Kannada, the local language of Karnataka State, South India, and has been given to researchers, extension workers and farmers. This leaflet continues to be freely available.

How can Tomato Leaf Curl Disease be prevented?

In the nursery:

Use a nylon net to cover the seedbed and stop whitefly from reaching the seedlings

Use a small (40) mesh nylon net

Make a frame to support the net

Cover the seedbed completely, making sure there are no gaps where the whitefly could enter

Make sure there are no holes in the net

To prevent the whitefly reaching the seedlings, do not raise the sides of the net at any time

In the main field:

No chemical can cure a plant once it is sick with Tomato Leaf Curl Disease However, spraying with insecticide can kill the whitefly and therefore delay the spread of the disease from one plant to another

Spray within 3 days after transplanting with an approved insecticide such as Confidor (or Hostathion)

Alternatives to conventional insecticides are Neem, Neem extract (Neemark) and mycopesticides such as Biorin

Spray again 8 days after transplanting

Note: Fungicides (for example Dithane) will have no effect on Tomato Leaf Curl Disease

Spraying late in the season (after 35 days after transplanting) will have no effect on Tomato Leaf Curl Disease

Translated excerpt from IPM recommendations distributed to farmers in Karnataka

FUTURE

The project's IPM recommendations have been given to UASB's Directorate of Extension and the State Horticultural Department for dissemination. In the next phase (R7460) it is intended that the ToLCV-resistant genotypes will undergo multilocation and farm trials. If these are successful, these genotypes will be officially released for general cultivation in Karnataka. It is highly probable that these genotypes could also be grown in other parts of India. Ultimately there will be benefits in other regions where *B. tabaci* and ToLCV cause serious losses: North Africa, the Middle East, the Caribbean and Central/South America.

Use of insect viruses to control *Helicoverpa*

R5540, R7004

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The widespread appearance in the late 1980s of resistance to chemical pesticides by the American bollworm (*Helicoverpa armigera*) means that the pest now poses a major threat to food security and farm incomes in India and elsewhere in South Asia. An alternative to synthetic chemical insecticides is the use of indigenous natural control agents. The most promising of these is a virus, the *H. armigera* nuclear polyhedrosis virus (NPV). Strains of this highly specific virus isolated from India are infective and lethal to this pest, yet are completely safe for man, animals and even other insects. Attempts to promote the use of biological pesticide products from NPV in India began in the early 1980s, but were held back by the poor quality and unreliability of locally produced NPV pesticides. Earlier projects have provided training courses for local scientists and commercial producers in improved production and quality control techniques. Since then, commercial production has expanded rapidly and a marked improvement in the quality of products has been seen. The first regulations incorporating NPV products under the Pesticides legislation and setting national standards in India will be enacted in 2000, and continue the ongoing effort to improve the quality of locally produced biological pesticides. The projects described here have built on earlier efforts to lay the groundwork for in-country researchers to develop effective biological pesticides, as well as helping to establish a new biotechnology industry producing cheap and safe pest control products.

ISSUES

A major problem in the whole of southern Asia is the widespread appearance in key pests of resistance to chemical insecticides. Among the most important pests showing resistance is the podborer or American bollworm, *Helicoverpa armigera*. This is a major pest of cotton, legumes such as chickpea, gram and pigeonpea, and vegetables including tomatoes and chillies. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and a number of national agricultural research services have identified *H. armigera* as the single most damaging insect on cotton and legumes in the Indian subcontinent and the major pest constraint to increased production. It is also an important pest in other south Asian countries.

Currently on much of the Indian subcontinent only the young larvae less than 7 days old are at all susceptible to insecticides. To control this pest, farmers must spray crops as often as every week during the growing season, often spraying mixtures of pesticides at two to three times the recommended dose in an attempt to overcome the pest resistance. This strategy is often ineffective and results in serious overuse of pesticides. In addition to the damaging environmental effects of pesticide overuse, the costs of crop protection are higher for small-scale farmers who often have to borrow to pay for inputs. If serious crop losses occur despite their efforts, farmers are often left with debts.

An alternative to chemical control is the use of natural control agents. The most promising is a specific insect virus pathogenic to *H. armigera*: the nuclear polyhedrosis virus (NPV). The *H. armigera* NPV (HaNPV) is under development as a commercial biopesticide in a number of countries including the UK, USA, Australia and Thailand.

Work carried out at Tamil Nadu Agricultural University (TNAU) in India prior to 1992 had shown that HaNPV was a potentially viable crop protection agent, but they lacked the expertise to produce standardized, stable formulations of the NPV that would be appropriate for farmers. Their product was a simple liquid suspension which, if not stored in a deep freezer, fermented giving it a highly offensive odour which seriously discouraged many farmers. The absence of standardized, stable formulations of HaNPV and the resulting variability was also identified by farmers as a major problem.

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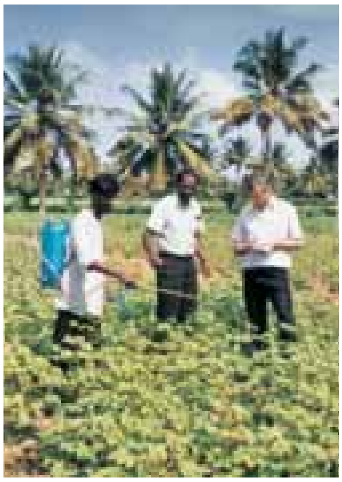
Left, workers in India are trained in the production of virus formulations; above and right, spray application of HaNPV in the field



This project builds on previous work developing NPV formulations (R5268/69/70; see *Research Highlights 1989–95*), and studies of mass production *in vivo* and field testing in Thailand (R5290). The aims were to set up a new insect virus formulation facility at TNAU to produce improved standardized formulations of HaNPV; to equip, commission, and train staff for a DNA analysis laboratory to enable NPVs to be identified to strain level; to train staff in NPV formulation procedures and commission an NPV formulations laboratory at TNAU; to train staff in quality control procedures and set up a quality control laboratory; to build up a stock of 100 ha equivalent of HaNPV; to provide NPV and technical assistance for use in the IPM cotton trials being undertaken at ICRISAT in 1995 to demonstrate new *H. armigera* management strategies to farmers (R6734; see page 95); and to hold a training course at ICRISAT, Patancheru for local commercial virus producers and extension service personnel.

The emphasis on NPV processing and formulation was designed to complement two major Government of India-funded projects to develop improved NPV production techniques.

ACHIEVEMENTS

The DNA analysis laboratory was commissioned in March 1995. This is the first laboratory dedicated to insect virus identification in India. Staff were trained both in the UK and at TNAU, and the first profiles were produced in India in March 1995. Although most of the equipment and consumables were initially supplied from the UK, considerable efforts have been made to identify local sources to ensure sustainability.

A database of NPV profiles and a gene bank of standard strains was also set up, and it is intended that this work will continue. The laboratory profiles any insect virus on request, and a number of research and extension groups have already utilized this diagnostic service, either to identify potential pathogens or to check the purity of NPV products they intend to use.

Setting up the DNA laboratory posed some unexpected technical difficulties. The main problem was that the electrical power supply was prone to severe voltage fluctuations and frequent power cuts. Voltage fluctuations mean most modern microprocessor-controlled molecular biology apparatus is unable to function; power cuts make long electrophoresis runs and cold storage difficult. It was therefore necessary to select simple, mechanically controlled equipment that can tolerate these power fluctuations; to provide battery back-up; and to adopt practical measures such as storing sensitive restriction enzymes in insulated labtop coolers inside freezers. Due to delays in building the new quality control laboratory, the production target of a stockpile of 100 ha of HaNPV was not met in full. However by starting work in temporary facilities a stock of NPV for 70 ha was produced.

HaNPV formulations from this project are the first NPV products with guaranteed activity available in India. These have been used in IPM trials at TNAU, and NPV formulation was supplied in 1995 to the legumes IPM project based at ICRISAT. In addition, NPV has been made available for crop protection trials at the Central Institute of Cotton Research, Coimbatore, and the Banaras Hindu University (BHU), Varanasi, India.

One serious limitation is the problem of NPV mass production. The methods currently in use at TNAU, while they produce a very good quality product, are far too time-consuming and expensive to be the basis of a commercial mass-production system. Two Government of India projects at TNAU aimed to develop a practical system but have so far been unsuccessful. One of the most important outputs has been for TNAU to produce high-purity NPV for distribution to commercial producers as seed stock. This has directly improved the poor quality of NPV previously sold by commercial producers.

The provision of NPV to CGIAR centres, NARS, Indian Council of Agricultural Research (ICAR) and agricultural extension service staff has provided high-quality NPV formulations for the use of researchers and agricultural extension workers in India for the first time. This should promote the use of biopesticides, with a consequent reduction in pesticide use leading to reduced costs to farmers, and environmental and health benefits.

Glasshouse trials indicated that while the current recommended application rates were justified on tomato and pigeonpea, on cotton the recommended rate might be reduced, and on chickpea it was not effective. The objective of a further 1-year project (R7004) was thus to carry out field trials on the application efficacy and persistence of HaNPV on these crops in India, obtaining quantitative field data for the first time.

Application and persistence trials were completed on cotton (in collaboration with project R6734; see page 95), tomato, chickpea and pigeonpea. This work confirmed that the efficacy and persistence of HaNPV in the field is significantly affected by the nature of the crop, and this effect needs to be quantified before recommendations can be developed. While the prospects for succesful use of NPV on tomato are good, its use on cotton may be more problematic as higher application rates are needed for good larval kills. Its use on chickpea and pigeonpea will need further consideration, the former because of doubts about its effectiveness, and the latter because of poor persistence. Before NPV use on these crops is promoted to farmers, field trials should be carried out in a number of different climatic zones in India to validate the proposed application rates.

The new formulations laboratory enables Indian researchers to produce and test new NPV formulations with the aim of improving the storage, persistence and rainfastness of the NPV. The provision of these high-quality NPVs has stimulated ICRISAT in developing HaNPV as an IPM agent for a number of key legume crops. As part of the Indian Government's biocontrol research programme, a series of national trials of NPV on legumes is being run at TNAU. This will provide an opportunity to test the recommendations for NPV use on a national scale using improved field trial protocols. The ICRISAT legumes programme has proposed further collaboration with TNAU/NRI to continue this work by developing new NPV biopesticide formulations for control of a number of other target pests, including *Amsecta albistriga* and *Maruca testulalis*.

A range of HaNPV products are now commercially available, and a number are being marketed via the Internet.

The viral diagnostic facility and database for HaNPV and other NPVs will be of major assistance in development of new and improved strains for IPM of *H. armigera* and other pests. There is an agreement in place to use the facilities of the DNA laboratory to support a DFID-funded project based at Kerala Research Station on the development of NPV for control of the teak defoliator, *Helicoverpa pura* (R6295).

The quality control facility at TNAU provides a model for a national standards laboratory for viral biopesticides. The work on determining the scope of the problem of bacterial contamination in HaNPV will underpin setting national standards for NPV products in India.

Prior to this project, training for commercial and other producers of NPV was one of the most important needs. Many producers lacked the knowledge to produce consistent quality products. As a result the quality of NPV products varied wildly and many were totally ineffective, and Government regulatory agencies lacked the technical know-how to test products.

The provision of certified pure strains of NPV from TNAU as the seed stock for commercial production has improved the quality of Indian-produced NPV biopesticides. Following the work of these projects the biological pesticides sector in India expanded rapidly after 1996, and by 1998 33 companies, state enterprises or other organizations had been registered with the government of India as suppliers of *H. armigera* NPV pesticides. Many of these had sent staff to the training courses funded by the CPP during 1994–96 to promote improved production and quality control techniques. Some NGOs and farmers' groups have established simple, low-tech production of viruses as a small-scale cottage industry. In Thailand, too, commercial biopesticide products have been registered and are now on sale to farmers.

FUTURE

In 1999 the CPP funded a further study of the biopesticides sector in India and Thailand (R7299), to help promote the improved uptake and marketing of biological pesticides. An initial survey has confirmed the successful development of local production in both countries, and will go on to look at the socio-economic, regulatory and technical factors that contribute to successful uptake. This will identify environments and policies that encourage the use of biopesticides and stimulate the establishment of local production. The information generated will be disseminated to producers, state organizations, agricultural extension services, scientists and NGOs in both countries to further stimulate adoption of biological pesticides. The lessons learned will also be of value to other developing countries in Asia and Africa where the development of local biopesticides has the potential to provide poor farmers with cheap control techniques against insect pests resistant to conventional chemicals.

Detection, identification and epidemiology of mycoplasma-like organisms (MLOs) associated with little leaf of sweet potato (*Ipomoea batatas*)

R5881, R5885

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Little leaf, witches' broom or 'ishuku-byo' disease of sweet potato is widespread in Asia, South-East Asia, Australia and the western Pacific, and on occasion can lead to almost total yield loss. This project has improved knowledge of the diversity and host range of the disease, allowing local cultivars with stable disease resistance to be identified for immediate use by local farmers. Infected planting material is important in the dissemination of little leaf mycoplasma, and practical diagnostic techniques have been developed which will be of value primarily to international and local crop protection programmes concerned with developing management strategies for the disease. In the long term the beneficiaries will be sweet potato smallholder farmers in the region.

ISSUES

Of the world's root and tuber crops, sweet potato is second in importance only to white potato, and 97% of world production is from developing countries. Sweet potato little leaf mycoplasma, caused by a mycoplasma-like organism (MLO), has been recorded on the crop in more than 12 countries throughout Asia and the Pacific. Leaves are yellowed and significantly reduced in size, resulting in weak, stunted plants with few or no harvestable tubers. Yield losses of 30–90% have been recorded, and are particularly severe in dry years. Infected planting material is important in the dissemination of little leaf mycoplasma, and as the pathogen has a very long latent period – up to 283 days by graft transmission – infected planting material can appear healthy, making detection difficult.

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ACHIEVEMENTS

Detailed information was obtained on the geographic distribution of the disease, and on the molecular and serological characteristics of isolates from different geographic regions and their cross-reactions with other related phytoplasmas. This information was used to develop rapid, sensitive screening procedures for use by field operatives and research technicians.

Polyclonal antibodies have been produced to a New Caledonia sweet potato little leaf isolate (NC1), and oligonucleotide-specific primers (SP3A/4B) for use in PCR investigations were obtained from a random-cloned DNA fragment.

Detection of field infection was possible by ELISA using NC1polyclonal antibodies, but was not reliable or consistent. ELISA is not recommended as a method of screening for infection. Not all sweet potato little leaf isolates could be detected by PCR with SP3A/4B primers, so the use of these primers to detect sweet potato little leaf in field samples is unreliable and is not recommended.

A simple, rapid screen for the presence of phytoplasma in sweet potato samples comprised (i) squashing tissue between glass slides, (ii) adding two drops of the DNA stain DAPI, and (iii) examining the squash by UV fluorescence microscopy. The phytoplasmas show as brightly fluorescing spots in the phloem cells. This test cannot discriminate among different phytoplasmas, and is recommended only for detecting the presence of phytoplasma.

A plate-capture PCR (PC-PCR) procedure was developed as a simple, sensitive and rapid method for detecting phytoplasma in plant or insect extracts. As with the DAPI staining procedure, this test is not able to discriminate among different phytoplasmas. However, when necessary the amplification product can be analysed further using fingerprinting techniques such as restriction fragment length polymorphism (RFLP).

FUTURE

Information on the spread of the disease from weeds and in sweet potato planting material will allow improved phytosanitary practices to be introduced to farmers through the International Potato Center (CIP) and, in particular, its South-East Asian Program for Potato Research and Development (SAPPRAD), regional programmes and national extension officers.

The procedures and reagents developed will be useful to any future investigations on the epidemiology of the disease. The PC-PCR procedure is being evaluated in a separate project (R7318) to improve field testing and identification of corn stunt spiroplasma and maize bushy stunt phytoplasma in the corn stunt disease complex in Mexico.

Sustainable insect pest management in Indian cotton

R6734, R6760

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R6760
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Throughout the cotton-growing areas of India, intensified production, increased use of irrigation and the excessive use of pesticides have led to the major cotton pests evolving resistance to the chemicals used against them: for example, resistance to common pyrethroids used in bollworm control can reach close to 100% by the end of the cotton season in heavily sprayed areas. This resistance encourages the application of more and stronger insecticides, leading to a classic 'pesticide treadmill'. Two related projects, focusing on southern India (R6734) and the irrigated cotton-growing systems of the Punjab (R6760*) have developed and tested integrated pest management (IPM) packages of methods that reduce the need for insecticides. Using the recommended IPM methods, farmers encourage the build-up of the bollworm's natural predators, and target limited sprays of recommended insecticides on the pest only when absolutely necessary. The results have been dramatic. Reduced costs of production and increased yields of cotton resulted in massively increased incomes to farmers. In the last (1998/99) season, farmers using the IPM package in southern India achieved average profits of £176 per ha, compared with £38 per ha for other farmers. Farmers' strong enthusiasm generated by these results attracted widespread coverage by local news media, and this in turn has fuelled strong demands for expansion into other districts. Use of the recommended IPM package has already reduced hazards to the environment and human health, and improved the profitability and reliability of cotton harvests for hundreds of poor rural families dependent on the cotton crop. The future widespread adoption of these methods now seems assured, and will have a major and sustainable impact on improving the livelihoods of small-scale farmers, on human welfare and on the environment.

ISSUES

India produces 2.5 million tons of cotton each year, sustaining the livelihoods of over 17 million people. Most are poor farmers who must support their families on less than 2 ha of land. For these smallholders the cotton crop is often the only source of income for food, medicines, education and shelter. Unfortunately cotton crops have become less and less viable, partly because of the increasing cost of pest control which accounts on average for more than 40% of the cost of growing the crop. Without chemicals, farmers face devastating attacks of pests such as the voracious cotton bollworm caterpillar (*Helicoverpa armigera*), which not only ruins their cotton but also attacks their food crops.

The threat of cotton bollworm has dramatically increased in recent years because of intensified land use. In addition, poor spraying techniques and over-use of chemicals have made the pest resistant to most available insecticides. Seeing their crops devastated by bollworms, and desperate to salvage something from their losses, farmers have continued to buy more toxic (and expensive) chemicals and to spray ever more frequently, but with decreasing effectiveness. The cost of chemicals has pushed farmers into dramatically increasing spirals of debt: in 1986/87 this drove hundreds of farmers to suicide – often by drinking the very pesticide which had brought them to the brink of desperation.

The aim of this work was to develop and demonstrate alternatives to the current over-reliance on conventional pesticides without compromising cotton production, through the development of Integrated Pest Management (IPM) methods for an area-wide approach to cotton pest management.

ACHIEVEMENTS

R6734

Effective components of IPM in cotton, explored on a small scale under a preceding project (R5745), were refined and developed into a package. The use of appropriate agronomy and resistant cotton varieties and seed treatments to protect against sucking pests allowed the use of pesticides to be delayed as long as possible, taking

*Project R6760 was jointly funded by the DFID Natural Resources Systems Programme.

Table 1. Results of trials by 1600 farmers in 23 villages in four states

	Tamil Nadu	Andhra Pradesh	Maharashtra	Punjab
Reduction in pesticide use (%)	46	69	92	29
Reduction in health hazard* (%)	77	89	92	48
Yield increase (%)	17	25	70	49

maximum benefit from beneficial insects. When insecticides were necessary, the results of the resistance monitoring programme and the study of mechanisms of resistance and of field efficacy against the different insect pests provided the rationale for the choice of materials and the timing and sequences of chemical applications. Simple pest management guides were developed for the states of Maharashta, Andhra Pradesh and Tamil Nadu.

Extension of the work of the International Crops Research Insitute for the Semi-Arid Tropics (ICRISAT) laboratory to cover whitefly (*Bemisia tabaci*) showed, for the first time in India, that whitefly had developed resistance to the bollworm chemicals chlorpyrifos and acephate (organophosphates) and cypermethrin (pyrethroid) chemicals, but that whitefly were still susceptible to the widely used sucking pest products. These results were incorporated into the control programme.

Making full use of farmer and village participatory methods, these management schedules were extended into single villages in the three states in 1997. These resulted in an average of 40% reduction in insecticide use and a 20–40% increase in the value of the yield, turning a marginal crop into a profitable one. Following end-of-season farmers' field days and excellent media coverage, in the 1998 season this work was expanded to 13 villages and over 600 farmers. Utilizing local people as effective extension agents, insecticide use was reduced by over 92% in Maharashtra, 69% in Andhra Pradesh and 42% in Tamil Nadu, with equal or enhanced yields.

These very positive results were supported by the provision of advanced equipment to detect mechanisms of nerve insensitivity to the Central Institute of Cotton Research (CICR) Nagpur which, with the ICRISAT and Tamil Nadu Agricultural University (TNAU) laboratories, undertook the regular weekly resistance (and thus insecticide efficacy) monitoring on which the pest management programme was built. Nerve insensitivity has now been demonstrated to be a major mechanism of resistance in India. A technical bulletin produced by the project, the *Podborer Newsletter*, has chronicled these advances and raised awareness and understanding of the problems and their solution amongst India's scientific community. A practical training workshop in insecticide resistance monitoring and management was run at CICR on semi-commercial lines. The production of two fast-selling editions of a detailed cotton IPM brochure aimed at farmers in Hindi, Marati, Tamil and now Punjabi has helped to implant the messages.

The project has unequivocally demonstrated that, with careful design supplemented by a detailed understanding of insecticide resistance patterns, effective and economic IPM programmes can be developed and extended. Insecticide use can be delayed, with consequent environmental and biodiversity benefits. Scouting for pest infestations can form an effective basis for decisions on interventions, and the resulting pattern of insecticide use can be much less environmentally damaging and can minimize the risk of developing further insecticide resistance. This represents a considerable step forward in the provision of much more economically acceptable cotton pest control which also addresses environmental and human health concerns.

R6760

Studies of 260 farm households in 13 villages within the Punjab cotton belt showed that cotton yields and gross revenues per hectare have been declining across the belt since at least 1994. Over the same period, insecticide use has increased by 22% and the costs of spraying by 50%. As a result most farmers are making a loss on cotton. There are biological reasons for this – unseasonal rains and exceptionally high outbreaks of cotton bollworm and whitefly have contributed. There are also social reasons: the intensification of production, the move to irrigation, and the use of input levels that damage both groundwater and the viability of the agricultural system. Although farmers' educational background was correlated with improved yields, the clearest correlation was with the quantity of insecticide used. The yield increase with increased insecticide use did not, however, translate into higher profit margins because of the costs of inputs. Agricultural advice is strongly concentrated with the commission agents, who are also the vendors of insecticide, which is often poorly formulated and usually sold on credit. Increasing insecticide use is selecting strongly for evolved resistance to the main chemicals used against both bollworm (cypermethrin, fenvalerate, quinalphos and endosulfan) and whitefly (cypermethrin, acephate and chlorpyrifos). This was well documented through the measurements made in the project-supported laboratories at Punjab Agricultural University (PAU), with resistance to common pyrethroids used in bollworm control rising to close to 100% by the end of the cotton season. This resistance encourages the application of more and stronger insecticides and their mixtures to control the resistant pests.

This situation is exacerbated by the fact that whitefly are the vectors for the debilitating cotton leaf curl virus disease (CLCuV). Epidemiological studies demonstrated the range of crop and weed alternative hosts for CLCuV and identified a number of tolerant cotton varieties, of which LH 1556, F 846 and LHH 144 appeared to have the other agronomic characters suited to conditions in the Punjab.

The project used the knowledge gained from these studies to construct a 'best-bet' package of practices for the cotton farmer. This strategy included the use of appropriate short-stature, sucking pest- and CLCuV-tolerant varieties at appropriate spacings; the use of insecticides only when specific pest thresholds were exceeded; and a sequence of single insecticide active ingredients which maximized efficacy against the pest complex and minimized further resistance development. The materials to be used and their sequence depended on the severity and nature of the pest complex at the time.

This strategy was demonstrated in the 1997 season in farmer-participatory work in two villages. Insecticide use was reduced by 40% and yields increased by 38% in a season otherwise disastrous in the surrounding areas due to unseasonal heavy rains and very high bollworm attack. The Punjab government partially adopted these practices in five villages and achieved 10–20% yield improvements. The work stimulated great interest in the region.

In the 1998 season an attempt was made to implement all aspects of the cotton management plan to over 1000 farmers in 10 contiguous villages of the Lumbi block in the cotton belt, as an initiative of the Chief Minister of Punjab. Good seeds, fertilizer, good pesticides and timely irrigation were promised in addition to field support and mobility. For a variety of reasons, these non-project inputs either did not materialize or were partially provided in this, the worst year on record for high pest levels and low cotton production across the Punjab. Farmers were demoralized and spraying rose amongst the participants despite a determined effort by PAU and project staff. However, the use of undesirable pesticide mixtures and pyrethroids was reduced by half and the yields were 49% higher than that of non-participants. As a result this provided marginal profitability rather than significant loss to the participators. The need for careful insecticide use and active management of resistance is now appreciated by all stakeholders.

Farmers in Tamil Nadu discuss IPM with extension workers

The project has successfully identified the pest management issues within the Punjab that are contributing to the decline of cotton production, and has found ways to tackle these production constraints. Pest management decision recommendations have been developed and demonstrated that are based on better understanding of both biological and socio-economic factors. These recommendations have been shown to greatly reduce the costs and environmental impact of control, and to increase cotton yields by over 50% for participating farmers, even in the two worst pest attack years on record. The PAU now has the proven capacity to monitor insecticide resistance in the two most important species of cotton pest.

FUTURE

In 1999, the CPP promoted these positive results in India by helping to train industry and government agri-business stakeholders in the principles and practices of appropriate cotton IPM. Recognising the potential of these improved pest control methods, the Indian Ministry of Agriculture is now funding promotion of IPM in 500 villages in the 20 major cotton districts which account for 80% of the total insecticide used on cotton in India. The Government of India has agreed to provide 30 million rupees (about £450 000) over 3 years Significant inputs are being provided from the pesticide, fertilizer and seed industries. The value of this work has been recognised in a major collaborative project funded by the Common Fund for Commodities (CFC), DFID CPP and the governments of China, Pakistan and India (2000–2004) and the insecticide industry's Resistance Action Committee. This new work will deepen our understanding of the technical constraints to the best use of insecticides for cotton pest control, and will make the benefits of the earlier work available to many millions of cotton growers across Asia. The findings of the projects from 1993 onwards are being used to inform the curriculum-building exercises of the European Community's Asian Cotton Farmer Field School project which is active in Bangladesh, China, India, Pakistan, Vietnam and the Philippines.

Use of pheromones in insect pest management on cotton

R5272

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April 1992–March 1996

Cotton is the major export crop of many developing countries. Insect pests are a major cause of yield losses, and worldwide more insecticide is applied to cotton than to any other crop. Pheromones provide a means of monitoring and control of insect pests. They are not toxic to animals or plants, and are specific for the target pest. As such, they are compatible with all other methods of pest control and thus provide ideal components of integrated pest management programmes which aim to provide cost-effective, sustainable control of pests with minimal use of conventional insecticides. This project arose from previous work in Egypt and Pakistan which had demonstrated the possibility of controlling pink bollworm (*Pectinophora gossypiella*) with pheromones. As well as pink bollworm, the main insect pests in Pakistan include spiny bollworm (*Earias insulana*), spotted bollworm (*E. vittella*) and American bollworm (*Helicoverpa armigera*). The aim of this project was to develop improved methods for management of insect pests in cotton production systems. The project aimed to develop and validate integrated strategies for controlling the pest complex on cotton in Pakistan based on application of pheromones for monitoring and control of bollworm pests.

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ISSUES

Pakistan is the world's fourth largest cotton producer. Cotton is responsible for more than 60% of export earnings, provides 55% of domestic edible oil, and is the basis for an industry employing 12.5 million people. In Pakistan the area under cotton has more than doubled over the past 40 years, and productivity has increased from 157 (1947/48) to 769 (1991/92) kg/ha. Much of this increase in productivity occurred during the 1980s as a result of increasing use of chemical pesticides. Since 1991/92, productivity fell to 487 kg/ha in 1993/4, to a large extent due to outbreaks of leaf curl virus transmitted by whitefly, and to increasing prevalence of the American bollworm, *Helicoverpa armigera*. The increased incidence of these pests is attributed to destruction of beneficials by misuse of pesticides, and both whitefly and *H. armigera* from Pakistan have been shown to be highly resistant to the commonly used insecticides.

Pheromone formulations to control pink bollworm (*Pectinophora gossypiella*) were previously developed by NRI and successfully evaluated in Pakistan in collaboration with the Pakistan Central Cotton Committee at the Central Cotton Research Institute, Multan. However, significant reductions in pesticide use were not achieved due to the need to use pesticides to control other cotton pests, particularly *Earias insulana* and *E. vittella*. Following the identification and synthesis of the female sex pheromones of *Earias* spp., small plot trials indicated that these bollworms could be controlled by a single, early season application of their combined pheromones.

This project aimed to develop improved methods for management of insect pests in cotton production systems by developing and validating integrated strategies for controlling the bollworm pest complex on cotton in Pakistan, based on the application of pheromones for monitoring and control.

ACHIEVEMENTS

All trials were carried out in farmers' fields rather than on a research station, involving the end-users of the technology in the trials at an early stage. Flooding in 1993/94 did not affect application of pheromone, but greatly reduced the effectiveness of insecticide applications and hence worked to the benefit of the project; however an abnormally severe outbreak of *H. armigera* in 1994/95 necessitated applications of insecticide

Left, pink bollworm caterpillars on cotton

Right, Selibate pheromone formulation on cotton

that reduced the information available from the pheromone trials and hence was unfavourable to the project.

The major results of this work were:

- separate, single applications of either of two different, commercially available pheromone formulations against *P. gossypiella* and *Earias* spp. can virtually eliminate the need for application of insecticide against these species;
- trials with pheromone against *P. gossypiella* showed that this species was better controlled than with insecticide, and that numbers of beneficial arthropods were greatly increased in a normal season, greatly reducing the need for insecticide application against *Earias* spp. and *H. armigera* (although the pheromone of *Earias* spp. is still expensive and is not yet readily available);
- combined with a single application of insecticide against sucking pests, this approach provides a realistic IPM programme;
- the 'Selibate' formulation, developed at NRI and commercialized by Agrisense-BCS, applied at rates as low as 250 point sources/ha and 40 gm a.i./ha, is effective against *P. gossypiella*;
- studies of the distribution of *H. armigera* eggs and larvae on cotton plants emphasized the importance of timing any insecticide application against the young larvae when they are still exposed on the leaves;
- there is a significant correlation between pheromone trap catches of *H. armigera* male moths and oviposition by female *H. armigera* on the following day, such that pheromone trap catches can be used as an aid to scouting for this pest;
- the African spiny bollworm *E. biplaga* was observed for the first time as a pest of cotton outside Africa, and a fruit pest, *Dichocrocis punctiferalis*, was also seen causing significant damage on cotton; the latter could be important when cotton fields are near to fruit orchards.

Work was carried out in close collaboration with the Pakistan Central Cotton Committee and the Central Cotton Research Institute, Multan, who will provide the main uptake pathways in Pakistan. The UK-based commercial companies Agrisense-BCS and International Pheromone Systems (IPS) Ltd provided formulations for evaluation free or at cost, and will be responsible for commercializing the products.

FUTURE

The manufacturers have now modified the formulation to release a higher proportion of active ingredient, and two pheromone formulations have been registered for use against pink bollworm in Pakistan and are now available commercially there. This work is being carried forward by the Pakistan Ministry of Agriculture.

In the Punjab, a province-wide network of over 3000 pheromone traps has been used to monitor *Helicoverpa* over a 3-year period, and recently similar networks of traps for pink bollworm and *Earias* have been established.

Following on from this research, pheromones are now being evaluated for potential control of a range of pests on other crops including sugarcane and brinjal (aubergine).

A biocontrol strategy for management of the alien perennial weed *Mikania micrantha* in tree crop-based farming systems in India

R6735

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July 1996–June 2000

Mikania micrantha, or mile-a-minute weed, is an invasive weed that smothers tree and other crops in homegarden production systems in the tropical moist forest regions of India. The project sought to assess and develop the potential for management of this weed through biological control utilizing fungal pathogens, in particular exotic pathogens as classical biological control agents, and also native pathogens. Exotic biocontrol agents, once they have become widespread, have the potential to reduce the abundance of the weed, providing a self-perpetuating, long-term sustainable management option for the *M. micrantha* problem. A number of potential biocontrol agents were collected within the weed's centre of origin; from these an isolate of the rust fungus *Puccinia spegazzinii* from Trinidad was selected for detailed assessment, and shows great promise as a biocontrol agent. Exotic biological control agents require little or no input from resource-poor farmers, and are environmentally benign. Local marginal and smallholder farmers will benefit from increased yields and decreased labour costs.

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ISSUES

In the moist tropical forest region of the Western Ghats in southwest India, agroforestry is the principal form of agriculture. The type of system depends on the type of community and can range from semi-permanent holdings of hill tribes to the more common permanent holdings or 'homegardens' characteristic of the region. The term homegarden refers to the intimate association of tree crops, multipurpose trees and shrubs with annual and perennial crops and livestock within the compounds of individual houses. In the state of Kerala, for example, most homegardens (about three-quarters) belong to marginal farmers with less than 1.5 hectares of land, and a further 35% to smallholders with 1.5–5 hectares.

Both food and commercial crops are grown throughout the Western Ghats, but the cropping pattern differs depending on geography. For example, in the highlands (above 750 metres) coffee, tea and cardamom are predominantly cultivated; bamboo and reed are also harvested from the natural forests by local tribes. The midlands (80–750 metres) are an area of intensive cultivation, where crops such as banana, plantain, cashew, coconut, arecanut, cocoa, cassava, yam, ginger, pepper and vegetables are grown. These homegardens are interdispersed with multipurpose trees including teak, casuarina and *Ailanthus*. Coconut is the major crop in the lowland areas (less than 80 metres).

Cultivation cost has always been a primary factor in the economics of homegardens, particularly for marginal and smallholder farmers. Weeds, in particular, form a major proportion of cultivation costs. Over the past few decades the invasive weed *Mikania micrantha* has spread throughout the southern part of the Western Ghats, causing severe damage to several tree crops, multipurpose trees and seasonal crops (such as cassava and yam). The weed is known as 'mile-a-minute': young plants grow extremely quickly (8–9 cm in 24 h), and use trees and crops to support their growth; the weed rapidly forms a dense cover of entangled stems bearing many leaves, smothering and choking crop plants and penetrating tree crowns. There is also evidence from studies on rubber in Malaysia that the weed can retard plant growth, probably through the production of chemicals.

Mikania micrantha is a native of South and Central America and the Caribbean, and was probably introduced intentionally into north-eastern India as a non-leguminous ground cover for crops. It is also suggested that it may have been introduced during the Second World

War for camouflaging purposes.

The project aimed to assess the range and economic impact of the weed, and to develop a management strategy based on biological control utilizing fungal pathogens.

ACHIEVEMENTS

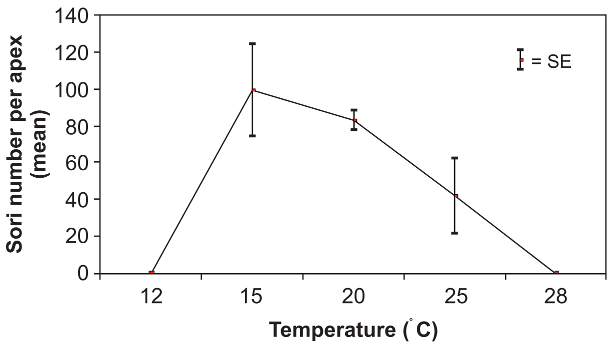
The range of *M. micrantha* is now mapped in the Western Ghats. Twenty-eight permanent sample plots have been established in Kerala. The weed is present in most of Kerala and is now moving northwards into Karnataka. Significant impacts of *M. micrantha* in tree crop/agroforestry systems have been confirmed. Crops particularly affected include banana, coconut, coffee, cocoa, cassava, pineapple, ginger and teak. Intensive weeding of *M. micrantha* has now become necessary to reduce its effect on productivity, resulting in the escalation of production costs. In evergreen forests, infestation by *M. micrantha* is on the increase, which affects harvesting by tribals of reeds, bamboo and other non-wood forest products.

The status of *M. micrantha* in northeastern India has also been assessed. The main impact is on tea production. Herbicide residues on tea have resulted in some exports being rejected by Western Europe.

DNA analyses indicate that the weed population probably originates from Central America rather than elsewhere in the indigenous range from Mexico to Paraguay, therefore this area has been of particular interest.

Surveys for potential exotic fungal pathogens were carried out in Brazil, Mexico, Trinidad and Costa Rica; 29 suspected fungal pathogens were recorded, of which four are considered to have most potential as classical biological control agents. Surveys in India revealed only nine minor fungal pathogens, none of which was found to be damaging, thus these local pathogens were inappropriate for mycoherbicide development. The exotic rust fungus *Puccinia spegazzinii* was selected for detailed assessment; eleven isolates

a.



b.

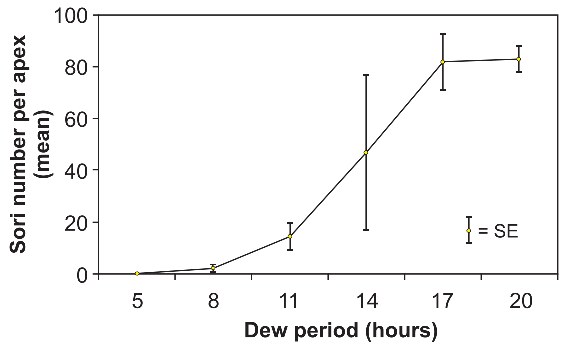


Figure 1. Effects of a. temperature, and b. dew period on the infection of Mikania micrantha *by* Puccinia spegazzinii

The search for a solution:

In its neotropical native range (Brazil to Mexico), *Mikania micrantha* has a sporadic distribution and is typically restricted to riparian habitats, growing along the edges of water courses, particularly river banks and wetlands. It can be found on occasions in urban situations climbing over hedges and fences but is seldom invasive or aggressive. In these habitats, the plant is found intertwined with the natural vegetation, and rarely aggregates into mats. The characteristic growth habit in a Brazilian swamp is shown opposite. Within such an ecosystem, the plant is attacked by a variety of coevolved natural enemies, particularly arthropods and fungal pathogens, those which impact directly on the photosynthetic efficiency of the plant reduce its vigour and competitive ability.

Biological control: The answer

Herbicide control is not feasible where infestation is widespread, and environmentally undesirable in conservation areas. Cultural control is also uneconomic and potentially dangerous if badly managed. Damaging, host-specific natural enemies have been identified in the neotropics, during surveys undertaken by the International Institute of Biological Control (IIBC), and these could offer the only sustainable, economically viable and ecologically benign solution to this weed problem. IIBC, in collaboration with Kerala Forestry Research Institute, has recently initiated a project, managed by the UK Natural Resources International and funded by the Department for International Development, to assess their potential. A highly promising rust fungus which kills both leaf and stem tissues, is currently being screened for possible release into Southern India (left).

Invasive Weed Alert No. 1 (1997); prepared by IIBC, Silwood Park, Ascot, Berks. SL5 7TA, UK.

have been collected, and the high biocontrol potential of an isolate of this pathogen from Trinidad has been confirmed in the quarantine labs of CABI Bioscience. The life cycle of the rust has been elucidated, and some of the factors affecting successful infection of *M. micrantha* have been determined (Figure 1).

It is essential that exotic biocontrol agents are carefully screened for any effect on the local flora, and particularly on crop plants. Fifty-five species were screened for infection by *P. spegazzinii*, and none was infected despite consistent infection of *M. micrantha* controls. Chlorotic spots were observed on *Helianthus annuus* and *Eupatorium canabum*, and necrotic spots on two other *Mikania* species. A microscopic analysis was undertaken of these species and a range of other test species. The results revealed that in all cases fungal spore germination and/or penetration was inhibited by the test plants and no infection occurred. This confirms that the rust is highly specific and therefore likely to be acceptable as a biocontrol agent.

A protocol for the introduction of exotic fungal pathogens was discussed and agreed with relevant institutions. For this protocol, the high specificity and biocontrol potential of *P. spegazzinii* has been demonstrated, and support for introduction from all collaborators has been confirmed.

Kerala Forestry Research Institute (KFRI) staff have been trained in ecological and socio-economic survey techniques for alien invasive species. Also pathologists from KFRI and the Indian Council of Agricultural Research (ICAR) were trained in classical biological control and mycoherbicide development and application, through training attachments at CABI Bioscience.

A national workshop was held at KFRI in November 1999, which produced recommendations for a further research phase; support was also expressed for the introduction *P. spegazzinii* as a biocontrol agent for the weed.

An alert sheet (left) was prepared and distributed to KFRI and other relevant organizations. Once KFRI had determined that the front of the weed invasion lay at the border between Kerala and Karnataka, copies of the alert sheet were also given to the Karnataka Forest Department based in Bangalore.

FUTURE

The national workshop recommended that the project be followed up by:

- development of an implementation phase involving farmer validation of the integrated weed management programme
- an application should be made for the introduction of the *M. micrantha*-specific exotic rust fungus *P. spegazzinii*
- further ecological and socio-economic studies are needed on *M. micrantha*, in particular on dispersal, prediction of spread, modelling, and ecological and socio-economic impact on agroforestry farming systems
- adaptation of the integrated weed management technology for use and implementation in the northeastern states of India

There is no written protocol for the introduction of biological control agents for weeds into India, particularly pathogens; this is now being revised and the *Mikania* project is contributing to the process.

Pest constraints affecting tree crops in Bolivia

R6820

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January–March 1997

Tree planting for farmers and local communities is common in many development programmes. Bolivia has many projects working in rural development forestry – a catch-all term used to describe anything from agroforestry to small-scale reforestation. In Bolivia, rural development forestry uses exotics and valuable native species, and encompasses forest species, multipurpose trees and fruit trees. All have an important value to local communities. A mechanism is needed for assessing and monitoring the health of these trees, and to provide technical support and advice on managing diseases. Such services do not exist at present in Bolivia. The cataloguing of a series of tree diseases and damage by this project therefore represents a significant advance on previous knowledge.

ISSUES

The purpose of this short project was to investigate the pest constraints affecting tree crops in selected agroforestry schemes in Bolivia; to identify suitable research approaches to manage these constraints; and to explore partnerships between institutes and organizations to tackle problems relating to tree health.

ACHIEVEMENTS

Work was carried out in collaboration with five key institutions: the UNDP Programme on Forests (PROFOR); University of the Beni; Silsoe Hillsides Project; CARE Amboró Project; and the International Center for Tropical Agriculture (CIAT). Samples of pests and diseases were collected, and a large photographic record of symptoms compiled.

Key pest problems were identified on many of the important tree species observed (Table 1). The results emphasized that the importance of a pest constraint can be defined from different perspectives. Two examples at opposite ends of the spectrum include *sika sika* (lepidopterous larvae) on *Schinus molle*, probably of minor economic importance but of significant concern to foresters and local communities; and a spectacular rust on *Inga cylindrica* which is of biological interest, is not recognized by local people, yet could pose a problem in the future. Between these two extremes lie problems of unequivocal importance, such as dothistroma blight on pines and tristeza and gummosis on citrus. The causes of these diseases are well known and advice on their management is available. However, there is confusion about the extent of the citrus diseases, how to differentiate the reported two leading diseases, and their geographic distribution.

A general guide has been prepared to *Diagnosis of Diseases and Damage on Trees*. Copies, in English and Spanish, have been distributed to main collaborators (see Bibliography on CD).

FUTURE

This work has been continued in a further 1-year study (R7479), in collaboration with with CIAT and CARE Sucre, involving a more detailed look at the tree pests in two departments of Bolivia, Santa Cruz and Sucre. The study has identified fruit trees as the most important perennial component of agroforestry systems, in particular citrus and peaches. No systematic effort has been made to diagnose the causes of ill-health, and the aim of this work is to determine which pests are most important. Weak research capacity is being strengthened, and community-based approaches are being used to resolve technical and scientific gaps.

Table 1. Important diseases of trees noted in Bolivia

Type	Host	Problem
Tree crops	*Bixa orellana* (urucú)	Sudden death - possible new and potentially serious disease
	Citrus spp.	Tristeza and gummosis - well known diseases but diagnosis difficult
Community forest trees	*Eucalyptus* spp.	Psyllid attack
		Foliage blights (to be confirmed)
		Cerambycid, probably *Phoracantha semipunctata*
	Pinus spp.	*Dothistroma* blight
		Seedling blight (undiagnosed)
	Schizolobium amazonicum (cerebó)	“Elephant’s foot” disease (basal swelling; undiagnosed)
Rural development trees	*Polylepis incanae* (kewiña)	Seedling blight (undiagnosed)
	Schinus molle (molle)	Psyllid attack
		Seedling blight (possibly *Alternaria*)
		Lepidopterous larvae (*sika sika*)
	Spartium junceum (retama)	Mildew

Improved ecological and economic recommendations for the control of *Hypothenemus hampei* in coffee in Mexico

R6812

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The coffee berry borer is the most serious pest of coffee in many of the major coffee-producing countries. Losses can be severe, ranging from 50–100% of berries attacked if no control measures are applied. Even if borers do not destroy the berries, the damage caused produces poor quality coffee, and damaged berries are difficult to market. A computer program modelling the production of berries in the field and the dynamics of the pest, first developed in Colombia, was extended by this project to coffee production in Mexico. This model has achieved a high level of complexity in its short development, and covers a broad range of pest management aspects and their implications under the varying conditions and cultivation practices in Mexico. It can be used to predict the consequences of different management decisions in the context of the current coffee market in Mexico.

ISSUES

The scolytid beetle *Hypothenemus hampei*, the coffee berry borer, presents a threat to the viability of coffee growing in many countries. Coffee is a major crop in Mexico, and in 1995 the Mexican government began a programme to provide US$80 million in credit to 260 000 small-scale coffee growers (accounting for 92% of growers) to improve cultural practices. With higher domestic producer prices, growers have improved cultural practices and expanded the use of inputs, mostly to control coffee rust and *H. hampei* (colloquially known in Mexico as the *broca*). While overall coffee production in Mexico is increasing, it is declining in the southern states which are badly affected by the *broca*.

ACHIEVEMENTS

The existing computer program was improved in terms of the flexibility of the management actions and local cropping systems that could be tested; quality payment systems were added; and the overall function and structure were improved. This was followed by a review of the outputs with collaborators and the coffee industry.

The model illustrates some important points, summarized below.

The flowering pattern and berry production induced by the rainfall in southern Mexico limit the damage inflicted by the borer. This is principally because of the 5-month berry-free period between January and April/May.

Applications of pesticide or *Beauveria* (a fungus that attacks some insect pests, including *H. hampei*) work only when the pest, which breeds within coffee berries, is exposed to external conditions. The model demonstrates that injudicious pesticide applications against the *broca* are uneconomic. However, well applied sprays between 6 and 20 weeks after a major flowering (and particularly between 7 and 15 weeks) are likely to be efficacious and cost-effective.

Efficient harvesting reduces the availability of berries for attack and removes a considerable part of the *broca* population from the field, and should be conducted from the first year after pruning onwards.

For the rainfall and flowering pattern in Mexico, repasé (post-harvest clearing of berries of all ages) is a very effective way of reducing the *broca* population. This technique is currently rarely used except in some of the more commercial, organic operations. Badly timed sprays and inefficient repasés represent a worse return for the farmer than the 'harvest only' option.

Recently, major buyers in the south have begun to pay more for robusta type coffee than for arabica (a very rare occurrence). Cultivation of robusta coffee extends the time that ripe berries are available to *broca* attack, reducing the period that is free of ripe berries from 5 to 2 months. The model demonstrates the implications of this in terms of potential future damage by the *broca*.

Combined strategies, including efficient harvesting and well timed sprays or repasé, are far more likely to be effective against the *broca* than single approaches, although they may not be economically feasible.

It was not possible to build a model that encapsulates all aspects of the berry borer's dynamics in so short a period. There are other factors to include in future modelling efforts, for example, more detailed descriptions of the dynamics of the *broca* in berries on the ground, and of aestivation in berries both in the tree and on the ground. A parasitoid model was not specifically included because a simulation model of these complex three-way interactions was neither possible in a spreadsheet model, nor necessary given the relatively low success of the parasitoid species currently being applied. However, the model can provide support for scientists developing biocontrol strategies by assisting in the design of parasitoid release experiments, and also in the interpretation of data generated by field trials.

FUTURE

Interest in use of the model has been stimulated through demonstrations to staff from El Colegio de la Frontera Sur (ECOSUR), Texas A&M University, the US Department of Agriculture, the International Institute of Biological Control (CABI Bioscience), Zamarano Pan-American Agricultural College, farmers from Union Regional Productores de Café Tacana, Nestlé plc, and the International Coffee Organisation.

Publications: see Bibliography on CD.

Development of an integrated management strategy for itchgrass in maize-based cropping systems in selected areas of Latin America

R6690

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April 1995–March 1999

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Itchgrass (*Rottboellia cochinchinensis*) is a tropical weed of maize, sugarcane, rice and other crops which has been introduced to the New World relatively recently and is particularly severe there. This project continued to test previously developed, sustainable methods for itchgrass management in farmers' fields in Costa Rica, Mexico and Bolivia. Specific research aimed to improve knowledge of the biology and importance of itchgrass, and address the best combinations of planting density and timing of cover crops to allow effective weed suppression while maintaining profitable grain yields. Interactions between the three key species of the production system (maize, itchgrass and the cover crop *Mucuna*) have been well characterized and demonstrated to collaborating growers in Costa Rica. A mycoherbicide has been developed that may have potential for integrating in the overall control strategy, and a classical biocontrol agent (head smut) studied. As it is not yet possible to release head smut in the field, a modelling exercise was carried out, and the results confirm that a biocontrol agent which prevents seed production in itchgrass could have a significant impact on itchgrass populations. Overall, the project has contributed important management alternatives for one of the most troublesome weeds in tropical America, that should allow sustainable control with reduced environmental impact.

ISSUES

Itchgrass (*Rottboellia cochinchinensis*) is a pantropical agricultural weed that is increasing its range at an alarming rate. It is native to the Old World, but was probably introduced at the beginning of the 20th century to the New World, where infestations are now considered to be the most severe. This could be due to a number of factors including better compatibility with the climate; man's activities spreading the grass; favourable agronomic practices; and the absence of co-evolved natural enemies. In Central America itchgrass infests both annual and perennial crops, and has been reported to cause significant yield losses in maize, sugarcane, upland rice, beans and sorghum. Infestations can result in up to 80% crop loss, or even abandonment of agricultural lands.

Previous studies and surveys conducted in Costa Rica documented the importance of itchgrass and the need to develop suitable and economically feasible control alternatives for small-scale farmers. Initial research demonstrated that effective in-crop control was essential for maintaining low levels of the weed, but that planting in zero tillage and prevention of seed set during the fallow period were also important. It was also shown that little viable seed remained after 12 months in the soil, underlining the importance of prevention of seed set in the weed's management.

Sustainable methods for managing itchgrass in the seasonally dry Pacific and humid tropical Atlantic regions of Costa Rica were further developed and began field testing under R6047 (*see Research Highlights 1989–95*); results demonstrated the usefulness of combining in-crop herbicides, control of residual plants during the off season, and zero tillage. Early planting of *Mucuna* and *Canavalia ensiformis* gave good ground cover, suppressed itchgrass and increased maize yields. In initial validation plots, despite higher initial costs farmers perceived the control methods developed by the project very favourably.

A promising area of research is the use of fungal pathogens to control itchgrass. Both mycoherbicide and classical biological approaches have been investigated in Costa Rica (R6047) and the UK (R5883). Since many farmers currently use chemical herbicides, adopting mycoherbicides as an environmentally benign alternative should be a useful approach. The use of a classical biological control agent is considered to be of direct value to farmers as they do not cost farmers time or money. These organisms target areas not typically tended by farmers (fallow fields, roadsides and headlands), and weeds that escape the control measures used by farmers (such as weeds between crop plants within a row), all of which constitute an important source of seed for re-infestation.

Previous investigations had identified two exotic pathogens of *R. cochinchinensis* with potential as classical biocontrol agents for Costa Rica: a head smut, *Sporisorium ophiuri*; and a rust, *Puccinia rottboelliae*. The dynamics of the itchgrass–head smut system were explored in a previous project using a modelling approach (R6003; see *Research Highlights 1989–95*) . This work suggested that a very high annual infection rate (>85%) would be required for the smut to be effective as the sole agent of control. However, the smut cannot be released in Costa Rica until host specificity tests are completed.

The aim of this project was to build on the achievements of previous work in order to improve methods for managing itchgrass in maize by developing an integrated management strategy and disseminating the results to target farmers in Costa Rica, Mexico and Bolivia.

ACHIEVEMENTS

Field research over two years in Costa Rica showed that mucuna suppressed *R. cochinchinensis*, but lower maize grain yields were obtained if maize was grown in association with the ground cover crop *Mucuna* at 50 000 plants/ha, especially when the cover crop was planted simultaneously with maize. However, itchgrass itself decreased maize yield by about 46%.

Three-year validation plots in farmers' fields in Costa Rica evaluated the integration of no-tillage; use of a selective herbicide (pendimethalin) in the first season to lower the initial density of itchgrass; planting of velvetbean (*Mucuna deeringiana*) between maize rows as a cover crop; and prevention of itchgrass seed set in the fallow period. Pendimethalin effectively controlled itchgrass at the onset of validation plots and allowed the establishment of the cover crop during the first maize crop. At all sites itchgrass densities were lower in validation plots than in growers' fields, and infestation levels decreased over the years with integrated management.
In general, yields (maize and dry beans, planted as a rotation crop in one of the sites) were higher in validation plots at all locations and over all cropping seasons; however soil fertilization regimes differed between validation and growers' plots and, in some cases, improved maize varieties were used in validation plots. Soil core samples taken each year at the beginning of the cropping season revealed substantial reductions in the itchgrass soil seed bank in validation plots.

Partial budget analyses demonstrated that integrated itchgrass management was economically feasible for smallholders.

A validation plot was also established in Oaxaca, Mexico in 1998 but included only minimum tillage and the use of pendimethalin to reduce the initial itchgrass infestation. Nevertheless, this validation plot was always less infested with itchgrass than the commercial one.

Preliminary screening of cover crops for itchgrass management was conducted at El Vallecito Experiment Farm in Santa Cruz, Bolivia. Promising species were *Dolichos lab lab*, *Canavalia ensiformis* and *Mucuna* (*Stizolobium*) *cinereus*.

In addition, information on itchgrass density-dependent mortality and seed production under field conditions at two locations in Costa Rica was generated to support modelling studies.

During the first two years of research, native pathogens with biocontrol potential were identified and greenhouse experiments performed with stress factors to increase the severity of the pathogens. To identify the stress factors that could improve the effectiveness of native pathogens, trials were conducted with shading, flooding and sublethal doses of many herbicides including pendimethalin and nicosulfuron. Good results were observed with haloxyfop methyl. In order to evaluate the native itchgrass pathogens under field conditions, trials were conducted in five maize plots located in Guanacaste, Costa Rica. The pathogens applied as mycoherbicides were tested in water or formulated with canola oil and Tween 40, and inoculated after the application of sublethal doses of haloxyfop methyl.

The results showed that both pathogens in combination with the two lowest herbicide doses (1 and 1.5 ml/l) caused the death of 15–25-day-old seedlings, depending on the environmental conditions. Under field conditions the best results were observed with lower doses. Individual pathogens were more effective than a mixture. Combining the pathogen formulation with a *Mucuna* cover crop did not improve itchgrass control.

The mycoherbicide component requires the implementation of a validation stage, in different areas and for a minimum of 2 years. Virulent isolates are available for which other formulations need to be tested. The stability of pathogen virulence should be evaluated over time.

The potential of head smut as a classical biocontrol agent for use in an integrated management strategy against itchgrass in Costa Rica was investigated. A comprehensive host-range screening programme was undertaken using a Madagascan isolate of the smut. The results show that the smut is extremely host-specific, as none of the 49 species/varieties of graminaceous test plants became infected.

Electrophoretic techniques were used to characterize the genotypic variation of itchgrass biotypes.

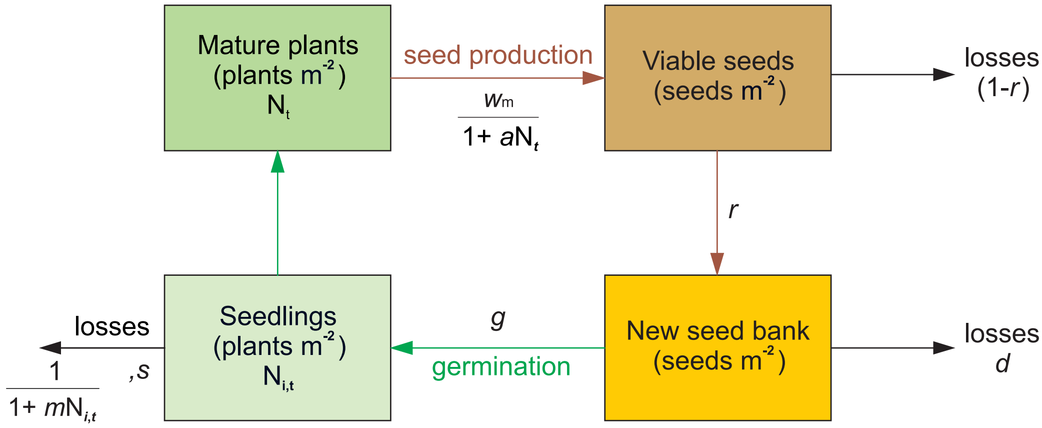

Figure 1. Structure of the model of the itchgrass life cycle showing flows between the state variables (seedbank, itchgrass seedlings per m^2, $N_{i,t}$; itchgrass plants per m^2, N_t; seed production per m^2) and parameters (proportion of seed germinating from the seed bank each season, g; proportion of seed lost per season, d; density-independent seedling mortality rate, s; degree of density dependence in seedling survival, m; seeds produced per plant in the absence of competition, w_m; degree of density dependence in seed production, a; proportion of seed grain incorporated into the new seed bank, r)

The results suggest that the biotypes form a narrow genetic base with greater than 80% similarity. This high degree of similarity can be related to the inbreeding nature of the weed, and to the relatively recent expansion of its geographic range. Itchgrass biotypes can be broadly grouped according to their geographic origins. Latin American biotypes form two distinct groups, indicating that these populations probably arose from a relatively small number of introductions. Neotropic invasions of the weed appear to have mainly been from Africa, although biotypes in Brazil and Colombia probably originated in Asia. This genetic homogeneity suggests that the smut should infect the majority of Latin American biotypes, some of which would be new associations.

Molecular characterization of a range of smut genera was also undertaken. The genus *Sporisorium* could be readily distinguished from other smut genera, and this should enable the Madagascar strain to be fingerprinted if the need should arise to track the fungus in the environment. In addition, smut pathotypes from Africa and Asia could be separated.

Infection studies showed that only the teliospores (resting spores) of the smut induced infection. Laboratory and scanning electron microscope studies indicated that sporidia (propagative spores) may also be involved in the disease process, however no smutted plants were achieved through sporidial inoculations.

Because release of the head smut is not yet possible, an existing model was adapted to explore itchgrass population dynamics in maize-based cropping systems in Costa Rica. The effects of the head smut, on its own and in combination with suppressive cover crops, were explored. A simple simulation of smut population dynamics was incorporated later. The interaction of smut and cover crop depends on how they are modelled, and hence on how biocontrol with the smut is implemented. Under a purely natural infestation the cover crop affects smut reproduction as well as the itchgrass, and therefore reduces effectiveness of the smut. However, when smut infection was modelled as a constant proportion of itchgrass plants each season (for example by augmentation or if applied as a mycoherbicide), then the smut in combination with a cover crop could be highly effective. Results also suggest that under a natural infestation of smut there can be a trade-off between infectivity, reproductive rate, and mortality rate in the soil which should be considered in selecting effective smut strains. The interaction between head smut and itchgrass is stable over a wide range of values for the smut. The ability to reduce population density to a low, stable equilibrium density is one of the requirements for a good biological control agent.

FUTURE

The results of all this work have been submitted as part of a dossier on the biological control potential of head smut to the Costa Rican plant health authorities. On the basis of this information an assessment was made by the Costa Rican Sanidad Vegetal on the risks of introducing the smut into the New World, and permission was granted (1999) for the importation of the smut. However, they were keen to introduce it first into quarantine in Costa Rica, and to undertake selective host specificity screening prior to field releases. The screening is to be conducted at the Tropical Agricultural Center for Research and Higher Education (CATIE) in a specially converted screenhouse. Bulking up of inoculum prior to field release will also be undertaken in this facility. The introduction and successful establishment of head smut will potentially help in the management of *R. cochinchinensis* and thus lead to a reduction in the infestation and spread of this weed.

Management of herbicide-resistant weeds of rice in Bolivia, Mexico and Central America

R6652, R6793

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Rice production costs in Latin America have increased as control of the annual grass weed junglerice (*Echinochloa colona*) has become increasingly difficult due to the evolution of herbicide-resistant populations. Rice weed management in the region has become dependent upon herbicides, and it is vital that growers adopt a rational herbicide resistance management programme based on affordable options, including rotation of herbicides to reduce selection pressure, to ensure that rice production remains competitive with imported supplies. A competitive rice industry will also safeguard employment opportunities. This project has built on previous work to contribute further to an understanding of the resistance problem, and has demonstrated options for resistance management in both dryland and flooded rice cultures. Equally important has been the contribution to raising awareness of the resistant weed problem in Central American, Bolivian and Mexican agricultural systems.

ISSUES

Weed management in Latin American rice production systems is heavily dependent on herbicide applications, with propanil being the usual choice for post-emergence control of the important annual grass junglerice (*Echinochloa colona*), as well as other grasses and several broad-leaved weeds. Previous work undertaken by the Tropical Agricultural Center for Research and Higher Education (CATIE), Costa Rica (R5884; see *Research Highlights 1989–95*) confirmed that repeated use of propanil has led to the evolution of propanil-resistant populations of junglerice. By 1995, resistant populations infested an estimated 70% of the major rice-producing areas of Costa Rica, El Salvador, Guatamala, Nicaragua and Panama. In addition to using higher application rates of propanil, growers have responded to the evolution of resistance by adopting late post-emergence applications of fenoxaprop-p-ethyl, but populations of *E. colona* have evolved resistance to this graminicide within three seasons of its use in Costa Rica.

Collaboration between CATIE, Costa Rica, the Institute for Arable Crops Research (IACR), Long Ashton Research Station and Natural Resources Institute (NRI) in projects R5226 (see *Research Highlights 1989–95*) and R5473 resulted in the discovery that the propanil resistance mechanism in *E. colona* is an elevated level of the enzyme aryl acylamidase, which is responsible for detoxification of the herbicide. It was demonstrated that propanil-resistant biotypes could be controlled by mixtures of the herbicide with synergists containing carbamates and mono-oxygenase inhibitors, while integrated approaches using herbicides with alternative modes of action, and combinations of pre-planting and in-crop weed control, were demonstrated in the field in Costa Rica in dry seeded upland rice.

The aims of the project described here were to complete the development and field validation of junglerice management strategies in upland rice, to investigate modifications of the system in flooded rice, and to extend the collaboration to institutions in Bolivia and Mexico. The project was therefore designed to provide an understanding of the status of herbicide resistance in rice-cropping systems in Bolivia and Mexico, and to recommend appropriate weed management systems for the prevention and management of resistance. An important aim was to raise awareness of the resistance problem among growers, farm advisers and the pesticide industry in collaborating countries.

ACHIEVEMENTS

Surveys in Mexico revealed the presence of propanil-resistant junglerice (*Echinochloa colona*). Propanil resistance was not found

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RICHES, C.R., KNIGHTS, J.S., CHAVES, L., CASELEY, J.C. and VALVERDE, B.E. (1997) The role of pendimethalin in the integrated management of propanil-resistant *Echinochloa colona* in Central America. *Pesticide Science* **51**: 341–346.

VALVERDE, B.E., CHAVES, L., GARITA, I., RAMÍREZ, F., VARGAS, E., CARMIOL, J., RICHES, C.R. and CASELEY, J.C. (2001) Modified herbicide regimes for propanil-resistant *Echinochloa colona* control in rice. *Weed Science* **49** (in press).

VALVERDE, B.E., RICHES, C.R. and CASELEY, J.C. (2000) *Prevention and management of herbicide resistant weeds in rice: experiences from Central America with* Echinochloa colona. San Jose, Costa Rica: Crop Protection Association of Costa Rica.

*Junglerice (*Echinochloa colona*) infesting rice*

in Bolivia, probably due to a different rice production system. However, populations of the grass *Eriochloa punctata*, which are resistant to ACCase-inhibiting herbicides including fluazifop-butyl, were described from soya/rice systems in Bolivia.

Laboratory and glasshouse work in the UK led to the development of a range of rapid diagnostic tests for propanil and fenoxaprop-p resistance in junglerice over a range of growth stages. These tests use a variety of plant organs – seeds, seedlings, tillers and stem nodes – and require a minimum of facilities and equipment. The seedling test was validated on plants taken from the field in Costa Rica.

Field trials in Costa Rica investigated the management of resistant junglerice populations by the integration of pre-plant and in-crop control options. Timely stubble incorporation after harvest was not effective, but long-term trials demonstrated that control of the initial junglerice flush before planting, by chemical or mechanical means, and improved in-crop control with alternative herbicides, can serve as the basis for integrated management of herbicide-resistant junglerice in rain-fed rice. A number of graminicides with alternative modes of action to propanil and fenoxaprop, including quinclorac, pendimethalin and bispyribac-sodium, also controlled resistant junglerice in field trials and increased grain yields. Herbicide options for flooded rice were also demonstrated at sites in Costa Rica.

Although it proved impossible to improve propanil activity on junglerice using additional surfactant in the tank mix, this approach was successful in glasshouse trials with fenoxaprop. Additional surfactant did not lead to increased damage to rice when used with fenoxaprop in the field, but in two field trials in Costa Rica junglerice control was not improved. Propanil has been a useful herbicide in rice systems because of the relatively wide spectrum of species controlled. Use of propanil in mixture with a synergist, either piperophos or anilophos, was shown to be a further effective option for sites where resistant populations of junglerice are found.

Research and extension staff from Bolivia, Mexico and across Central America meet in Costa Rica in July 1998 to discuss herbicide resistance management in rice

Graminicides which are selective in rice against *E. colona,* but which have different modes of action to propanil and fenoxaprop, have an important role to play in management of resistant populations in high-potential rice production systems. Additional work was carried out (project R6793) to assess the activity of recently developed and registered rice herbicides on glasshouse-grown junglerice, and effective treatments were selected for field trials in Costa Rica.

Project results were disseminated to growers, extension staff, herbicide manufacturers' technical and sales representatives, researchers, students and government officials in Central America, Bolivia and Mexico through a series of publications and presentations at seminars or conferences. A workshop attended by delegates from six countries in Latin America was organized by the project in Costa Rica, to provide a forum for raising awareness of herbicide resistance in weeds and to disseminate findings.

Staff of herbicide manufacturers and local sales outlets play an important role in Central and South America in providing advice to growers. The project has therefore placed emphasis on increasing awareness of herbicide resistance within the industry by inviting staff to seminars, field days and workshops. The industry has also been well represented at the conferences attended by project staff. This will also be one important target audience of the project publication *Prevention and management of herbicide resistant weeds in rice,* published and circulated in collaboration with the Crop Protection Association of Costa Rica.

FUTURE

Lessons have been learnt from the propanil-resistance story which it is hoped will influence future weed management decisions to allow important herbicides a long life, as growers take action to prevent further resistances developing.

Internationally, the true extent of herbicide resistant rice weed populations is unknown, but important cases are recognized in the USA and the Far East. The approach taken by the project and the weed management strategies that have been developed therefore have a wider relevance to the major rice-producing areas of the world where herbicide use either is already intensive, or is increasing due to labour and other costs.

Improved monitoring of conventional and microbial pest management sprays

R6620

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April 1996–March 1999

While integrated pest management is being adopted in many developing countries, conventional pesticides are likely to continue to play a major role in crop protection for the foreseeable future. Pesticides are often poorly managed and applied, resulting in inefficient and uneconomic usage, environmental and human health problems, build-up of pest resistance, and excessive residues in produce. When mismanaged they may also prevent the activity of important natural control agents in the cropping ecosystem. These problems are often difficult to relate in a quantifiable way to the pesticide management regimes in use due to the lack of appropriate technologies. To address these problems, this project has developed a range of techniques to monitor the processes and the consequences of spraying practices.

ISSUES

Crop production is expanding and intensifying in peri-urban regions of many developing countries, with corresponding increases in the use of pesticides. The limited area of productive land in peri-urban areas puts pressure on farmers to maximize yields through very intensive agriculture, which is often characterized by high pesticide use, threatening the welfare and livelihood of inhabitants as well as the long-term welfare of the environment, and resulting in the rejection of export crops due to excessive pesticides. Information on best spray practice is often not available to farmers.

There is a need for feedback on the fate of sprayed products on the plant, on the soil, and travelling out of the target area as drift. Newer microbial insecticides pose similar application and monitoring problems, and also present additional challenges related to non-uniform distribution of microbial particles in the droplets. Accuracy of application is particularly important with microbial pesticides: they must be ingested or come into direct contact with their hosts to be effective, and this must occur soon after application due to their short field persistence.

ACHIEVEMENTS

Four simple spray samplers likely to be able to capture the very small droplets found in drift were selected and tested in a specialized wind-tunnel facility. Their collection efficiencies for a range of very small droplet sizes and low wind speeds were measured, and these data can be used to correct field drift sample data to give quantitative assessments of drift through human habitations, natural enemy refugia and ecologically sensitive areas.

An attempt was made to develop a rapid method for quantifying volumes of deposited spray directly from visual interpretation of two-dimensional deposit patterns on target plant surfaces. When tested, the variability in correlations between apparent deposit and actual volume was too great to justify pursuing the technique — the great range of microstructures and surface characteristics between different crop types, and even within individual plants, made universal correction factors unreliable.

The third component of the project looked at methods for tagging spray formulations for later recovery and deposit analysis. Ideal performance characteristics were established for dye tracers, and one of the principal limiting characteristics – photostability – was tested for four promising visible dyes and three fluorescent dyes in a sunlight simulator. On the basis of results, conclusions were drawn as to which dyes suit which modes of use.

In ultra-low-volume spraying, the oil-based droplets must remain airborne for many seconds without significant reduction in size. A simple laboratory method, involving sequential weighing of a series of filter papers wetted with a known quantity of the pesticide, was developed to test the volatility of ultra-low-volume formulation.

The final component related to the distribution of nuclear polyhedrosis virus (NPV) particles in spray droplets. These particles infect certain insect pests when sprayed onto crop surfaces, and can be used instead of conventional chemical pesticides. A method was developed to visualize deposited droplets of spray formulation at the same time as the NPV particles within them, and a series of trials carried out to assess distribution uniformity. A disproportionate number of particles were found in the larger-sized droplets. This has implications for the type of spray equipment and nozzle performance required for the application of microbial pesticides.

FUTURE

Some of the outputs of this project have already contributed to more effective sampling of sprays, both in large-scale migratory pest control operations and in smallholder horticultural production systems. For example, the deposition and drift sampling techniques were used in quality monitoring of aerial spraying against the migratory locust in Madagascar. Thus the project contributes to the overall goal of promoting pest management methods which will allow higher yields to be produced in a manner that is safe to operators, communities and the environment.

Publications: see Bibliography on CD.

Acronyms and abbreviations

ACMV	African cassava mosaic virus
AfFOResT	African Farmers' Organic Research and Training, Zimbabwe
Agritex	national agricultural extension service, Zimbabwe
APAARI	Asia-Pacific Association of Agricultural Research Institutions
ARI	agricultural research institute/advanced research institute
ASARECA	Association for Strengthening Agricultural Research in Eastern and Southern Africa (Uganda)
AVRDC	Asian Vegetable Research and Development Center, Taiwan
BACTID	bacterial identification system (NRI)
BAT	bait application technique
BBTV	banana bunchy top virus
BHU	Banaras Hindu University, India
BLRS	Bah Lias Research Station, Indonesia
Bt	*Bacillus thuringiensis*
CABI	Centre for Agriculture and Biosciences International
CATIE	Centro Agronomico Tropical de Investigacion y Enseñanza (Tropical Agricultural Center for Research and Higher Education), Costa Rica
CBSD	cassava brown streak disease
CBSV	cassava brown streak virus
CCRI	Central Cotton Research Institute, Pakistan
CFC	Common Fund for Commodities
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CICR	Central Institute of Cotton Research, India
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center)
CIP	Centro Internacional de la Papa (International Potato Center)
CMD	cassva mosaic disease
CORAF	Conseil ouest et centre Africain pour la recherche et le développement agricoles, Senegal
CORNET	Coffee Research Network (East and Central Africa)
CPP	Crop Protection Programme (DFID)
CPCRI	Central Plantation Crops Research Institute, India
CRF	Coffee Research Foundation, Kenya
CRI	Coconut Research Institute, Sri Lanka
CRRI	Central Rice Research Institute, India
CSIR	Council for Scientific and Industrial Research, Ghana
DFID	Department for International Development, UK (formerly ODA)
DRR	Directorate of Rice Research, India
DRSS	Directorate of Research and Specialist Services, Zimbabwe
EC	European Commission
ELISA	enzyme-linked immunosorbent assay
ECLO	Emergency Centre for Locust Operations (FAO)
FAO	Food and Agriculture Organization of the United Nations
FCRDI	Food Crops Research and Development Institute, Sri Lanka
FOSEM	Food Security and Marketing for Smallholder Farmers network, Uganda
FRIM	Forestry Research Institute of Malaysia
GNP	gross national product
GRAV	groundnut rosette assistor luteovirus
GRV	groundnut rosette umbravirus
HaNPV	*Helicoverpa armigera* NPV
HRI	Horticulture Research International, UK
IACR	Institute for Arable Crops Research, UK
ICAR	Indian Council of Agricultural Research
ICIPE	International Centre for Insect Physiology and Ecology, Kenya
ICOSAMP	Information Core on Southern African Migrant Pests
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDEA	Investment in Developing Export Agriculture (USAID)
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
INGER	International Network for Genetic Evaluation of Rice

INIBAP	International Network for the Improvement of Banana and Plantain
IOPRI	Indonesian Oil Palm Research Institute
IPM	integrated pest management
IPMSA	Integrated Pest Management Strategy Area
IPS	International Pheromone Systems Ltd
IRRI	International Rice Research Institute
KARI	Kenya Agricultural Research Institute
KFRI	Kerala Forest Research Institute, India
KIOF	Kenya Institute of Organic Farming
MALNR	Ministry of Agriculture, Livestock and Natural Resources (Tanzania)
MAT	male annihilation technique
MLO	mycoplasma-like organism
MSVD	maize streak virus disease
NAARI	Namulonge Agricultural and Animal Production Research Institute (Uganda)
NARL	National Agricultural Research Laboratories (Kenya)
NARS	national agricultural research system
NARSIS	Natural Resources Information System (DFID)
NARO	National Agricultural Research Organization (Uganda)
NDVI	normalized difference vegetation index
NGO	non-governmental organization
NPV	nuclear polyhedrosis virus
NRI	Natural Resources Institute, UK
NRIL	Natural Resources International Limited, UK
NRSP	Natural Resources Systems Programme (DFID)
OB	occlusion bodies
ODA	Overseas Development Administration, UK (now DFID)
PAU	Punjab Agricultural University, India
PCR	polymerase chain reaction
PEDUNE	Protection ecologiquement durable du niébé—Swiss Development Corporation-Funded project in West Africa
PORIM	Palm Oil Research Institute of Malaysia
PPRI	Plant Protection Research Institute, South Africa
PROFOR	UNDP Programme on Forests
PSRP	Plant Sciences Research Programme (DFID)
PVC	poly vinyl chloride
PxGV	*Plutella xylostella* granulosis virus
RAMSES	Reconnaissance and Management System of the Environment of *Schistocerca*
RAPD	random amplified polymorphic DNA
RLD	Rural Livelihoods Department (DFID)
RT-PCR	reverse transcriptase polymerase chain reaction
RYMV	rice yellow mottle virus
SACCAR	Southern African Centre for Co-operation in Agricultural Research, Botswana
SADC	Southern Africa Development Community
SAPPRAD	Southeast Asian Program for Potato Research and Development (CIP)
SARRNET	Southern African Roots and Tubers Research Network
SPCSV	sweet potato chlorotic stunt closterovirus
SPVD	sweet potato virus disease
SWARMS	*Schistocerca* Warning Management System
TARO	Tanzanian Agricultural Research Organization
TNAU	Tamil Nadu Agricultural University, India
ToLCV	tomato leaf curl virus
UAS	University of Agricultural Sciences, Bangalore, India
UNDP	United Nations Development Programme
UNPP	Uganda National Potato Programme
UNBRP	Uganda National Banana Research Programme
UPM	Universiti Putra Malaysia
UV	ultra-violet
VLR	vertical-looking radar
WARDA	West Africa Rice Development Association
WCGA	western cotton-growing area, Tanzania
WECARD	West and Central African Council for Agricultural Research and Development

Project list 1996–2000

R No.	PROJECT TITLE	DATES	LOCATION	*Page*
R5272	Use of pheromones in insect pest management in cotton	1992–1996	Pakistan, Egypt, China	*98*
R5445	Field demonstration of vertical-looking radar as a cost-effective, automatic monitor of desert locust migration	1992–1996	Mauritania	*42*
R5540	The improvement of insect virus application for control of *Helicoverpa armigera* in India	1993–1997	India	*91*
R5735	Control of yam diseases in in Nigeria	1992–1996	Nigeria	*8*
R5881 R5885	Detection and identification of mycoplasma-like organisms (MLOs) associated with little leaf of sweet potato (*Ipomoea batatas*)	1993–1996	Indonesia, Solomon Islands, Papua New Guinea	*94*
R6006/7CB	Adaption of novel techniques for the detection and characterization of the fungi causing fusarium wilt and Sigatoka leaf spots of banana and plantain	1994–1996	Tanzania, Uganda, Kenya	*32*
R6008CB	Sustainable agriculture in forest margins in Bolivia: weed science component	1996–1999	Bolivia	
R6009CB	Management of rice nematodes in West Africa	1994–1996	Ghana	*38*
R6115	Development of pheromones for monitoring and control of sweet potato weevils *Cylas brunneus* and *C. puncticollis*	1996–1997	Uganda	
R6391	Development of nematode resistance in bananas and plantains	1995–1999	India	*72*
R6392	Control of water hyacinth in the Shire River, Malawi	1995–1999	Malawi	*7*
R6519	The epidemiology and management of rice tungro virus disease in relation to the ecology of the leafhopper vectors	1996–1998	India, Indonesia, Philippines	*80*
R6520	Molecular and biochemical techniques for identification and characterisation of *Ralstonia solanacearum* and other plant-pathogenic bacteria	1995–1998	Tanzania, Malawi	*29*
R6521	Detection and identification of phytoplasmas (mycoplasma-like organisms, MLOs) in putative insect vectors of lethal yellowing-like diseases in Africa	1996–1997	Ghana	*46*
R6579	Identification, vector relationships, epidemiology and control of virus and bacterial diseases of banana	1996–1999	Philippines	*74*
R6580	Non-chemical management of banana nematodes in East Africa	1996–2000	Uganda	
R6581	An investigation into the epidemiology and control of fungal pathogens of sorghum in semi-arid production systems in East Africa	1996–1999	Tanzania, Kenya	
R6582	Epidemiology, toxicology and management of the maize ear-rot complex in African farming systems	1996–2000	Kenya, Malawi	
R6583	Analysis of the pathogenic variability and genetic diversity of the plant-parasitic nematodes *Radopholus similis, Pratylenchus coffeae* and *P. goodeyi* on bananas and plantains in East and West Africa	1996–2000	Ghana, Uganda	
R6604	Investigation of lethal coconut diseases of uncertain etiology	1996–1998	Indonesia, India, Sri Lanka	*68*
R6611	Biological control of root-knot nematodes	1996–1999	Ghana, Pakistan	
R6614	Control of African cassava mosaic virus	1996–1998	Uganda, Tanzania	*15*
R6615	Investigation of biorational methods for control of insect pests of vegetables in Kenya	1996–1999	Kenya	*53*

R No.	PROJECT TITLE	DATES	LOCATION	*Page*
R6734	Development of an area-wide strategy for management of insecticide-resistant cotton pests in southern India	1996–1999	India	*95*
R6735	The development of a biocontrol strategy for the management of the alien perennial weed *Mikania micrantha* HBK (Asteraceae) in tree crop based farming systems in India	1996–2000	India	*100*
R6736	The assessment of major soilborne pests of the multi-purpose agroforestry tree, *Sesbania sesban*, and the development and promotion of integrated pest management strategies	1996–2000	Kenya, Zambia, Malawi	*63*
R6737	Management of *Cyperus* in smallholder farming systems on vertisols and vertic clay soils	1996–2000	Ghana	
R6738	Identification and characterisation of key screening sites for blast and scald resistance in West Africa	1996–1999	Ghana, Nigeria, Côte d'Ivoire	
R6739	Application of mating disruption to control yellow rice stem borer in India	1996–1999	India	*83*
R6746	Entomopathogenic baculoviruses for control of the African armyworm, *Spodoptera exempta*, in Tanzania	1996–2000	Tanzania	
R6760	A systems approach to sustainable insect pest management in irrigated cotton in India	1996–1999	India	
R6761	Integrated management of the fusarium wilt/root-knot nematode disease complex on cotton	1996–2000	Tanzania	*60*
R6762	Decision tools to aid armyworm surveillance and outbreak prediction	1996–1999	Tanzania	
R6763	The epidemiology of rice yellow mottle virus disease in rice farming systems in Tanzania	1996–1999	Tanzania	*35*
R6764	Environmentally acceptable crop protection strategies based on the improved use of pesticides and adoption of integrated pest management strategies by smallholder farmers in Zimbabwe	1997–2000	Zimbabwe	
R6765	Control of cassava virus diseases in coastal coconut-based farming systems in Tanzania	1996–1999	Malawi, Tanzania	*13*
R6766	Epidemiology and population structure of *Phytophthora* species causing diseases of coconut in Indonesia	1996–2000	Indonesia	
R6782	Development of coffee IPM components in Kenya	1996–1999	Kenya	*59*
R6788	Development of an outbreak forecasting tool for the Senegalese grasshopper, *Oedaleus senegalensis*, using satellite and ecological data	1997–2000	Senegal, Niger, Chad, Cameroon, Mali	
R6793	Selection of herbicides for use in the management of propanil and fenoxaprop-P resistant *Echinochloa colona* in direct seeded rice	1997	Central America	*108*
R6794	Investigation of banana leaf speckle in Africa	1997	Kenya, Uganda, Cameroon	*31*
R6795	Isolation, identification and culture of indigenous entomopathogenic nematodes and preliminary investigations into their use for control of insect pests of peri-urban agriculture	1997	Kenya	
R6796	An investigation to elucidate the basis of resistance in wild and cultivated species of chickpeas to botrytis grey mould, *Botrytis cinerea*	1997	India, Bangladesh	
R6797	Development of pheromone traps as a component of an IPM approach to control of cabbage webworm, *Hellula undalis*	1997	Malaysia, India	
R6807	An investigaton of pesticide and microbial interactions on coffee as a means of developing an IPM strategy for economically important coffee pests in smallholder farming systems in Malawi	1996–2000	Malawi	

R No.	PROJECT TITLE	DATES	LOCATION	Page
R6809	Statistical analyses of locust movements and their determinants	1996–1998	Sub-Saharan Africa	*44*
R6811	Groundnut rosette disease epidemiology	1996–1999	Malawi	*27*
R6812	Improved ecological and economic recommendations for the control of *Hypothenemus hampei* in coffee in Mexico	1997	Mexico	*104*
R6820	Pest constraints affecting tree crops in Bolivia	1997	Bolivia	*103*
R6822	Identification of the factors that lead to changes in desert locust populations at the beginning and end of recession periods	1996–1999	Sub-Saharan Africa	*43*
R6823	Models of *Quelea* movements and improved control strategies	1996–1999	Namibia, Mozambique, Angola, Malawi, Botswana, Zimbabwe, South Africa, Swaziland, Zambia	*45*
R6835	Evaluate plate capture PCR (PC–PCR as a rapid detection procedure for screening maize plants for infection by maize bushy stunt phytoplasma and corn stunt spiroplasma in Mexico	1997	Mexico	
R6921	Improved methods for the management of *Striga*: nitrogen, tolerance, screening and cultural practice	1997–2000	Tanzania, Kenya	*1*
R6924	Fruit and vegetable pest control in Pakistan	1997–1999	Pakistan	*86*
R6928	Development of pheromones for management of coffee white stemborer, *Xylotrechus quadripes*	1997	India	
R6929	Development of pheromones for management of red palm weevil and rhinoceros beetle on coconuts in Sri Lanka	1996	Sri Lanka	*71*
R6940	Analysis of plant quarantine pest risks for Tanzania	1997	Tanzania	
R6941	The use of composted urban wastes in integrated pest management systems to control pests and pathogens in peri-urban agriculture	1996–1998	Ghana	
R6944	Development of improved IPM technologies for dry season (rabi) vegetables in the Sunderbans coastal saline zone of eastern India	1997	India	
R7004	The improvement of insect virus application for control of *Helicoverpa armigera* in India	1997–1998	India	*91*
R7065	Modelling the performance of the barrier control technique for locust and grasshopper control to maximise their efficiency and minimise their environmental effects	1998–2000	Madagascar	*40*
R7071	Development of improved pest control technologies for dry season vegetables in the coastal saline zone of north-eastern India	1997–2001	India	
R7189	Cultivar competitiveness and interactions with on-farm seed priming for integrated weed management	1998–2001	Côte d'Ivoire, Ghana, Philippines, India, Bangladesh, Zimbabwe	
R7246	Development of pheromones for management of coffee white stemborer, *Xylotrechus quadripes*	1998–1999	India, Malawi	
R7247	Entomopathogenic viruses for control of the legume pod borer, *Maruca vitrata* (Fabricius) (= *M. testulalis* Geyer) (Lep: Pyralidae) in West Africa	1998–1999	West Africa	
R7248	Analysis of a host specificity gene in vascular bacterial pathogens of banana and plantain	1998–1999	Global	
R7249	Development of mycoinsecticides and pheromones for cocoa mirids	1998–2001	Ghana	
R7266	Development and evaluation of a pilot field handbook on natural enemies of vegetable pests in Kenya and Zimbabwe	1998–1999	Zimbabwe, Kenya	*48*

R No.	PROJECT TITLE	DATES	LOCATION
R7462	The development of integrated management systems for the control of pests and diseases in the potato farming systems of the Mesothermic Valleys of Bolivia	1999–2002	Bolivia
R7471	Developing weed management strategies for rice-based cropping systems in Bangladesh	1999–2002	Bangladesh
R7472	Integrated management of root-knot nematodes on vegetables in Kenya	1999–2002	Kenya
R7473	Weed management options for seasonally inundated land in semi-arid Zimbabwe	1999–2002	Zimbabwe
R7474	Weed management options for cotton-based systems of the Zambezi valley	1999–2002	Zimbabwe, Zambia
R7478	Management strategies for banana streak virus: variation of BSV in Uganda as an adjunct to diagnosis and epidemiology	1999–2000	Uganda, Rwanda
R7479	Assessment and significance of tree pests in Bolivia	1999–2000	Bolivia
R7488	Study of factors affecting the uptake and adoption of outputs of crop protection research in banana-cropping systems in Uganda	1999–2000	Uganda
R7489	Study of factors affecting the uptake and adoption of outputs of crop protection research in maize systems in East Africa	1999–2000	Kenya, Uganda
R7490	Integrated pest and soil fertility management	1999–2000	Kenya, Tanzania
R7491	*Nacobbus aberrans* and weeds in Bolivian potato fields: environmental consequences of current and future nemotode control options	2000	Bolivia
R7492	Promotion and technical support for methods of controlling whitefly-borne viruses in sweet potato in East Africa	1999–2002	Uganda, Tanzania
R7499	Crop protection research methodologies for agroforestry systems	1999–2000	Nepal
R7500	Analysis of farmers' decision-making in pest management	1999–2000	India, Kenya, Uganda
R7503	Integrating pest management and soil fertility management	1999–2000	Ghana
R7504	Study of factors affecting the uptake and adoption of outputs of crop protection research on yams in Ghana	1999–2000	Ghana, Nigeria
R7505	Strategies for the sustainable deployment of cassava mosaic disease-resistant cassava in eastern Africa	1999–2002	Uganda, Tanzania, Kenya, Rwanda
R7506	Review of technical and institutional options for sorghum grain mould management and the potential impact on the poor	1999–2000	India
R7512	Factors affecting update and adoption of outputs of crop protection in peri-urban vegetable systems in Kenya	1999–2000	Kenya
R7513	Factors affecting uptake and adoption of outputs of crop protection in vegetable systems in India, Bangladesh and Nepal	1999–2000	India, Bangladesh, Nepal
R7518	Promotion of sustainable control of covered kernel smut of sorghum through broadening the cropping base	1999–2002	Kenya, Tanzania, Uganda
R7529	Management strategies for banana streak virus; epidemiology, vector studies and control of banana streak virus in East Africa highland bananas	1999–2002	Uganda, Tanzania, Kenya, Rwanda, Burundi
R7552	Strategies for development and deployment of durable blast resistance in West Africa	1999–2002	Ghana, Côte d'Ivoire
R7561	Factors affecting uptake and adoption of crop protection research in rice systems in West Africa (Ghana)	2000	Ghana
R7563	Management of cassava brown streak disease and mosaic disease in eastern and southern Africa	2000–2002	Tanzania, Mozambique, Malawi
R7564	*Striga* on cereal crops in East Africa	2000–2003	Tanzania

R No.	PROJECT TITLE	DATES	LOCATION
R7565	Participatory breeding of superior, mosaic disease-resistant cassava	2000–2003	Ghana
R7566	Management strategies for maize grey leaf spot (*Cercospora zeae-maydis*) in Kenya and Zimbabwe	2000–2003	Zimbabwe, Kenya, Swaziland
R7567	Integrated management of banana diseases in Uganda	2000–2002	Uganda
R7568	Characterisation and epidemiology of root rot diseases caused by *Fusarium* and *Pythium* spp. in beans	2000–2003	Uganda, Congo, South Africa
R7569	Participatory promotion of disease-resistant and farmer-acceptable phaseolus beans in the southern highlands of Tanzania	2000–2003	Tanzania
R7570	Determining the nature and function of crop associated biodiversity for sustainable intensification of rice-based production systems	2000–2003	Côte d'Ivoire, Vietnam, Bangladesh
R7571	Management of virus diseases of important vegetable crops in Kenya	2000–2003	Kenya
R7572	Management of key insect pests of sorghum in southern and eastern Africa: developing IPM approaches with expert panels	2000–2003	Southern and eastern Africa
R7576	Factors affecting uptake and adoption of outputs of research systems in India	2000	India
R7579	Strategies for forage production and erosion control as a complement to hillside weed management	2001	Bolivia
R7585	Use of transgenic pest-resistant crops in developing countries	2000	Bolivia, Côte d'Ivoire, India
R7587	Field guide and posters of key natural enemies of vegetable pests in southern and eastern Africa: production and dissemination in Zimbabwe	2000–2001	Zimbabwe
R7778	Rice sheath blight complex caused by *Rhizoctonia* species: pathogen epidemiology and management strategies	2000–2003	Bangladesh
R7779	Forecasting outbreaks of the brown locust in southern Africa	2000–2003	Angola, Botswana, Lesotho, Mozambique, Namibia, South Africa, Zambia, Zimbabwe
R7796	Cassava brown streak virus, virus isolates and the application of the diagnostic test	2000–2001	Tanzania, Malawi, Uganda, Kenya, Mozambique
R7813	Sustainable control of the cotton bollworm, *Helicoverpa armigera*, in small-scale production systems	2000–2004	India, Pakistan, China
R7818	Development of biologically-based control strategies for environmentally sustainable control of red locust in central and southern Africa	2000–2003	Zambia, Tanzania
R7821	IPM promotion in pigeonpea	2000–2001	India
R7858	Promoting potato seed-tuber management for increased ware yields in Kenya, Uganda and the Republic of South Africa	2000–2001	Kenya, Uganda, South Africa
R7876	Investigations into the epidemiology of Kalimantan wilt of coconuts in Indonesia	2001–2003	Indonesia
R7885	Promoting the adoption of improved disease and pest management technologies in chickpea by poor farmers in mid hills and hillside cropping systems in Nepal	2000–2002	Nepal, India
R7890	Establishment of an information core of southern African migrant pests (ICOSAMP)	2001–2002	South Africa, Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, Zimbabwe

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This report highlights achievements from research carried out between 1996 and 2000 under the Crop Protection Programme (CPP) of the UK's Department for International Development (DFID). The programme focuses on generating and promoting knowledge to improve pest, disease and weed management in cropping systems that are relevant to poor people. The CPP and its predecessor, the Integrated Pest Management Strategy Area (IPMSA), have funded over 350 research and dissemination projects since the inception of the IPMSA in 1989.

The work of the programme is guided by DFID's Renewable Natural Resources Research Strategy, which has as its objective the generation and application of new knowledge which will benefit the livelihoods of poor people. The programme is managed on behalf of DFID by Natural Resources International Limited, a specialist research and development management company.

Perspectives on Pests presents the work and findings of CPP-funded research in sub-Saharan Africa, South Asia and South America. The report begins with an overview of how crop protection research relates to poverty alleviation, sustainable livelihoods and environmental issues. Summaries of selected research projects outline the background to each project, the key findings, and current and potential uptake of the technologies developed. A full listing of all CPP projects undertaken between 1996 and 2000 is given, as well as contact information for the main organisations participating in the research. Also provided (on CD-ROM) is a bibliography of publications generated by the programme since 1989.

Perspectives on Pests is intended to be of use to technical specialists and non-specialists alike, and should be of interest to researchers, research managers and policy-makers in the field of crop protection.

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CROP PROTECTION PROGRAMME

DFID Department for International Development

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