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Mobilizing IPM for sustainable banana production in Africa

Proceedings of a workshop on banana IPM held in Nelspruit, South Africa — 23-28 November 1998

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The opinions in the publication are those of the authors and not necessarily those of INIBAP.

Acknowledgements

INIBAP is grateful to all participants at the International Workshop "Mobilizing IPM for sustainable banana production in Africa" for their contribution to these proceedings. INIBAP would especially like to thank:

- The Rockefeller Foundation, the Swiss Agency for Development and Cooperation (SDC) and Natural Resources Institute (NRI) for their financial support to this event.
- In addition, INIBAP thanks the other members of the Organizing Committee, the International Institute for Tropical Agriculture (IITA), National Agricultural Research Organization (NARO) and Institute of Tropical and Subtropical Crops (ITSC) for their keen efforts in successfully organizing this workshop. Special thanks go to ITSC for contributing material and staff resources to ensure the workshop's success.
- E.A. Frison, C.S. Gold, E.B. Karamura and R.A. Sikora for their conscientious work as scientific editors of the proceedings.
- E. Lipman who undertook the style editing of the proceedings.

Editorial note

Some references have been submitted without complete publishing data. They may thus lack the full names of journals and/or the place of publication and the publisher. Should readers have difficulty in identifying particular references, staff at INIBAP will be glad to assist.

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Session 1
Opening

Opening ceremony: welcome and opening speeches[1]

Johan van Zyl, Director ITSC, cordially welcomed the participants to Nelspruit. He informed the participants that Nelspruit is in the province of Mpumalanga, home of the famous Kruger National Park. Nelspruit is also famous for the mining of coal for electrical power which is much needed in the South African industries. He indicated that 7% of the South African population lives in Nelspruit, and that Nelspruit is one of the major banana-growing areas in South Africa, a sufficient reason to make it the most appropriate place for the banana IPM workshop. He wished participants a successful and fruitful meeting and promised that ITSC would endeavour to provide a good environment for the success of the meeting.

Dr Emile Frison, Director INIBAP, also welcomed the participants to the workshop, on his behalf and on behalf of IPGRI. He informed that the workshop was a joint initiative by INIBAP and IITA. He heartly thanked ITSC, especially Dr Zaag de Beer, for the excellent preparation of the workshop. He singled out the hotel bookings, airport arrangements which he termed as marvelous. Dr Frison reiterated that organizing the workshop would have not been possible without the support provided by the donors (The Rockfeller Foundation, NRI, the Swiss Agency for Development and Cooperation). He thanked those donors for their generous support. He reckoned that it was going to be failure of duty if he failed to thank the "Best Western Hotel" management and staff for their hospitality and homely service to the participants. He sincerely hoped that participants would interact effectively to achieve fruitful results and with that note he wished the workshop a successful meeting.

On behalf of IITA, Dr Cliff Gold briefly summarized the activities of IITA pertaining to pest management on *Musa* in eastern Africa. He said his project began in Uganda in 1990 with two senior staff scientists. By 1993 ESARC was established and the scope of the project broadened to include not only entomology but also nematology, training, and breeding, all of which are crucial elements of IPM. He informed the workshop that all these activities are carried out in close collaboration with National Banana Research Programmes.

Mr Simphiwe Mkhize, Representative of the Ministry of Agriculture, noted that the workshop aimed at addressing issues of future sustainability of agricultural research outputs. He reiterated the importance of investing in science and technology and the need to ensure adequate sustainability of genetic improvement. He informed the participants that South Africa is taking steps to fully join other research organizations, that it contributes 1.7 million dollars to CGIAR and is in the process of negotiating with IPGRI to be recognized as a gene-indexing centre. Mr Mkhize however indicated that he

[1] (Rapporteur notes)

was not pleased by the fact that the previously disadvantaged groups (e.g women and coloured people) are left behind in the development of technologies and policies concerning agriculture. In this regard the Ministry of Agriculture has requested the South African government to pass an affirmative action. The request also justifies all scrutiny and checks for approving funds to ensure that there is productivity and sustainability for future generations of all races.

The Opening Ceremony Chief Guest Mr Jons Terblanche, President of South Africa's Agriculture Research Council (ARC), was unable to attend and asked Dr John Van Zyl, Director ITSC, to perform the Opening Ceremony. In his speech Dr Van Zyl emphasized the need to look at Integrated Crop Management for bananas so that other factors such as soil fertility, postharvest and socioeconomics which affect banana production in general and IPM in particular are taken care of. He thanked INIBAP-IPGRI, BARNESA and ITSC for initiating useful linkages and advised that those linkages should be strengthened further for the good of the banana farming communities in Africa.

Workshop objectives

E.B. Karamura[1]

Importance of bananas in sub-Saharan Africa

Bananas[2] (*Musa* spp.) are one of the world's most important and yet poorly studied crops. Total world production of *Musa* is estimated at around 86 million tons, of which approximately one third is produced in sub-Saharan Africa. In Africa, the crop is particularly important in the humid forest and mid-altitude regions where it provides more than 25% of food energy requirements for around 70 million people. Bananas grow in a range of environments and will produce fruit all year round, thus playing an important role in bridging the "hunger-gap" between crop harvests. As well as being an easily produced source of energy, bananas are also rich in a number of important vitamins and minerals. In addition to being a staple food crop for rural and urban consumers, bananas are also an important source of rural income. The crop is also environment-friendly, combating soil erosion on hilly slopes, and readily lends itself to intercropping and mixed farming.

A wide range of genetic diversity of bananas is found in Africa, with different types being specifically adapted to different sub-regions. In East Africa, highland AAA cooking and beer bananas predominate, and it is in this region that bananas reach their greatest importance as a staple food crop. In countries such as Uganda, Burundi and Rwanda, annual per capita consumption has been estimated at 220-440 kg, the highest in the world (Karamura 1992). In West African humid lowlands, plantains (AAB) dominate banana production systems. The crop provides an important source of rural income, especially for resource-limited farmers.

Although bananas come fourth after rice, wheat, and maize with regard to gross value on the global scale, the crop actually comes second after cassava in sub-Saharan Africa.

Production constraints

Bananas may be produced under systems of shifting cultivation (West/Central Africa), or in permanent farming systems (eastern African), where they are often grown in association with tree crops, such as coffee and cocoa. They may also be produced in intensively managed homegardens where they benefit from the regular application of

[1] INIBAP, Kampala, Uganda

[2] Throughout the text the term "banana" is used to cover all varieties of bananas and cooking bananas including plantains

manure and household refuse. Although these systems worked well in the past, they are now unable to meet the demands of a rapidly growing population. Rising population pressure on the land has led to shortened fallow periods and consequently declining soil fertility. Pest and disease pressures have also increased considerably in recent years, leading to a situation where a well-managed banana garden in East Africa, previously expected by the farmers to last up to 50 years, now begins to deteriorate after only 4 years, as is the case in parts of Uganda.

A major constraint to banana production in sub-Saharan Africa is black Sigatoka. This leaf spot disease, caused by the fungus *Mycosphaerella fijiensis*, was introduced into Africa in the mid-1970s and spread rapidly, initially in West and Central Africa and later in East Africa. All the traditional plantain cultivars of West and Central Africa are susceptible to the disease, as are many of the widely grown cultivars in East Africa. The disease causes severe leaf necrosis and can reduce yields by 30-50%.

Considerable losses are also caused by fusarium wilt, *Fusarium oxysporum* f.sp. *cubense*, a soilborne disease which affects many important cultivars of banana. Other *Fusarium* spp. appear to cause damage to bananas in East Africa, and this, together with the banana weevil *Cosmopolites sordidus*, and a complex of plant parasitic nematodes (*Radopholus similis*, *Pratylenchus* spp. and *Helicotylenchus multicinctus*) is causing serious crop losses in the region. Both weevil and nematode infestation interfere with nutrient uptake and transport, resulting in slow growth, reduced fruit filling and susceptibility to wind-lodging.

Banana research in Africa

Banana research in ESA has remained *ad hoc* since the turn of the century (Jameson 1979). Most of the work, particularly during the colonial era, was short-term survey reports and focused mainly on crop taxonomy and pest control. In the quest for providing raw materials for the metropolitan industries, governments largely emphasized and supported traditional cash crops (coffee, tea, tobacco, etc.) to the neglect of staple foods like bananas which were viewed as hardy native food, requiring no research attention (Churchill 1908). The post-colonial political turmoil in the region however did not help the situation and by 1970 food production, including that of bananas, began to decline (Karamura 1992). Moreover, during the period, there was an escalation of disease and pest attack (weevils and nematodes, fusarium wilt (Ddungu 1987)) as well as of new diseases (black Sigatoka, banana streak virus, bunchy top) which helped accelerate the rates of yield and plantation life decline.

Pest management in banana production systems in sub-Saharan Africa

Banana production systems in Africa are characteristically complex, even on one farm. They range from single cultivar to multiple cultivars, mixed cropping and mixed farming

systems. Similarly farm management is also extremely variable to include household, hired and communal labour, all three sometimes occurring on the same farm. Equally variable are the purposes for which the crop is grown. In parts of Africa there are expensive commercial farms (e.g. South Africa) while in others (e.g. Kenya) a semi-commercial systems predominates, but in most parts of sub-Saharan Africa the crop is grown for subsistence purposes as a backyard/garden crop and/or other smallholdings not exceeding 0.5–2.0 acres.

Another characteristic feature of banana production in sub-Saharan Africa relates to yield trends (Table 1). Over the last two or so decades banana productivity has been on the decline. This sharply contrasts with the ever increasing population growth rates. As can be seen from Table 1, the solution for increased population and decreasing yields has been to increase acreage. This in return has pre-disposed the natural resource base to diverse agents of erosion. Consequently soil fertility has gone down together with yield and in all sub-Saharan regions. Thus soil fertility in banana production systems is a top-rated constraint in the region.

Table 1. Banana production in Rwanda and Uganda (FAO 1998).

Country	Year			
	1970	1980	1990	1997
Rwanda				
Area (ha)	150,100	224,600	392,000	420,000
Production (Mt)	1,651,100	2,063,100	2,747,000	2,248,000
Yield (Mt/ha)	11.00	9.19	7.01	5.35
Uganda				
Area (ha)	1,051,500	1,275,000	1,506,000	1,803,000
Production (Mt)	7,989,000	6,068,000	8,402,000	9,893,000
Yield (Mt/ha)	7.60	4.76	5.58	5.49

Banana production systems in sub-Saharan Africa are also characterized by low-input application. In general most farmers do not apply inorganic fertilizers, and/or technical know-how. Consequently soil fertility is progressively on decline in these systems. Similarly most farmers do not apply pesticides to control the numerous pests and diseases that have emerged on the crop, nor do they maintain crop hygiene to bring down pest/disease incidence. The traditional method of using planting materials from existing stands in the neighbourhood has helped to spread pests and diseases that lodge in the planting material.

The complexity in production systems is also matched by a multitude of pest problems. As already pointed out above, there are no single pest/disease situations in sub-Saharan Africa banana systems but a complex of pest/disease systems. The incidence and distribution of pest/diseases in the sub-Saharan banana systems in Africa is greatly influenced by the broad agroecological as well as by socioeconomic factors. These complex but interacting factors constitute the banana production systems in sub-Saharan Africa and must be taken into account when planning pest management strategies. Ecologically

some pests are K-strategists, living longer and surviving in stable environments (e.g. the banana weevil), while others are V-strategists and reproducing rapidly, living for a short time but will survive in unstable environments (e.g. nematodes). In planning management strategies in a given banana production system the survivorship strategies of the target pests must be appreciated. Similarly the effects of a given management strategy on other pests and diseases and above all on yield will need to be appraised. Equally important is the need to appreciate the banana plant, its nutritive requirements and response to a given pest stress/load. How does the plant phenology respond to pest attack in a given soil fertility level in a commercial, semi-commercial or subsistence production systems? What about the farmers' actions, expectations, options and priorities and their impact on both plant and growth and on pest/diseases population? In short therefore any pest management strategies planned must take into account the pest-plant-farmer circumstances in a complex of agroecological and socioeconomic situations. It is because of this complexity that increasingly scientists have advocated for the integration of tactics rather than single tactic approaches. Moreover over years single tactic approaches have been tried – trapping to control weevils, nematodes and fungal diseases and cultural controls against the pest systems, to no avail.

Thus the overall purpose of this workshop is to draw up integrated pest management strategies, taking into account the technical review papers here presented. The workshop should evaluate the various tactics being developed/applied and decide which of those still require more research, testing and/or evaluation. Finally the meeting is expected to draw up an implementation plan for evaluating "ready-to-go" tactics in an integrated system. A research plan should also be drawn up for addressing IPM information gaps. In short therefore the workshop will proceed with the following objectives:

- Review banana IPM activities in SSA and identify information gaps.
- Identify ready-to-go pest/disease management tactics for incorporating into IPM strategies for bananas in SSA.
- Draw up an IPM implementation research programme strategy for SSA.
- Draw up strategies for addressing banana IPM information gaps.

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Integrated pest management: an overview

E.A. Frison

Introduction

It is universally acknowledged that agricultural pests represent a major threat to the global food supply. Insects consume an estimated 13% of the world's food production and to fight them and to keep diseases and weeds at bay costs billions of dollars every year. Indeed modern agriculture is impossible without efficient control of pests, diseases and weeds and since the beginning of agriculture some 10,000 years ago farmers have been developing strategies to overcome pest attack. The first recorded use of insecticides dates back to 2500 BC when the Sumerians used sulphur compounds to control insects and mites. Somewhat later, 1500 BC, comes the first description of a cultural pest control method – manipulation of planting date. Following from this, farmers and scientists continued to develop a multitude of pest control methods, based largely on natural products and cultural control. It was not until the 1940s that the use of chemical pesticides to control crop pests began in earnest. Within the space of 10 years the insecticide DDT, the fungicide Ferbam and the herbicide 2,4-D were developed. No longer was there a need to carry out the traditional pest control practices; farmers came to expect 100% pest-free crops and consumers blemish-free products. Pesticide use increased steadily from 1950 to 1970, but instances of pesticide resistance, pest resurgence, secondary pest attack and environmental contamination were noted. The effect of pesticides on non-target organisms also became a cause for concern, and with the publication of Rachel Carson's book "Silent Spring" in 1962 a pesticide backlash was sparked.

The primary motivating force behind the development of IPM programmes was thus the anti-pesticide movement that developed in the 1960s. More recently however, worldwide public attention has been focused on the importance of IPM by the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992. Agenda 21, the blueprint for action prepared by the conference, recognized pesticide pollution as a major threat to human health and the environment worldwide and identified IPM as a key element in sustainable agricultural development.

INIBAP, Montpellier, France

Integrated pest management can be defined as 'the use of multiple tactics in a compatible manner to maintain pest populations at levels below those causing economic injury while providing protection against hazards to humans, animals, plants and the environment'. IPM is thus ecologically-based pest management that makes full use of natural and cultural processes and methods, including host resistance and biological control. IPM emphasizes the growth of a healthy crop with the least possible disruption of agroecosystems, thereby encouraging natural pest control mechanisms. Chemical pesticides are used only where and when these natural methods fail to keep pests below damaging levels.

Developing IPM strategies

For farmers to accept the concept of IPM, they must generally be convinced that it is economically worthwhile. They may have to change from a pest control philosophy, which tends towards annihilation or 100% control, to a pest management approach, which tries only to suppress the pest population below an economic threshold. The pest control philosophy tends to favour the single best means of killing a pest (usually a chemical), while pest management considers simultaneously all the possible management strategies (which may include chemicals where appropriate).

As the practice of IPM is site-specific in nature, individual tactics are determined by particular crop/pest/environment scenarios. Thus the development of IPM strategies, which may include prevention, avoidance, monitoring and suppression of pest populations, requires an integrated and holistic approach. Because IPM involves multi-pest interactions with a large number of variables to consider, a "systems approach" is recommended when developing IPM programmes. As a methodology for solving complex problems, a systems approach involves multidisciplinary teamwork in planning and management and in the organization of physical and human resources. A systems approach provides the tools to explore interconnections between farming and other aspects of the environment. It also implies interdisciplinary efforts in research and education. This requires not only the input of researchers from various disciplines, but also farmers, farmworkers, consumers, and policymakers. The inclusion of this latter group is important as in order to develop cost-effective IPM strategies, it may be necessary to influence public policy towards the creation of an economic environment in which the benefits of IPM outweigh the costs. This could for example include the removal of subsidies on pesticides, or the imposition of fines for pollution in run-off from agricultural land or pesticide residues on agricultural produce.

The rationale behind IPM is that the combination of several tactics, each offering only partial control of the target pest species, can suppress the pest population below the desirable threshold. Such complex pest management schemes help to build in long-term stability to the system. Combinations of different control tactics limit both the intensity and duration of the selection pressure imposed by a single tactic on the pest.

IPM strategies can exist at various levels of integration:

- Tactics for the control of a single pest on a particular crop.
- Control of several pests on the same crop.
- Several crops (and non-crop species) within a single production unit (farm).
- Several farms in a region (area-wide pest management).

Examples of integration at all four levels are rare – most IPM programmes still operate at the single pest or no higher than the single crop level.

IPM tactics

There are many different tactics that can be employed, either alone or in various combinations in IPM strategies. These include regulatory control, cultural control, genetic manipulation of the pest population, host plant resistance, biological control and chemical control. These different tactics are described in more detail below.

Regulatory control

Many crop plants are grown where they are not endemic and they have often been successfully introduced into new areas without the pest species that attack them in their place of origin. However because they have continued to grow and be selected in the absence of their natural pests and pathogens, they have lost what resistance they may have had. In addition, many of the barriers to the spread of pests (oceans, mountains, deserts etc.) are no longer effective. High-speed modern transport increases the likelihood of the successful transport of short-lived pests.

Regulatory controls (quarantine) are put in place in order to restrict the movement of pests into areas where they do not occur. Considering the enormity of the job, quarantine is generally considered an unstable method of pest management, but may buy time while alternative control measures are developed.

Quarantine usually goes hand in hand with eradication, such that small, localized newly-arrived infestations are eliminated before they can spread. The success in eradication of a pest depends on the sensitivity of detection methods, the ability to mobilize the eradication effort quickly and the effectiveness of the eradication methods. The costs and benefits of quarantine as a pest control method must be weighed against the costs and benefits of alternatives. In a study on the Mediterranean fruit fly in California (*Ceratitis capitata*), the cost of eradication after an introduction in 1980 was more than $80 million. However, the estimated costs to the horticultural industry if it became established were considered to be around $413 million/year.

Cultural control

Cultural control can be defined as the deliberate manipulation of the environment to make it less favourable for a pest or pests. Cultural control was, and still is in many areas, an integral part of farming practice. There is no general theory of cultural control and the various methods have developed by empirical means. Such methods include

crop sanitation, tillage, crop rotation, the use of border rows and trap crops, the deployment of diversity and the timing of crop cycles.

Genetic manipulation of pest population

Sterile insect release

This method involves the release of sterile or genetically incompatible insects into a wild population. The success of this technique relies on the timely release of large enough numbers of healthy competitive insects. It is particularly effective when combined with the use of an insecticide to initially reduce the wild population and becomes more efficient as the wild population declines. It has the potential to drive the wild population to extinction, but has the disadvantage of being expensive. In fact one of the major limitations of the use of this technique is that the costs generally outweigh the benefits. This technique has been used with some success against the Screw-worm in Venezuela and Florida (Bartlett *et al.* 1996) and a programme is presently being developed against a Mexican Fruit Fly invasion in California (Anonymous 1998).

Delayed sterility

This is a modification of the above technique, but in this case the reared and released insects are fertile but their progeny are sterile. While effective population suppression is possible with far fewer released insects, this technique has the disadvantage that the creation of a population of ecologically fit, genetically altered insects is difficult.

Genetic displacement

The goal here is to replace the wild population with a population of insects genetically altered to suit our needs. The rationale behind this is that the extinction of species results in a vacant ecological niche and can upset the natural balance. The type of genetic alterations which might be considered are reduced crop damage or increased pesticide sensitivity. The method is however still largely theoretical and has not yet been commercially applied (Bartlett *et al.* 1996).

Genetic manipulation of the crop (host plant resistance)

Host plant resistance can be considered the foundation on which IPM is built. The inherent genetically-based resistance of a plant can protect it against pests or diseases without recourse to pesticides. Moreover to use it the farmer has no need to buy extra equipment or learn new techniques.

Types and methods of resistance

Resistance to pests is the rule rather than the exception in the plant kingdom. In the co-evolution of pests and hosts, plants have evolved complex defence mechanisms. Such mechanism may be either physical (waxy surfaces, hairy leaves etc.) or chemical (production of secondary metabolites) in nature. Pest-resistant crop varieties either suppress pest abundance or elevate the damage tolerance level of the plant. In other words, genetic resistance alters the relationship between pest and host. The functional

response of the pest to the resistance may be antixenosis (non-preference) or antibiosis (early-death, abnormal development).

Sources of resistance

Genetic resistance may be under the control of single or multi-genes. In the former case, which is easier to study and therefore more well-known, there is a gene-for-gene relationship between the inheritance of the defence mechanism on the part of the plant and the mechanism for overcoming the defence mechanism on the part of the pest. There are also many defence mechanisms that are multigenic in their inheritance and that are quantitative in their effects.

Pest resistance genes are predominantly found in wild species within the same genus or family as the crop plant. Because such plants are in dynamic equilibrium with the pests, the resistance genes are present in a high enough frequency to be readily found. Unfortunately resistance genes from wild species are often combined in linkages with undesirable genes and many recombination and selection steps are required to incorporate them into useful cultivars. Another source of resistance genes is primitive cultivars or landraces, although this is a much smaller reservoir of diversity than wild species. For example, in potato, high levels of resistance to the green peach aphid (*Myzus persicae*) has been identified in about 6% of examined accessions of wild *Solanum* species, but in 0% of over 360 accessions of *S. tuberosum* and other cultivated *Solanum* species (Flanders *et al.* 1992). Wild crop relatives have yielded pathogen resistance in, amongst others, rice, wheat, barley, cassava, sweet potato, tomato, sunflower, grapes, tobacco, cacao, sugarcane and *Musa* (Eigenbrode 1996). It is worth noting here that many of these wild relatives of crop plants are under-represented in germplasm collections, making up only about 10% of accessions in national collections (FAO 1996).

Genetic transformation

New recombinant DNA technologies have extended the pool of resistance genes to unrelated organisms and also spawned the development of a large and growing plant biotechnology industry. The development of transgenic plants that are resistant to viruses and insects has been more successful than for resistance to bacteria and fungi, but this gap is steadily closing. Resistance genes for fungal and bacterial genes have now been cloned and there is a greater molecular understanding of plant-pathogen interactions.

Despite the fact that in some countries genetic engineering has elicited fears of genetic catastrophes and talk of "Frankenfood", the total acreage of genetically-modified crops in the USA has expanded rapidly in the last few years, with this year's acreage estimated at 50 million acres. According to recent report in the Washington Post, an estimated 45% of this year's US cotton crop was genetically engineered and tens of millions of acres of engineered soybeans, corn, canola and potatoes have also been planted. The story also says that in the Southeast USA, for example, insecticide doses on cotton have been reduced by as much as 45% and weed control has been made easier.

Genetic transformation techniques hold particular potential for the improvement of crops such as *Musa*. For this species, genetic transformation provides a unique opportunity for the introduction of useful genes into otherwise highly sterile cultivars

which cannot normally be used in breeding programmes. Moreover, since many of the cultivated varieties are sterile, crossing with other plants cannot occur and the introduced genes will thus remain confined to the plants into which they have been inserted.

Deployment of resistance genes

Various mechanisms can be employed to prevent or delay the "breakdown" of the resistance as a result of changes in the pest population. Such mechanisms include the pyramiding of selective single genes ("vertical" resistance), the use of "horizontal" resistance, and the use of multilines, synthetic hybrids and cultivar combinations.

Use of host plant resistance in IPM

The IPM concept stresses the need to use multiple tactics to maintain pest populations and damage below levels of economic significance. Thus a major advantage of the use of pest-resistant crop varieties is its compatibility with other methods of direct control. Pest-resistant cultivars allow a synergy of the effects of cultural, biological and even chemical pest control tactics. Host plant resistance is of particular importance in developing countries where farmers lack the resources for other control measures.

Biological control

The use of natural pests to reduce the impact of pests has a long history. The ancient Chinese, observing that ants were effective predators of many citrus pests, augmented their populations by taking nests from surrounding habitats and placing them in their orchards.

Importation of natural enemies

The importation of natural enemies, sometimes referred to as 'classical biological control', is used when a pest of exotic origin is the target of the biocontrol programme. Pests are constantly being introduced into countries where they are not native – usually accidentally, but sometimes intentionally. For example, since the Plant Quarantine Act was passed in 1912, more than 1000 insect species have become established in the USA. It is not surprising that some of these become pests due to a lack of natural predators to suppress their populations. The introduction of natural enemies has to be done with great care to ensure that no undesirable species (diseases, hyperparasites) are also introduced and to monitor the environmental effects of the introduced species. Over 6000 programmes of classical biological control of insect and mite pests have been executed since 1888, when the Australian ladybird, Rodolia cardinalis, was introduced into California to successfully control outbreaks of the introduced Australian cottony cushion scale insect, Icerya purchasi. A notable recent example, described in more detail later in the text, is the control of the cassava mealy bug in Africa.

Augmentation

Augmentation is the direct manipulation of natural enemies to increase their effectiveness. A good knowledge of population dynamics of both pest and biocontrol agent and their responses to environmental variables is essential. A well-known example of the use of augmentation is the use of the parasitoid wasp *Encarsia formosa* to

suppress populations of the greenhouse whitefly. The most widely augmented arthropod biocontrol agent in the world is *Trichogramma*. These minute endoparasitoids of insect eggs are released in crops timed to the presence of pest eggs. It is estimated that some 32 million hectares of agricultural crops and forests are treated annually with *Trichogramma* spp. (Li 1994). The pests it controls include sugar cane borer, codling moth and European corn borer.

Chemical control

In many cases pest outbreaks occur in spite of efforts in prevention or avoidance. If effective biological or other controls do not exist, chemical pesticides may be the only alternative for saving a crop. Pesticide use in IPM systems should be directed by the following approaches:

- The cost:benefit ratio should be confirmed prior to use (economic threshold).
- Pesticides should be selected on the basis of least negative effects to beneficial organisms, the environment and human health.
- If feasible, precision agriculture or other advanced technologies should be utilized to limit pesticide applications.
- To avoid resistance development, chemicals with the same mode of operation should not be used continuously on the same field.

It has been shown that the regular application of economic thresholds can result in reduced pesticide use by decreasing the frequency of application. Indeed, it has been estimated that pest monitoring, establishment of economic injury levels, and reduced pesticide dosage can reduce pesticide use by 30 to 50% (Pedigo 1996).

"Third generation" insecticides

Such insecticides include insect growth regulators and semiochemicals. The former group of chemicals consists of hormones or hormone mimics which interfere with the insect's normal growth, development and reproduction. They are generally specific to insects, but may be equally damaging to beneficial insects as to pest species.

Semiochemicals (chemicals "carrying messages") include pheromones and allelochemicals. The use of these types of chemicals is generally constrained by the lack of biological information on stimuli, responses and interactions. More long-term, fundamental research is required in this area (Anonymous 1995).

IPM implementation

IPM concepts and principles apply equally well to pest control on farms of all sizes and levels of technological sophistication, from small subsistence farms to huge, highly mechanized corporate farms. While some of the trappings of IPM (computers, monitoring devices etc.) can require substantial capital investments, IPM is possible without them. More important than computer technology is a fundamental understanding of the ecology of the system.

The implementation of IPM programmes does however require a certain level of investment in research, extension and training. Research must be interdisciplinary, rather than carried out exclusively within the traditional disciplines (this can be difficult when peer recognition and academic promotion occurs within disciplines). Extension workers require training in IPM philosophy and methodologies, as well as in effective communication skills. In addition, farmers may need to carry out pest monitoring and identify 'action' thresholds, thus training is needed in these areas.

In many developed countries, farmers are now switching from conventional pest control practices, which are heavily reliant on pesticides, to alternative practices, which substantially reduce pesticide use. In these countries, pressure from environmentalists and consumer groups and growers' concerns about the personal health hazards of the applications of pesticides provide strong incentives for the adoption of IPM technologies. Moreover IPM technology delivery systems are generally in place and the necessary information and support services are available. This is not the case in most developing countries.

IPM in developing countries

In many developing countries, during the Green Revolution, pesticides were considered a necessary part of crop intensification. A number of policy instruments were applied to make purchased inputs, including subsidized pesticides, available to the farmer. Pesticides also became part of loan packages and extension messages. This often resulted in a substantial mis- and over-use of pesticides. Such methods of plant protection have proven to be increasingly unsustainable and cost-ineffective due to the development of pest resistance, the rising costs of pesticide use, pesticide-induced outbreaks of anthropod pests and the negative effects of pesticide use on human health and the environment.

IPM is clearly an appropriate, ecologically sound, viable alternative to pesticide use for small-scale farmers in the tropics. Moreover, the high crop diversity and traditional practices of intercropping and mixed farming favour the implementation of IPM. Since the mid-1960s, FAO has advocated IPM as the preferred means of pest control and more recently, the CGIAR has established a System-wide programme on IPM. In addition, many national programmes are also focusing their crop protection activities into IPM.

However, despite these initiatives, the prevailing trend in developing countries still seems to favour increased use of chemical pesticides and it appears that the misconception that pesticides are essential for high yields persists with many farmers. Within the last decade it is estimated that pesticide use grew by 200% in Africa, 40% in Latin America and less than 25% in Asia. The average growth in the developing countries was about 55% as against 20% for the world total (Mengech *et al.* 1995).

Major constraints to the development and adoption of IPM programmes fall into four categories:

- **Technical:** lack of basic studies on pests and their natural enemies; lack of effective and economic means of producing natural enemies; few studies on interactions between different means of pest control; complexity of IPM; lack

of determination of economic/action thresholds; difficulties in developing an appropriate IPM programme in which all components are compatible.

- **Economic:** competing simplicity and apparent efficacy of chemicals; lower prices for IPM-produced goods (cosmetic damage); high cost of selective pesticides; lack of fiscal policy that favours IPM over pesticide use; high perceived risk if spraying is not carried out; failure to consider long-term advantages.
- **Institutional:** poor linkages between research and extension; lack of extension services, monitoring services, private consultants etc.
- **Educational:** illiteracy, lack of understanding of IPM by farmers/extension workers; lack of multidiscipline training for researchers/extension workers; lack of IPM specialists.

It should also be noted that IPM has arisen mainly from needs expressed by consumer groups and environmentalists, not from farmers' needs. In many cases farmers are satisfied with the use of pesticides and are therefore intolerant of imperfections in the new technology. Growers often have experience of and confidence in the use of chemicals and there is an established infrastructure for their supply. A key factor in the success of an IPM programme therefore is grower participation in all stages, from planning, through implementation to evaluation.

IPM in Africa

The majority of farmers in sub-Saharan Africa are smallholders, many of whom do not own the land they farm. These smallholder farmers have been practising some forms of IPM for centuries – traditional methods of intercropping, mixed farming and uses of diversity are important components of IPM. However despite this, pesticide use is growing in Africa at the highest rate in the world. Although many African governments still favour subsidizing pesticides, less than half of all countries in Africa appear to have legislation on pesticides and most countries cannot comply with all the provisions of the FAO Code of Conduct on the import/export, distribution and use of pesticides. (Mengech *et al.* 1995).

While work on single IPM components (resistant varieties, biological control) is fairly common in most countries across the continent, there are few comprehensive IPM projects. In addition there are generally too few crop protection researchers, and extension services are grossly under-funded. A particular problem is lack of female extension workers and therefore poor communication with the majority of farmers, who are women. In addition, lack of access to information, lack of transport and poor motivation also tend to inhibit the development and transfer of IPM technologies.

With the exception of South Africa, where IPM research for a number of crops/pests is being carried out within the framework of the Agricultural Research Council, much of the work on IPM in Africa is carried out in projects funded by international donors or by International Agricultural Research Centres (IARCs). The International Institute of Tropical Agriculture (IITA), which is located in Nigeria, is the convening centre for the CGIAR's System-wide programme on IPM and the International Centre of Insect

Physiology and Ecology (ICIPE) in Kenya has a particular focus on IPM for the control of insect pests. A recent review of IPM projects in Africa listed 51 such projects across the continent. Of these, ten were national projects funded by national governments (Mengech *et al.* 1995). It is also interesting to note that only 12 were reported as having farmers' active involvement in the project and only three included more than two main components of IPM. Nearly half of the projects focused on biological control and the use of natural enemies.

It is characteristic of African agriculture that only a few of the cultivated crops are indigenous to Africa. Although two of the important staple food crops of dry areas, millet and sorghum are native, many of the other major food crops, maize, rice, cassava, sweet potato and banana for example, have been introduced. The pest situation in the region has worsened in the last couple of decades, as illustrated by the introduction of the cassava mealy bug, cassava green mite and the larger grain borer. The main reasons for these introductions have been increased trade and travel between continents and inadequate plant quarantine services. Many introduced pests have caused severe damage due to a lack of natural enemies, and it is therefore not surprising that some considerable success has been achieved with classical biological control programmes.

A notable IPM success story in Africa has been the control of the cassava mealy bug. When the cassava mealy bug, together with the cassava green mite, first appeared in Africa in the early 1970s, they caused widespread damage and loss and the livelihoods of millions of people were threatened. Both pests originated in South America where they generally do not cause such dramatic damage. Predators and parasitoides that were specific to the mealy bug were discovered in 1980 in South America and, following rigorous screening in the UK, these natural enemies were introduced into Africa. After mass-rearing at IITA, the first releases took place and monitoring was initiated. The results were astonishing. Three years after the first release, one of the parasitoids (*Epidinocarsis lopezi*) was found in 70% of all cassava fields in more than 200,000 km^2 in southern Nigeria. In 1985 this programme was expanded into the Africa-Wide Biological Control Programme and by 1990 *E. lopezi* had become established in 25 of the countries where cassava is cultivated. The biological control of cassava mealy bug has proved to be not only ecologically, but also economically sound, with a benefit/cost ratio of 178 to 1 (Mengech *et al.* 1995). The main reason for the high ratio is that biological control is a self-sustaining strategy and requires only a single, low-cost input.

This example serves to illustrate that there have been successes in IPM in Africa. Considerable progress has been made in developing components for integrated pest management, mainly in the form of resistant varieties and agents for classical biological control. In addition, a number of regional networks have been set up, some crop-specific and some pest-specific. However many NARS still suffer from various financial, educational, organizational and administrative constraints which hamper local research and extension activities. Extension services particularly are sparsely staffed and are generally poorly trained in IPM. Most farmers are therefore left without advice on IPM, apart from projects executed by donors or IARCs.

IPM in Asia

South and Southeast Asia is the world's most densely populated region, and the rapidly growing population is exerting an ever-growing demand on agriculture. The intensification of crop production programmes with an emphasis on increasingly higher yields has resulted in more intensive pesticide inputs and unsustainable land and water use. Despite the fact that the consequences of injudicious use of pesticides in Asia are well documented, crop protection continues to be dominated by a dependence on chemicals. The practice of calendar spraying is common amongst Asian farmers and pesticide subsidies remain a major aspect of plant protection policies in many countries.

In spite of this, almost all the countries of the region have now declared IPM as part of their agricultural development policy. Pest survey and surveillance programmes have been established in most countries, including China, India, Indonesia, Malaysia, Republic of Korea, Pakistan, the Philippines and Thailand and most countries have pesticide legislation to control the production, import, export, handling and use of pesticides. However the enforcement of pesticide regulations is frequently constrained by a lack of trained personnel and inadequate facilities such as residue testing labs.

A number of successful IPM projects have been developed in different parts of Asia over the last 2 decades, with a prime example being that of rice production in Indonesia. Indonesia became self-sufficient in rice in 1984, thanks to the Green Revolution technology. However increased rice production was closely linked with increased pesticide use. Pesticides were considered an insurance against pest attack and farmers were given pesticides at heavily subsidized rates. The consequences of overuse of pesticides first became clear in 1986 with an explosion of the brown planthopper (BPH) population affecting most of the rice growing areas of Indonesia. Outbreaks continued despite heavy pesticide use and it was subsequently established beyond doubt that BPH outbreaks had occurred as a result of, and not in spite of, massive pesticide applications (Wardhani 1991). The three main factors that were considered to have contributed to the failure of chemical control in Indonesia were the elimination of natural enemies, the resurgence of pests after pesticide application and the development of pesticide resistance.

In 1986, the Indonesian government banned the use of broad-spectrum insecticides for use on rice and only a few narrow-spectrum chemicals were allowed to be used. In addition pesticide subsidies were reduced and eventually completely withdrawn. By 1991 rice production had risen by 15% from 1986 levels while at the same time, pesticide use had decreased by 60%, thus demonstrating the effect of macroeconomic policies on the adoption by farmers of alternative pest management strategies.

Several agencies and institutions are involved in rice IPM development and implementation in Asia. The FAO Intercountry Programme for Integrated Pest Control in Rice in South and Southeast Asia has assisted countries in developing IPM strategies and policies and has been instrumental in developing the concept of Farmers' Field Schools. Through this programme a total of 670,000 farmers have been trained in rice IPM and the experience gained in implementing IPM in rice is being extended to other crops and other regions. In many national programmes in Asia, IPM implementation is

expanding to cotton, vegetables, legumes and maize and following a global IPM meeting held in Asia in 1993, countries from other regions are initiating similar projects. Rice IPM training programmes in Ghana, Côte d'Ivoire and Burkina Faso are showing that the concepts and methodologies used for IPM implementation in Asia are adaptable to African conditions. In the Sudan, an IPM project for vegetables, wheat and cotton has recently introduced the concept of Farmers' Field Schools with excellent results.

However, in spite of the fact that IPM has been demonstrated to be economically viable for farmers in Asia, its large-scale adoption remains limited. In many countries pesticide subsidies continue to be part of agricultural policy and the use of such chemicals continues to increase. However the adverse effects of pesticides are now well recognized and appreciated and new approaches are being developed. In some countries the use of broad-spectrum pesticides has been reduced and the focus has changed from pest control to pest management and from achieving maximum yield to yield stability.

Increasing IPM in developing countries

Some recommendations towards encouraging increased IPM activity and research in developing countries are given below.

- Supporting farming systems that promote the conservation of natural enemies and maintain diversity – e.g. intercropping, mixed farming, highly restricted use of broad-spectrum pesticides.
- Increased direct involvement of farmers in IPM projects. Farmers' priorities, experiences, socioeconomic conditions and constraints must be taken into account when considering IPM methods.
- Carrying out IPM research in farmer's fields, thus ensuring good feedback from farmers and proper focus on the farmers' needs. In addition, farmers should be trained in crop monitoring and determination of economic/action threshold levels.
- Wide promotion of resistant/tolerant varieties and classical biological control technologies which can benefit large and small farmers at little cost to them in terms of money and time.
- Development of efficient production and delivery systems of natural enemies where they do not already exist.
- Promotion of the use of botanical pesticides such as neem as a low-cost technology. This needs to be supported by the development of improved formulations, on-farm production methods, etc.
- Continued support for biotechnology research, as this can play an important role in developing resistant plants.
- Adoption of multidisciplinary approaches to pest control research by research institutes, universities, etc.

It is crucial that extension services focus on the recruitment of more women and train them not only in IPM technologies, but also in communication skills. In addition, governments and donors should be encouraged to put more emphasis on IPM in agricultural projects – projects should not be labelled as 'IPM projects', but as projects

in which IPM is seen as a strategy to improve agriculture and farmers' incomes as a whole. And finally, governments should facilitate the IPM approach through proper pesticide legislation and pricing without subsidies.

Conclusions

In adopting IPM technologies, farmers aim towards the production of a healthy crop with the least possible disruption of agroecosystems, thereby encouraging natural pest control mechanisms to operate. IPM is in fact a complex system involving the careful integration of a number of available pest control techniques that discourage the development of pest populations and keep pesticides to levels that are economically justified and safe for human health and the environment. IPM thus addresses more than purely pest management, it offers an entry point to improve the farming system as a whole. However IPM is complex and for farmers to understand and adopt IPM strategies they frequently have to change their whole pest control philosophy.

It is clear that an understanding is developing among practitioners of IPM that maintaining pest populations below the economic injury level by use of all available control methods, rather than an insistence on complete eradication of pests, is indeed successful control. However, while progress has been made in defining simple economic thresholds and economic injury levels for key insect pests in developed countries, much research is still needed for the development of comprehensive thresholds for other insect pests, pathogens, and weeds, especially in developing countries. Also, there has been relatively little accomplished in terms of integrating economic considerations relating to pest management activities into comprehensive benefit/cost analyses for agricultural enterprises. There still remains a perception that using economic thresholds as criteria for management decisions increases the risk of economic losses. This perception is often cited as a major limiting factor preventing the adoption of IPM (Cuperus and Berberet 1994).

From examining the situation in Africa and Asia, it seems that, in spite of some remarkable success that have been achieved using IPM in both regions, the wide-scale adoption of IPM by small-scale farmers in developing countries remains an enormous challenge. While the development of IPM programmes must be a farmer-participatory process, it is also clear that governments must take a proactive role in initiating IPM activities, by providing financial support and appropriate incentives. At the same time they should make chemical control less attractive, through legislation, registration and taxation. Farmers' favourable perception of IPM is essential and emphasis must be placed on farmer participation from the earliest stages of developing IPM strategies.

IPM is a key element in sustainable agricultural development and offers a unique opportunity to bring great benefits to both agricultural and urban environments. In view of the fact that at least 17 insect species are known to be resistant to all major classes of insecticides and several plant pathogens are resistant to nearly all systemic fungicides used against them, including in some areas the black Sigatoka pathogen *Mycosphaerella fijiensis* on bananas, the development and adoption of alternative pest control strategies is essential in both the developed and developing world.

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Crop protection in food security crops: examples and lessons from developing countries

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Introduction

Food is the most fundamental of human needs and is the most important priority of the poor who may spend 80% of their income on food (Lipton and Longhurst 1989). It remains the major concern of most of the population in sub-Saharan Africa although food production has tripled since the middle of this century. Much of this increase can be attributed to the outputs of agricultural research which often achieve internal rates of return of 30-50% but it has been estimated that losses due to pre- and postharvest depredations of pests, diseases and weeds still reach about 50% in many developing countries and would be even higher were it not for the continuing effort made by crop protection research (Lenne 1998). Despite continuing advances in agricultural output, such as that brought about by the Green Revolution and the increasing areas brought under cultivation across the world, the problem of food supply does not go away. This is largely because population increase has kept pace with agricultural output; add to this the disruptions, both natural and man-made which continue to hamper agricultural activities and it is hardly surprising that food security remains a priority in many countries It is estimated that the food gap could more than double for developing countries over the next 25 years; demand for staple foods will increase and numbers of food-insecure people will rise in sub-Saharan Africa and parts of Asia (Pinstrup-Andersen *et al.* 1997).

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Crop protection and developing agriculture

Traditional systems

Traditional agricultural practices have evolved since man first cultivated the land and the need to cope with biotic and abiotic stresses has been a significant part of this process. This has led to the development, albeit unwittingly, of a *de facto* type of integrated pest management strategy incorporating many of the elements used in modern integrated approaches to pest management. Crop selection has resulted in landraces having a significant, if partial, resistance to major diseases. Rotational systems have resulted in the control of soilborne pests, and other cultural practices have promoted crop vigour and tolerance to pest damage while restricting development of epidemics. Under these traditional systems, the relative stability of the ecosystem has enabled the production of relatively low yields of food crops with relatively low risk.

Resource-poor farmers in these traditional systems recognize crop damage by pest and diseases especially if they cause deviations from the 'normal' but they are often unsure about the cause, even though a wide range of measures directly aimed at control of pest and disease are used in traditional farming systems (Thurston 1992). Nevertheless, poor crop health remains a significant impediment to agricultural productivity in traditional systems. In particular, plant diseases which cause insidious extensive rather than dramatic intensive damage, or where symptoms are not obvious, limit crop productivity. Food sources also remain insecure due to external factors such as climatic fluctuations and outbreaks of exotic or cyclical pests. Changing economic and social pressures coupled with the emergence or introduction of new pests and diseases has also increased the vulnerability of traditional systems.

Agricultural development

The need for increased food production brought about by expanding populations and the development of large urban centres has driven the agricultural development process. Increased food production can come either from an expansion of the area under cultivation or from intensifying production from existing cultivated areas; both of these processes lead to ecosystem disruption, the need for more inputs, greater pressure from pests and diseases and threaten food security (Waller 1984). At the core of the problem is the basic fact that the very process of agricultural development leads to the increased vulnerability of crops to pests and diseases, so that there is a continuing need to keep potentially burgeoning damage of pests under control. Many of the examples of crop protection problems in developing agriculture have their origins in this need to increase agricultural productivity.

Expansion

The 'globalization' of agriculture has involved both the distribution of crop germplasm and the extensive cultivation of new crops in new areas; this has led to the emergence and

spread of both old and new pests and diseases. Expansion of cultivated area into virgin territory may lead to the emergence of new pest problems as crops encounter pests or pathogens previously confined to natural ecosystems and the cultivation of crops in exotic regions can lead to the emergence of 'new encounter' diseases. Another common effect is that partly due to the pressure of urbanization, agricultural expansion extends to new land that is often ecologically marginal for crop growth. This results in poor crop health, predisposition to common diseases and inability to withstand pest damage.

Intensification

Soil nutrition and pathogens

One of the first measures taken to intensify crop production is to grow crops more frequently on the same piece of land; the long rotation times typical of the bush fallow and other systems are lost, so that natural replenishment of the soil's physical and nutritional status does not occur. Furthermore the natural degradation of soilborne pest and pathogens in the absence of crop hosts is halted and problems caused by these increase. In the upland valleys of Bolivia, reduction of the normal seven-year rotational period to one of one in three years has resulted in the buildup of soil pathogens such as *Fusarium*, bacteria and the sclerotial fungi with a consequent threat to the yields of staple crops such as potatoes. Deterioration of the soil also results in the predisposition of crops to disease and inability to tolerate pest damage.

Selection pressure

Crop uniformity, the area under single crop varieties and the increased frequency of cultivation all add to the selection pressure for the emergence and spread of apparently new pest or pathogen biotypes - a well recorded effect which often results in the resistance of widely grown cultivars being overcome by new pathogen biotypes. Related to this is the epidemic continuity which sequential cropping, often a consequence of dry season irrigation, allows. The natural break to seasonal epidemics is reduced and pests and pathogens may flourish unchecked. The temporal and spatial continuity of plant hosts is one of the major outcomes of intensified agriculture, allowing continuous epidemic development and pathogens to adapt quickly to new resistances (Robinson 1976).

New germplasm and management systems

The breeding and cultivation of new, higher yielding varieties was at the forefront of the Green Revolution; this has brought about very significant increases in crop productivity, including improved resistance to several major pest and disease problems. However, these new crop varieties sometimes exposed apparently new problems. Previously minor pathogens, to which the old landraces were resistant, developed to become significant constraints which then had to be overcome and new forms of resistance bred in to some crops was not durable. The cultivation of new crop varieties has often been accompanied by changed management practices to maximize yields; in some instances these have also exacerbated the effect of some pests and pathogens.

Management and economy

Greater investment in crop production means that there is more at risk and the value of losses assumes a greater importance where profit margins are at stake. Intensification of management systems in conjunction with increased pest and disease pressure was the driving force for increased pesticide usage to protect crops and the well-known 'pesticide treadmill' effect ensued.

The most dramatic effect of the factors mentioned above which can pose an immediate threat to food security is the sudden emergence of new pest or disease epidemics. Resource-poor farmers have the greatest difficulty in coping with such events and the results can be catastrophic. These often receive widespread recognition but outshine older well-established and more intractable problems of perhaps greater overall economic significance. In the longer term, it is the continuing toll which these more insidious problems exact that may present the greater threat.

Crop examples

Rice

Rice provides examples of the contrasting effects of new cultivars and changed management practices. The development of disease- and pest-resistant lines of staple crops is the front line defence in crop protection and this has been a key but often underrated element in the Green Revolution. In the Philippines for example, losses to the rice drop from insect pests have decreased from 23% to less than 10% since the 1970s and this has been attributed to the widespread use of resistant cultivars and improved IPM methods and has had the added benefit of reducing pesticide use by farmers (Rola and Pingali 1993). However, the introduction of new rice germplasm and the widespread adoption of new varieties and associated changes in crop management practices during the Green Revolution was associated with an apparent upsurge of some new pest and disease problems. Pathogens which had been insignificant, such as leaf scald and sheath blight, became constraints which limited the performance of the new cultivars, and minor pests such as the brown planthopper assumed major importance. These created further challenges for research. In Asia pest outbreaks have often been associated with the injudicious use of pesticides rather than with the breakdown of plant resistance and the emergence of the brown planthopper after the 1970s as a major problem in Indonesia highlights this. Indonesia was spending £75M per year to control the pest during the early 1980s (Perfect 1998) but a presidential decree in 1987 banned the use of 57 insecticides on rice as the prerequisite to a successful campaign to develop and introduce IPM techniques to farmers. This required a major effort to understand the ecology, population dynamics and natural enemies of the insect. The pest was controlled, yields raised and costs lowered (Thomas and Waage 1995). Notwithstanding these setbacks, rice production has doubled from 260 to 520 M tons during the last forty years, prices have decreased but profitability to farmers has increased, and the area under rice cultivation has remained fairly stable since the 1980s.

Cassava

Cassava is the staple food for 200 million people in sub-Saharan Africa; pest and disease outbreaks have been major constraints to production in many areas. Cassava green mite and mealy bug are pests introduced to Africa from the centre of diversity of cassava (South America) and have been largely controlled by adopting a classical biological control approach with the introduction of natural enemies from that region (IITA 1998). However, the recent epidemic of a severe strain of African Cassava Mosaic Virus (ACMV) in Uganda appears to have been the result of the emergence and spread of a new form of the virus thought to be a hybrid between different strains of the virus. This has caused severe problems of food shortage for the local population, but is now being brought under control through the selection of resistant cultivars. The production of new cultivars acceptable to farmers, their bulking up and distribution throughout Uganda is requiring an integrated effort from the Ugandan government, NGOs and international organizations such as IITA (Otim-Nape *et al.* 1997). The risk from new forms of this and other diseases arising which may cause similar disasters needs to be assessed, but this can only be done with a thorough biological understanding of the processes leading to their development and regular monitoring of crop health.

Yams

Yams are a major staple food in West Africa, the Pacific and the Caribbean. Recent research to determine production constraints in traditional yam cultivation systems in West Africa has concluded that availability of healthy seed tubers is a major factor (J. Peters, personal communication). A complex of diseases such as anthracnose, viruses and nematodes have a major effect on yam seed tuber health, and seed tuber production techniques which reduce the impact of diseases can result in significant yield increases. This is an example of how close analysis of crop health can reveal endemic insidious yield-limiting diseases and can provide new insights for improving crop productivity.

Bananas

Bananas and plantains are among the most important staple food crops in the East African highlands with a production of some 13M tons or 25% of the world total. In Uganda banana production to meet the expanding urban populations has extended further from Kampala as constraints to productivity have increased in the traditional areas. These include a variety of biotic factors, many of which interact between themselves and with soil fertility decline. This complex situation can only be tackled by firstly using relevant diagnostic techniques to properly evaluate the different problems and then undertaking trials to partition the different interacting effects. The situation is further complicated by the spread of black Sigatoka to Uganda and the appearance of banana streak virus in some areas. With these problems on a perennial crop such as banana the solution cannot wholly rely on improved cultivars - efficient integrated approaches to control are required which utilize a range of biological options. These require research to develop and an example is a new approach to control of a major

postharvest problem in bananas. Crown rot is the bane of marketed ripe bananas in many parts of the world, but recently the possibility of biological control with antagonistic microorganisms has been developed (Krauss *et al.* 1998).

Food security for resource-poor farmers

The burden of food security is especially acute for resource-poor farmers; only when food supply is secure can the farmer turn to other ways to improve his livelihood. Resource-poor farming systems support more than 1.5 billion people across Asia, Africa and Latin America - about a quarter of the human race. They are very risk-prone due to climatic and other environmental perturbations. The productivity of these systems is low and unstable and very vulnerable due both to intrinsic environmental factors and to external shocks often caused by socioeconomic and political instability. There is a need to understand the constraints and priorities of resource-poor farmers in order to gain some insight into how the knowledge generated by agricultural research can improve their food security and how this can be delivered and integrated into their farming systems. One approach is to examine what assets resource-poor farmers have available for crop production and how these might influence crop health. These can be grouped as follows (Carney 1998):

Natural capital. Natural resources stocks include land, water, wildlife, biodiversity and environmental resources. A major problem in crop health in developing countries is sustaining the quality of the land. Land shortage results in crops being grown more intensively, rotations are reduced and soilborne pathogens diseases become more important.

Social capital includes networks, membership of groups, relationships of trust, access to wider institutions. This can be a major asset in farming communities which can improve access to new ideas and knowledge. Farmer-participatory activities have an important role to play here in adapting and validating new technologies through the direct involvement of farmers groups.

Human capital is basically labour, skills and health that a farmer and his/her family can use for pursuing different livelihood strategies. Although labour is the major asset in these systems, it is subject to much demand and farmers look for labour-saving options (e.g. use of pesticides?) rather than taking on more labour-intensive activities in the name of sustainability. Competing demands for labour are frequently a major impediment to adoption of new practices and the skills needed to understand and absorb new technologies are often lacking. However, knowledge of pest biology is rapidly taken up by farmers and readily used to adapt farming practices to reduce pest and disease damage.

Physical capital is the basic infrastructure, such as transport, shelter, water, energy and communications which a farmer possesses. Shortage may prevent access to new technology and can mean that the basic agricultural operations are more difficult, production and storage more vulnerable. Labour and physical resources are compensatory;

transport and equipment make access to markets and timely operations easier, reducing incidence and damage from pathogens.

Financial resources are usually meagre and inputs required to grow crops properly, or to protect them against pest and diseases cannot be purchased. There are competing demands for financial assets and the farmer may decide to put his financial resources into something more profitable.

Integrated crop protection strategies must take account of how farmers can best use these assets to maximize crop production while minimizing the damage from pests and diseases. Quite clearly external resource inputs, particularly the seed material of improved crop cultivars have a major role to play, but even if the farmer has access to these he still has to be able to use them in the best possible way. However good new cultivars are, there will remain the need for IPM practices by the farmer and this depends on practical knowledge of pest biology. Pest control in situations where external inputs are few becomes a knowledge-intensive activity. Knowledge of the pests' biology, their interactions with the crop and other species in the system, their numbers in relation to economic thresholds and the likely impact of control measures on the rest of the crop system as well as on the pest (both short- and long-term), is necessary for the best decisions to be made.

Assuming appropriate IPM technologies are available, external support for farmers comes down to two areas:

a) getting appropriate non-chemical methods validated in farmers' fields and putting robust economic thresholds in place;
b) transferring the 'knowledge package' sufficiently widely through farmers' training for its benefits to become self evident and its momentum to become unstoppable.

Each crop/pest and farm-level situation is unique and it is not likely that there will be an available 'off the shelf' IPM solution to each crop/pest crisis as it arises. Basic and applied R&D becomes, if anything, more necessary, as the 'easier' nuts are cracked.

Processes and outcomes

Firstly it is important that constraints are recognized and defined. Accurate disease diagnosis is still one of the major limiting factors for efficient control of diseases in resource-poor farmer situations. Often there are complexes of pests and diseases, interacting effects of biotic and abiotic factors and successions of organisms. Some may be new problems requiring specialist identification. Although the identity of these organisms may be well established with herbarium specimens, exquisite drawings and Latin descriptions, the actual field biology of many, and their significance to crop health, still remains obscure.

Secondly, having defined the causes of constraints, the next process is to gather information on these. This might require research to determine particular biological attributes; there is a fundamental need for improved knowledge in this area however currently unfashionable it might seem. Knowledge of pest interactions with other

organisms and with the environment is required before new sustainable control methods can be developed. Biological options for control need to be drawn up from both existing and new information with some understanding of how these could be used by farmers. In this process farmers themselves must be closely involved and selection and adaptation of the options becomes a farmer-participatory process.

Thirdly comes operational integration. How can new methods, new knowledge, be incorporated into existing resource-poor farming situations? This is a difficult task requiring much ingenuity and effort; a major part of the process must be working with farmers, informing them of the way in which various options work and how they might improve productivity. In the end it is farmers who will undertake the operational integration.

Finally, outcomes are reflected not only in improved productivity, in terms of larger yields, better quality, but also in terms of reduced asset use, making crops easier to grow, requiring less inputs, so that farmers can diversify their livelihoods, secure their food sources and make them more sustainable.

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Session 2
Review of IPM research activities

Session 2A
Review of IPM research activities

Weevils

Recent advances in banana weevil biology, population dynamics and pest status with emphasis on East Africa

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Introduction

The banana weevil, *Cosmopolites sordidus* Germar, is the most important insect pest of banana and plantain. Plantain and highland banana are especially susceptible (Gold *et al.* 1994). The weevil has been implicated in the decline and disappearance of highland banana from traditional growing zones in central Uganda (Gold *et al.* 1998) and western Tanzania (Bosch *et al.* 1995).

The foundation of any integrated pest management (IPM) programme is a clear understanding of the biology, behaviour, population dynamics and pest status of the target insect. Studies on pest biology will provide insight into intrinsic mortality, dispensable mortality, stages best targeted for control, and interpretation of the effects of control methods on pest populations and damage. For example, reductions in adult weevil numbers (e.g. by trapping or use of entomopathogens) may not result in corresponding decreases in damage if oviposition is strongly density-dependent or if there are high levels of immigration from surrounding fields. Similarly, the effects of a natural enemy attacking weevil eggs may be less important if there is already high mortality in the egg and early instars.

Banana weevil biology

Banana weevils are narrowly oligophagous, attacking only plants in the genera *Musa* and *Ensete* (Zimmerman 1968, Arleu and Neto 1984, Esquivel 1990). The adult is free-living (i.e. not confined to the host plant) but rarely encountered outside of banana stands.

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Eggs are placed singly in chambers excavated in the base of the host plant. The emerging larvae tunnel into the corm and, occasionally, the pseudostem and true stem. The larvae are the only damaging stage of the insect. Pupation is within the host plant. The adult passes its teneral stage within the corm or pseudostem and may exit from the plant as much as a week after emergence.

Adult population density, sex ratio and size

Banana weevil populations and damage levels show considerable variation both within and between sites (Gold *et al.* 1994, 1997). For example, population estimates in Ntungamo district, Uganda (0.53oS latitude) (N = 50 farms) ranged from 1600 to 149,000 adults/ha. In this study, populations on all farms may have been underestimated as a proportion of the population may be sedentary, not attracted to traps and therefore not included in population estimates (S. Lux, personal communication).

Delattre (1980) found a 1:1 sex ratio (male:female) of reared banana weevils in Cameroon. However, he encountered more females than males in the field during the rainy season, suggesting sexual differences in behaviour patterns. In contrast, Sponagel *et al.* (1995) found sex ratios of field collected weevils in Honduras to be 2.2:1. In the Ntungamo survey, sex ratios ranged from 0.60 to 1.56 with a mean value of 0.90 (C. Gold *et al.*, unpublished data). Females were, on average, larger than males on 46 of 48 farms and the average weight of the females (0.090 g) was significantly higher than that of the males (0.079 g).

Adult longevity, distribution and movement

The banana weevil displays a classical "k" selected life cycle (Pianka 1970), with long lifespan and low fecundity. Adults have been reported to live up to two years (Frogatt 1925, Waterhouse and Norris 1987, Gowen 1995), while in Uganda a few marked weevils were recovered in experimental trials 4 years after release (N. Rukazambuga and C. Gold, unpublished data).

Banana weevils are negatively phototrophic and active between 18.00 and 06.00 hours with greatest activity periods between 21.00 and 04.00 hours (Uzakah 1995). Adults are not commonly observed in the field unless recovered in traps. In distribution studies in Uganda, most banana weevils were associated with the plant (mainly in leaf sheaths) or in the soil at the base of the mat (Table 1) (C. Gold and G. Night, unpublished data). Weevil density was greatest on flowered plants, although more total weevils were associated with preflowered plants and stumps. A few marked weevils had reentered the corm or pseudostem of living plants through existing galleries. Many weevils were attached to cut residues (i.e. pseudostems or corms), while a negligible number were found in the leaf trash or burrowed in the soil away from the mats. Thus, crop sanitation practices will influence weevil distribution. Distribution patterns of males and females were similar.

The adults feed on crop debris and may survive for extended periods without feeding (Froggatt 1925, Simmonds 1966). However, they commonly die within 72 hours when

Table 1. Distribution of adult banana weevils in experimental plots at Namulonge Agricultural Research Institute, Uganda, 1997.

A. Within field

Location	Female (%)	Male (%)
Plants	62	67
Mat	(36)	(45)
Soil	(26)	(22)
Cut residues	30	27
Trash	6	5
Soil	2	1

B. Within mat

Plant stage	Female (%)	Male (%)	Numbers/Plant
Sucker	14	13	0.8
Preflower	44	48	3.3
Flowered	12	9	7.3
Stump	30	30	3.4

Source: C. Gold and G. Night (unpubl. data)

maintained on dry substrates. This suggests that they are very sensitive to soil moisture. The weevils are positively hygrotrophic (Roth and Willis 1963, Delattre 1980). Rainfall is believed to increase adult activity (Delattre 1980) and, in Uganda, trap catches tend to be higher in the rainy season (C. Gold *et al.*, personal observations).

This may also explain why weevil populations are often greater in mulched rather than in unmulched fields (Price 1993, Rukazambuga 1996). For example, Rukazambuga (1996) allowed weevils to move freely between mulched, unmulched and intercropped banana plots. From 4 to 36 months after release, weevil density was 1.7 to 2.5 times as high in the mulch as in other plots (Fig. 1). With this in mind, farmers often place mulches away from the base of a banana mat as a means of reducing weevil damage. The utility of such practices is currently under study in Uganda.

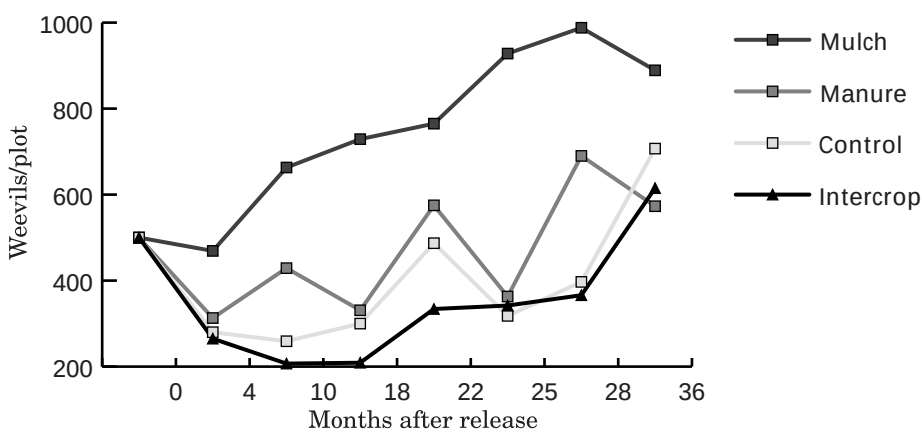

Figure 1. Weevil density in mulched, manured and intercropped plots.

Although banana weevils have functional wings, they rarely fly. Most commonly, dispersal is passive by movement of infested planting material containing eggs, larvae, pupae and/or adults. The adults may also move over limited distances by walking. Behavioural studies at the International Centre for Insect Physiology and Ecology (ICIPE) in Kenya suggest that only a small percentage (6-8%) of weevils might be active on the soil surface at any time (S. Lux, personal communication).

Trivial movement of adult banana weevils is currently under study in an ongoing trial in Uganda. Two thousand weevils were marked individually and released at recorded locations in adjacent mulched and bare soil plots. Plot size was 4368 m2 and weevil density was 4-5 adults/mat. At 2- to 3-week intervals, pseudostem traps were placed at the base of banana mats and the location of marked weevils was recorded. Observations were made in each trap for 4 consecutive days. The distance moved and time elapsed since their last observation were determined for marked weevils found in the traps.

In mulched plots, the percentage of trapped weevils captured at the site of release decreased from 49% at 2 weeks after release to 17% at 6 and 9 weeks after release (C. Gold and G. Kagezi, unpublished data). For trapped weevils which had been last observed 1-7 days earlier, 75% were recorded on the same mat and 17% had moved less than 9 m. A few weevils moved 30-50 m in less than a week. In contrast, only 16% of weevils last observed 6-10 weeks earlier were on the same mat, while 60% had moved more than 10 m.

In bare soil plots, the percentage of weevils captured at the site of release decreased from 79% at 2 weeks to 25% at 13 weeks (Table 2). For all time intervals, a higher percentage of weevils were captured on the original mat than in mulched plots, while fewer weevils moved more than 10 m. Thus, activity and trivial movement appear greater in mulched rather than unmulched plots. This suggests that high soil moisture stimulates movement. The data also suggest that many weevils are sedentary for extended periods of time.

Similarly, in a field trial, more than 15,000 weevils were marked to identify plots (15 x 30 m) of release. Over a 3-year period, less than 3% of marked weevils later recaptured in pseudostem traps were recovered from plots other than those in which they had been initially released (C. Gold and G. Night, unpublished data). Nevertheless, it is a common belief among farmers that the efficacy of control methods may be reduced because of weevil invasion from neighbouring fields.

Movement patterns of banana weevils have management implications. Use of traps for collecting adults or infecting them with biopesticides (e.g. *Beauveria bassiana*) will most likely capture only those weevils in the immediate vicinity of the traps.

Trapping efficacy might be increased by the use of pheromones and plant volatiles although it remains to be seen over what distances such semiochemicals might be attractive.

Similarly, non-host plants, including intercrops and green manures, may interfere with host plant location or serve to repel specialized herbivorous insects. Thus, diversified cropping systems often reduce herbivore pressure by decreasing immigration and/or increasing emigration rates (Risch *et al.* 1983). However, sedentary insects, such as the banana weevil, may be less likely to come in contact with and be affected by intercrops and green manures.

Table 2. Trivial movement of banana weevils in mulched and unmulched experimental plots at the Kawanda Agricultural Research Institute, Uganda, August-November 1998.

A. Percentage of weevils on original mat

Weeks after release	Mulched (%)	Unmulched (%)
2	49	79
5	31	48
7	17	26
10	17	36
13	-	25

B. Distance moved since previous observation

Days after last observation	Mulched			Unmulched		
	Distance moved (%)			Distance moved (%)		
	0	1-9	>10 m	0	1-9	>10 m
1-7	75	17	8	86	11	3
15-21	36	33	31	49	39	11
22-28	34	35	31	53	35	12
36-42	22	37	41	43	42	16
43-49	19	44	37	31	37	32
57-70	16	24	60	33	39	27

Source: C. Gold and G. Kagezi (unpubl. data)

Oviposition

Sexual maturity is attained by male banana weevils at 18 to 31 days after emergence (DAE) and by females at 5 to 20 DAE and the first oviposition occurred 27 to 41 DAE (Uzakah 1995). The first oocytes were recorded at 11-28 DAE, while chorionated eggs first appeared at 25 DAE. This suggests that it takes around 2 weeks for an oocyte to mature.

Egg production of the banana weevil is low, with oviposition in the laboratory estimated from 1 to 2.7 eggs/week in the laboratory (Cuille 1950, Delattre 1980, Arleu and Neto 1984, Koppenhofer 1993) and 10 to 270 in the lifetime of the insect (Cuille 1950, Viswanath 1976, Arleu and Neto 1984, Castrillon 1989). Further studies in Uganda have found laboratory oviposition rates of 4 to 11.2 eggs/week (Abera 1997, M. Griesbach and C. Gold, unpublished data; C. Gold and P. Nemeye, unpublished data). Under field conditions, oviposition was estimated at 0.5-1.2 eggs/week under field conditions (Abera 1997). Oviposition rates appear to be related to temperature but not to relative humidity or precipitation (Uzakah 1995).

Although Uzakah (1995) found no relationship between female size and egg production, research in Uganda suggests that smaller weevils produce fewer eggs. Field collected banana weevil females were divided into "large" (mean weight 0.11 g) and "small" (0.06 g) individuals. Large females laid significantly more eggs (mean = 0.43/day) than small

females (0.28/day) (T=4.76; p<0.01) (M. Griesbach and C. Gold, unpublished data). Larger weevils also produced significantly larger eggs (0.47 mg) with higher rates of eclosion (81%) than eggs produced by smaller weevils (0.41 mg; 73%). After being held in the laboratory for 2 weeks, large females contained 7.2 chorionated eggs and 4.8 developing oocytes, while smaller females had 4.6 chorionated eggs and 4.0 developing oocytes.

In a separate experiment, Abera *et al.* (unpublished data) found that large and small field-collected weevils contained similar numbers of chorionated eggs (4.0 and 4.3). However, when held in the laboratory for 2 or 6 weeks without exposure to an oviposition substrate, larger weevils maintained twice as many chorionated eggs (10.5 and 11.3, respectively) as did small weevils (5.0 and 4.6). The data suggests that small weevils resorb eggs or oocytes when unable to oviposit. It is unclear why egg number was the same following 2 and 6 weeks without exposure to an oviposition substrate.

Uzakah (1995) reported up to 17 (mean 5) chorionated eggs retained in the calyx, while in Uganda, A. Abera and C. Gold (unpublished data) found up to 22 chorionated eggs (mean 10). These data suggest that realized oviposition in the field may be considerably less than the weevil's potential fecundity.

The effect of population density on oviposition was studied in laboratory trials in Uganda. Five, 10, 20 and 40 females were placed in drums containing corm material. Total oviposition was greater at higher population densities (Table 3a) although egg production per female was greater at the lowest density (C. Gold and P. Nemeye, unpublished data). Dissections at the end of the experiment showed that weevils at lower population densities also contained a greater number of eggs and developing oocytes (Table 3b).

Under field conditions, weevils were released into small plots (36 mats) at densities of 5, 10, and 20 females per mat. Prior to release, these plots supported few if any banana weevils. Plots were then uprooted in their entirety 2-5 weeks after weevil release. Oviposition per female declined with increasing weevil density with averages of 1.4 eggs/female/week at a density of 5 females/mat, 0.8 eggs/female/week at 20 females/mat, and 0.5 eggs/female/week at 40 females/mat (Abera 1997).

Timing and distribution of attack in highland banana by the banana weevil was studied in field trials in Uganda (Abera 1997). At a density of 20 weevils per mat, oviposition occurred on 26% of peepers, 36% of suckers, 81% of preflowered plants, 93% of flowered plants and 92% of standing residues. Egg density increased with plant age (Table 4). In Brazil, however, younger plants were shown to be more suitable for developing larvae (Mesquita and Caldas 1986). Almost all oviposition was on the pseudostem and the majority of eggs were placed below the soil surface (Table 5). Subterranean placement of eggs suggests that predators such as ants might be more effective than (yet undiscovered) egg parasitoids.

Number of stadia and stage duration

The banana weevil has been variously reported to have 5 (Cendana 1922, Beccari 1967), 6 (Koppenhofer and Seshu Reddy 1994, Traore *et al.* 1996), 7 (Viswanath 1976), 5 to 7 (Schmitt 1993), and 5 to 8 (Mesquita *et al.* 1984, Mesquita and Caldas 1986) instars. The variable number of larval instars suggest that banana weevils may display developmental

Table 3a. Weevil oviposition at different densities for 30 days.

Weevil density	Mean total oviposition	Mean eggs/female/day
5 Female:5 Male	233.0c	1.6a
10 Female:10 Male	262.8c	0.9b
20 Female:20 Male	485.0b	0.8b
40 Female:40 Male	736.5a	0.6b
F value	46.3*	23.1*

* P < 0.01

Means within a column followed by the same letter are not significantly different (P<0.05) - test by Student Newman Keuls (SNK).

Table 3b. Banana weevil fecundity indices under different densities after 30 days exposure to oviposition substrate.

Weevil density	Mature medium eggs	Small oocytes	Total oocytes	Fecundity
5 Female:5 Male	2.4ab	3.0a	5.3ab	10.7ab
10 Female:10 Male	3.5a	2.0b	5.4a	10.8a
20 Female:20 Male	1.6b	1.9b	5.6a	9.1ab
40 Female:40 Male	1.8b	2.0b	5.2a	8.9b
F value	5.6*	2.3	0.6	2.4

* P < 0.01

Means within a column followed by the same letter are not significantly different (P<0.05) - Contrast by LSMEANS.

Table 4. Banana weevil oviposition by plant stage in field trials at the Namulonge and Kawanda Agricultural Research Stations.

A. Namulonge (following release of 20 weevils per mat)

Stage	% acceptance	Eggs/plant	Eggs/100 cm^2
Peeper	26	0.6c	0.2c
Maiden	36	1.3c	0.3c
Preflowered	81	4.5b	0.7b
Flowered	93	12.0a	1.9a
Residue	92	10.5a	1.9a
F value		144.27**	74.47**

** P < 0.01; df = (4, 696)

B. Kawanda (field population)

Stage	Eggs/plant	Eggs/100 cm^2
Peeper	2.4c	1.9c
Maiden	5.1bc	2.6bc
Preflowered	9.5b	3.6b
Flowered	15.6a	4.7a
F value	83.7**	17.2**

** P < 0.01; df = (3,19)

Values within a column with same letter are not significantly different by Tukey multiple range test. Source: Abera (1998).

Table 5. Banana weevil oviposition sites in East African highland banana in a 2-year-old banana stand at Namulonge Agricultural Research Institute, Uganda.

A. Location on plant

Plant stage	Pseudostem	Corm
Peeper	2.3	0.1
Maiden sucker	3.1	0.2
Preflowered	5.8	0.4
Flowered	10.5	1.0
Residues	10.6	0.8

B. Location relative to soil surface

	Soil surface		Paired T-test
Plant stage	Below	Above	T - value
Peeper	0.1	0.0	2.11*
Maiden sucker	0.2	0.0	2.30*
Preflowered	4.1	2.0	4.71**
Flowered	9.9	5.8	5.39**
Crop residues	9.3	5.6	7.44**

* P < 0.05; ** P < 0.01

Source: Abera (1998)

polymorphism, i.e., the occurrence of "supernumerary" instars other than those which are thought to be customary for a particular species (Schmidt and Lauer 1977).

Larval stages can then be separated on the basis of head capsule widths. Separation of banana weevil larvae to instar was determined by model fitting to frequency distributions of larval head capsule widths of laboratory-reared and field-collected larvae (C. Gold, P. Nemeye and R. Coe, unpublished data). In the laboratory population, most weevil larvae passed through 5-7 instars, with 74% pupating after 6 instars. A few individuals had 8 or 9 instars. Mean head capsule widths for the first four instars showed close agreement among both laboratory and field collected populations. The method of analysis was not sensitive enough to separate later instars.

Studies on banana weevil developmental rates (reviewed by Schmitt 1993, Traore *et al.* 1993) have been conducted under ambient temperatures and show wide variability in stage duration: 4-36 days for eggs, 12-165 days for larvae, 1-4 days for prepupae, 4-30 days for pupae and 24-220 days from egg to adult. While temperature is certainly the most critical factor in determining developmental rates, relative humidity, cultivar, age of plant, food quality and population density may also be involved (Mesquita *et al.* 1984, Schmitt 1993).

Traore *et al.* (1993) determined the duration of the egg stage under six constant temperatures and found eclosion time ranged from 4.9 days at 30°C to 34.9 days at 15°C. Using linear regression, it was determined that the eggs had a developmental threshold of 12oC and a thermal requirement of 89 day-degrees.

Traore *et al.* (1996) estimated the duration of individual instars under five constant temperatures. He found that the total larval period ranged from 33.7 days at 30oC to 69.7

days at 16oC. Developmental thresholds and degree-day requirements were not determined. The larvae passed through 6 instars with mean relative stage durations of 10.6%, 10.1%, 14.0%, 16.9%, 18.3% and 29.5%, respectively. No data were presented on the prepupal stage (which may have been included in L6). Larval mortality, under experimental conditions, ranged from 59 to 77%. The pupal stage ranged from 5.5 days at 30oC to 23.0 days at 16oC, with 10 to 19% mortality.

In India, banana weevil larvae passed through seven instars with estimated mean durations of 4.1, 5.6, 5.8, 5.8, 5.9, 5.9, and 6.8 days, respectively, with a 2.7 day prepupal period and 7.2 day pupal period (Viswanath 1976). Although the total larval period varied by season (ranging from 36.6-44.4 days), the relative time spent in each instar was fairly constant.

Stage duration for banana weevil eggs and larvae was determined under ambient conditions in three experiments in Uganda. The egg stage lasted 6-8 days. Larvae completed development in 23-33 days and spent between 3 and 5 days in each instar. The mean relative stage duration was 14.9%, 12.5%, 15.6%, 17.0%, 18.2% and 22.2% for the 6 instars, respectively. Mortality ranged from 56% to 73%. The prepupal period averaged 4.6 days, while the pupal stage averaged 7.0 days. Overall, the egg to adult period lasted 6-8 weeks. In both this and the Traore *et al.* (1996) studies, mortality may have been inflated by lower food quality and by repeated handling of the larvae.

Population dynamics, natural enemies and survivorship curves

Rukazambuga (1996) monitored banana weevil populations for 3 years following release of adults at densities of 19,250 and 11,111 weevils/ha, respectively, into 9- and 11-month-old banana stands. In the first trial, weevil numbers peaked 32 months after release at 2.25% the original population. In the second trial, the population peaked 36 months after release at 1.4 times the release rate.

Such slow rates of population buildup suggest high mortality in the egg and larval stages. For example, Abera (1997) found 6-12 times as many eggs as mid- to late-instar larvae during dissections of banana mats. A net emigration from the field would also contribute to retarded population increase, although the available data suggest limited movement of adult weevils. Thus, if a banana weevil female produces 1 egg/week, one would expect >92% loss (immature mortality and/or net adult emigration) for population doubling within a year.

The banana weevil is largely protected by virtue of its secluded lifestyle. The adults are heavily sclerotized and not known to be attacked by arthropod natural enemies. The egg, larval and pupal stage all occur within the host plant or crop residues. Although weevil immatures developing in crop residues may be vulnerable to predation by histerids, staphylinids, hydrophilids and dermaptera as the plant tissues break down (Koppenhofer *et al.* 1992), eggs and larvae in standing plants may be inaccessible to parasitoids and most opportunistic predators. However, ants in the genera *Tetramorium* and *Pheidole* have been reported as effective predators on banana weevil eggs and larvae

(Castineiras 1982, Bendicho and Gonzalez 1986, Castineiras *et al.* 1991). These ants may enter both crop residues and living plants in search of weevil eggs and larvae.

Neuenschwander (1988) suggests the egg stage may be most vulnerable to natural enemies. Of particular interest would be the possible existence of egg parasitoids. Success in establishment and efficacy of egg parasitoids (if they exist) would be affected by population density, oviposition sites and exposure of eggs.

In Uganda, survivorship studies have been designed to determine levels of intrinsic mortality in the egg and larval stages of banana weevil. Eight plots were planted in November 1996. Half of the plots will exclude predatory Myrmicine ants (e.g. *Tetramorium* and *Pheidole*) by application of a selective pesticide (Amdro). Maiden suckers and flowered plants will be systematically sampled to set up population curves.

Pest status

Banana weevil is often severe in newly planted fields where heavy attack can kill a high percentage of suckers and lead to crop failure (Mitchell 1980, Ambrose 1984). After crop establishment, the weevil may not be an important pest for several crop cycles. With slow population buildup, most weevil problems are seen in ratoon crops (Mitchell 1980, Lescott 1988, Rukazambuga 1996).

Damage to banana plants is caused by larvae feeding within the corm and pseudostem. Larval galleries weaken the plant and provide entry points for ants and secondary pests, including fungi, which accelerate the destruction and decomposition of the rhizome tissues. Damage may also be manifested in weakened root systems, retarded and stunted growth, premature leaf drop and decreased bunch size. In extreme cases, plants topple (uproot) or snap at the base. Toppling is generally associated with nematode damage, but has been observed in fields with low levels of nematodes and heavily infested with banana weevils in Tanzania (N. Rukazambuga, personal observation) and Uganda (Rukazambuga 1996). Finally, attack may affect suckers, including their number and vigour, and the proportion of water suckers.

Yield loss in highland banana due to the banana weevil was studied in field trials in Uganda (Rukazambuga *et al.* 1998). Adults were released at the base of banana mats 9 months after planting at a rate of 19,250/ha. Weevil populations, corm damage, plant growth and yield were assessed over four crop cycles. Banana weevil damage increased with crop cycle, with high levels of attack and related plant loss in the third ratoon cycle (Table 6). The effects of banana weevil damage on plant growth were negligible in the first two crop cycles, while very heavy levels of damage (>20%) caused reductions in plant height, girth, and number of functional leaves in later ratoon crops.

In general, the effect of damage was greater on bunch weight (Table 7) than on plant growth and rate of development. When plants failing to produce bunches are included, there was an average bunch weight reduction of 8% (range 0-13%) for plants with low damage (5-10%), 18% (range 13-27%) with moderate damage (10-15%), 34% (range 17-57%) with heavy damage (15-20%) and 65% (range 57-72%) with very heavy damage (>20%).

Table 6. Banana weevil damage and plant loss in banana (cv. Atwalira) yield loss trial at Kawanda Agricultural Research Station, Uganda, 1991-1995.

A. Weevil damage distribution (%)

Damage (%)	Plant crop	Ratoon crops		
		First	Second	Third
0-5	74	38	24	6
>5-10	19	31	30	14
>10-15	5	18	19	18
>15-20	2	4	8	10
>20	-	8	19	52
Plants	428	450	458	307

B. Plants lost[2] without producing harvestable bunches

Damage (%)	Plant crop	Ratoon crops		
		First	Second	Third
0-5	2	5	10	0
>5-10	4	13	14	0
>10-15	2	5	14	3
>15-20	4	3	6	7
>20	-	13	43	80
Subtotal	**12**	**39**	**87**	**90**
% loss	**3**	**9**	**19**	**29**

[1] *C. sordidus* damage scored in the central cylinder of harvested plants.
[2] Dead, snapped and toppled plants.
Source: Rukazambuga *et al.* (1998).

Table 7. Bunch weights (kg) for harvested plants suffering different levels of banana weevil attack in banana (cv. Atwalira) yield loss trial at Kawanda Agricultural Research Station, Uganda, 1991-1995.

A. By within-cycle damage

Damage (%)	Plant crop	Ratoon crops		
		First	Second	Third
0-5	9.5 ± 0.2	11.9 ± 0.3	12.4 ± 0.4	16.7 ± 1.3
>5-10	8.6 ± 0.3	11.5 ± 0.3	12.5 ± 0.4	17.4 ± 0.8
>10-15	8.8 ± 0.6	10.0 ± 0.4	11.5 ± 0.5	13.6 ± 0.7
>15-20	6.0 ± 1.1	11.1 ± 0.9	10.5 ± 0.8	12.5 ± 1.0
>20	- - -	7.3 ± 0.8	7.8 ± 0.6	10.6 ± 0.6
F-value	5.10**	10.64**	12.62**	14.10**

** P < 0.01

B. By cumulative damage for current and preceeding cycles

Damage(%)	Ratoon crops		
	First	Second	Third
0-5	12.2 ± 0.3	12.9 ± 0.4	16.8 ± 0.7
>5-10	10.1 ± 0.3	11.7 ± 0.3	14.3 ± 0.6
>10-15	9.8 ± 0.8	9.3 ± 0.6	11.2 ± 0.8
>15-20	7.1 ± 1.7	9.9 ± 1.4	8.3 ± 1.0
>20	7.0 ± 1.0	7.4 ± 1.0	9.1 ± 1.5
F-value	15.27**	10.76**	16.17**

** P < 0.01

[1] Mean weevil damage by mat to central cylinder of current and preceding crop cycles.
Source: Rukazambuga *et al.* (1998).

Yield loss increased with crop cycle. Using plants with negligible damage as controls, yield losses were estimated at 5% in the plant crop, 9% in the first ratoon, 17% in the second ratoon and 44% in the third ratoon (Table 8) (Rukazambuga *et al.* 1998). The cumulative effect of heavy damage sustained over several crop cycles resulted in greater reduction in bunch weight than that inflicted by similar levels of damage in a single cycle. These results suggest that C. sordidus damage may affect both field productivity and longevity.

Table 8. Estimated banana yield loss to *Cosmopolites sordidus* in different crop cycles at Kawanda Agricultural Research Station, Uganda, 1991-1995.

	PC	1	2	3
Negligible damage mean yield[1]	9.4	11.5	11.2	16.7
Expected yield[2]	4153	5175	5130	5127
Actual yield	3961	4709	4281	2896
Yield loss	5%	9%	17%	44%

[1] Mean yield for all plants with 0-5% weevil damage

[2] Mean yield for plants with negligible damage multiplied by number of plants in crop cycle

(Adapted from Rukazambuga *et al.* 1998)

Effects of management

A parallel study on the effects of management on banana weevil population levels, damage and related yield loss in highland banana was also undertaken in Uganda (Rukazambuga 1996). Four treatments were used to create different levels of host plant vitality, viz. (1) intercrop with finger millet; (2) control; (3) addition of manure at planting; and (4) addition of manure plus continuous mulch. Adult banana weevils were released at the base of the banana mats 11 months after planting. Plant growth, yield and banana weevil damage to the corm were assessed over four crop cycles and compared among management systems.

Banana performance was influenced by field management with larger, more vigorous plants and largest bunches in mulched plots, while intercropped bananas displayed the poorest growth and produced the smallest bunches. However, banana weevil populations were greatest in the mulched systems and lowest in the intercrop (Rukazambuga 1996). Damage, expressed as percent corm tissue consumed, was similar among treatments. However, the total area consumed was greater in the mulched plants, reflecting the larger size of plant corms in this system.

Plants were divided into categories according to the level of banana weevil damage. Yield loss attributable to the weevil was inferred from the yield differences between infested and uninfested plants. The effect of weevil damage was greater on bunch weight (yield) than on plant size and growth in all treatments. The yield loss increased with crop cycle irrespective of host vigour, with greatest loss in the fourth crop cycle. The percentage yield loss was similar for mulched and intercropped bananas (Table 9). However, the reduction in tons/ha was greatest in the mulched system.

Table 9. Total yield loss in four crop cycles in bananas grown under different management regimes at Kawanda Agricultural Research Station, Uganda, 1991-1995.

A. Percentage yield loss

Cycle	Intercrop	Control	Manure	Mulch
Plant crop	10.0	10.0	4.4	8.5
Ratoon 1	13.9	15.7	17.6	18.9
Ratoon 2	25.8	16.4	9.5	15.5
Ratoon 3	25.5	15.2	17.1	27.4

B. Tons per hectare lost

Cycle	Intercrop	Control	Manure	Mulch
Plant crop	0.8	1.0	0.5	1.4
Ratoon 1	1.6	1.7	2.5	3.7
Ratoon 2	3.4	2.0	1.2	2.3
Ratoon 3	2.5	2.2	3.0	6.3

Source: Rukazambuga (1998)

Discussion

Banana and *Ensete*, the host plants of the banana weevil are perennial crops which are commonly grown in semi-permanent stands. Thus, host plants are continuously available for ovipositing females.

The bioecology of the weevil is well suited for such a system. The adults are long-lived and produce low numbers of eggs over extended periods of time. Since host plants are normally abundant, dispersal capacity should be of restricted importance. In fact, the weevil has limited mobility as it rarely flies. The adults feed on plant residues and can go extended periods without feeding. While the weevils require soil moisture, they are able to burrow in the soil or find refuge in leaf sheaths, plant tissues or crop residues. Finally, the weevil is largely immune from many opportunistic predators by placement of the eggs beneath the soil level and the protected nature of the larval feeding niche.

Banana weevils normally gain entrance into newly planted fields by movement of infested planting material or immigration from established neigbouring fields. With low oviposition rates and (most probably) high mortality in the larval stage, population buildup is slow. The banana weevil is attracted to cut corms (Treverrow 1993) and this may explain why detached suckers used as planting material are especially susceptible to attack. Otherwise, pest problems most often appear in ratoon crops. In heavy attacks, the weevil can cause failure of new plantations, increasing yield loss and reducing plantation life.

Control methods being recommended, tested or proposed target the adult (trapping, sanitation, mulch placement, entomopathogens, entomophagous nematodes, intercrops, botanicals), egg (predators, parasitoids and endophytes) and larvae (predators, endophytes, botanicals and resistant varieties). Understanding the population dynamics of the banana weevil will be essential for evaluating the efficacy or potential of these methods.

For example, only poor to modest relationships have been shown between adult weevil numbers and damage (Gold *et al.* 1997). Thus, it is unclear how reductions in weevil numbers will be reflected in damage and yields. Similary, crop sanitation has been proposed to eliminate weevil breeding grounds, reduce weevil populations and, subsequently, decrease damage to maturing banana plants. However, residues may also act as traps, being more attractive to ovipositing females than standing plants. In addition, it is unclear how much intrinsic mortality occurs in the egg and larval stages and whether density-dependent processes may be in play in determining oviposition levels or larval success. Thus, it would seem that control methods targeting the damaging larval stage may have greater impact then those methods directed at adults.

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Cultural control strategies for banana weevil, *Cosmopolites sordidus* Germar

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Introduction

The banana weevil *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae) is a major insect pest in all the banana- and plantain-growing areas of the world (Waterhouse and Norris 1987), particularly of plantains and cooking bananas (Sikora *et al.* 1989). Due to the fact that chemicals are expensive and hazardous to health and environment, alternative control strategies have to be developed/identified for the resource-limited small-scale farmers, who are the major banana producers. Several strategies, including habitat management (cultural control), host plant resistance and biological control have been advocated for controlling this weevil borer (Gold 1998). Cultural control tactics in particular are the tactful use of regular farm practices to delay or reduce the pest attack.

Weevil damage and losses

The weevil lays eggs in the rhizome of the plant and after hatching the larvae tunnel and feed on the rhizome, weakening the plant, reducing bunch weight and in serious cases, leading to snapping of the rhizome at the ground level before the bunch is ripe.

The yield losses associated with the weevil range from 40% to 100% in severe infestations (Mitchel 1980, INIBAP 1986). In order to reduce yield losses due the weevil, a number of cultural control options have been identified and studied. The cultural control tactics are an important component of biologically intensive pest management technologies for the banana weevil (Fig. 1) and include the selection of clean planting material, paring procedure, hot water treatment, deep planting, mulching, trapping, intercropping, application of organic-based manures, weeding, field sanitation, desuckering, propping, varietal mixtures and crop rotation. The advantages of these cultural control options, particularly for the small-scale farmers, are that they constitute the main farming operations and are environment-friendly, less costly, sustainable and offer long-term benefits.

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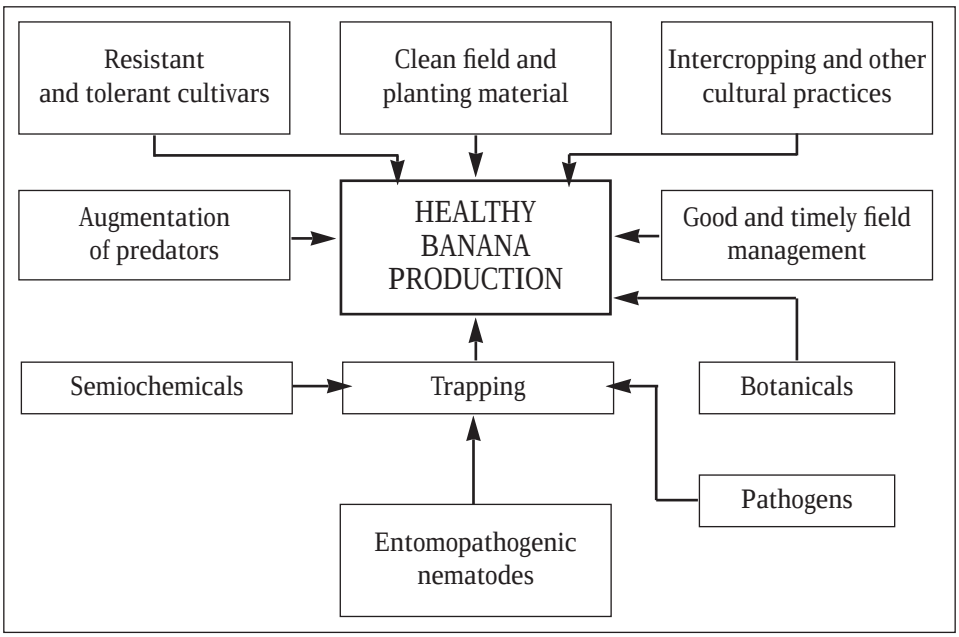

Figure 1. Diagrammatic representation of biologically intensive pest management technologies for banana weevil.

Selection of field for planting banana

The field selected for planting banana should not have a bad record of having grown bad banana crops the previous two years.

Clean planting material in weevil management

The most important mode of spreading of banana weevil to new fields is through infested planting material. The adult weevils move, but over short distances; therefore clean planting material reduces initial population and checks population buildup. Planting material should be selected by taking suckers from fields known to be free of the weevils.

Paring procedure and hot water treatment have been found to be effective and simple for eliminating weevils from planting material. The technique had earlier been quite difficult to manage by the small-scale farmers due to the critical balance in administering the required temperature at 54°C for 20 minutes. Prasad and Seshu Reddy (1994) developed a simple method suited to the small-scale farmers, hence overcoming this drawback. In this method, a metal piece is attached to a wooden piece by using molten wax having a melting point of 55°C. This assembly is dropped into the drum where suckers are to be given hot water treatment. When the temperature in the tank reaches 55°C, the wax melts and releases the wood to float on the surface and

heating is stopped at this stage. Studies on the effect of paring and hot water treatment have shown that the treated planting material have faster rate of development, delayed/low infestation and improved yield (Ngode 1998) as opposed to untreated material (Table 1). The associated crop losses over three crop cycles were 53.1% in the infested material as opposed to only 16.6% in the infested material subjected to paring and hot water treatment. The advantages of clean planting material are best when there are no proximal sources for large weevil migration. It may have limited benefits for gap filling or planting adjacent to infested field. Gold *et al.* (1998) reported most benefits for the first crop cycle in the experimental plots in their studies in Uganda (Table 2).

Table 1. Effect of planting material on bunch weight (kg/bunch).

Treatment	Plant crop	First ratoon	Second ratoon
Infested suckers	8.7 ± 0.4a	7.6 ± 1.1a	6.8 ± 1.0a
Healthy suckers	11.0 ±1.5a	12.4 ± 1.0b	15.3 ± 1.0b
Infested, pared hot water-treated	10.3 ± 0.7a	11.9 ± 0.8b	13.3 ± 0.7b
Infested, pared hot water- and Furadan-treated	12.3 ± 0.1a	14.4 ± 0.5b	14.5 ± 0.5b

Table 2. Bunch weight and yield (kg) in plots grown from treated and untreated banana propagation material.

A. Trial 1.

	Bunch weight			Yield	
	Plant crop	First ratoon	17-28 MAP*	29-37 MAP	Total
Untreated	7.0b	9.7b	184b	171	355b
Pared	8.4a	13.3a	514a	198	712a
Pared/hot water	7.7b	12.4ab	398ab	225	623ab
F Value	0.59	5.55	7.02*	0.67	7.83*

* MAP = months after planting

B. Trial 2.

	Bunch weight		Yield
	Plant crop	First ratoon	15-27 MAP*
Untreated	12.6a	19.1a	865c
Pared	13.2a	19.2a	1162b
Pared/hot water	13.6a	20.2a	1461a
F Value	0.54	0.74	36.06**

* MAP = months after planting

Analysis of variance df (2, 6): ** P<0.01

Treatments with same letter are not significantly different by Least Square Means multiple range test.

Source: Gold *et al.* (1998)

Importance of deep planting

Bananas should be planted to a depth of at least 30 cm or more (Chalker 1987). The effect of planting depth on the incidence of weevils was studied at different planting depths of 15, 30, 45 and 60 cm (Seshu Reddy *et al.* 1991). Results indicated that shallowly-planted suckers were more prone to weevil infestation than deeply-planted suckers. The weevil populations were significantly higher (18.8) in shallow planting of 30 cm as opposed to deep planting of 60 cm (7.2). The weevils were still able to go as deep as 60 cm to find a site for egg laying. Kehe (1988) in Côte d'Ivoire observed low infestation levels where farmers covered the base of stools with a mound of soil around 30 cm. This made the corms less accessible to the egg-laying females. However due to the high mat effect, the bananas soon expose their corms, thus encourage weevil infestation and subsequent snapping. Deep planting has an added advantage of delaying high mat formation, and providing firm anchorage for the plant.

Effect of mulching

In cropping systems, mulches conserve water, regulate soil temperatures, prevent soil erosion, control weeds and provide organic manure in decomposition. Studies to determine the effect of mulching and intercropping on the population densities of *Cosmopolites sordidus* were conducted by Uronu (1992). The studies included maize, beans and sweet potato intercropped with banana and also their respective mulches. Results showed that mulches had higher population growth of *C. sordidus* but despite this, they had the best results in terms of plant growth parameters, crop maturity and yield.

Rukazambuga (1996) also showed that the populations were much higher in mulches. The plants in mulches were larger and cross-section samples revealed more damage in square centimetres and more yield loss in kilogrammes. This implies that overal yields were higher in mulches and so were yield losses. Therefore more studies are still needed to determine the contribution of mulches to weevil management.

Effect of intercropping

In intercropped systems, the insect pressure is maintained at low pressures due to interference with host plant location, by discouraging colonization and encouragement of the natural enemies. Studies conducted in Tanzania by Uronu (1992) on banana-maize, banana-sweet potato and banana-beans showed that there were no significant differences on population growth of *C. sordidus* in the intercrops. Sweet potato and maize had adverse effect on banana due to nutrient competition reflected in delayed banana maturity and reduced yield. Similarly, results of intercropping banana with groundnut did not influence weevil colonization on banana and their subsequent population buildup. It only influenced their distribution during the early banana growth stages (Ngode 1998). However studies conducted in Côte d'Ivoire suggested that intercropping banana with coffee may reduce weevil numbers (Kehe 1988). With a

sedentary insect like the weevil, emigration and immigration rates are not likely to be so affected and so the chances of cropping systems affecting weevils are less than with other insects.

Effect of weevil trapping

The use of trapping for weevil control has been a subject of controversy (INIBAP 1988, Gowen 1995). Seshu Reddy *et al.* (1993) showed that traps made of cooking-type bananas are more attractive to the weevil than traps made of dessert-type bananas. The influence of continuous trapping using split pseudostem traps was conducted in western Kenya over a 2-year period and this brought about a 47% reduction in weevil numbers and a 31% increase in banana yields (Seshu Reddy *et al.* 1995). The use of split pseudostem traps for weevil management has been shown to be very effective at low weevil population density and has the potential of suppressing weevil population and damage. However when the infestation and resulting damage are left to build up to high levels, traps may not reduce weevil populations and increase banana yields significantly (Ngode 1998). In Uganda, Gold and Okech (unpublished data) concur that following one year of trapping in researcher-managed fields, weevil populations declined by 61%, by 43% in farmer-managed fields and by 23% in the controls. The populations were however variable with no significant treatment effect and so it was concluded that trapping can, but does not always reduce weevil numbers. The concern for the use of pseudostem traps is the labour requirements and presence of pseudostems for traps when needed. Thus, reducing the amount of pseudostem needed and increasing trap efficiency through the use of semiochemicals at farm level economically and sustainably may provide some solution. More studies are required to develop these aspects.

Field and crop sanitation

The destruction of crop residues from harvested plants and exposing them to dry reduces damage to the growing plants and limits weevil breeding sites. If old plantations are to be re-established, all the old corms, banana trash and volunteer crop must be ploughed and destroyed to reduce infestation. The cut surface of the corm is more attractive to the weevils for oviposition and since the weevils can burrow up to 60 cm, they may still locate it (Seshu Reddy *et al.* 1993). Observations in Uganda, Ntungamo district, suggest that crop sanitation was closely related with differences in the level of management among farms, but was not related to weevil population levels (Gold 1998). Weevils thrive in trashy and weedy plantations and hence the need for good weeding and detrashing (Wallace 1938). However, more information is needed on field sanitation and weevil population dynamics.

Favourable growing conditions combined with good cultivation and manuring induces high degree of tolerance and helps banana escape attack by *C. sordidus*. Reduction of competition for growth factors through desuckering should be encouraged to leave few

plants in a mat leading to sturdy plants which can withstand weevil and wind damage. Plants with heavy bunches are prone to breakage and snapping if they have weevil infestation leading to premature bunch losses. This can be reduced by propping and guying, hence premature losses due to snapping can be minimized.

Conclusion

From the foregoing it is evident that culturally-based practices provide the first line of defence against the weevil attack and are the widely available options practiced by most banana-farming communities in East Africa. Research and extension protocols should lay more emphasis on them, especially when addressing banana-based IPM options for the small-scale farmers in the region. However, studies are being undertaken to assess what farmers know, who adopts, modifies, rejects, how weevil management fits into priorities of farming systems and how farmers perceive feasibility of control methods, their costs and benefits.

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Potential of classical biological control for banana weevil, *Cosmopolites sordidus* Germar, with natural enemies from Asia (with emphasis on Indonesia)

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Potential for biological control of banana weevil

General basis and protocol for classical biological control

Biological control is defined as "the action of parasites (parasitoids), predators or pathogens in maintaining another organism's population density at a lower average than would occur in their absence" (Debach 1964). Thus, biological control represents the combined effects of a natural enemy complex in suppressing pest populations. The concept of biological control arose from the observed differences in abundance of many animals and plants in their native range compared to areas in which they had been introduced in the absence of (co-evolved) natural enemies. As such, populations of introduced pests, unregulated by their natural enemies, may freely multiply and rise to much higher levels than previously observed. Biological control is a component of **natural control** which describes environmental checks on pest buildup (Debach 1964). In agriculture, both the environment (i.e. farming systems) and natural enemies may be manipulated in an attempt to reduce pest pressure.

Classical biological control concerns the search for natural enemies in a pest's area of origin, followed by quarantine and importation into locations where the pest has been introduced. One underlying assumption is that herbivores are under natural biological control by co-evolved natural enemies and may be inconspicuous (i.e. non-pests) in their endemic range. These herbivores may reach pest status when they move into areas when freed from control by their natural enemies. Chances of natural enemy establishment

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and success are greatest when ecological conditions are similar between the areas of collection and release.

The objective of a classical biological control programme is the establishment of an equilibrium between pest and natural enemy populations such that damage levels are below economic threshold. Pest eradication is neither a sustainable nor a desirable outcome. The most effective natural enemies are monophagous or narrowly oligophagous (i.e. have narrow host or prey ranges) and they would quickly disappear if they were to exterminate their hosts. This would create new problems should the pest be reintroduced from a nearby area.

An example of a successful biological control programme involved the introduction of natural enemies (most notably the encyrtid wasp *Epidinocarsis lopezi* De Santis) into Africa for the control of the cassava mealybug *Phenacoccus manihoti* Matile-Ferrero 1977 (Herren and Neuenschwander 1991). The cassava mealybug was accidentally brought into sub-Saharan Africa during the 1970s. It quickly spread across the cassava growing belt, causing devastating losses. Searches were undertaken in Latin America (the area of origin for cassava) for the mealybug (where it was virtually unknown) and its natural enemies. These were eventually found on cassava in Paraguay and Brazil. Release of *E. lopezi* and several predacious coccinellids quickly brought the mealybug under control throughout most of Africa.

Biological control is only one of many approaches available to reduce the abundance of pests and the damage they cause. In some cases, biological control may be sufficiently effective that no other control measures are required. Quite often, however, only partial control may be achieved and it is necessary to integrate biological control with other measures. Biological control may require an initial research expenditure, but has the advantages that it is permanent, ecologically sound, compatible with most farming practices (except the use of pesticides) and requires little or no investment on the part of the farmer. Occasionally, modification of farm management practices might be encouraged to enhance the efficacy of natural enemies.

In general, parasitoids are more effective than predators. Parasitoids tend to have narrower host ranges while many predators (including all known enemies of banana weevil) are opportunistic predators. Specialist natural enemies are likely to have more efficient searching behaviour in locating their hosts, and to be more adapted to the range of conditions under which the host lives. Ants might be an exception: although opportunistic predators, they are very effective foragers.

It is also important to ensure that candidate natural enemies do not attack other beneficial insects such as herbivores which control undesirable weeds (e.g. water hyacinth). In South Africa, for example, two coccinellids (the native *Exochomus flavipes* and the imported *Cryptolaemus montrouzieri*) effectively control *Leucaena* pysillid (*Heteropsylla cubana*), while at the same time interfering with the biological control of prickly pear cactus by the introduced cochineal insect *Dactylopius tomentosus*. Natural enemy host or prey range is normally ascertained through a careful review of the literature (on what is known about the candidate natural enemy and other species in the same genus or family), and by testing in the laboratory. A careful study of

the biology and behaviour of selected natural enemies, including detailed observations in their original home, often permit sound conclusions to be drawn as to their probable host range in a new site.

The primary advantage of a classical biological control programme is that exotic natural enemies (from the area of origin) most often tend to be far more effective at controlling introduced pests than endemic natural enemies already present in the pest's new range. Natural enemies from the area of origin have had a long period of association with the pest during which both have co-evolved together. Such natural enemies are often specialists well adapted to locate the host plant and/or the pest insect. Though this line of reasoning is sometimes contested (Pimentel 1961), the fact remains that most successful biological control programmes have used natural enemies from a pest's area of origin.

Sampling both the pest and its natural enemies is necessary to determine pest density and whether adequate numbers of natural enemies are present to control the insect. For example, natural enemy numbers may initially lag behind those of pests. Thus, in some cases, pest numbers may be nearing action levels (e.g. a threshold for pesticide application), while natural enemy populations may also be increasing such that they will overtake and suppress the pest before it effects serious damage. However, it is often necessary to demonstrate to producers, accustomed to using pesticides on a timetable or at first sight of a pest, that natural enemies may bring the pest under control if they refrain from applying chemicals.

Area of origin of banana and banana weevil

The genus *Musa* originated in Southeast Asia and has a centre of diversity in Assam-Burma-Thailand-Indonesia-Papua New Guinea, with a minor centre on the Southeast African Highlands (Simmonds 1966). Edible bananas originated in South and Southeast Asia from two wild progenitors, *Musa acuminata* (donor of A genome) and *Musa balbisiana* (donor of B genome), and have spread throughout the humid tropics (Stover and Simmonds 1987). Secondary centres of crop diversity exist in East Africa (highland cooking bananas, unique to the region) and West Africa (plantains) (Stover and Simmonds 1987).

The banana weevil (*Cosmopolites sordidus* Germar) is believed to be a native of the Indo-Malaysian region (Zimmerman 1968, Clausen 1978). However, bananas (and the weevil) have long been disseminated throughout the world; therefore, the centre of origin of the weevil remains obscure. Furthermore, the existence of but a single congeneric species (*C. pruinosus*, reported from Borneo and the Philippines (Zimmerman 1968) makes it difficult to use taxonomic evidence to speculate on the origin of banana weevil.

Pest status of banana weevil in Asia

The banana weevil egg, larval and pupal stages all occur within the host plant or crop residues. The eggs are placed superficially within the host, but are at low density and often below the soil surface (Abera *et al.* 1999). The damaging larvae live in galleries within the banana corm, making them largely inaccessible to parasitoids and

opportunistic predators. This suggests that the most likely natural enemies would either be specialized parasitoids or predators which can attack eggs or enter crop residues.

The weevil appears to be unimportant in much of Asia, although it may be among the most destructive banana pests in certain parts of the region. Other important banana herbivores include the banana pseudostem borer, *Odoiporus longicolis* (Olivier) and banana leaf roller, *Erionota thrax* L. In Indonesia, for example, the banana weevil is considered a major problem in some lowland and highland zones, yet many clones and areas have low levels of damage. In general, banana weevil pest status in Asia is unclear, with most reports being subjective rather than based on conclusive data (Table 1).

Table 1. Banana weevil pest status in Southeast Asia.

Country	Pest importance (*)	Data on incidence	Data on yield loss
Burma	?	-	-
Thailand	+	-	-
Laos	?	-	-
Cambodia	+	-	-
Malaysia	+++	-	-
Vietnam	++	-	-
Brunei	++	-	-
Indonesia	++	-	-
Philippines	++	-	-
India	+	-	-
Sri Lanka	++	-	-

(*) +++ Important / ++ Moderately important / + Present.

Sources: Viswanath (1977), Geddes and Iles (1991), Waterhouse (1993); adapted from Gold (1998).

The pest status of banana weevil outside of Asia is also controversial (Purseglove 1972, Ostmark 1974, Waterhouse and Norris 1987) and may be related to the genome group and management practices (Gold *et al.* 1994, 1999). In New South Wales, Lobel (1975) controlled banana weevils over a 2-year period in experimental plots using insecticides, yet failed to find improved growth or yield. He concluded that heavy infestations by this weevil in New South Wales are a symptom, rather than a cause, of declining plantations. However, Rukazambuga *et al.* (1998) found that yield losses to banana weevil in highland banana increased with crop cycle and reached 44% in the third ratoon of an on-station yield loss trial.

Prospects for biological control for banana weevil

Classical biological control of banana weevil in Africa may be possible. The banana weevil evolved in Asia, from which it has spread to all of the world's major banana-growing regions (Neuenschwander 1988). Introduced pests, unimportant in native habitats, often reach damaging levels when released from the control of co-evolved natural enemies. The

banana weevil appears to fit this pattern, although there is some belief that the weevil might reach pest status in parts of Asia (Waterhouse 1993). Nevertheless, exploration for banana weevil natural enemies in Asia followed by selection, quarantine and release of suitable species could establish an herbivore equilibrium below economic thresholds.

Possibilities and considerations for classical biological control of banana weevil have been reviewed by Greathead (1986), Waterhouse and Norris (1987), Neuenschwander (1988), Greathead *et al.* (1989), Kermarrec (1993) and Koppenhofer (1993a,b) while Schmitt (1993) provides a partial list of arthropod natural enemies. Koppenhofer *et al.* (1992) and Koppenhofer (1993a) found that endemic natural enemies of the weevil in Kenya did not show much promise. In contrast, ants (i.e. *Tetramorium guinensee, T. bicarinatum* (Nylander) and *Pheidole megacephala* Fabricius) contribute to control of banana weevil in Cuba (Roche 1975, Roche and Abreu 1983, Castineiras *et al.* 1991). Based on the weevil's biology, Greathead *et al.* (1989) give a 30% chance for a complete success in biological control.

In Asia, a large number of beneficial organisms (parasites, predators and pathogens) occur naturally in banana plantations and may provide some degree of pest control. Predatory spiders, coccinellids, lacewings, reduviids, ants, and parasitic flies and wasps are the most important beneficial insect groups active in banana plantations. Cane toads feed on beetle weevil and other insects near the ground. Tree frogs, which frequent the banana plants also, feed on insects. Many natural enemies appear small and insignificant, or are nocturnally active, and may go largely unnoticed. Their real value is only appreciated when they are destroyed by inappropriate use of insecticide.

Previous searches for natural enemies of banana weevil in Asia have produced a number of generalist predators. These have been largely unsuccessful in biological control attempts (Waterhouse and Norris 1987). In contrast, egg parasitoids may be effective against banana weevil (Neuenschwander 1988). The existence of parasitoids can only be determined from extensive surveys. As of yet, no parasitoid has been reared from any banana weevil stage in Asia or anywhere else.

Natural enemies of banana weevil in Southeast Asia

Natural enemies of banana weevil observed in Asia include predatory beetles (histerids, staphylinids, silvanids and hydrophilids) and larvae of a rhagionid fly (Jepson 1914, Frogatt 1928, Cuille 1950, Waterhouse and Norris 1987) (Table 2). Most of these occur in banana residues. In addition, unidentified ants, elaterid larvae, carabid larvae and earwigs in crop residues have been observed (Hasyim and Gold, personal observation). All are generalist, opportunistic predators and may feed on banana weevil. The most important banana weevil predator identified to date is the histerid *Plaesius javanus*. Both larval and adult *P. javanus* will attack banana weevils and they are often found inside of crop residues.

Table 2. Common natural enemies of banana weevil in Southeast Asia.

Coleptera	
Histeridae	*Plaesius javanus* Erichson
	Hyposolenus (Plaesius) laevigatus (Marseul)
	Hololepta quadridentata (F)
	Hololepta spp.
Staphylinidae	*Belonuchius ferrugatus* Erichson
	Leptochirus unicolor Lepeletier
Silvanidae	*Cathartus* sp.
Hydrophilidae	*Dactylosternum hydrophiloides* MacLeay
Diptera	
Rhagionidae	*Chrysopilus ferruginosus* (Wied.)

Successful biological control attempts require establishment of the insect in a new environment and repression (control) of a pest population. To date, biological control attempts against banana weevil have met little success (Table 3). Most attempts were made before 1940, using limited numbers of predators. *Plaesius javanus* has been successfully introduced into both the Pacific region and Trinidad, but failed to establish following introduction attempts into Australia, Cameroon, Jamaica, Japan, Samoa, Tanzania and Uganda (Waterhouse and Norris 1987). Among other predators, only *Hyposolenus laevigatus*, *Hololepta quadridentata* and *Dactylosternum hydrophiloides* have been established outside of Asia.

In Fiji, *P. javanus* successfully established following introduction from Java and reportedly provided control in an area severely infested by banana weevil (Kalshoven 1981, Waterhouse and Norris 1987). However, it took eight years for the predator species to become fully established. Otherwise, there are no reports of any introduced natural enemy controlling banana weevil.

Table 3. Introductions of natural enemies for the biological control of banana weevil.

Insect	**Attempts**	**Established**	**Location established**
Plaesius javanus	23	8	Fiji islands
Hyposolenus laevigatus	1	1	Cook island
Dactylosternum abdominale	1	0	
D. hydrophiloides	4	2	Australia, Jamaica
Hololepta quadridentata	6	1	Saint Vincent
Hololepta sp.	3	0	
Chrysophylus ferruginous	1	0	
Total	**39**	**12**	

Source: Waterhouse and Norris (1987); adapted from Gold (1998)

Current research activities on banana weevil in Indonesia

Banana production systems in Indonesia

Indonesia is one of the most important banana growing countries in Asia, with production spread across Sumatra, Java, Bali and Sulawesi. These areas are hot and humid, with mean temperatures ranging from 27.5ºC at sea level to 20°C at 1000 masl. Relative humidity in these areas varies between 60-95%, while annual rainfall ranges from 1200-4250 mm.

Most banana production can be categorized into four systems. These are backyard production, mixed crop production, commercial smallholder production, and corporate farm (agribusiness) plantations. The majority of banana growers are smallholders, with most field management done with household labour and by hand. The banana is advantageous because of its year-round nonseasonal fruit production. The leaves also have an economic value as wrapping material for traditional food in areas near the cities.

The backyard production is the dominant system and attractive to smallholders because of the availability of land around the homestead, the ease of crop establishment, minimum capital investment, and easy monitoring. The system is characterized by high diversity of clones (which vary by region) and primary use of bananas for home consumption. As a result, clone selection is based on family preferences rather than market demand. Management demands include weeding, removal of dried leaves, and harvesting. House wastes, animal manure, and compost are commonly used as soil amendments. Generally, commercial fertilizers and chemical pesticides are not applied.

Mixed production systems may be complex. Banana may be planted as a primary or secondary crop and as either a perennial or short-term crop. As a primary perennial crop, banana can be intercropped with rice, cassava, or vegetables. Banana may also serve as the primary (short-term) crop during the first 2-3 years in a cocoa plantation during which it provides shade to the young cocoa. As a secondary crop, banana is often associated with coconut, cocoa, clove and coffee. Banana is a popular choice for mixed farming systems because it is relatively easy to propagate, and provides both food and cash for household.

Indonesia possesses a great wealth of banana germplasm. Nationally, the most important commercial clones in Indonesia are dessert bananas: Pisang ambon, Pisang ambon lumut, Pisang raja serai, Pisang raja, Pisang berangan, Pisang mas, and cooking bananas: Pisang tanduk, Pisang oli, Pisang nangka and Pisang kepok. In West Sumatra, the main clones are Pisang kepok, Pisang buai, Pisang ambon randah, Pisang ambon, Pisang raja, Pisang raja serai and Pisang manis.

Farmer management of banana weevil

In areas where banana weevil is viewed as important, farmers employ a variety of cultural methods to reduce pest incidence. These include selection of clean planting

material, regular removal of old leaf sheaths, and digging up and drying of old corms. However, the use of clean planting material to prevent dissemination of weevils is only recognized by a few farmers. Trapping is viewed as too labour-intensive with unclear benefits. Farmers at most sites expressed a desire to use pesticides against banana weevil although, in fact, only a few of commercial growers do so.

Research activities on banana weevil

Population dynamics of banana weevil borer in West Sumatra

This study was carried out from September 1997 to February 1998 in Sitiung, located inland (110 masl). The annual rainfall was 2884 mm. The main study field (50 m x 50 m) contains 225 mats of banana. Adult weevils were trapped, sexed, marked on their elytra with lacquer and released on the same plant. Figure 1 shows the fluctuation in the adult numbers, as estimated using the formula of Jolly and Seber (Jolly 1965, Seber 1973). The results show that weevil abundance at Sitiung fluctuated with distinct peaks. Field data suggest that weevils populations were negatively correlated with numbers of *Plaesius javanus* and that *P. javanus* may be inherently capable of regulating weevil populations (Fig. 1).

Twenty plants were evaluated 1-2 weeks after harvest on each visit. In spite of using a susceptible clone, banana weevil damage (Table 4) at this site was probably lower than elsewhere in Sumatra (Table 6), because of the site's low elevation.

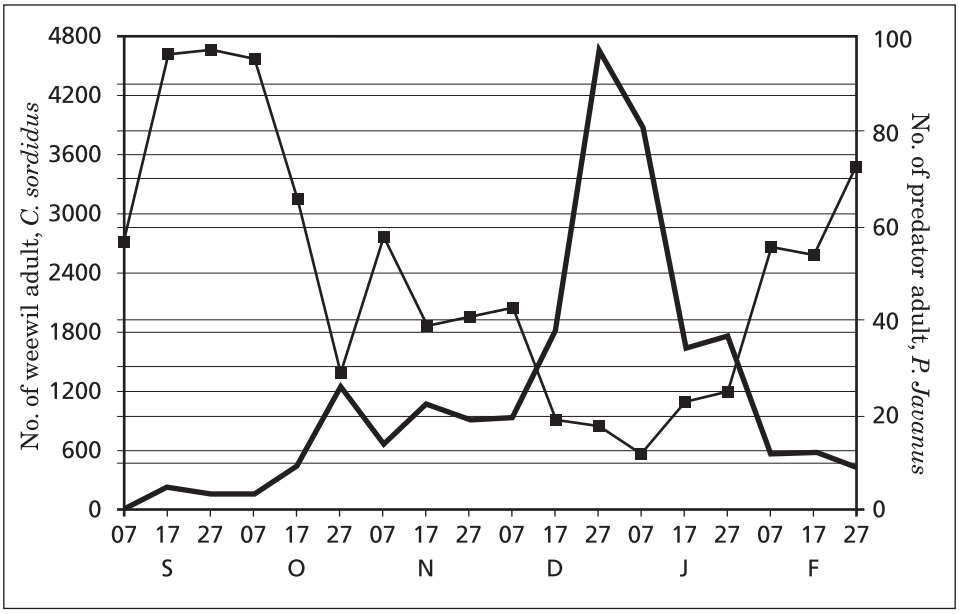

Figure 1. Seasonal fluctuations in adult banana weevil (estimated by Jolly-Seber method) and predator Plaesius javanus **(■)** in a banana field in Sitiung, West Sumatra, Indonesia.

Table 4. Banana weevil damage source for Pisang kepok (AAB) at Sitiung location, diagnostic survey for site at 110 masl (September 1997 - February 1998).

Date (month)	Surface damage		Cross-section damage	
	PCI	DP	Inner	Outer
September	10.9	3.6	0.0	0.7
October	11.1	4.6	0.1	1.5
November	13.4	5.4	0.1	1.5
December	18.8	7.6	0.1	2.1
January	18.2	7.5	0.2	1.9
February	14.9	6.0	0.2	1.5
March	14.5	5.8	0.1	1.5

PCI = Percentage coefficient of infestation. Presence/absence on grid of 20 section

DP = Damage to periphery. Percentage area in galleries

Source: Hasyim and Harlion (1998)

Mortality agents of immature banana weevils

Preliminary experiments were undertaken to assess mortality of banana weevil immatures at two sites in West Sumatra. Banana weevil eggs, larvae and pupae were collected from field sites in Sitiung and Baso and transferred to the entomology laboratory of the Research Institute for Fruit (RIF) at Aripan-Solok where they were reared under ambient temperatures. Egg mortality was largely attributed to fungus (which may have been from laboratory contamination). Both the larval and pupal stages were attacked by phorid parasitoids.

Table 5. Mortality factors of egg and immature stages of field-collected banana weevil during rearing in the laboratory.

Stage	Initial number reared	Mortality			
		Parasites	Fungi	Dried/rotten	Recruitment to next stage
Egg	210	0.0	19.0	2.8	78.1
Larva 3-5	637	5 a	3.5	16.5	79.6
Pupae	115	1 a	4.5	13.0	81.7

a. Phoridae

Candidate natural enemies for biological control programme

Hymenopterous parasitoids were absent from weevil immatures, while larval and pupal parasitism by phorids was low. Nevertheless, a more intensive search in the Indonesia-Malaysian region may reveal more promising arthropod natural enemies. Currently the only promising predator for the control of banana weevil is *P. javanus*. Both the larvae and adults prey on weevil larvae in banana residues. The larvae are very voracious. In the laboratory, they will attack all larval instars and may consume 30-40 per day. In natural surroundings, the larvae are omnivorous and cannibalistic.

Research on microbial antagonists of banana weevil is currently being undertaken in Indonesia. In Sumatra, the fungi *Beauveria bassiana* and *Metarrhizium* sp. attack the larvae and adult of *C. sordidus* more frequently in highland sites than lowland.

Factors required for developing a microbial control programme and influencing the efficacy of entomopathogens have been described by Falcon (1971). An understanding of pest biology, ecology and behaviour as well as life table parameters can be used as a foundation for knowing when and where to apply entomopathogens. Naturally occurring fungal infections are dependent upon a high host density and favourable temperature and moisture. The banana weevil tends to occur in low population densities and it is unclear to what degree fungal spores might be passed from one individual to another.

Falcon (1971) also notes that ideal microbial agents pose no human health hazard, are easy to produce, have a narrow host range and do not attack beneficials, and are sufficiently virulent against the host. Many strains of *Beauveria bassiana* and *Metarrhizium anisopliae* have effected high mortality of banana weevils in the laboratory, but problems in cost-effective delivery systems, field persistence and efficacy in controlling banana weevils under field conditions remain to be demonstrated. Pathogen virulence, persistence and dispersal are likely to be affected by abiotic and biotic environmental factors (Falcon 1971).

Both *B. bassiana* and *Metarrhizium* sp. have been isolated from banana weevil adults in Indonesia. While these entomopathogens may have an important role in controlling banana weevil within Indonesia, it remains unclear whether or not these fungi would be more effective then local strains in controlling banana weevil biotypes found in Africa. Protocols do exist in Uganda and elsewhere for the importation of microbial agents but determination of pathogen host range remains a critical concern.

Host plant resistance to banana weevil

Host plant resistance might be integrated with biological control to form an integrated pest management strategy for the control of banana weevil. Partial control by a natural enemy might be sufficient if farmer clones are resistant or tolerant to attack. Similarly, it is important to understand factors influencing weevil population dynamics under field conditions when selecting sites for searches for natural enemies. Low weevil populations may be due to resistant clones rather than natural enemy control.

To date, little information is available on the susceptibility or resistance of Indonesian banana clones to banana weevil. In order to search for resistance to banana weevil borer, a screening trial on the response of various clones of banana is necessary. Under field conditions in West Sumatra, *Musa* genome group AAB was most susceptible to banana weevil attack, while AA clones were relatively resistant with little damage and limited penetration into the corm (Hasyim *et al.* 1997, see Table 5). In Uganda, plantain (AAB) and highland banana (AAA-EA) were most susceptible to banana weevil attack, while Gros Michel (AAA) demonstrated peripheral damage similar to highland cultivar but penetration into the corm was limited (Gold *et al.* 1994). The introduced beer type (AB, ABB) was relatively resistant with peripheral damage and limited penetration into the corm.

Table 6. Banana weevil damage for different banana genome groups in diagnostic survey of West Sumatra (Indonesia) banana-based cropping system (April 1995 - March 1996).

Genome group	Banana type	Surface damage		Cross-section damage	
		PCI	DP	Inner	Outer
AAB	Jantan, Raja, Raja serai	38.6 b	17.7 b	6.3 b	10.7 b
ABB	Kepok, Kalek, Awak	51.0 a	36.6 a	12.6 a	19.7 a
AAA	Buai, Ambon, Randah	32.6 ab	18.8 b	7.5 b	11.6 b
AA	Rotan, Lidi dan Mas	10.0 c	4.0 c	0.5 c	2.8 c

PCI = Percentage coefficient of infestation. Presence/absence on grid of 20 section
DP = Damage to periphery. Percentage area in galleries
Cross-section damage = Percentage area in galleries
Data collected from 20-40 days after harvested plant
Source: Hasyim *et al.* (1997)

Research needed

A successful biological control programme is based on a solid foundation of ecological research and studies on population dynamics for both the pest and candidate natural enemies. In order to study the feasibility of biological control against banana weevil, we propose that the following studies be undertaken in Asia:

1. Seasonal fluctuations in abundance of banana weevils should be documented in detail. The cause of fluctuation should be analyzed in relation to the change in climatic conditions and the action of natural enemies.
2. Determine areas where the weevil indeed is of minor importance and whether cultural methods and biological agents may be responsible for this low pest incidence.
3. Ecology of banana weevil adults especially longevity and fecundity under field and laboratory conditions.
4. Biology of natural enemies including host specificity, searching behaviour, fecundity and generation time, intra- and interspecific competition.
5. Quantitative data relating life table parameters to environmental and food conditions are needed in order to develop efficient techniques for rearing and for predicting population development.
6. Experimental methods should be applied for evaluating the impact of natural enemies. This information should provide insight into when natural enemies should have maximum effect.

In Indonesia, environmental conditions are extremely diverse. Therefore, the results obtained from one geographical location can rarely be applied elsewhere. The high diversity of habitat conditions in which crop-pest-natural enemies systems exist, is not only essential to develop effective control measures, but also provide a fascinating arena for ecological study in general. It is hoped that this workshop will provide the foundation for establishing a network for exploration of candidate natural enemies in Asia so that they may be introduced in other countries.

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Recent advances in microbial control of banana weevil

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Introduction

The banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is considered a major pest worldwide. The damage is primarily the result of the destruction of the corm or rhizome tissue by the larvae, which tunnel through it as they feed. Tunnelling interferes with root initiation and development, impedes water and nutrient uptake and eventually leads to weakening of the whole plant (Acland 1971, Wright 1977). Severe attack in young plants result in stunting or complete death of the plants. In old plants tunnelling causes stunting, premature leaf drop and delayed maturation of plants (Treverrow 1985, Rukazambuga 1996). The crop losses attributed to attack by *C. sordidus* vary from place to place depending on environment, cultivar and management condition (Fogain and Price 1993, Rukazambuga 1996). The banana weevil is a serious pest in small-scale farms especially in Africa (Simmonds 1982, INIBAP 1986, Gold *et al.* 1993, 1994).

The chemical and cultural control methods, which are most frequently used for banana weevil control, have several deficiencies and are not completely effective under subsistence farm level. There is a worldwide concern about the negative effect of chemical insecticides. The indiscriminate use of chemicals has resulted in the development of resistance in insect pests, adverse ecological events, affecting beneficial fauna, and accumulation of residues in the environment. In addition, most chemicals are very expensive and frequently unavailable to the subsistence farmers typical of many countries in Africa. There is considerable need therefore to develop safe and cheaper biologically-based control alternatives that can be used to complement existing control methods. Of particular interest is the use of microbial organisms.

A number of microbial pesticides are being developed for various insect pests in developed countries (Ferron 1981, Hall and Papierok 1982, Feng *et al.* 1994, Jenkins *et al.* 1998). Successful microbial pesticides are sold commercially by companies such as

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Koppert, Mycotech, Natural Plant Protection, Agricura and EcoScience (Jenkins *et al.* 1998). Although no biopesticides have been recommended against the banana pests, recent laboratory and field evaluation of entomopathogenic fungi has shown potential for their use as biocontrol agents.

Review of microbial control of the banana weevil *Cosmopolites sordidus*

In Brazil, Batista *et al.* (1987) infected field-collected *C. sordidus* with *Beauveria bassiana* (Balsamo) Vuillemin and *Metarhizium anisopliae* (Metschnikoff) Sorokin, cultured on rice and beans. The two fungal cultures on rice caused weevil mortality between 85 and 97% while *M. anisopliae* cultured on beans caused 56% mortality. Busoli *et al.* (1989) also tested strains of *B. bassiana* isolated from *Ligyrus* sp. (Coleoptera: Scarabaeidae) and Diatrea saccharalis (Lepidoptera: Pyralidae), and *M. anisopliae* isolated from *Ligyrus* sp. and *Deois flavopicta* (Homoptera: Cercopidae) against the banana weevil at different spore doses. The *B. bassiana* isolate from *Ligyrus* sp. was most virulent, causing mortality of 98.6% when applied at a rate of 1000 spores per 15 insects and 94.7% at 2000 spores per 15 insects, 33 days after inoculation. In Guadeloupe, Delattre and Bart (1978) tested *B. bassiana*, *B. brongniartii* (Sacc.) Petch (= *B. tenella* (Delac) Siemi), *M. anisopliae* and *Nomuraea rileyi* (= *Spicaria rileyi*) Farlow, under field conditions, and obtained infections ranging from 64 to 100% at a rate of 1 x 10^{11} spores per square metre of soil.

Mesquita (1988) tested the pathogenicity of four strains of *B. bassiana* and one of *M. anisopliae* to adult *C. sordidus* applied by direct spraying on the insects, spraying of the soil and immersion of pseudostem traps in spore suspensions. Strains of *B. bassiana* isolated from *C. sordidus* were most pathogenic when applied directly on the insects, causing 70 to 100% mortality within 36 days. For weevils exposed to sprayed soil and immersed pseudostem traps, 40-64% mortality was attained in the same period of time. Comparable results were obtained for *M. anisopliae*.

In Kenya Kaaya *et al.* (1993) tested exotic and local isolates and found that four local isolates of *B. bassiana* and one of *M. anisopliea* were pathogenic to the third instar larvae of *C. sordidus*, causing 98-100% mortality 9 days post exposure to the dry fungal spores. In general, the isolates were less pathogenic to adult weevils with LT50 between 12 and 22 days. In the same studies, one entomogenous bacteria, *Serratia marcescens* was tested and showed LT50 of 2.8 days but did not kill the adult weevils even at 10 times the concentration applied on larvae.

In Costa Rica Toribio (1996) reported studies by Carballo and Arias (1994) who tested *B. bassiana* on *C. sordidus* and *Metamasius hemipterus* in the field. Application of spore suspension (5.8 x 10^{10} conidia/ml) to soil and pseudostem traps caused 30.7-63% mortality in 11.3 days and 34-80% mortality in 15.7 days in *C. sordidus* and *M. hemipterus* respectively. There was 3% fungal infection in weevil from untreated plots.

Toribio (1996) evaluated *B. bassiana* in spore suspension (5 x 10^8) and rice substrate (2.75 x 10^9 conidia/g), applied to disc and longitudinal pseudostem traps in the field. Mortality of 44-74.8 and 51.7-69% was caused to banana weevils in disc and longitudinal pseudostem traps respectively.

In Cuba Toribio (1996) reported 17 strains of *B. bassiana* and 11 strains of *M. anisopliae* tested by spraying spore suspension (105 conidia/cm^2) on soil and caused 61 and 85% weevil mortality respectively. In Cuba *B. bassiana* has been used in combination with ants (*Pheidole megacephala* and *Tetramorium guineense*) against the banana weevil (Castineiras and Ponce 1991, Perfecto 1994).

In Ghana Godonou *et al.* (1998) applied water-based *B. bassiana* formulation to corm and pseudostem pieces and caused 25%, 46% and 59% infection of eggs, larvae and adults respectively. In pot experiments, 26.4-62.0% mortality was caused to adult weevils, and the dry conidia formulated in a mixture of kerosene + groundnut oil (70:30 v/v) applied to soil surface caused more than 60% mortality. In the field, weevil mortality ranged from 53 to 81% on suckers dusted with *B. bassiana*, compared with 7-8% mortality in untreated plants.

Banana plant harbours a large number of mutualistic endophytes. Recent research on exploring the possibility of using endophytes to control the banana weevil have revealed isolates pathogenic to banana weevil immatures (Griesbach *et al.* 1997). Studies in Uganda showed that some fungi can cause over 60 % mortality of eggs in the laboratory (Griesbach *et al.* 1997).

Case studies in Uganda

Since 1991, attempts have been made to incorporate fungi into the management options for *C. sordidus* (Allard 1991). Laboratory assays by Nankinga (1994) with indigenous isolates of *B. bassiana* and *M. anisopliae* showed that six out of the seven isolates tested were pathogenic to *C. sordidus* adults, eggs and larvae. Mortality in adults started within 5-10 days, and 50-100% mortality was attained within 2 to 3 weeks post-inoculation, depending on the virulence of the isolate. The mortality recorded for the highest spore dose (3.35 x 10^7 spores/ml) was 91.7-98.6% and 91.4-94.3%, for female or male weevils respectively, while that recorded for the lowest dose (3.35 x 10^4 spores/ml) was 8.6-28.6% and 7.1-11.4% and 7.1%, respectively (Nankinga *et al.* 1994). Preliminary results also demonstrated that the method of application significantly influenced the infectivity of *B. bassiana*. Exposure of *C. sordidus* adults to infected dead weevils resulted in higher mortality (64.0-98.0%) than exposure to live infected weevils (26.0-82.0%). Weevils sprayed with or immersed in spore suspensions of the pathogen suffered the highest mortality (56.0-69.0%) while those exposed to pseudostem traps or soil treated with water spore suspensions suffered the lowest mortality (6.0-19.0%). When weevils were exposed to maize or rice cultures of the pathogen without use of pseudostem traps, 100% mortality was caused within three weeks post-inoculation (Nankinga and Latigo 1996). On the other hand, when the pathogen spores were sprayed to the soil and pseudostem traps used, 18.6-54.3% mortality was caused to the

weevils within the same period. The infected weevils were, however, able to transmit the pathogen to eggs and larvae within the traps. The studies demonstrated that good potential exists for the use of *B. bassiana* as a biological control agent (Nankinga 1994, Nankinga *et al.* 1994, Nankinga and Latigo 1996, Nankinga *et al.* 1996).

In order to translate these preliminary results into a practical control programme, further studies were recommended to establish the biological and ecological conditions for effective use of the fungal pathogens. To achieve this, biochemical and molecular characterization studies that would assist in the selection of further isolates were undertaken. Environmental factors (e.g. temperature, sunlight, and soil moisture) that influence the efficacy and persistence of the fungus in the field were incorporated and the study investigated in more detail the potential of using dry *Beauveria* spores, oil and water formulated spores applied to soil, banana planting and trapping material as delivery systems of the fungus. As this was a new intervention in the ecosystem, there was need for risk assessment to determine the level of potential hazard involved in the exploitation of microorganisms as biological control agents. Therefore, preliminary investigations were done to assess the effect of *B. bassiana* on non-target arthropod predators and other soil microfauna in the banana ecosystem.

Characterization and pathogenicity of fungal isolates

Biochemical and molecular characterization of the fungal isolates was done at CABI Biosciences UK Centre at Egham. Twenty-three *B. bassiana* and 12 *M. anisopliae* Ugandan isolates were characterized and compared with eleven isolates from other parts of the world using biochemical methods (production of protease-degrading enzymes, growth on media with inhibitory compounds) and molecular methods (PCR and isozymes electrophoresis) described by Bridge and Paterson (1994). Similarities among isolates were observed for biochemical characteristics but some Ugandan isolates expressed distinctly different genotypes with some PCR primers suggesting a host-locality relationship within the indigenous isolates. For example, *B. bassiana* isolates derived from soil collected from different banana-growing areas of Uganda, using the *Galleria* bait method had characteristic bands that were different from isolates derived from *C. sordidus* and other parts of the world.

While developing a pathogen for biological control, it is important to select an isolate which is highly pathogenic to the target pest (Prior 1992, Moore and Prior 1993). In these studies, apart from two *Metarhizium flavoviride* isolates, most local and foreign *Metarhizium* and *Beauveria* isolates infected the banana weevil with mortality ranging from 20-97% within 14 days. Ugandan isolates that are well established in terms of exposure to the banana weevil were highly pathogenic to the banana weevil as were some foreign isolates such as IMI 330194, IMI 298059 and IMI 228343.

Mass production and formulation of *B. bassiana*

There are three well-tried methods of mass-producing entomopathogenic fungi: solid-substrate, liquid fermentation or a mixture of both techniques (Soper and Ward 1981,

Jenkins *et al.* 1998). A two-stage system or diphasic method was adopted, based on liquid sucrose yeast media and maize as a solid substrate. Other substrates such as rice sorghum, soil, barley straw and sawdust were evaluated but maize was easier to handle and showed better germination and spore production.

Cracked maize obtained from a local grain-milling factory was sterilized in locally-made autoclaving bags and then inoculated with a 4-day-old grown fungal culture on sucrose yeast media (SYM). Spent yeast was obtained from Uganda Breweries Ltd. and processed by sterilizing, filtration and sun drying to produce yeast granules used to make the sucrose yeast liquid media. The growth of the fungus in liquid and solid substrates was done at room temperatures (22-23°C) and took 2-3 weeks to complete the production process. On harvesting, the maize substrate yielded approximately 5-6.7 x 10^9 *Beauveria* spores/g.

Delivery systems

Three main methods of delivering *B. bassiana* to the banana weevil pest were evaluated in pot and on-station field experiments at Kawanda Agricultural Research Institute, Uganda. These were (i) application of the fungus to banana planting material, (ii) pseudostem and corm traps, and (iii) on soil around the banana plants. Field evaluation was done in 1996 and 1997 in a 2-3-year-old banana plantation (1.73 ha) of a single cooking banana (AAA-EA) cultivar, Nakyetengu. The efficacy of the fungus was evaluated using four formulations:

(a) dry maize culture formulation = 2.3 x 1012 spores applied at 500 g/banana stool or 250 g/trap,
(b) soil-based formulation = 250 g maize culture + 250 of sterilized soil applied at 500 g/banana stool or 250 g/banana pseudostem on corm trap,
(c) water formulation = 2.5 x 10^{12} spores/ml sprayed at 15 ml/trap, and
(d) vegetable oil formulation = 2.5 x 10^{12} spores/ml sprayed at 30 ml/banana stool or 15 ml/trap.
(e) Untreated plants were included in the evaluations.

Use of banana planting material

In pot experiments, *B. bassiana* caused 20-70% weevil mortality in 2 weeks and reduced egg lying and hatchability was observed in corms treated with the fungus. Under field conditions, banana corm suckers and tissue-cultured plants of cooking cultivars were planted with maize, soil and oil formulations in holes dug in an established banana field. The treatments reduced the eggs, larvae, pupae and adults weevils in the corms. Eleven, ten and eleven dead weevils with *Beauveria* growth were found with plants treated with maize, soil and oil formulations respectively. No dead weevils were found in untreated plots. A 25.7%, 30.0%, 46.3% and 58.2% damage was caused to banana suckers treated with maize formulation, soil formulation, oil formulation and untreated plots respectively.

Results of tissue-cultured plants showed that in *Beauveria*-treated plants, damage was 20% compared to 30% in untreated ones. The 20% of *Beauveria* treated plants and

30% of untreated plants showed damage levels above 50% to complete death of the plant due to banana weevil attack.

The mean damage levels observed in *Beauveria*-treated and untreated plants was higher than the economic threshold level ($P<0.05$) described by Rukazambuga (1996). These results suggest that application of the tested *Beauveria* formulations as a biocide during gap-filling in an established banana plantation may not be an economically sustainable measure. However, younger banana weevil larval instars were found in suckers treated with *B. bassiana* and this might have been due to delayed infestation by the weevil because of the protection rendered by the fungus planted with it. Dead larvae with fungal growth were also found in the treated corms, thus supporting the immature stage infection.

Use of pseudostem and corm traps

In the laboratory, 97%, 77%, 17%, 30% and 0% mortality was caused to weevils collected from buckets where pseudostem traps were laid with *Beauveria* in vegetable oil, maize culture, water suspension, oil (control) and water (control) respectively after incubating the weevils for 14 days.

In the field weevil infection within the first 14 days after treatment application was 7-25%, while weevils collected from pseudostem and corm traps and incubated in the laboratory showed 30-80% and 33-92% mortality respectively. Less than 5% and 2-25% mortality was caused in weevils collected from traps sprayed with water and oil without *Beauveria* spores. It is likely that some of the infected weevils left the traps and died somewhere else. The fate of such weevils that carry a latent infection in the spreading of the fungal disease in the field needs to be established.

To test infectivity of *Beauveria* after field application, weevils were exposed to pathogen cultures collected from the field at 2, 3, 4, 5 weeks and later at 4 months. The maize and soil formulations caused 62%-100% weevil mortality in 14 days. The oil formulation caused less than 3% mortality and no mortality was recorded in soil collected from untreated plots. Contamination of the cultures by saprophytic fungi was observed after 5 weeks during the dry season. However, during the rain season, because of rotting of the pseudostem traps, fungal contamination was observed between 3-4 weeks and this was later accompanied by mite contamination. This probably explains the low infectivity (2-10% mortality in 35 days) caused to banana weevils exposed to soil collected from the field after 4 months.

Application of *Beauveria* on top soil around the banana stool

The treatments significantly reduced the field weevil population, with the maize formulation showing the best results, followed by soil formulation and last oil formulation (Fig. 1, Table 1). *B. bassiana* also reduced the weevil damage to plant.

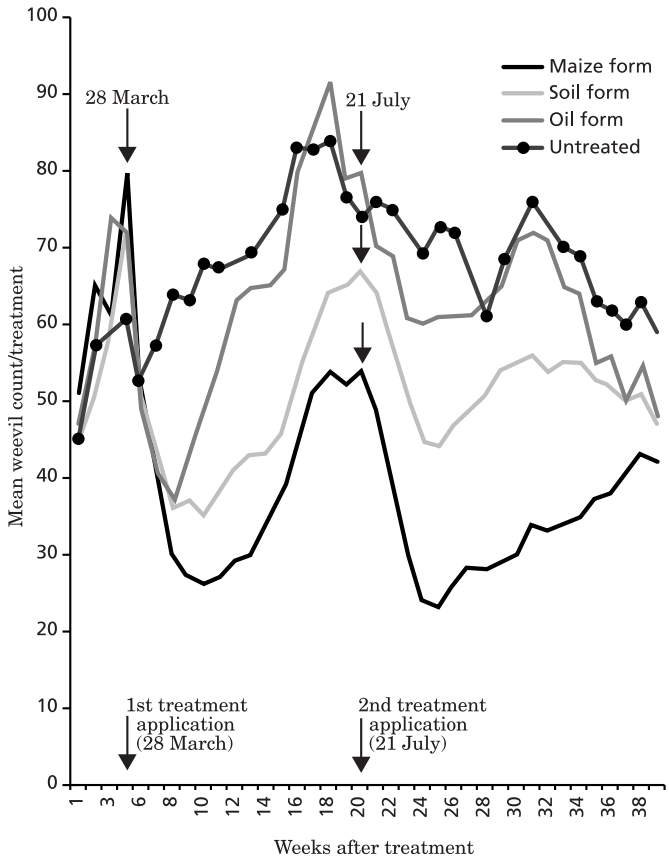

Figure 1. Weevil population in a banana field treated with *B. bassiana* on 28 March and 21 July 1997 at KARI.

Table 1. Banana weevil population counts in the banana field treated with *B. bassiana* at KARI.

Treatments	Mean weevil count
Maize formulation	40 d
Soil formulation	54 c
Oil formulation	67 b
Untreated	80 a
LSD (0.05) df 569	4.24

Means significantly different by separation of log-transformed weevil counts.

Table 2. Banana weevil damage taken in December 1997, in plants treated with *B. bassiana* on 28 March and 21 July 1997.

a) Damage in the corm cortex

Treatment	Percentage damage (mean + SD) in each plant stage				
	Harvested	Flowered	Pre-flowered	Maiden sucker	Peeper
Maize formulation	7.6 ± 3.99	5.1 ± 4.04	1.7 ± 2.89	1.5 ± 3.10	0.1 ± 0.41
Soil formulation	8.8 ± 11.36	4.8 ± 3.93	2.5 ± 2.61	1.1 ± 1.44	0.6 ± 1.30
Oil formulation	5.7 ± 4.13	7.7 ± 5.48	2.3 ± 2.58	3.5 ± 11.45	0.8 ± 2.06
Untreated	14.0 ± 5.35	11.0 ± 7.29	8.9 ± 6.60	3.1 ± 4.90	1.2 ± 4.53

b) Damage in the corm central cylinder

Treatments	Percentage damage (mean + SD) in each plant stage				
	Harvested	Flowered	Pre-flowered	Maiden sucker	Peeper
Maize formulation	4.3 ± 3.33	1.3 ± 1.83	0.1 ± 0.6	0.3 ± 0.70	0
Soil formulation	8.9 ± 14.94	2.0 ± 3.26	0.5 ± 1.02	0.7 ± 1.91	0.2 ± 0.56
Oil formulation	4.7 ± 4.45	4.1 ± 4.42	0.9 ± 1.18	2.2 ± 9.6	0.4 ± 1.19
Untreated	6.7 ± 9.14	6.2 ± 4.78	5.1 ± 4.68	2.1 ± 4.68	0.5 ± 2.26

The mean damage was 0-7.6%, 0.2-8.8%, 0.4-5.7% and 0.5-14% for banana plants treated with maize, soil, oil formulation and untreated plants respectively (Table 2).

Damage assessment was done in December 1997, approximately 9 months after the first treatment application done on 28 March 1997. Therefore weevil damage in the pre-flowered plants (6-9 months old) or the maiden suckers and the peepers (< 6 months old) may give a better estimate of *B. bassiana* effect as this weevil damage would have been caused during the study period. The damage in the harvested and flowered plants (older than 9 months) might have been a carry-over from 1996, since these plants are known to express cumulated damage from the previous plant cycles (Rukazambuga 1996).

According to Rukazambuga (1996), damage of the central cylinder showed a better relation to banana growth and bunch size than the cortex damage. A cumulative damage above 5% significantly reduced the yield in subsequent plant cycles and therefore an intervention control measure was suggested at light damage (5% internal damage) or below. In this study, internal mean damage of the pre-flowered plants was lower than 5% for maize and soil and oil formulation treated plants but higher than 5% in the untreated plants. These results suggest an economically significant control of the banana weevil to the banana plants.

Effect of *Beauveria* on non-target organisms

Effects of *B. bassiana* were assessed by (i) monitoring the arthropod populations using pitfall traps (Southwood 1978), (ii) microorganisms activity as reflected by decomposion of avocado leaf discs buried under the *Beauveria* treated and untreated soil, by adopting

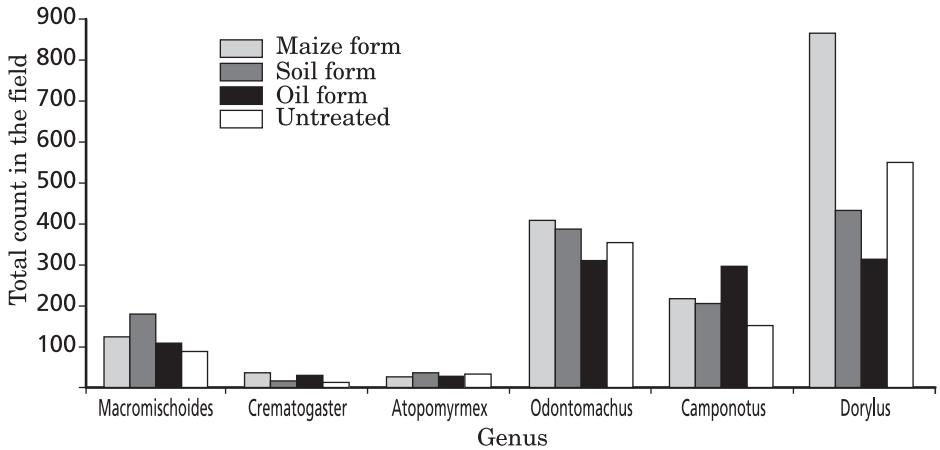

Figure 2. Hymenopteran predators captured in 21 weeks from banana plots treated with *B. bassiana* at KARI.

the litter bag method (Edwards 1989) and (iii) monitoring soil earthworms populations (which also play a role in decomposing litter in the field) using the Formalin expulsion method (Raw 1959). *B. bassiana* did not reduce the populations of hymenopteran predators (Fig. 2), the microorganisms activity (Table 3) or the earthworms (Table 4) in the soil. These preliminary studies suggest no ecologically hazardous early effects of *Beauveria* on non-target species in the banana system.

Table 3. Effect of *B. bassiana* on microorganisms decomposing humus as reflected by decomposition of leaf litter buried in the banana field at KARI.

Treatments	Dry weight of avocado leaf discs (mean + SD)		
	Before burying in soil	After decomposition in soil	Weight loss (decomposed leaf material)
Maize formulation	14.2 ± 0.19	3.1 ± 1.26	11.1 ± 1.36
Soil formulation	14.1 ± 0.29	4.3 ± 1.36	9.7 ± 1.26
Oil formulation	13.9 ± 0.15	4.5 ± 1.09	9.4 ± 1.18
Untreated	14.0 ± 0.23	3.8 ± 1.31	10.2 ± 1.33

Table 4. Effect of *B. bassiana* on earthworms in the banana field at KARI.

Treatment	Earthworm counts expelled from the soil			
	5 days before treatment		6 weeks after treatment	
	Total count	mean count/sq.ft (mean +SD)	Total count	mean count/sq.ft (mean +SD)
Maize formulation	108	3.4 ± 1.14	223	7.3 ± 1.39
Soil formulation	72	2.3 ± 0.67	197	7.3 ± 1.39
Oil formulation	72	2.3 ± 1.19	218	6.8 ± 2.07
Untreated	61	1.9 ± 1.23	212	6.6 ± 2.64

Suggestions for future work

Mass production

Culture material is wasted due to caking of the maize substrate. The subculturing of inoculum cultures and physiological changes that occur in the yeast during storage are some of the factors that may cause these imbalances. There is need to standardize the production process of *B. bassiana*.

Formulation

The maize, soil and oil formulation loose infectivity and persistence in the field due to contamination by saprophytic fungi and mites. More research is required to improve the formulation of the fungus so as to improve its persistence in the field. While developing these formulations, it is essential to consider the users. In the developing countries for example, fungal pathogens must be formulated in such a way as to facilitate application by untrained small-scale farmers.

Biology and behaviour of the banana weevil

There is need to investigate the biology and behaviour of the *Beauveria*-infected weevils and how they assist in transmitting the fungal disease in the field weevil population. This information together with other environmental factors is necessary in timing the frequency of application of the fungus in the field.

On-farm evaluation with other control measures

Beauveria bassiana applied to banana traps, planting material and soil caused significant reduction in the weevil populations and damage to planting material. Further evaluation of these delivery systems with other cultural practices (use of birationals and alternation with trapping) is required on farmers' fields. Since some commercial farmers use systemic insecticide (e.g. Furadan) and herbicides such as glyphosate (Roundup), it is necessary to assess how such chemicals would affect the efficacy of the fungus in the field.

Integration with other biological control agents

Most research on entomopathogenic fungi integrated cultural control practices. Attention should also be given to integrating fungi with other potential biological control organisms such as entomopathogenic nematodes and predatory ants. Work on *Beauveria* integrated with predatory ants in Cuba has shown good results that can be adopted in other countries (C. Gold, personal communication).

Conclusions

Microbial control of the banana weevil has basically depended on the fungal pathogens, *B. basssiana* and *M. anisopliae*. More work has been done under laboratory conditions than in the field. In this review, water-based formulations and solid substrate cultures are most frequently used in combination with banana pseudostem or corm traps as delivery systems of the fungal pathogens. While we acknowledge that these results demonstrate the potential of using microorganisms in the integrated management of the banana weevil, there is still need to explore other delivery systems and integrate them with other control measures. As suggested above, there is great need for research in formulations that will overcome the problems associated with field fungal persistence.

Control of the banana weevil is a real need and recognizing the limits of chemical control, everything possible should be done to institute a system of control which does not damage the environment and which is economically viable. All initiatives in this direction are therefore firmly supported and cooperation in research of different disciplines is highly recommended.

Acknowledgements

The Rockefeller Foundation supported work in Uganda. Support from National Agricultural Research Organization (NARO) in Uganda is acknowledged.

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Recent advances in host plant resistance to banana weevil, *Cosmopolites sordidus* (Germar)

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Introduction

Banana weevil (*Cosmopolites sordidus* Germar) is an important pest of banana and plantain. It is especially important in low-input small-scale production systems characteristic of subsistence farming systems in Africa and elsewhere in the tropics and subtropics. Attack by banana weevil results in severe crop losses from plant toppling, snapping, death and reduced bunch weights (INIBAP 1986). The developing larvae tunnel through the corm, weakening the plant, reducing bunch weight and causing toppling during wind storms (Rukazambuga *et al.* 1998). Crop losses of between 50% to 100% have been reported (Hord and Flippin 1956). Reddy (1989) found severe damage (>80% expressed as percentage coefficient of infestation) in 10 out of 22 districts in Kenya, while in Tanzania corm damage ranged between 52 and 95% among the different cultivars studied. In general, green cooking types were found to be more damaged than dessert bananas. Rukazambuga *et al.* (1998) in an on-station trial in Uganda, found yield loss greater in ratoon crops and, under heavy attack, it reached 44% by the fourth cycle.

Chemical control may be effective but is economically infeasible for most small-scale producers, contaminates the environment, and is poisonous to humans and their domestic animals. In addition, the weevil has demonstrated resistance to a wide range of insecticides (Collins *et al.* 1991). Cultural controls may contribute to weevil management but labour and material requirements often limit adoption (Gold 1998, Gold *et al.* 1998). At present, no candidate natural enemies have been identified for the control of banana weevil in Africa. Host plant resistance has been suggested a potential long-term intervention to control banana weevil on small-scale farms within an integrated pest management (IPM) perspective (Seshu Reddy and Lubega 1993). After resistance has been identified, then it can also be incorporated into breeding programmes to improve the available germplasm.

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Host plant response to banana weevil

The first question to answer in a resistance breeding programme is: "is there any useful resistance in the available germplasm?" Pavis and Lemaire (1997) have reviewed cultivar and clonal comparisons, and found that although studies are fragmented with widely varying results, certain clonal groups appear to be more resistant than others. The ABBs (Pisang awak and Bluggoe) are generally considered more resistant than AAB plantains and East African Highland Bananas (EAHB) (Seshu Reddy and Lubega 1993; Speijer *et al.* 1993, Fogain and Price 1994, Gold *et al.* 1994, Musabyimana 1995, Ortiz *et al.* 1995, Abera *et al.* 1997). Not much resistance has been found among cultivars within susceptible groups such as plantains EAHB. This leaves resistance breeding rather than simple selection and release as the only way forward.

From a diagnostic survey conducted in Uganda, Gold *et al.* (1994) found that EAHB were more susceptible to banana weevil attack than the other bananas, which include Bogoya (Gros Michel, AAA) and the introduced cultivars Kisubi, Ndiizi (AB) and Kayinja (ABB). They have also found that levels of susceptibility to weevils within highland bananas varied significantly with some cultivars, Nassaba and Kisansa showing twice as high damage scores as Mbwazirume and Nakyetengu. The degree of larval penetration into the corm was higher in Nakitembe, Namwezi and Musakala.

Similar observations were made by Speijer *et al.* (1993) and Seshu Reddy and Lubega (1993).

Fogain and Price (1994), working in Cameroon, screened a total of 52 varieties of *Musa* for weevil damage. Of these, plantains (AAB) showed the highest susceptibility, while AAA bananas generally escaped attack. Ittyeipe (1986) mentioned that weevil infestation in Jamaica ranged from very high in plantains and medium for cultivar Cavendish, to very low in diploid (AA) cultivars. In Guadeloupe, a cultivar of the subgroup Pisang awak showed high tolerance despite heavy tunnelling (Pavis 1991). From the same study, cultivar Yangambi Km5 was almost free of attack.

Some studies are however not in agreement. For example in India Viswanath (1981) found that ABB cultivars supported larval development more than AAB and AAA, or diploid cultivars. While in Puerto Rico, cultivar Lacknau (an AAB) was resistant to weevils (Irizarry *et al.* 1988).

The inconsistencies in response to weevil attack and damage found in the available literature (Table 1) may result from working in different ecological conditions. These conditions present different biotic and abiotic factors, which influence pest-plant interactions. Besides, there could also be a series of banana weevil biotypes, which have not been identified. The issue of biotypes complicates current work on screening because it is not known whether there may be virulence differences. A nematode-weevil complex that appears to influence damage levels (Speijer *et al.* 1993) may also complicate field screening experiments.

However, there is general agreement that plantains (AAB) are more susceptible than the other banana types (e.g. AA, AB, AAA and ABB). From these studies there is therefore a possibility that resistant varieties could be developed. No studies have yet been done on the wide range of AA (wild or cultivated) diploid bananas, which could be used in breeding for weevil resistance.

Resistance mechanisms

There are three possible resistance mechanisms in insect-host plant relationships: non-preference, antibiosis and tolerance (Painter 1951). Non-preference, also referred to as antixenosis, involves insects locating and accepting to either oviposit or feed on a particular type of plant; antibiosis involves adverse, usually biological effects to the insect trying to utilize a plant species; while tolerance relates to a variety being able to survive a pest population that would otherwise be destructive to another susceptible variety.

Non-preference

In some classical experiments, Mesquita *et al.* (1984) found out that banana weevil preferred particular cultivars for feeding and oviposition, and that the susceptibility of banana plants varies both between and within genomic groups. Subsequent studies however do not seem to agree with these findings.

Pavis *et al.* (1992), basing on results from a trapping study using pseudostem traps, considered attractivity not an important resistance mechanism in banana. More recent studies also indicate that there seems to be little or no non-preference mechanisms in banana. Musabyimana (1995) found differential attraction of weevil adults to plants, but found no relationship between cumulative trappings and weevil damage indicated by Percentage Coefficient of Infestation (PCI) (Mitchell 1978) on the same cultivar. This is supported by Abera *et al.* (1997) who did not find differences in plant attraction (based on trap catches) nor acceptance (based on oviposition levels) among three EAHB cooking, two EAHB brewing and Pisang awak. Pavis and Minost (1993) found that there was no correlation between pseudostem attractivity and infestation. They also indicated that resistant varieties were as attractive to weevils as susceptible ones, thus ruling out non-preference (antixenosis) as a resistance mechanism in bananas. This is supported by the fact that Ortiz *et al.* (1995) did not find a correlation between corm hardness and host plant resistance in segregating plantain progenies. They suggest that further investigations on banana resistance mechanisms should consider antibiosis as the possible mechanism of resistance.

Semiochemicals are important in banana, as has been shown by the attraction of adult weevils to freshly cut plants and pseudostem traps. Studies have tried to elucidate the differences in attractivity to semiochemicals from different cultivars but the results seem inconclusive.

Budenberg *et al.* (1993) found that female weevils were equally attracted to freshly cut rhizomes of resistant and susceptible cultivars. They postulated that attraction by semiochemicals from banana plants was for feeding rather than for oviposition since weevils did not seem to be able to distinguish volatiles from the different cultivars studied. But Abera (1998) found no variation in oviposition on susceptible and resistant cultivars. In another study Rwekika (1996) found that the compound salicin (a phenolic glucoside) was a significant feeding attractant to banana weevils. Salicin was found to be present in higher quantities in the susceptible cultivars Githumo, Mbidde, Lusumba (EAHB) and Gonja (plantain). He also found that these susceptible cultivars had higher quantities of

glucose. On the other hand, he found salicin almost absent in the resistant cultivars Pisang awak (ABB), Ndiizi (AB) and Kivuvu (ABB). Glucose was absent in Kivuvu and significantly lower in the other resistant cultivars. Rwekika (1996) therefore attributes resistance to the absence of feeding stimulants, mainly salicin and glucose. Another compound, 1,8-cineole, was identified as the active component of volatiles released from a known susceptible cultivar, Githumo (EAHB) in Kenya (Ndiege *et al.* 1996).

It is possible that different stimuli may be at play - one attracting the weevil to move and locate the host, and the other to stimulate feeding. It would appear that all *Musa* cultivars (resistant or susceptible) would attract the weevil, but on reaching the weevil needs a feeding stimulant to feed.

Antibiosis

Not much work has been done on antibiosis in banana, yet many studies cited above seem to point towards antibiosis as the major resistance mechanism in banana and plantain. However, Lemaire (1996) showed that Yangambi Km5 had a significant antibiotic effect on developing larvae, causing substantial mortality and lengthening of the developmental stages.

Abera *et al.* (1997) reported that egg and larval survival was significantly influenced by cultivar Pisang awak, hinting at antibiosis as the possible resistance mechanism.

Preliminary experiments from a current study in Uganda show that FHIA-03 (a hybrid) and Pisang awak (ABB) cause considerable levels of larval mortality (40-55%). Within the East African Highland group, brewing cultivars (Mbidde - AAA-EA) show higher larval mortality than the cooking types (Kiggundu, unpublished data).

Corm hardness and latex (sap) appear to be important in biophysical- and biochemical-related resistance to banana weevil. Pavis and Minost (1993) found a weak negative correlation (r=–0.47) between corm hardness and weevil damage. But Ortiz *et al.* (1995) did not find any relationship between the two among segregating plantain progenies. Some resistant cultivars such as Calcutta 4 and Km5 showed negligible damage and high corm hardness, but other resistant cultivars such as FHIA-03 have soft corms (Kiggundu *et al.*, unpublished data). Hardness of the corm therefore may apparently play a major role in larval development and may be an important resistance component in some banana and plantain cultivars.

Latex has been found to be a defence mechanism against insects in several plants (Bonner and Galston 1947). In Uganda preliminary results of an ongoing study indicate that banana sap/latex may have a negative effect on egg hatchability and first instar larvae. It has also been observed that different banana cultivars produce varying amounts of sap, which also differ in viscosity. High mortality of first instar larvae was observed in some cultivars such as Pisang awak and a local beer type, Nalukira (Kiggundu *et al.*, unpublished data). The direct mechanism is not known but may be related to viscosity, whereby the latex sticks larvae to the substrate, preventing them from moving and thus starving to death. In cultivars producing copious amounts, a drowning effect may be responsible. Direct toxicity of the latex to the tender larvae has not been investigated.

Tolerance

Very few studies have reported tolerance as a mechanism of resistance to banana weevil. However, large corm size was recognized by Balachowsky (1963) as a resistance mechanism in Gros Michel. This probably makes it able to tolerate attack, as larvae may not tunnel deep enough to damage the central cylinder. Large corms may also be able to tolerate many tunnels without significantly affecting their strength. To determine levels of tolerance to banana weevils there is need for long-term studies to compare damage and yield loss among different cultivars. This is because weevil populations and thus damage increase slowly and yield loss may not show up for a number of cycles (Rukazambuga *et al.* 1998).

Breeding banana for resistance to banana weevil

Before the transfer of resistance genes from related species (wild and cultivated types) to cultivars could begin, sources of resistance must be identified. The genetics of resistance such as its inheritance, gene action, and linkage to other characters may need to be studied. Banana weevil resistance is unfortunately a complex trait. Ortiz *et al.* (1995) found that it involves one or more incomplete or partially dominant resistance genes, coupled with a dosage effect at higher ploidy levels.

Conventional breeding

Crossbreeding programmes for improving banana and plantain have registered considerable successes in the last decade (Rowe and Rosales 1996, Vuylsteke *et al.* 1997, Ortiz and Vuylsteke 1996). Breeding for resistance to banana weevil has, however, not featured prominently in any breeding programme. This is probably because of the absence of good sources of resistance, and the lack of a simple screening method for weevil resistance, to enable breeders to rapidly pinpoint resistance across the germplasm available.

Ortiz *et al.* (1995), using hybrids from Calcutta 4 (a wild diploid) and landrace plantain in West Africa, found that most of the diploid hybrids were resistant, while most of the polyploids were susceptible. Selections from this diploid population could make good parents for use in further crossings to attempt introgression of resistance into elite cultivars.

Genetic engineering

New techniques may be used to identify and generate resistance to banana weevil. Host resistance has often been difficult to determine and field-testing is cumbersome, time-consuming and expensive. Furthermore, from the literature available, results from screening studies have been inconsistent. As conventional breeding methods continue, it seems necessary to include some of the latest genetic engineering techniques. Three techniques are now available for banana genetic transformation: these include *Agrobacterium*-mediated transformation (May *et al.* 1995), electroporation (Sagi *et al.*

1994), and particle bombardment (Sagi *et al.* 1995). These can be used to develop transgenic banana plants with resistance to the weevil. In other crop pests, resistance has been achieved through the expression of genes encoding toxins of the insecticidal bacterium *Bacillus thuringiensis*. Other proteins like protease inhibitors have also been used in pest resistance (Frutos 1993). Previous attempts to screen *B. thuringiensis* toxins against banana weevil have not yielded anything and other protease inhibitors may be a better place to look (D. De Waele, personal communication). Therefore, before *Musa* transgenic work against banana weevil can be developed, there is need to identify insecticidal proteins, effective against the banana weevil. Crouch *et al.* (1998) believe that genetic engineering should be used as a supplement to conventional breeding methods by introducing unique and important genes into elite germplasm for use in further crossing.

Host plant resistance as an IPM component

Plant resistance to pests is a major component of integrated pest control, which aims at keeping pest populations below damaging levels. The method is most effective in pest populations which develop slowly (de Ponti 1982). In Uganda, banana weevil population buildup is slow (Rukazambuga *et al.* 1998). High oviposition and slow increase in population suggest high (up to 80%) egg or larval mortality (Abera 1998, Gold *et al.*, this volume[1]). This may suggest that antibiosis is one of the factors regulating population buildup and can be exploited in banana IPM strategies. However until the resistance mechanisms are clearly understood, the use of host plant resistance will remain *ad hoc*.

Conclusion and recommendations

Simmonds (1966) reported that weevils attacked all banana species and that there was no useful degree of resistance. Recent studies have however shown that useful resistance is available, such as in diploid accessions of hybrid and wild origin. Resistance also seems available in Yangambi Km5, and FHIA-03. Breeding bananas is however a tedious and slow process due to poor fertility levels and long crop duration. This highlights the need to include new biotechnological tools to incorporate weevil resistance into current breeding materials. This could begin by screening known insecticidal proteins against the weevil.

As more work continues on host plant resistance to the elusive banana weevil, it is important that workers try as much as possible to standardize the methods. For example, even from a single study, significantly different conclusions can be drawn from using different methods. Seshu Reddy and Lubega (1993) found cultivars Pisang awak and Kivuvu (Bluggoe), both ABB, showing significantly different responses from two different experiments. In one experiment their test plants were grown in pots while in

[1] Gold C.S., N.D.T.M. Rukazambuga, E.B. Karamura, P. Nemeye & G. Night. Recent advances in banana weevil biology, population dynamics and pest status with emphasis on East Africa.

the other experiment the tests were performed on corm pieces placed in plastic containers. In other crop species however, it has been observed that depending on the mechanisms involved, the use of excised plant parts in bioassays alters the expression of resistance of an actively growing plant (Sams *et al.* 1975). If the mechanism is a chemical compound from secondary metabolism, then its production will stop as soon as the plant part has been detached.

The development of a rapid and easy screening method is necessary. This may go a long way in developing a standard method to be used worldwide so that results can be easily compared. Equally important is the need to identify markers for weevil resistance or to produce an index of several factors to help easy and rapid quantification of banana weevil resistance.

If work on the identification of resistant varieties is to succeed, there is an urgent need to clear the question of biotypes, if indeed weevil biotypes exist, and to incorporate that information in screening trials. Studies are also needed to identify the chemical basis of resistance targeting secondary metabolites (e.g. phenolic compounds) that may be toxic to the banana weevil larvae. Finally even with the gaps highlighted above, good sources of resistance are available, making it possible for banana weevil resistance to be incorporated into current and future breeding programmes.

Table 1. Genomic response to banana weevil in literature.

Genomic response	Reference	Country
AAB susceptible	Fogain & Price (1994)	Cameroon
	Haddad *et al.* (1980)	Venezuela
	Seshu Reddy & Lubega (1993)	Kenya
	Speijer *et al.* (1993)	Kenya
	Musabyimana 1995	Kenya
	Gold *et al.* (1994)	Uganda
AAB resistant	Irizarry *et al.* (1988)	Puerto Rico
ABB susceptible	Viswanath (1981)	India
ABB resistant	Ortiz *et al.* (1995)	Nigeria
	Abera *et al.* (1997)	Uganda
	Seshu Reddy & Lubega (1993)	Kenya
	Speijer *et al.* (1993)	Kenya
	Musabyimana 1995	Kenya
	Gold *et al.* (1994)	Uganda

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Session 2B
Review of IPM research activities

Nematodes

Musa and *Ensete* nematode pest status in selected African countries

P.R. Speijer[1] and R. Fogain[2]

Introduction

Most of the bananas in Africa are produced in two major, tropical production regions. In West and Central Africa, cultivars of the plantain subgroup, mainly False Horn and French Horn, predominate. In East Africa, however, the endemic East African highland bananas and diverse introduced cultivars predominate (Sebasigari and Stover 1987, Wilson 1987). In both production regions, bananas are mainly produced by smallholder farmers. Enset (*Ensete ventricosum* (Welw.) Cheesman) is cultivated from mid-altitude to the highlands (ca. 1500-3000 masl) of the south, southwest and central regions of Ethiopia (Bezuneh and Feleke 1996, Westphal 1975).

Musa and *Ensete* production in many regions is declining due to a combination of abiotic and biotic production constraints, soil fertility decline being one of the major abiotic production constraints (Karamura 1993, Kena 1996). The major diseases found in plantain and highland bananas are black Sigatoka, caused by the fungus *Myscophaerella fijiensis* (Stover and Simmonds 1987) and virus diseases (Tushemereirwe *et al.* 1996, Hughes *et al.* 1998). Major pests are the banana weevil, *Cosmopolites sordidus* (Gold *et al.* 1994) and different plant parasitic nematodes, including *Radopholus similis, Pratylenchus goodeyi, Pratylenchus coffeae, Helicotylenchus multicinctus* and *Meloidogyne* spp. (Sarah 1989, Bridge 1993, Luc and Vilardebo 1961, Gowen and Quénéhervé 1990, Kashaija *et al.* 1994). Bacterial wilt and virus diseases are major biotic constraints of *Ensete* (Quimo and Tessera 1996).

The relative importance of the major nematode pest species attacking *Musa* and *Ensete* in the different geographic regions and production systems is poorly understood (Frison *et al.* 1997). This paper therefore aims at providing an overview of data collected in diagnostic surveys conducted in Africa, which are used to prioritize nematode constraints by *Musa* genotype and region, based on occurrence and densities. The data are supplemented by results of yield loss studies conducted in various countries.

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Material and methods

Extensive data sets were available, providing nematode species occurrence and densities for the following countries: Côte d'Ivoire (Adiko 1988), Ghana (Speijer *et al.* 1997), Cameroon (Bridge *et al.* 1995), Nigeria (Speijer *et al.* 1997), Kenya (Seshu Reddy *et al.* 1997), Tanzania-Bukoba (Speijer and Bosch 1996), Rwanda (Bagabe *et al.* 1997), Uganda-central (Speijer *et al.* 1997), Uganda-western (Speijer *et al.* 1998), Tanzania-Zanzibar (Salim 1998) and Ethiopia (Bogale 1998) (Table 1). The data sets were combined and nematode species occurrence was compiled for each *Musa* genotype or for *Ensete* separately. Although the ratio of nematode species is affected by plant age, it generally changes after flowering and therefore species ratio's in roots detached from suckers can be compared. (Quénéhervé and Cadet 1986, Quénéhervé 1990). Nematode densities were established in roots of suckers detached from harvested or flowered plants in Ghana, Nigeria, Zanzibar, Rwanda and Uganda (Speijer and de Waele 1997). In Côte d'Ivoire, Cameroon and Tanzania-Bukoba densities were established in roots of relatively older plants (Bridge and Gowen 1993). As none of the samples were specifically collected from flowered plants, the species occurrence was considered as comparable. Densities within the roots are affected by plant stage (Sarah 1991), therefore, nematode densities observed in the various countries were considered as relatively less comparable as the species ratio.

Table 1. Data sets evaluated for nematode species associated with *Musa* genotypes and *Ensete* in Africa.

Country/ Region	Elevation range (masl)	*Musa*				*Ensete*	Reference*
		AAA	AAA-EA	AAB	ABB		
Côte d'Ivoire	0-300			+			Adiko 1988
Ghana	0-300			+			Speijer *et al.* 1997
Nigeria	0-150			+			Speijer *et al.* 1997
Cameroon	0-1600			+			Bridge *et al.* 1995
Tanzania (Zanzibar)	0-50	+		+	+		Salim 1998
Tanzania (Bukoba)	1150-1600		+		+		Speijer and Bosch 1996
Kenya	0-1650		+		+		Seshu Reddy *et al.* 1997
Rwanda	900-1900		+		+		Bagabe *et al.* 1997
Uganda (central)	1000-1350		+		+		Speijer *et al.*, *in prep*
Uganda (western)	1350-1450		+		+		Elsen *et al.* 1998
Ethiopia	1500-2800					+	Bogale 1998

Results

Occurrence

The most common occurring nematode species was *H. multicinctus*, followed by *Meloidogyne* spp. (Table 2,). *Helicotylenchus multicinctus* occurred in over 70% of the samples, however it declines quickly at elevations above 1500 masl (Figs. 1-4). High densities of *H. multicinctus* were observed in Nigeria and Cameroon (Table 3). In Cameroon the high *H. multicinctus* densities were detected in lower elevation zones, however, only in sites where *R. similis* has not yet been detected (Fogain, personal observation). *Meloidogyne* spp. are found at a wide range of elevations, from sea level on plantain to over 2500 masl on enset. *Radopholus similis* occurred in 30% to 50% of the samples (Figs. 1-4). Exceptions are the commercial Cavendish banana plantations in Cameroon, where *R. similis* occurred in 100% of the samples, and the highland banana farms in central Uganda, where the nematode was found in over 70% of the samples. High densities of *R. similis* are found in Cameroon (Table 3). *Radopholus similis* occurrence rapidly declined at elevations above 1400 masl. Cooler temperatures at higher elevations have been hypothesized as the most important factor that limits the establishment of *R. similis* at higher elevations (Bridge *et al.* 1995, Sarah 1989). *Pratylenchus goodeyi* is a typical highland nematode rarely observed below 800 masl (Bridge *et al.* 1997, Fogain 1998) (Figs. 1-4). At elevations above 1300 masl only one species was observed in high densities on *Musa*. *Pratylenchus goodeyi* was the dominant species found on *Ensete* (Fig. 4). *Pratylenchus coffeae* appears to occur only in pockets in Africa. It is very common in Ghana (66 %) and Nigeria (49 %), but was only found in 3% to 10% of the samples (Table 2). Central Kenya is an exception in East Africa, where this species occurred in 25% of the samples. Where found, *P. coffeae*can reach high densities like in Cameroon and Kenya (Table 3). *Hoplolaimus pararobustus* also appeared to have a more clustered distribution and was restricted to Nigeria and Cameroon (Table 2).

Importance

In West Africa generally a mixture of *R. similis*, *H. multicinctus* and *P. coffeae*is observed. In Ghana production losses were of over 56%, due to plant toppling and bunch weight reduction, observed for the plant crop in the first cycle of plantain cultivar Apantu-pa (Speijer *et al.* 1995). The dominant species in this trial was *P. coffeae* In Nigeria in the second cycle, for the plantain cultivar Obino l'Ewai a production loss of over 90% was observed; losses were associated with *R. similis - H. multicinctus* found in mixtures in the roots (Table 4) (Dubois *et al.*, personnal communication). Fogain (1998) reported that losses associated with *R. similis* in Cameroon were as high as 60% in the first crop cycle for the commonly grown plantain cultivar French Sombre (Table 5). In East Africa a species mixture of *R. similis* and *H. multicinctus* is commonly observed. In Uganda production losses as high as 50%, associated with a mixture of *R. similis* and *H. multicintus*, were observed in the first crop cycle for the commonly grown highland banana cultivar Nakitembe (Speijer and Kajumba 1996) (Table 6). Production losses associated with *R. similis - H. multicinctus* mixture, were in the range of 31% to 37% for the highland cultivar Mbwazirume, grown for four cycles under various crop management systems (Speijer *et al.* 1999). Both species appear to be equally important in reducing bunch weight of

Table 2. Frequency of occurrence of nematode species in roots of *Musa* or Ensete in Africa.

Region	*Musa* genome group or *Ensete*	*Rs*	*Hm*	*Pc*	*Pg*	*Me*	*Hp*
Côte d'Ivoire	AAB	33	98	3	0	80	0
Ghana	AAB	32	98	66	0	56	-
Nigeria	AAB	46	100	49	0	68	64
Cameroon	AAB	39	38	5	33	36	44
Tanzania (Zanzibar)	AAA	29	87	3	0	8	0
Tanzania (Zanzibar)	AAB	42	80	17	0	14	0
Tanzania (Zanzibar)	ABB	15	92	20	0	5	0
Tanzania (Bukoba)	AAA-EA	50	100	5	100	80	0
Tanzania (Bukoba)	ABB	20	100	0	100	80	0
Kenya	AAA-EA	42	75	8	62	17	0
Kenya	ABB	20	62	25	55	50	0
Rwanda	AAA-EA	40	60	0	80	0	0
Rwanda	ABB	40	40	0	60	20	0
Uganda (central)	AAA-EA	70	89	0	48	35	0
Uganda (central)	ABB	78	88	0	51	82	0
Uganda (western)	AAA-EA	0	10	0	100	5	0
Uganda (western)	ABB	0	20	0	100	10	0
Ethiopia	*Ensete*	0	0	0	100	60	0

Rs: Radopholus similis, Hm: Helicotylenchus multicinctus, Pc: Pratylenchus coffeae, Pg: Pratylenchus goodeyi, Me: Meloidogyne spp., *Hp: Hoplolaimus pararobustus*

Table 3. Nematode densities per 100 g fresh root weight for *Musa* or *Ensete* in Africa.

Region	*Musa* genome group or *Ensete*	Rs	Hm	Pc	Pg	Me	Hp
Côte d'Ivoire	AAB	560	1600	1100	0	600	0
Ghana	AAB	480	2900	3800	0	390	-
Nigeria	AAB	930	10 580	3480	0	260	106
Cameroon	AAB	23780	3420	9400	15375	3420	1542
Tanzania (Zanzibar)	AAA	540	2470	5	0	40	0
Tanzania (Zanzibar)	AAB	370	2720	15	0	60	0
Tanzania (Zanzibar)	ABB	210	1870	70	0	50	0
Tanzania (Bukoba)	AAA-EA	60	820	0	13540	90	0
Tanzania (Bukoba)	ABB	90	590	10	1700	120	0
Kenya	AAA-EA	6050	120	9300	14520	940	0
Kenya	ABB	3320	40	1700	8520	2450	0
Rwanda	AAA-EA	400	60	0	1550	0	0
Rwanda	ABB	270	10	0	800	0	0
Uganda (central)	AAA-EA	4000	2800	0	4200	50	0
Uganda (central)	ABB	1200	1500	0	4700	100	0
Uganda (western)	AAA-EA	0	10	0	33370	5	0
Uganda (western)	ABB	0	780	0	13770	70	0
Ethiopia	*Ensete**	0	0	0	5640	30	0

0: reported as not observed in root samples, -: not reported.

Rs: Radopholus similis, Hm: Helicotylenchus multicinctus, Pc: Pratylenchus coffeae, Pg: Pratylenchus goodeyi, Me: Meloidogyne spp., *Hp: Hoplolaimus pararobustus*

Figure 1.
Occurence of nematode species on *Musa* AAB.

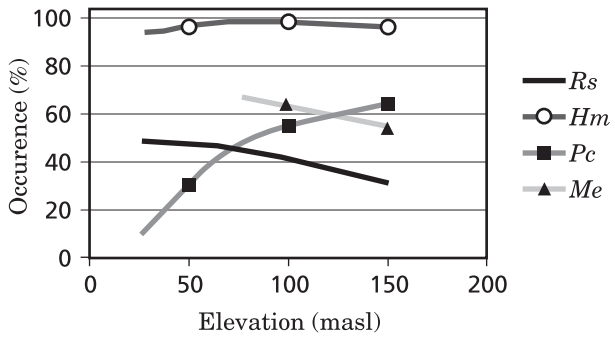


Figure 2.
Occurence of nematode species on *Musa* ABB.

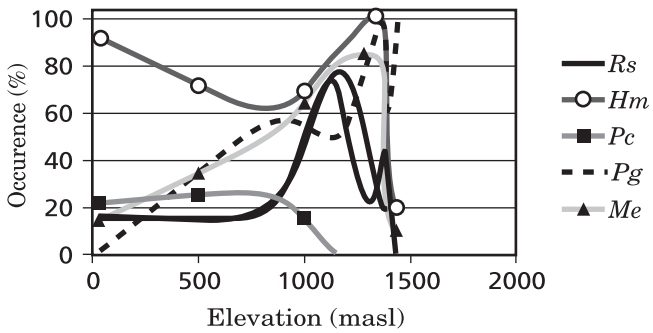


Figure 3.
Occurence of nematode species on *Musa* AAA-EA.

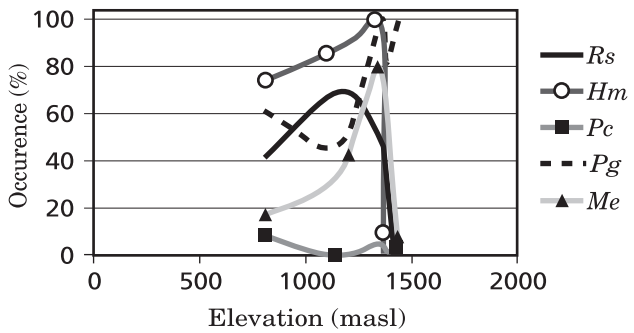
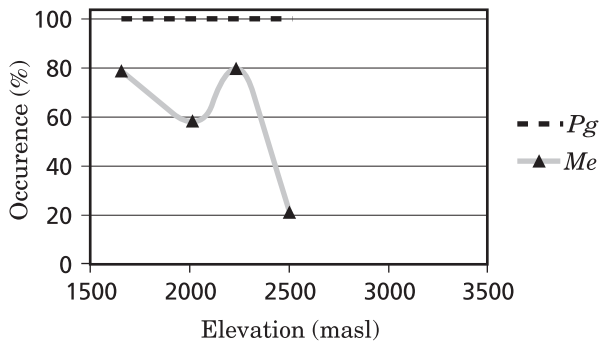


Figure 4.
Occurence of nematode species on *Ensete.*



Rs: Radopholus similis, Hm: Helicotylenchus multicinctus, Pc: Pratylenchus coffeae, Pg: Pratylenchus goodeyi, Me: Meloidogyne spp.

highland banana. However, Belpaire (1997) reported that *R. similis* appears to be more destructive, as it also contributes significantly to plant toppling (Table 7). *Pratylenchus goodeyi* causes bunch weight reduction of highland banana at elevations above 1350 masl (Speijer *et al.* 1998, Elsen *et al.* 1988). A trial to establish yield loss to the highland cultivar Mbwazirume has been established in Mbarara, Uganda. A production loss exceeding 20% is anticipated in the second cycle (Speijer, personal observation). It has not been established to what extent *P. goodeyi* causes losses to *Ensete*. However, based on the extent of the necrosis, considerable losses also can be expected (Peregrine and Bridge 1992).

Discussion

The commonly found nematode species, *H. multicinctus*, *R. similis*, *P. coffeae* and *P. goodeyi*, appear all to be associated with production losses ranging from 30% to over 80% per cycle. Nematode densities observed in the various yield loss experiments are not much different than generally observed in farmer's fields. The trials may therefore be considered as representative for the farmer's situation. The results imply that the most widely grown *Musa* groups, plantain and highland banana, are highly susceptible and are incurring large annual losses. Losses caused by nematode infestations are even more serious in the lower elevation zones of Africa, compared to the higher zones. A major reason for this could be the relatively higher soil temperatures, which promotes root decay processes. Production losses are genotype-dependent (Speijer and Bosch 1996, Speijer and Ssango 1996, Fogain *et al.* 1996). For example at Njombe, Cameroon (80 masl), a production loss of 50% was observed for the plantain cultivar French Sombre, while for Yangambi Km5 in the same trial no production loss was recorded (Fogain and Gowen 1997).

Pest status of *P. goodeyi* on *Ensete* needs to be confirmed. Also more knowledge is required on the interactions between the different nematode pest species and other biotic and abiotic production constraints. A strong interaction between nematode infestation and the banana weevil has been observed in Kenya (Speijer *et al.* 1993, Fogain 1994), and interactions with other biotic and abiotic constraints are expected (Frison *et al.* 1997). A good understanding of the various interactions will increase the impact of integrated pest management programmes on such pest and disease complexes.

In order to reduce the production losses caused by the various nematode species, several control methods have been suggested (Gowen and Quénéhervé 1990). However banana nematodes are a difficult group of organisms to control as they generally live well protected in the roots and rhizomes. In addition the ratoon nature of *Musa* reduces almost completely nematode population reduction through crop rotation. Nematodes may be controlled with chemicals to a certain extent, but these may cause adverse environmental effects and, generally, nematicides are too expensive for subsistence farmers. Therefore, it is anticipated that the replacement of the present genotypes with less susceptible cultivars (Speijer and Gold 1995, De Waele and Speijer, this volume[1]), or the preferred inclusion of nematode resistance to the commonly grown landraces (Jones 1996) and/or application of biological control agents (Niere *et al.* 1998), can have a very high impact in our efforts to increase or sustain *Musa* and *Ensete* production in Africa.

Table 4. Nematode-related production loss in the second cycle crop for the plantain cultivar Obino l'Ewai (Musa AAB), Onne, Nigeria. (Dubois *et al.*, in preparation).

Treatment	*Hm* per 100 g	*Rs* per 100 g	Dead roots (%)	Root necrosis (%)	Bunch weight (kg)	Toppling incidence (%)	Production (t/ha)
Obino l'Ewai							
- not infested	3661	0	15	10	7.6	0	12.5
- infested	9222	11569	42	26	1.4	48	1.2
	ns	**	***	***	***	***	*
Production loss							90%

Hm: Helicotylenchus multicinctus, Rs: Radopholus similis
n = 20, ns: no significant differences; *: P<0.05, **: P<0.01 and ***: P<0.001 (t-test)

Table 5. Production loss in the first and second cycle of plantain cultivar French Sombre (*Musa* AAB) associated with *Radopholus similis*, Njombe, Cameroon (Fogain, 1998a).

	1st cycle			2nd cycle		
	Treated	Infested		Treated	Infested	
Bunch weight (kg)	9.4	8.4		16.0	15.6	
Toppling (%)	3.0	18.0	*	8.0	53.0	*
Production (t/ha)	13.1	5.3	*	15.6	7.5	*
			60%			52%

Treated plots: cadusaphos application at the rate of 30 g/plant 3 times a year

Table 6. Nematode-related production loss in the first cycle crop of the East African Highland banana cultivar Nakitembe (*Musa* AAA, Matooke group), Sendusu, Uganda. (Speijer and Kajumba 1996).

Cultivar/ Treatment	*Hm*	*Rs*	Dead roots (%)	Root necrosis (%)	Bunch weight (kg)	Toppling incidence (%)	Production[1] (t/ha)
Nakitembe							
- not infested	55	52	5	3	9.0	0	7.1
- infested	7772	6916	25	23	7.3	11	3.4
	***	***	**	**	***	**	*
Production loss							52%

Hm. Helicotylenchus multicinctus, Rs: Radopholus similis

1 at 70% of the best treatment harvested
n = 216, ns: no significant differences
*: P<0.05, **: P<0.01 and ***: P<0.001 (t-test)

Table 7. Nematode-related production loss in the second cycle crop of the East African highland banana cultivar Mbwazirume (*Musa* AAA, 'Matooke' group), Sendusu, Uganda (Belpaire 1997).

Cultivar / Treatment	*Hm* per 100 g	*Rs* per 100 g	Dead roots (%)	Root necrosis (%)	Bunch weight (kg)	Toppling incidence (%)	Production (t/ha)
Mbwazirume							
- not infested	19 b	101 b	11a	1a	8.4a	2a	9.1
- *H.multicinctus*	1657a	162 b	13a	3ab	6.9 b	4a	7.4
- *R. similis*	479ab	1068a	45 b	8 b	6.3 b	17 b	5.8
Production loss	Hm						19%
Production loss		Rs					36%

Hm: Helicotylenchus multicinctus, Rs: Radopholus similis
Numbers followed by the same letter are not significantly different at P<0.05, Least Significant Means

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Habitat management for control of banana nematodes

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Introduction

Until the 1980s, most of the research on banana nematodes focused only on large-scale plantations of export bananas, Cavendish cultivars, and on control of *Radopholus similis* (Cobb) Thorne (Wehunt *et al.* 1978, Price 1960, O'Bannon 1977, Gowen 1977). In the past, control of plant parasitic nematodes depended largely on the use of chemical pesticides, the most efficient means of quickly reducing nematode populations (Gowen 1977, Melin and Vilardebo 1973, Badra and Caveness 1983). This, however, was restricted to producers of export bananas, as it was unaffordable in subsistence farming systems. Moreover, such subsistence farmers had no or very little knowledge of nematodes, as established recently in Uganda (Gold *et al.* 1993).

With increasing awareness of hazards associated with chemical pesticides (expensive, limited number of products on market, environment-unfriendliness, side effects to non-target organisms, contamination of surface and ground water), research has been directed towards development of nematode management (instead of nematode control) systems that operate with reduced nematicide inputs and increased cultural control practices in an integrated pest management (IPM) concept. Chiarappa *et al.* (1972) defined IPM as "the coordinated use of all possible control methods for pests, including biological, environmental, and cultural methods, within management techniques directed towards the fullest utilization of natural pest mortality and other suppressive factors in any given agrosystem". It is this concept that agricultural research needs to continue developing, as it would yield control measures applicable to both the intensive banana agrosystem and the resource-poor farmers' banana-based agrosystem. To achieve this, efforts need to be put into manipulation of the habitat, host physiology and habits and activities of the pest, a phenomenon referred to as "habitat management". The current thinking is that habitat management or cultural practices

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would offer prospects for nematode control. This paper focuses on environmental and crop-based elements that can be manipulated in order to regulate population numbers and/or offset damage caused by nematodes to the plant.

The banana crop is attacked by weevils and diseases (e.g. fusarium wilt, Sigatoka, BSV, etc). Socioeconomic aspects are also a big problem of sustainable production of the crop. Management of nematodes needs to be in agreement with that of these other constraints in an IPM concept in order to achieve optimum productivity of the crop. In view of the above, a background on the crop and nematode pest relationship is given first, to provide a basis for utilization of nematode research results into management of the other constraints.

Banana and plantain

The banana and plantain plants are giant herbs comprised of underground parts: the rhizome and roots, and aerial parts: the pseudostem, leaves and inflorescence. They grow well in hot and humid environments where minimum average temperature is above 15°C and annual rainfall above 1200 mm (Simmonds 1966).

The crops are cultivated under two cropping systems which places them in two distinct classes of importance.

i) The export bananas, comprised mainly of the Cavendish (AAA) group of cultivars, are produced intensively by large-scale farmers and as a monocrop. West Africa (Cameroon, Côte d'Ivoire) and South Africa are the leading producers in Africa.

ii) The East African highland bananas (AAA-EA) and plantains which are a major staple food crop in the Great Lake region and West Africa respectively. These are produced extensively by resource-poor farmers and generally in mixed cropping system with cash and other food crops.

In both production systems, nematodes have been reported as one of the major production constraints (Luc and Vilardebo 1961, Adiko 1989, Fogain 1994, Kashaija *et al.* 1994, Bridge *et al.* 1995).

Banana and plantain major nematodes

Several species of nematodes have been found associated with bananas and plantains as root endoparasites. Of importance in the major banana- and plantain-growing regions of Africa are *Radopholus similis*, *Pratylenchus goodeyi*, *Helicotylinchus multicinctus*, *Hoplolaismus* spp. and *Meloidogyne* spp. as exemplified by their occurrence in both East and West Africa (Table 1). Based on spread, damage caused and abundance, *R. similis* is the most important species while the importance of *P. goodeyi* and *H. multicinctus* varies with regions. Nematode species occurrence, distribution and abundance is influenced by many factors including elevation (temperature), soil characteristics, cropping history, host plant cultivar and crop husbandry. For example,

R. similis is restricted to areas below 700 masl in Cameroon and 1400 masl in Uganda, while *P. goodeyi* occurs almost exclusively above 1000 masl in Cameroon and 1400 masl in Uganda (Kashaija *et al.* 1994, Bridge *et al.* 1995, Fogain *et al.* 1998). The diversity of nematode species for example in the low elevation areas in Uganda, is attributed to cropping systems and field cropping history (Kashaija *et al.* 1994).

Table 1. Endoparasitic nematodes encountered in bananas and plantains in Cameroon and Uganda

Nematode species	Cameroon	Uganda
Radopholus similis	✔	✔
Pratylenchus coffeae	✔	✔
Pratylenchus goodeyi	✔	✔
Pratylenchus zeae		✔
Hoplolaimus pararobustus	✔	
Meloidogyne incognita	✔	✔
Helicotylenchus multicinctus	✔	✔
H. dihystera	✔	✔
H. erythrinae	✔	
H. pseudorobustus	✔	✔
H. variocaudatus	✔	
Scutellonema cavenessi	✔	
Trophotyenchulus	✔	
Rotylenchulus reniformis	✔	

Sources: Bridge *et al.* (1995), Kashaija *et al.* (1994)

The banana root system and nematode pest relationship

Banana and plantain plants have an adventitious root system which arises from the rhizome (or corm), and much of it is found in the top 40 cm of soil (Irizarry *et al.* 1981).

Nematodes feed on banana roots, causing root necrosis which gradually leads to root rotting and reduced number of functional roots. Reports have been given on positive correlations between nematode densities and increased necrosis or toppling and an increase in total root mass with nematicide treatment to a susceptible cultivar (Speijer *et al.* 1994, Fogain and Gowen 1997). The level of damage inflicted on the plant is greatly affected by pathogenicity of the nematodes, i.e the mode of parasitism, the distribution in the root system and population densities. The lesion-forming nematodes (*P. goodeyi*, *H. multicinctus* and *R. similis*) which feed in the root cortex obstruct conduction of solutes but can also reduce root branching and elongation and under severe damage they destroy the anchorage system. On the other hand, gall-forming nematodes feed from the stele and are mainly involved in reduction of water and nutrient absorption capability.

Unfortunately, the conditions that promote continuous root system development also encourage continuous reproduction of the parasitic nematodes. The solution therefore seems to lie in the balance between nematode numbers of the major species in a given location and rooting behaviour and/or root system of the plant. Control techniques have to target reducing nematode densities and/or improving the root biomass, size and ratio of primary to secondary and tertiary roots. These root parameters are important for the root functions of anchorage, water and nutrient exchange, as well as in overall response of the plant to nematode damage. This probably explains why habitat management, including cultural practices, could be a better alternative to nematicides for management for banana nematodes. An evaluation of nematode control strategies based on habitat management is presented below.

Evaluation of habitat management and cultural control practices as measures for management of banana nematodes

Crop rotation or break cropping and fallowing, as methods of nematode control, operate on the principle of starving nematodes to death, therefore inducing a decline in nematode populations in a field, so that the next banana crop starts with a low initial inoculum. There have been two major hindrances to fast adoption of these methods: land pressure and cultivation of bananas as a perennial crop. The rotation crops therefore need to have other economic benefits and must be non-hosts to target nematodes.

Root crops such as cassava and sweet potato have proved to be potential rotation crops against *R. similis* and/or *H. multicinctus* (Price 1994, Namaganda 1996). At least 15 months are required to significantly reduce populations of the two nematodes. An evaluation of ten plant species commonly grown by farmers in Cameroon showed that pineapple and sweet potato are poor hosts of *R. similis* (Fogain, unpublished). Therefore, cassava, sweet potato and pineapple are recommended to farmers for use as break crops. Search for other potential break crops is underway. Meanwhile, some farmers, where banana production has severely declined, have shown a willingness to uproot the less productive plantations and replant them using clean planting material after freeing the soil of banana nematodes using break crops (Kashaija *et al.*, unpublished).

Investigations have shown that when infested land is fallowed for 8 to 12 months, *R. similis* populations decrease significantly. In contrast root-knot populations tend to increase during fallow (Fig. 1). When tissue-cultured plantlets were planted after fallow, very low *R. similis* populations were recorded during the first two cycles, but severe root galls were found on roots three months after planting. This shows that as *R. similis* decreases during fallow, root-knot nematodes become the dominant species, probably because they have a wide range of alternate hosts. Nevertheless, in spite of their wide occurrence, *Meloidogyne* species have not been found a threat to banana and plantain production in Africa.

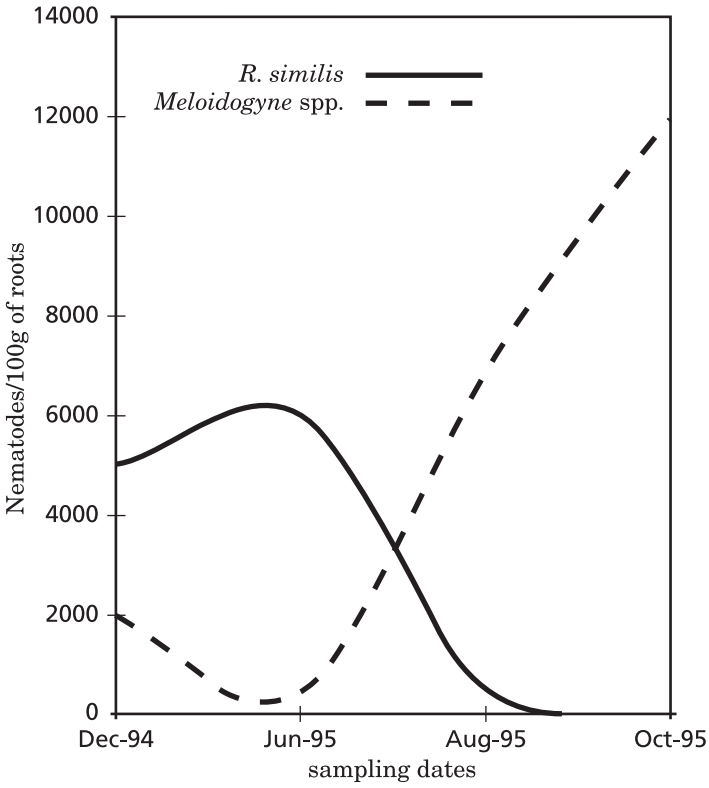

Figure 1. Dynamics of *Radopholus similis* and *Meloidogyne* spp. during fallow after 5 years of banana cultivation.

Mulching

Mulching seems not to have a direct and/or immediate effect on root endoparasitic nematodes. In one experiment at Sendusu, Uganda, the population of *R. similis* and *H. multicinctus* was similar between mulched and bare plots of bananas in each crop cycle. However, there was a gradual reduction in the population of *R. similis* from the first to the third crop cycle. On the contrary, mulching appeared to increase the population of *P. goodeyi* (Table 2). Overall, mulches enhance root and plant vigour (Table 3), making the plant able to tolerate nematode damage. The use of mulches, therefore, greatly increases the production of banana and plantain. In Uganda, an increase of production exceeding 60% was observed over a period of four cycles (Speijer *et al.* 1999). It has been shown that mulched nematode-infested plots are likely to produce more than non-infested but bare plots, because of the benefits of organic matter produced (Fig. 2). However the relative loss caused by nematodes in mulched and bare plots will remain approximately 30% per production cycle. When plants start toppling on a mat, the chance that this mat will produce a harvestable bunch in the following cycle is highly reduced and this process cannot be reversed when applying mulch.

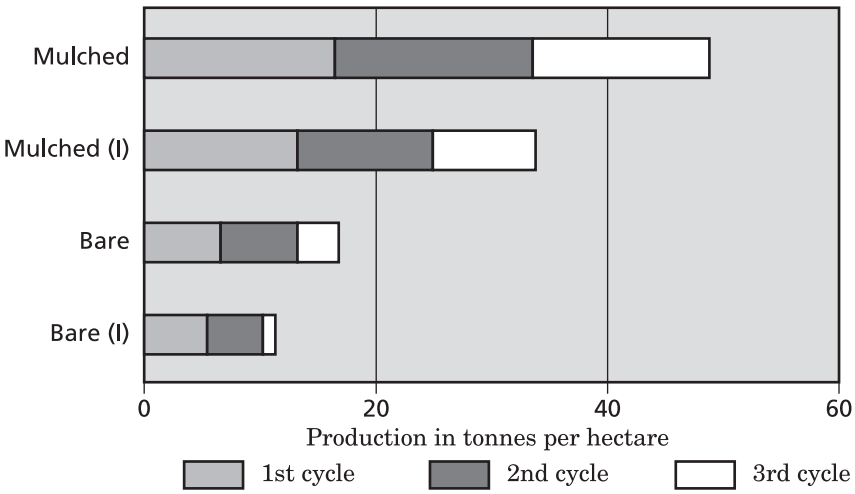

Figure 2. Effect of mulch on standard bare nematode-infested (I) or non-infested plots of highland banana (Mbwazirume). Source: Speijer *et al.* (1999).

Table 2. Nematode densities and damage of suckers detached from harvested plants in the ratoon crops of the East African banana cultivar Mbwazirume grown in non-infested and nematode-infested plots, under the management regimes of heavy mulching, clean weeding and millet intercropping, at Sendusu, Uganda.

Treatment	Nematode densities per 100 g			Root damage	
	R. similis	*H. multicinctus*	*P. goodeyi*	Dead root (%)	Root necrosis (%)
First cycle					
Mulched	20329	5943	3950	24	18
Bare	16966	8821	553	33	27
Second cycle					
Mulched	10223	4450	6763	37	38
Bare	7454	6395	69	37	35
Third cycle					
Mulched	3010	3177	7268	29	44
Bare	9185	5881	2104	35	42

Table 3. Plant height, primary root weight (wt) and diameter and lateral root weight as influenced by four different management practices.

Management practice	Height (cm)	Primary root wt (g)	Root diameter (cm)	Lateral root wt (g)
Mulch + manure	250	32.1	0.65	0.72
Fertilizer (NPK)	195	25.6	0.61	0.79
Millet intercrop	140	21.5	0.54	0.76
Control	172	21.2	0.58	0.53
SED	6.8	3.40	0.025	0.190

N=20. Primary root weight measurements were taken 5 months after planting while diameter and height records are of 12 months after planting

Organic amendments

Controversial results have been reported with regard to use of manure in the control of banana and plantain nematodes. In some situations the density of *R. similis* and *H. multicinctus* was higher in plots with manure (Kashaija 1996) and in others the density of *H. multicinctus* was reduced with application of poultry and farmyard manure (Obiefuna 1990). Organic manures are expected to reduce nematode populations indirectly by increasing biological control agents. The incorporation of plants with nematicidal activities (*Thitonia diversiflora, Azadirachta indica, Chromoleana odorata*) into soil at a rate of 30t/ha is under investigation for their possible control of *R. similis.*

Biological control

According to Pianka (1974), communities with many trophic groups provide greater possibilities for checks and balances to operate. The same author also pointed out that in nature resources are not wasted. When life supports for most species are destroyed, as is the case in cultivated land, especially monocultures, the species which remain generally enlarge their activities and exploit all the available resources. Identification and use of biological control organisms against nematodes and of the factors that favour the development of such indigenous strains would be the kind of habitat manipulation highly advocated since this works towards restoration of a self-regulatory habitat. The evaluation of native strains of arbuscular mycorrhizal fungi (AMF) is underway in banana- and plantain-producing zones in Cameroon for their possible use to alleviate nematode problems on bananas and plantains. Preliminary results indicate that more than 50% of the samples collected are mycorrhizal. *In vivo* production has been set up and the most interesting strains will be selected for future studies. It is well known that antagonistic fungi like *Arthrobotrys* spp. and *Paecelomyces pilacinus*, and a rhizobacteria (*Pseudomonas* spp.) are potential control agents of nematodes. Such microorganisms need to be studied for efficacy under the various agrosystems so as to contribute to reducing nematode damage on bananas and plantains.

Plant resistance

Plant resistance to a pest is attained by manipulation of host physiology, with great knowledge of host-parasite relationship. This, in a way, is a habitat management technique. Plant resistance is probably the best form of nematode control, especially for resource-poor farmers who cannot afford the high cost of nematicides. Several evaluations of plantains (AAB), Cavendish (AAA), Lujugira (AAA) and East African highland bananas (AAA-EA) have been carried out to look for clones with lower susceptibility level that could be recommended to farmers to replace the susceptible ones. Results revealed that these clones are susceptible to *R. similis* (Price 1994, Kashaija 1996, Fogain 1996, Fogain *et al.* 1996). Sources of resistance to *R. similis* have been identified in earlier studies in the diploid Pisang Jari Buaya (*Musa* AA) (Pinochet

and Rowe 1978, Wehunt *et al.* 1978). Recent studies have shown that most clones of the Ibota (subgroup *Musa* AAA) such as Yangambi Km5 are resistant to *R. similis* (Fogain 1996). Other diploids, e.g. Calcutta 4, Truncata, Selangor, Safet Velchy and most *M. balbisiana* varieties, are significantly less susceptible than Cavendish. The exploitation of these sources of resistance for incorporation into acceptable varieties is one of the long-term objectives for nematode control of the PRO*MUSA* Nematode Working Group and various research centres' breeding programmes.

Clean planting material

Above all else, the use of nematode-free planting material in clean fields is important for control. The practice has been proven to be an effective strategy to reduce production losses. In Uganda results of on-farm trials showed that even 2.5 years after planting, densities of *R. similis* and *H. multicinctus* were still lower ($P<0.05$) in plots with hot water-desinfested materials compared to those with farmers standard material (Speijer *et al.* 1999). Based on on-station trials it is anticipated that the use of nematode-free highland banana planting material under eastern African conditions will increase production by 30% to 50% for each cycle for a period of at least three cycles (Speijer *et al.* 1999). The impact of the use of nematode-free plantain planting material under conditions in Ghana or other West African countries may even be more drastic. Results of on-farm trials in Ghana showed an increase in production of 60% in the first cycle and a lengthening of plantation life from two cycles to over five cycles. Needless to say, clean planting material are obtained by tissue culture micropropagation and paring of corms. The pared corms may be heat-treated, and/or chemical-treated. Studies on the latter are underway to determine the appropriate chemical and application procedures.

Propping

In both intensive and extensive agrosystems, as well as in infested and non-infested fields, farmers aim at obtaining maximum yield. To avoid toppling and breaking of plants due to nematodes, weevils and strong winds, propping or guying is encouraged. A great percentage of the banana crop and yield loss is through plant toppling and breaking.

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Nematode resistance in *Musa*

D. De Waele[1] and P.R. Speijer[2]

Introduction

In 1968, FAO defined integrated pest management (IPM) as "a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible, and maintains the pest population at levels below those causing economically unacceptable damage or loss" (ter Weel and van der Wulp 1999). Pests includes plant pathogenic microorganisms (viruses, bacteria, fungi), invertebrates (nematodes, mites, insects), vertebrates (birds, rodents) and weeds. Examples of available techiques are: adoption of cultural practices that prevent buildup of pests (such as timing of planting, crop rotation, intercropping), biological control by parasites or predators, use of pest-resistant crop varieties. Selective and judicious use of pesticides is regarded as a last-resort management option. In a system approach, a framework is provided for the description of interactions among related entities and procedures for the description, modelling, evaluation, design and optimization of the system (Bird *et al.* 1985). The concept of IPM evolved in response to environmental concerns in general and the public desire to change the prevailing methods of controlling plant pests in a way that did not pollute or degrade the environment. IPM provides a working methodology for pest management in sustainable agricultural systems. It reduces the role of pest management in environmental degradation by using the safest tactics available in the context of environmental and economic needs and by invoking management only when it is determined to be necessary through biomonitoring and use of economic treshholds (Duncan 1991).

Pest-resistant crop varieties offer many of the same advantages for nematode management as rotation crops with the additional feature of permitting production of crops best suited to the needs of the grower (Duncan 1991). In this paper, the current knowledge on nematode resistance in *Musa*, especially with reference to *Radopholus similis* and *Pratylenchus* spp. is summarized.

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Definitions

Resistance/susceptibility on the one hand and tolerance/sensitivity on the other hand are defined as independent, relative qualities of a host plant based on comparison between genotypes. A host plant may either suppress (resistance) or allow (susceptibility) nematode development and reproduction; it may suffer either little injury (tolerance), even when quite heavily infected with nematodes. The comparison between genotypes results in such indications as completely, highly and partially resistant genotypes describing, respectively, genotypes supporting no, little or an intermediate level of nematode reproduction. A non-resistant or susceptible genotype allows nematodes to reproduce freely (Bos and Parlevliet 1995).

Screening for nematode resistance in *Musa*

Full descriptions of a methodology and protocols for carrying out nematode resistance and tolerance screening in *Musa* can be found in Speijer and De Waele (1997).

Plant material

Screening can be performed either with *in vitro* tissue-cultured plants or suckers. *in vitro* tissue-cultured plants can be initiated from a sucker or obtained from an *in vitro* laboratory. Before they can be used for screening, the tissue-cultured plants must go through three *in vitro* stages: proliferation (= multiplication), regeneration (= shoot formation) and rooting (= root formation) (Vuylsteke and De Langhe 1985). Suckers can be obtained from mother plants in the field. The suckers can be freed from nematode infection by peeling off the roots and the outer corm layers followed by immersion in a water tank at 53-55°C for 20 minutes.

Nematode inoculum

Plants can be infected with nematodes either by inoculation or by planting in nematode-infested soil. Inoculation is generaly used in pot and plastic bag experiments. Nematode-infected roots or nematodes extracted either from roots collected from a field infested with nematodes or from nematode cultures can be used as nematode inoculum. Carrot discs allow the rearing of high numbers of *R. similis* and *Pratylenchus* spp. (Pinochet *et al.* 1995).

Screening experiments

The screening experiments can be undertaken using either pots/plastic bags or in the field. Screening experiments in pots or plastic bags will only allow observations to be made for a relatively short period (2 to 3 months) of the crop cycle. During this period, the susceptibility of the genotypes can be determined by assessing the nematode reproduction rate and, if uninfected plants are included in the screening experiment, some observations can be made on the sensitivity of the genotypes (root necrosis and

plant growth: root weight, shoot weight, plant height). Screening experiments in the field will allow observations to be made during the whole crop cycle and subsequent ratoon crops. During this period the susceptibility of the genotypes can be determined by assessing the nematode reproduction and, if uninfected plants are included in the screening experiment, observations can be made on the sensitivity of the genotypes, including at the level of the yield.

The evaluation/interpretation of the data obtained during the screening should be based on a combination of nematode reproduction data (resistance/susceptibility) and host plant response data including: number of nematodes in the roots and percentage of dead roots and root necrosis index, eventually yield (tolerance/sensitivity).

Nematode resistance sources in *Musa*

Efforts to screen agricultural crop germplasm for resistance to plant parasitic nematodes have mainly been aimed at identifying resistance to sedentary endoparasitic nematodes, such as root-knot (*Meloidogyne* spp.) and cyst (*Globodera* spp., *Heterodera* spp.) nematodes. As a consequence, resistance to nematodes has primarily been identified in this group of nematodes which has the most specialized host-parasite relationships (Cook and Evans 1987, Roberts 1992). This is to be expected because host-parasite relationships are genetically controlled and the natural selection of resistance genes is thus more likely to occur in the most complex interactions (Sidhu and Webster 1981, Roberts 1992). In *Musa*, the most damaging and widespread nematodes are, however, migratory endoparasites: the burrowing nematode *Radopholus similis* and the root-lesion nematodes *Pratylenchus coffeae* and *Pratylenchus goodeyi* (Sarah *et al.* 1996, Bridge *et al.* 1997). Although sources of resistance to this group of nematodes are much less frequent, resistance to burrowing and root-lesion nematodes, albeit against different species than those occurring in *Musa*, has been found in citrus, groundnut, potato, alfalfa and lima bean (De Waele 1996).

In *Musa*, so far only two widely confirmed sources of resistance to *R. similis* are known: Pisang Jari Buaya and Yangambi Km5 (Wehunt *et al.* 1978, Sarah *et al.* 1992, Price 1994). The Pisang Jari Buaya group (PJB) consists of diploid AA varieties of which several varieties show either resistance to or are less susceptible for *R. similis* (Wehunt *et al.* 1978). Pollination of about 10,000 bunches of the almost sterile clone PJB II-115, collected in Sabah, Malaysia, lead to the *R. similis* resistant hybrid SH-3142 (Pinochet and Rowe 1979). This hybrid is readily usable as both a pollen and seed parent in cross-pollinations and is being used in the *Musa* breeding programme at the Fundacion Hondurena de Investigacion Agricola (FHIA) in La Lima, Honduras, to develop *R. similis* resistant bananas and plantains (Viaene *et al.* 1998). Yangambi Km5 is a triploid AAA variety collected in the Democratic Republic of Congo and possibly related to some varieties in Malaysia. Although male and female fertile this variety is not being used in *Musa* breeding programmes because all progenies produce abnormal leaves and/or erect and semi-erect bunches.

Recently, some additional sources of resistance to *R. similis* have been reported. In 1996, Fogain *et al.* reported that three diploids from the wild *Musa balbisiana* (BB-) group were as resistant to *R. similis* as Yangambi Km5. Stoffelen *et al.* (1999b) evaluated the host plant reaction to *R. similis* of 25 banana varieties of the section *Eumusa* (AA-group) and seven of the section Australimusa (Fe'i-group) collected in Papua New Guinea in greenhouse conditions. No resistance was found in the diploid varieties but Fe'i variety Rimina was resistant to *R. similis* while Fe'i variety Menei was identified as a possible source of resistance to *R. similis*. The resistance of all these new sources needs to be confirmed under field conditions.

There are no widely confirmed sources of resistance to *P. coffeae* and *P. goodeyi* in *Musa*. There are indications that Calcutta 4, a diploid AA variety which is used as a female parent in the *Musa* breeding programme at FHIA, is resistant to *P. coffeae* (Viaene *et al.* 1998) while Yangambi Km5 appears also to be resistant to *P. goodeyi* (Fogain and Gowen 1998). Also these sources of resistance need to be further examined and confirmed.

The nature of the nematode resistance observed in *Musa* is unknown. It has been suggested that resistance to *R. similis* is controlled by one or a few dominant genes (Pinochet 1996). According to Bingefors (1982) and Sidhu and Webster (1981), 52% of plant resistance to nematodes identified so far is monogenic, conferred by a single resistance gene while 28 and 20% of the resistance is due to a few (oligogenic) or many (polygenic) genes, respectively. Although this heavy reliance on single-gene resistance is often considered a weak aspect of nematode resistance, single-gene resistance may be more durable against some nematodes than it is for other pests because nematodes disperse slowly and often reproduce parthenogenetically and at relatively low numbers (Duncan 1991). Furthermore, Boerma and Hussey (1992) emphasize that predominance of monogenic and oligogenic resistance is desirable from the standpoint of ease of incorporation into superior breeding material.

Nematode resistance and biological diversity of *Radopholus similis* and *Pratylenchus* spp. in *Musa*

In general, nematode resistance is most often found to only one or a few, but not all pathotypes, of a nematode species. Pathotypes of a nematode species are populations distinguished by their inherited ability or inability to reproduce on a designated host plant. Biological diversity, such as the occurrence of pathotypes, complicates the identification of nematode resistance (Pinochet 1996).

Intraspecific biological diversity of *R. similis* populations isolated from *Musa* has been described (Pinochet 1979, Sarah *et al.* 1993, Fallas *et al.* 1995, Hahn *et al.* 1996, Stoffelen *et al.* 1999a). A direct relationship was found between the reproductive fitness (multiplication rate) on carrot discs of the different populations and their pathogenicity (induced damage on roots) on banana roots: the higher the reproductive fitness on carrot discs the greater the pathogenicity on banana roots. Populations of *R. similis*

from Africa often display the highest reproductive fitness and, consequently, the highest degree of pathogenicity (Sarah and Fallas 1996).

Biological diversity within *P. coffeae* and *P. goodeyi* has also been reported although it appears minor if compared with the pathogenic diversity found in *R. similis*. Wehunt and Edwards (*in* Stover 1992) suggested the existence of different pathotypes of *P. coffeae* following the observation of differences in host plant preferences between populations from Honduras and Panama. Stoffelen *et al.* (1999a) describe differences in reproductive fitness on carrot discs of *P. coffeae* populations from Honduras, Ghana and Vietnam. Pinochet (1998) reported differences in reproductive fitness and pathogenicity between *P. goodeyi* populations from the Canary Islands and East Africa.

Nematode resistance in *Musa* and participatory IPM

Because the old FAO definition of IPM does not reflect the crucial role of farmers in IPM implementation, the new term 'participatory IPM' is now being used to emphasize the responsability of farmers for diagnosing pest problems and actively seeking solutions best suited to situations in their field (ter Weel and van der Wulp 1999).

In East Africa, an example of 'participatory IPM', albeit unaware to the farmers, related to nematode resistance in *Musa* has recently been documented. In Tanzania, it was observed that the East African Highland cooking banana varieties and, to a larger extent, the East African Highland brewing banana varieties had been replaced with exotic varieties (Speijer and Bosch 1996). In the late 1960s, 98% of the banana mats grown in the Kagera Region of Tanzania were East African Highland varieties: 70% of these were cooking and 30% brewing varieties. Currently, 65% of all banana mats are East African Highland cooking varieties, 9% are East African Highland brewing varieties and 26% are exotic brewing cultivars. The cultivar Gros Michel (*Musa* AAA) is the most common replacement followed by Kanana (*Musa* AB) and Pisang awak (*Musa* ABB). These data show a 24% reduction in East African Highland banana varieties in 25 years. The East African Highland brewing varieties appear to have been replaced by exotic beer varieties in excess of 70% (Table 1). This replacement can be linked to the higher susceptibility of the East African Highland banana varieties to *P. goodeyi* (Speijer and Bosch 1996) and to *R. similis* and *H. multicinctus* (Table 2) compared with the exotic varieties. In the Kagera region, *P. goodeyi* and *H. multicinctus* are the dominant nematode species on *Musa*; *R. similis* occurs locally (Speijer and Bosch 1996).

The experience in the Kagera Region of Tanzania indicates that farmers in East Africa will readily adopt the introduction of new, nematode-resistant *Musa* varieties in their production system. However, this adoption will only be sustained when the varieties are superior to the varieties they replace. Very few adoptable nematode-resistant varieties are at the moment available but as our knowledge on the susceptibility and sensitivity to nematodes of the *Musa* germplasm increases the chances to discover or develop these superior varieties become more and more real.

Table 1. Banana varieties grown in the Kagera Region, Tanzania, in 1960 and 1995 (after Speijer and Bosch 1996).

Variety	1960 (%)	1995 (%)
East African Highland (AAA)		
cooking	69	65
brewing	29	9
Exotic: Gros Michel (AAA), Kanana (AB), Pisang awak (ABB)	2	26

Table 2. Population densities of *Radopholus similis* and *Helicotylenchus multicinctus* recovered from 100 g fresh roots of suckers detached from 18-month-old mats of seven *Musa* varieties grown in a nematode-infested field plot in Sendusu, Uganda.

Variety	Genome	*R. similis*	*H. multicinctus*
Gros Michel	AAA	340a	3631a
Pisang awak	ABB	2734a	1378a
Mbwazirume	AAA (East African Highland)	9478ab	6731ab
Obino l'Ewai	AAB	11,056bc	20,560c
Cardaba	ABB	15,621bc	13,280bc
Entendu	AAA (East African Highland)	23,824bc	4970ab
Valery	AAA	33,653c	8755b

Data were ln(x+1) transformed prior to statistical analysis.

Means in the columns followed by the same letter are not significantly (P<0.05) different according to the Least Square Means model in ANOVA.

Acknowledgements

The authors wish to thank INIBAP for the invitation to attend the workshop and present this paper. The first author thanks INIBAP, the Common Funds for Commodities/FAO/World Bank Banana Improvement Project (BIP) and K.U. Leuven for financial support.

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Novel approaches to nematode IPM

R.A. Sikora and R.P. Schuster[1]

Introduction

It is a well-established fact that plant parasitic nematodes are major factors limiting banana and plantain production worldwide. Integrated pest management (IPM) is the main method of control usually recommended to offset their impact on yield. However, control of nematodes as practiced in most commercial systems generally does not fall under what most plant protectionists would call IPM. Furthermore, well-structured IPM programmes, although recommended by most nematologists, are only sporadically used by commercial growers and are for the most part totally lacking where resource-limited or subsistence production is the rule.

We dare to say that the only place where well-planned nematode IPM is practiced is on the research stations of Universities, National Agricultural Research Organizations and at International Research Centers. To be provocative we would go so far as to state that IPM of nematodes has not been, is not and may not be an important topic for the vast majority of banana producers.

Let us be honest with ourselves - nematode IPM in banana production either is limited to the regular application of nematicides 2-3 times per year or nematode control is left to 'mother nature'. With the abovesaid, it might be concluded that there is no real need to discuss novel approaches to nematode IPM.

The opposite, however, is true! In a relatively short period of time a number of major external factors have changed how growers, both large and small, as well as scientists, look at IPM in banana:

- new debilitating disease problems have come onto the scene,
- major pesticides have been and are being lost for ecological reasons,
- worldwide market pressures are affecting production strategies,
- ecological disasters, war and famine require 'kick-start' planting options,
- interest in pesticide-free bananas has developed, and
- major breakthroughs in biocontrol and plant resistance have occurred.

These factors will influence how nematode IPM in banana and in other crops develops in the not so distant future. The factors mentioned above will require a closer examination of nematode IPM techniques in banana production as we now perceive

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them and how they will impact all growers and production regions of the world including Africa. In Table 1 a list of the most important IPM techniques that can be used to control nematodes are listed, along with our estimates of their acceptance in production systems ranging from large-scale commercial to subsistence. As can be seen there is not a great deal of acceptance of any of the technologies at the present time.

Table 1. Nematode IPM control techniques and estimated use for different scales of banana production.

IPM Techniques	Large scale	Medium scale	Limited resources	No resources
Rotation/break crop	+	–	–	–
Intercropping	–	–	++	+++
Antagonistic intercrops	–	–	–	–
Mulches	+++	+++	++	+
Pared corms	–	+	+/–	–
Hot water treatment	–	+	–	–
Nematicides	+++	++	–	–
Tissue culture	++	+	–	–
Resistant cultivars	+	+	–	–

However, with the possible loss of markets, increased international competition, the probable loss of some important nematicides, the development of tissue culture-production-based systems and the presence of resistant cultivars, new IPM approaches are drastically needed. They are needed to reduce overall nematicide costs, reduce environmental impact, protect sensitive tissue culture plantlets and reduce overuse of resistant cultivars that could lead to selection of nematode pathotypes that break resistance.

Novel approaches to nematode IPM

What exactly are 'novel approaches' for nematode IPM? First of all one must clarify what one means by novel. Novel is defined by Webster as: 'new and not resembling something formally known or used; original or striking especially in conception or style'.

Developing a novel approach that can be incorporated into IPM in banana production, therefore, is a real challenge to nematologists. It is not an easy goal since nematodes are difficult to control due to biology, physiology and the complexity of the habitat in which they live.

Of course IPM can only be effective if new and effective control techniques for nematode control are developed and/or refined to a degree acceptable to the growers. If effective, they could be incorporated into new nematode management practices in banana production systems at all economic levels. In commercial production systems, such approaches will probably be accepted more readily than at resource-limited and subsistence production levels where they will probably be incorporated as 'spin-offs' over time, due to inaccessibility and/or cost-related limiting factors.

It is important to realize that development of novel approaches has been delayed or restricted by the existence of effective nematicides. Their presence has reduced the need for study of alternative approaches as well as reduced funding for research to find new avenues for control of plant parasitic nematodes in banana production.

Very important is the fact that nematode IPM is presently in a state of transition around the world. For example, there is a strong movement to reduce the worldwide use of pesticides in banana production, both for economical and environmental reasons. Therefore, large banana producers need effective alternatives to maintain economic levels of production. In addition, resource-limited and subsistence growers are confronted with new technologies, e.g. tissue culture planting and resistant cultivars. Both require them to accept in their low-input systems new innovative approaches which are totally 'foreign' and difficult to accept.

There is a move to develop shorter cycle banana plantations in large commercial production units, using tissue culture plantlets after break crops i.e. maize, sorghum, pineapple etc. There are new developments in nematicide formulations that will reduce risk, and there is a general tendency to do more monitoring of fields before treatment to increase precision and maximize yield.

Many research projects being presented at this meeting are novel approaches and others greatly improve on already existing and outmoded nematode control techniques. Significant progress has been made in the following areas: sequential rotation, habitat management, antagonistic and non-host crops, resistant/tolerant cultivars, hot water and solarization of corms, mulching, plant nutrition and tissue culture production systems. Still required is training to ensure integration and acceptance of these individual components into working IPM systems for small-scale growers. Here is where extension and 'Farmer Field Schools' will need to come into action.

Biological System Management

Our strategy in Bonn is based on the premise that nematicides will not always be available and other alternatives techniques, based on biological control, could be used for effective nematode IPM. The fact that tissue culture plantlets are highly susceptible to nematode attack in the first months in the field underscores the need for alternatives to nematicides, especially for the resource-limited and subsistence size growers.

To accomplish this goal a better understanding of how nematodes interact with antagonists and their environment and how this affects overall root health problems is needed. We believe that an understanding of these interrelationships can lead to effective development of novel nematode control technologies for incorporation into IPM type systems based on a system we call Biological System Management (Sikora 1997; see box below).

Biological System Management

Plant health management based on understanding the epidemiology of major pests and diseases in a specific cropping system and integration of this knowledge with plant resistance, biological control and manipulation of pest/disease developmental biology.

One biological control approach that we have developed to incorporate into BSM systems is an attempt to find novel approaches to nematode control based on the isolation of biological control agents growing both on the surface as well as inside the root tissue. These microorganisms which are part of the naturally occurring antagonistic potential in agroecosystems are tested for biocontrol activity and then reintroduced on or into healthy plant tissue prior to planting. This is a process we have called biological enhancement of planting material.

Biological enhancement of planting material

Biological enhancement is seen as a targeted, environmentally safe and economically feasible approach to controlling plant parasitic nematodes that are obligate parasites and totally dependent on healthy root tissue for survival. The incorporation of this biological control component into BSM systems could reduce dependency on nematicides in the first crop and may have more persistent effects over time.

A number of organisms are being examined by our team of scientists and graduate students for biological control of nematodes, including arbuscular mycorrhizae, rhizosphere-competent fungi, rhizobacteria and mutualistic fungal and bacterial endophytes. To be acceptable for use in biological control purposes, however, they must meet many of the criteria set by industry for commercial use (See table 2 page 133).

Some of the characteristics often required by commercial companies for the development of a biocontrol agent are: 1) high level of antagonistic activity; 2) low inoculum level; 3) ease of production; 4) simple formulation techniques; 5) good storage life; 6) compatibility with other pesticides; 7) high level of environmental and human safety and 8) low cost factor.

Our research programme is designed to find new antagonists for incorporation into nematode management programmes that fit what we call 'outside-in' and 'inside-out' approaches (Sikora 1997). In this approach, a number of antagonists come into question as possible agents for developing control strategies: 1) plant health/growth promoting rhizobacteria; 2) rhizosphere and soilborne fungal pathogens of nematodes; 3) mutualistic fungal endophytes; 4) endophytic bacteria and 5) arbuscular mycorrhizal fungi.

The biology of the root-lesion nematodes affecting banana and plantain played a major role in determining which of these organisms should take priority in developing a biological control strategy for banana. Some of the questions we ask are: 1) presence of both organisms in same niche e.g. root tissue or soil; 2) limited to either/or: soil, rhizosphere, roots, suckers or corm tissue; 3) developmental stages and eggs limited to one ecological niche; 4) lack of resistant resting stages e.g cysts or egg masses in the bulk soil and 5) ease in bringing antagonist to nematode for effective control.

Mutualistic fungal endophytes were considered a prime candidate for the development of a novel approach to nematode control on banana, because 1) both organisms are simultaneously present in cortex; 2) control activity of these fungi toward insects and nematodes is known in other plants; 3) they can be produced in fermentors; 4) they are potentially quick and extensive colonizers of the root and possibly corm and suckers; 5) targeted application to

tissue culture plantlets, corms or bits is possible; 6) easy to apply to tissue culture plantlets and suckers and 7) moderate cost factor due to low level of inoculum needed.

The methodology used in our work has been published in detail elsewhere and is given here in abbreviated form as a series of Figures 1-3.

Isolation

Fungi are isolated at random from healthy tissue using pre-determined criteria considered important for biocontrol and detection of effective isolates (Fig. 1). These fungi are placed in pure culture and identified to genus. At this stage it is still not known whether or not these fungi have the ability to grow endophytically in the root tissue of banana. Many fungi found in the root enter the tissue through wounds in the epidermis. Others can be weak pathogens that colonize stressed tissue or are dormant in that area. Mycorrhizal fungi have not been added to the test due to difficulty in producing large amounts of inoculum and due to slow growth in the root system of most plants.

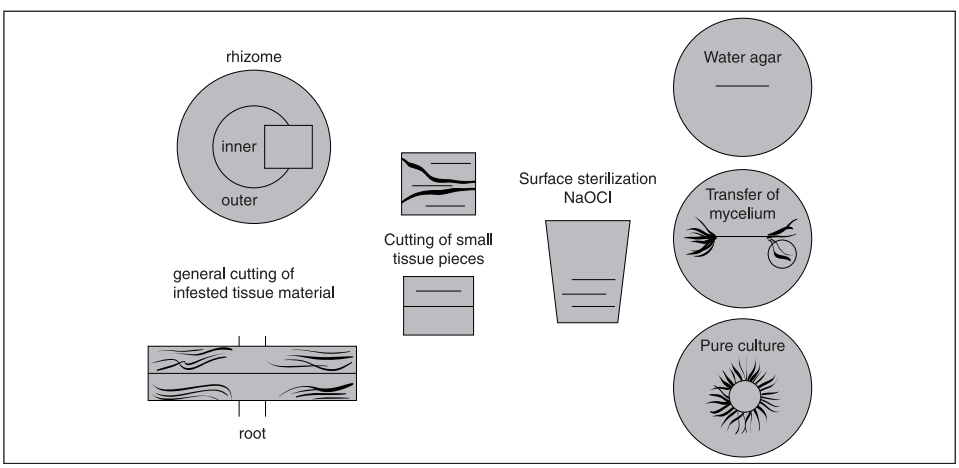

Figure 1. Isolation of endophytic fungi from banana tissue.

Bioassay

In vitro and *in vivo* screening techniques have been designed to test endophytic fungi isolated from healthy plant tissue for nematode biocontrol activity. These biotests have been designed to make early decisions on activity and/or to elucidate specific modes of action that help in making decisions on further testing requirements. Inoculum production varies with fungal isolate and requires initial study. In general the fungi are produced either in solid state or liquid culture to obtain sufficient inoculum for preliminary bioassays.

In vitro laboratory tests conducted on fungi growing in Petri dishes are used to detect initial biocontrol activity by determining the presence of toxic metabolites to the target nematode. These tests were used too because of the labour and time involved in producing tissue culture plantlets. The relevance of this data in detecting isolates with potential under field conditions is of course questionable.

in vivo greenhouse tests are used to simulate field conditions. They are usually conducted in non-sterilized soil with nematodes added at predetermined inoculum levels to banana tissue culture plantlets, pre-colonized with the test fungus, for biological control activity. Using non-sterilized soil helps simulate to a small degree field conditions.

Endophytic activity

The term endophyte should not be seen as a new biological entity. The word endophyte simply describes fungi that prefer to grow inside plant tissue. Such fungi can be mutualistic, commensal, weak or aggressive plant pathogens. At the same time they can grow either as obligate endophytes, e.g. arbuscular mycorrhizal fungi, or as saprophytic fungi, e.g. species of Acremonium.

Fungi that have been shown to reduce nematode population densities in the root tissue or have other toxic characteristics in laboratory *in vitro* tests are always evaluated for their ability to grow endophytically inside the root system (Figure 2). Re-isolation of the inoculated antagonistic fungus from various segments of the root system after surface sterilization as compared to fungi present in non-inoculated controls is used as an initial indication that the fungus has the ability to effectively colonize the tissue of the plantlets. Speed and extent of colonization is also examined.

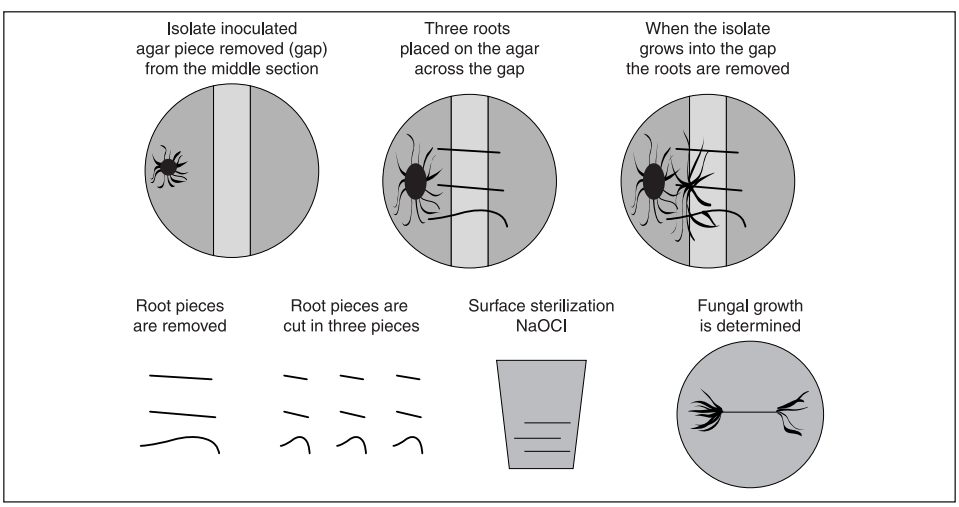

Figure 2. *In vitro* screening for endophytic potential of selected isolates.

Field application

When effective isolates have been found field trials are designed. In Figure 3 the concept of using mutualistic fungal endophytes for nematode control is shown. This last step is the most difficult and requires close cooperation with local scientists, government organizations, university teams and even small local industry.

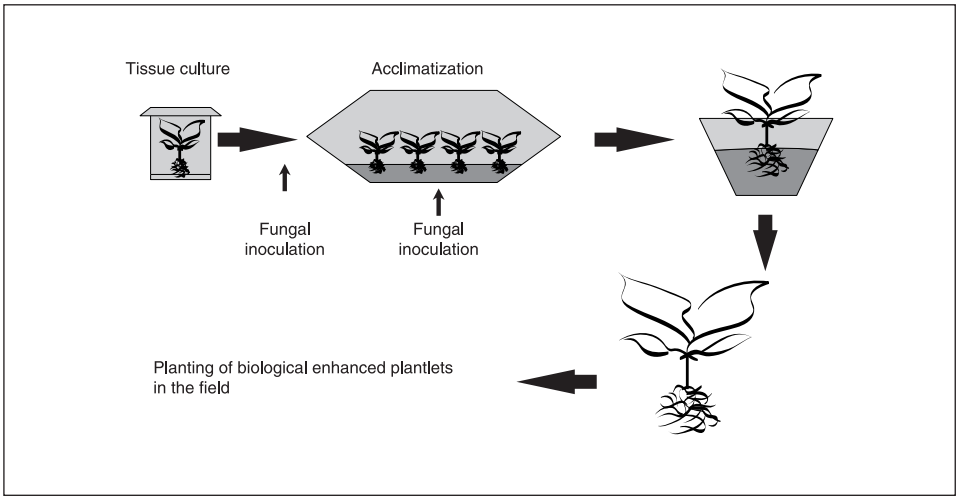

Figure 3. Mutualistic fungal endophytes. Theoretical application system on banana tissue culture plantlets.

Past - Present - Future

The highlights of the work conducted in Bonn and with collaborators outside of Germany are listed below (Table 2). The table lists research dealing with the importance of mutualistic fungal endophytes of banana on the biological control of lesion nematodes of banana, as well as findings related to other pest problems.

Table 2. Summary of results on the biological control of root-lesion nematodes with fungi growing endophytically in banana root and corm tissue with literature citations.

Research results	Literature citation
Toxic metabolites tested on *R. similis*	Amin and Sikora 1993
Endophytic fungi from Indonesia, *in vitro* and *in vivo* effects on *R. similis*	Amin 1994
Secondary metabolites and mortality of *R. similis in vitro*	Schuster *et al.* 1995b
Effects against *Cosmopolites sordidus*	Griesbach *et al.* 1996, 1999
Endophyte theory and practice	Sikora *et al.* 1999
Endophyte tissue culture root colonization activity	Reissinger 1995, Reissinger and Schuster 1995, Detert 1996
Lack of activity toward Panama Wilt	Pocasangre *et al.* 1998
Side-effects on other crops	Epie (in preparation)
Central American endophytes and effects on *R. similis* in greenhouse	Pocasangre *et al.* 1999, Pocasangre in preparation
Field efficacy toward nematodes	Niere *et al.*, this volume

The results obtained with mutualistic fungal endophytes of banana still have a short history. Initial studies were targeted at isolating large numbers of fungi from local banana cultivars in Indonesia (Amin 1994). A number of endophytic fungi found in Indonesia showed strong biological control activity toward *R. similis* in greenhouse tests (Amin 1994). These isolates were also tested in bioassays on agar for the presence of toxic metabolites (Amin and Sikora 1993) in an attempt to shorten the time needed to detect effective isolates when compared to greenhouse tests (Schuster *et al.* 1995). It should be noted that toxic metabolites were commonly found and are of interest as a source of natural products for industry.

These initial studies led to further investigations and survey work in 1996 in Uganda on East African highland banana in cooperation with IITA (Schuster, Sikora and Speijer, unpublished). Isolates of mutualistic endophytes were found that effectively controlled *R. similis*. These isolates were initially found in healthy root as well as central corm tissue of these local cultivars. These isolates were identified and have been re-tested for nematode control in both *in vitro* tests for toxins as well as *in vivo* tests on tissue culture plantlets.

Research was carried out on the ability of these fungi to recolonize the roots of tissue culture plantlets (Reissinger 1995, Detert 1996). Colonization varied greatly with isolate and ranged from low to high. Some isolates colonized a large proportion of the root system very effectively and in a short amount of time. This characteristic along with high spore production during fermentation are important in selecting isolates for further in-depth field research.

Tests also were conducted on possible pathogenic effects of the isolates on other crops existing in banana rotations (Epie, in preparation). This information is required due to the fact that many of the endophytically active isolates exhibiting biological control activity belonged to the genus *Fusarium*. No pathogenic effects on banana nor on other crops typically found intercropped in banana have been detected, even at very high inoculum levels.

More recently, extensive survey work was conducted to find effective endophytes in commercial banana cultivars in Central America. Strains have been isolated from a number of cultivars that produced high levels of biological control of *R. similis* in greenhouse tests (Pocasangre *et al.* 1999). The nematode population was reduced drastically, both in the roots and in the soil, of tissue culture plantlets pre-inoculated with select endophytes. High levels of root colonization were also detected.

Broad spectrum activity of these endophytes has been demonstrated in tests with the banana weevil borer *Cosmopolites sordidus* (Griesbach *et al.* 1997, 1999). Eggs and larvae are attacked by some isolates that control *R. similis*. Attempts to use endophytes to control Panama Wilt were not successful in our initial tests (Pocasangre *et al.* 1998).

Research is now being conducted in cooperation with IITA in Uganda on field efficacy towards nematodes and weevils. The results of some of these tests will be presented at this meeting (Niere *et al.*, this volume[2]). It should be noted that the size of the field trials is limited to a small number of isolates, many only tested to date in greenhouse

[2] Niere B.I., P.R. Speijer, C.S. Gold & R.A. Sikora. Fungal endophytes from bananas for the biocontrol of *Radopholus similis.*

trials. More extensive testing systems and collaboration is needed so that effective isolates can be studied under field conditions for a particular country. Future cooperation between research institutions is an absolute necessity.

Molecular markers are being examined to help us track the endophytes in the root system. New strains are being isolated and tested for activity. Research is also being conducted on genetic characteristics of the fungal isolates. Studies on vegetative compatibility and the genetics of effective isolates are being conducted in Bonn and Berlin, Germany with support from colleagues in Gainesville, Florida.

Conclusions

The novel approach described here is being developed for incorporation into nematode IPM targeted at enhancing clean planting material to ward off nematode attack in the first crop cycle. The treatment of pared and hot water-treated suckers or bits, as well as long-term effects in later crop cycles needs examination. The biological enhancement strategy is not seen as a panacea or as an alternative to resistance or nematicides. Our team's results indicate that we may be able to reduce initial damage to the first crop which could lead to the development of a stronger mat. Studies on antagonistic behaviour within the root and corm as well as in the suckers are needed. Mutualistic endophytes could be used to protect young tissue culture-produced plantlets in the early stages of plant growth where nematicides are not available, not desirable or are too costly. They could be an alternative for resource-limited and subsistence level growers in Africa. Another area where they could be of use is to biologically enhance nematode-resistant planting material which seems to be intolerant to nematode infection in early growth stages. This would be an ecologically and economically interesting alternative for resource-limited and subsistence production systems.

Although the exact cost of production and application of an endophyte is still unknown, we expect the initial cost to be below that of commonly used nematicides. Only small amounts of inoculum are needed for application to the substrate used for transplant production. This would mean that the approach described here would be of interest to large- and medium-scale commercial production systems. Should tissue culture become a standard practice in areas where growers have limited resources, biological enhancement could become a viable alternative, especially if costs are below that of nematicides.

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Session 2C
Review of IPM research activities

Pathology

Review of disease distribution and pest status in Africa

W.K. Tushemereirwe[1] and M. Bagabe[2]

Introduction

Bananas are of great socioeconomic importance in moist tropical and subtropical Africa. Their all year-round fruit production ensures continuous supply of food and income to the farmer, making them a major food security crop in the region. Compared to other staples, bananas are the most economical source of carbohydrates in terms of cost per hectare, per ton and per calorie (Swennen 1984) and among the major sources of potassium, calcium and phosphorous (INIBAP 1986). They yield diverse goods from sweet fruits to staple starches as well as numerous useful secondary products, such as fibres for handicraft and wrappers. On steep slopes, they control soil erosion and conserve soil fertility. In highly populated and dry regions of Africa or semi-urban areas, banana peels and pseudostems serve as animal feeds (INIBAP 1986). In turn, these animals provide manure which is used to improve soil fertility. However, banana productivity has failed to keep pace with increasing food demand despite the steady increase in banana acreage over the past 30 years. The decline in yield, attributed to declining soil fertility, pests, diseases and socioeconomic problems, has aggravated the food deficit situation.

Diseases constitute one of the most important production constraints. The major diseases limiting banana productivity in Africa are: Panama disease (Fusarium wilt), black Sigatoka, leaf speckle, banana bunchy top virus and banana streak virus diseases. This paper reviews the distribution and pest status of these diseases in Africa and highlights key information gaps.

Panama disease (Fusarium wilt)

Distribution

The disease caused by *Fusarium oxysporum* f.sp. *cubense* (FOC) is mainly transmitted through infected planting materials. It was first recorded in Australia in 1874 but

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initial extensive studies were made by Brandes in the late 1910s (Jeger *et al.* 1995). In subsequent years, the disease was recorded in Hawai, South America, Asia and West Africa. By 1955, the disease had been recorded in most East and Central African countries (Stover 1962). The disease appears to have been present in most of these areas for quite sometime before recognition but was most likely introduced on planting materials. The disease is now widespread in Africa, and virtually occurs wherever susceptible cultivars are grown.

Three races of the pathogen have been recorded in Africa. Race 1 of the pathogen (as indicated by Gros Michel attack) is the most abundant though occasionally race 2 (indicated by Bluggoe attack) is found in isolated pockets. Race 4 of the pathogen has been recorded only in South Africa and Canary Islands. In West Africa the disease is less important because plantains, which are the dominant varieties, are resistant. However, it is likely that the pathogen may be present in spots where susceptible clones were once grown.

Studies on variability of the pathogen using vegetative compatibility testing (ability to unite and form heterokaryons) have recently been initiated. Such studies shed light on how the pathogen population changes and new races evolve. According to these studies, the pathogen populations in Africa have been assigned to the VCGs as indicated in Table 1 but the sampling has not yet covered the whole continent.

Table 1. Presence of populations (VCGs) of *Fusarium oxysporum* f.sp. *cubense* in African countries.

Country	Vegetative compatibility groups (VCG)	Source
Burundi	0124	Ploetz 1990
	0124/0125	Ploetz *et al.* 1994.
DR Congo	0125	Ploetz 1990
Kenya	01212, 0124, 0125, 0128, 01220	Kung'u *et al.* 1997.
Malawi	0124/0125	Koenig *et al.* 1997
	0124, 01214	Ploetz *et al.* 1992
Rwanda	0124	Ploetz *et al.* 1994
	0124/0125	
South Africa	0120	Ploetz 1990
Tanzania	0124	Ploetz 1990
	01212	
Uganda	01212, 01222, 0124,	Kangire 1998
	0124/0125	Ploetz 1990
	0125	Ploetz *et al.* 1994
Comoros Islands	0128	Ploetz 1990
Canary Islands	0120	Ploetz 1990

Another key gap that requires urgent attention is linking these populations to pathogenic variability. It is not clear if the identified populations differ in pathogenicity. It is important to establish the different pathogenicity groups so that screening germplasm for resistance could target all the pathotypes.

Pest status

The importance of the disease is influenced by the cultivars in use. East African Highland bananas (AAA), plantains (AAB), Cavendish and several recently developed hybrids are resistant to race 1 and 2 of the disease. Gros Michel (AAA), Apple banana (AB), Pisang awak (ABB) and several others are susceptible to the two races. All banana clones except a few recently developed hybrids (eg. FHIA-01) are susceptible to race 4 of the pathogen.

Where resistant cultivars are in use, the disease is considered of minor importance. However, where susceptible cultivars are in use complete decimation of fields (100% loss) has been reported. Farmers have turned to new cultivars or new crops in such areas. Where farmers have continued using the susceptible clones, the main reason appears to be the absence of a suitable replacement. For instance Apple banana is used to supply niche markets in Europe and fetches good money to farmers. Preventing spread of the disease as production of disease-susceptible bananas expands is a challenge in East and Central African countries.

Virgin soils appear to be free of the pathogen. Production of susceptible clones such as Gros Michel and Apple banana is still possible in such areas, provided clean planting materials are used.

Use of host plant resistance or clean planting materials are the only control measures currently being tested in various countries.

Black Sigatoka

Distribution

The disease, caused by *Mycosphaerella fijiensis*, is windborne. It was first described in Fiji in the early 1960s (Rhodes 1964) and is considered to have originated in Papua New Guinea/Solomon Islands region (Stover 1978). Subsequently, the disease spread to other banana-growing areas across the globe.

In Africa, the disease was first reported in Gabon in 1978 (Frossard 1980). It was later reported in Cameroon in 1980, Nigeria in 1986 (Mourichon and Fullerton 1990), Burundi and Rwanda in 1986, Tanzania in 1987 (Dabek and Waller 1990), and Uganda in 1989 (Tushemereirwe and Waller 1993).

Recent studies in Uganda suggested a mean minimum temperature threshold of 14-150C below which the disease fails to establish in the field (Tushemereirwe 1996). This suggests that the high elevation areas (above 1500 masl) in countries where the disease has been reported are likely to be free of the disease. Similarly the cool countries of southern Africa (high latitude countries) are likely to remain free of the disease.

Recombination of genes leading to new populations occurs easily in the black Sigatoka pathogen because it has a perfect stage. Consequently the pathogen is genetically highly diverse (Buddenhagen 1987). This diversity is reported to be highest in the South East Asia (centre of origin of the pathogen) and lowest in Africa where the pathogen

arrived recently (INIBAP 1998). There is some evidence that some of the populations are pathogenically different (Fullerton and Olsen 1995) but the pathotypes in Africa and their distributions have not been established.

Pest status

Worldwide, black Sigatoka is currently considered the most important disease of bananas and plantains (Jeger *et al.* 1995). Although the disease does not usually kill the plant, it causes heavy defoliation which severely suppresses finger filling, leading to reduced bunch weight. The East African Highland bananas (dominant in East and Central Africa) and plantains (dominant in West Africa) are all susceptible to the disease. This further increases the importance of the disease in Africa. A yield loss trial conducted in a low elevation plantain system of West Africa (Nigeria) revealed a loss of 39% in bunch weight (Mobambo *et al.* 1993).

A similar trial conducted in the mid-elevation banana systems of eastern Africa (Uganda) revealed a loss of 37% in bunch weight in the first ratoon (Tushemereirwe 1996). The two sites of the trials represented ecological extremes for the disease and it is likely that all areas in the same ecological conditions or between the two extremes would suffer similar losses.

The Ugandan study was situated at Kawanda, at 1250 masl. However, the disease can still be observed up to 1450 masl. It is not clear how much loss the disease causes in the areas where the disease tails off. For instance in the Bukoba region of Tanzania (which is above 1250 masl) the disease is dismissed as minor in importance though yield loss studies to clarify the issue have not been undertaken.

Control measures: use of host plant resistance is identified as the most suitable technology, but for some cultivars such as Highland bananas, resistant hybrids are not yet generated. Other measures being tried include the use of plant vigour to reduce disease impact and removing diseased leaves to reduce inoculum.

Banana bunchy top virus disease

For a long time this is the only virus disease that was considered important on bananas (Jeger *et al.* 1995). The disease was first reported in Fiji in 1889 (Jeger *et al.* 1995). It has since been confirmed that the disease is present in several Asian, Pacific islands and African countries. In Africa the disease has been reported in Egypt, Congo, Rwanda, Burundi and Malawi.

The virus is disseminated in infected planting materials. Within the field, it is also transmitted by the banana aphid (*Pentalonia nigronervosa*).

Pest status

In Africa, no study to establish yield loss due to the disease is reported. However, severely infected plants of highly susceptible cultivars fail to produce bunches (Jeger *et al.* 1995). The severity of infection depends on virulence of the virus strain, susceptibility of

the cultivar, and stage of infection. Tolerant cultivars and those recently infected or with an avirulent strain will have mild infection and will give some yield.

Key information gaps

a) The disease appears restricted to the Rift Valley areas/a lowland stretching in central and southern Africa. Factors restricting distribution of the disease should be established.
b) There is need to quantify the losses caused by this disease. A yield loss study carried through several cycles to account for the cumulative effect of the disease would yield useful information.
c) There is need to establish the pathogen strains and their distribution so that future germplasm screening studies can target them.

No resistant cultivar has been identified. However, varietal differences in susceptibility have been reported (Stover 1972).

Control measures in use include:

- Prevention through quarantine: there is need to prevent the virus from entering free countries or areas where the distribution is still limited to a few zones.
- Use of virus-free planting materials: this can be achieved by starting clean mother gardens using virus-indexed plants. The alternative is to identify clean plantations from which suckers should then be obtained for more plantings.
- Roguing: this involves removing (and where possible, burning) all the infected plants. This may keep the disease incidence low if done regularly.
- Varietal resistance: the search for tolerant cultivars should be intensified. If found, these would be used as replacements for the highly susceptible clones.

Banana streak virus disease (BSV)

The disease is believed to be worldwide in distribution (Lockhart and Olszewski 1993). It was first described on bananas in Côte d'Ivoire (Lassoudière 1974) but the causal organism was not identified until 1985 (Lockhart 1986).

Since then the disease has been reported in Asia, Central America and other African countries: Morocco, Nigeria, Rwanda, South Africa, Tanzania (Lockhart and Jones 1993), Uganda (Tushemereirwe *et al.* 1996), Malawi (Vuylsteke and Lockhart 1997), Guinea, Ghana, Benin, Cameroon, Kenya and Madagascar (Jones and Lockhart 1994, Diekmann and Putter 1996).

It appears that BSV has been widely distributed for many years but has always been confused with other viral diseases, particularly cucumber mosaic virus. This is supported by the fact that after the disease was identified, it was recorded in most banana-growing areas in a very short time. The origin of the disease is not known (Frison and Sharrock 1998).

Recent molecular studies have revealed that there are three forms of BSV:

a) encapsidated episomal form; this is the ordinary form of the virus with the DNA viral genome encapsidated in a protein coat;
b) unencapsidated episomal form; this is thought to be a form characterized by periodic appearance and disappearance of host symptoms;
c) integrated forms; recent conclusions suggest that there are some forms of BSV which are integrated in the banana genome. These appear to be activated by certain stresses such as tissue culture to give rise to the infectious episomal forms. BSV reported in previously indexed clones but subsequently multiplied by tissue culture, mostly likely belong to this form.

Information on the relative importance of the three forms is still lacking. New methods for detection of BSV are being developed but most national programmes have not yet acquired the capacity to use them. This has severely hampered generation of information on BSV distribution within the countries. Virus strains are believed to exist but there is no information on them yet.

Pest status

BSV appears to have been around for many years but it has never caused widespread epidemics (Frison and Sharrock 1998). However, the disease has caused significant yield loss in localized places. For instance, some fields were knocked out of production in Rakai district, Uganda (Tushemereirwe 1996).

There is no published information on yield loss due to the disease and its economic impact. However, loss for individual plants may go up to 100% depending on susceptibility of the clone, severity of the disease strain and age of infection.

The pest status of the disease appears to vary with clones though none has been found resistant. For instance in Uganda, Pisang awak (ABB) exhibited only mild infections in severely infected mixed clones at "hot-spot" locations.

Other diseases

Fungal diseases

Yellow Sigatoka

This is an airborne disease caused by *Mycosphaerella musicola*. It was first observed in Java in 1902 (Stover 1962b) and thereafter it was reported in Asia, Africa and the Americas. In Africa the disease was first reported in Uganda in 1938 and was later quickly noted in Tanzania in 1939, Cameroon 1941 and thereafter in several other African countries. The disease is now reported present in all tropical Africa. The incidence of the disease is highest in high elevation systems where black Sigatoka is absent.

Though the disease was reported as important in the Americas and Caribbeans even before arrival of black Sigatoka (Stover 1972) there is no data on its importance in Afri-

ca. It has been reported that wherever black Sigatoka has arrived, it has completely or partially displaced yellow Sigatoka (Mourichon and Fullerton 1990) within two years (Jeger *et al.* 1995) though some doubts have been expressed about this phenomenon (Jones 1990). In Uganda, the observation appears to conform to the phenomenon for susceptible cultivars but not for resistant cultivars. Yellow Sigatoka is found on the resistant Kayinja (Pisang awak = ABB) at all elevations but rarely on the infected susceptible clones (Tushemereirwe 1996). The disease is most pronounced in high elevation systems where black Sigatoka has not established. However, its pest status in such systems is yet to be determined.

Leaf speckle

This disease is caused by a windborne fungal pathogen, *Periconiella sapientumicola*.

It is reported present in almost all banana growing areas. According to Stover (1972) leaf speckle has always been considered a minor disease that affects older, mature leaves of bananas growing in humid areas. As a result, there has been little research interest in the disease, leading to absence of key information. Highland bananas appear to be susceptible to the disease (Tushemereirwe 1996). The disease heavily defoliates the bananas even in the absence of Sigatoka leaf spots.

Unfortunately, it has not been possible to determine pest status of the pathogen in the absence of other leaf spots. Such a study should be possible in an area where black Sigatoka is absent on highland bananas. In Uganda such areas have extremely low incidence of yellow Sigatoka. About 95% of defoliation is due to leaf speckle.

Matooke wilt

This disease has been reported only in Uganda where it is traced back to about 1955. Highland bananas (AAA), known to be resistant to Fusarium wilt, were found to succumb to a wilt disease in western Uganda in areas above 1330 masl (Tushemereirwe and Ploetz 1993). Initial studies had attributed the disease to *Fusarium oxysporum* f.sp. *cubense* (Ploetz *et al.* 1994) but a recent study appears to suggest this may not be the causal agent (Kangire 1998). The disease is virtually restricted to areas around the homesteads, garbage dumping sites and animal kraals. It is not clear what the impact of the disease will have as fields become less fertile and more organic materials are used. The disease will require more monitoring on top of identifying its cause.

Other minor diseases

Other minor diseases include bacterial pseudostem rot (*Pseudomonas* spp.) and bacterial corm rot (*Erwinia* sp.). The fungal diseases include cordan leaf spot (*Cordana musae*), canana leaf freckle (*Guignardia musae, Mycosphaerella musae*), deightoniella leaf spot (*Deightoniella forulosa*), banana rust (*Uromyces musae*), fruit freckle (*Phyllostictina musarum*), cigar end rot diseases (*Stachylidium theobrome, Trachysphaera fructigena, Gloeosporum musarum*), crown rot (assortment of pathogens), anthracnose (*Colletotrichum musae*) (Waller *et al.* 1991, Tushemereirwe 1996). The viral diseases

include banana mosaic (cucumber mosaic cucumovirus), banana die-back (banana die-back virus reported in Nigeria) (Diekmann and Putter 1996).

Conclusion

In conclusion, it is noted that for all the important pathogens of bananas, there is lack of information on pathogenic strains and their distribution in Africa. This information is a prerequisite for effective deployment of host plant resistance as a disease control measure. Resistant clones for use as replacements for the susceptible clones should be tested against all the strains or should not be used in areas with a strain to which they succumb. Furthermore, it is noted that there are several diseases whose economic impact is not clear. These include banana bunchy top virus and banana streak virus diseases which are reportedly important in some areas but minor in others, and banana leaf speckle of highland clones and matooke wilt which have for some time been regarded as minor but appear to be severely damaging in some locations. There is need for hard data to clarify the importance of these diseases.

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Cultural controls and habitat management in the integrated management of banana leaf diseases

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Introduction: leaf spot diseases in East Africa

Highland bananas (AAA-EA) in Uganda have been known for many years to be attacked by a complex of leaf spot pathogens, principally *Mycosphaerella musicola* and *Periconiella sapientumicola* (*Cladosporium musae*). However, the effects of these pathogens have previously been thought negligible and more research attention has been focused on the more tangible effects of weevils and nematodes. However, the recent arrival and rapid spread of black Sigatoka/black leaf streak (*Mycosphaerella fijiensis*) through the countries of sub-Saharan Africa has posed a major threat to production and raised awareness of the risks from leaf spot diseases. The prolific sporulation of *M. fijiensis* and airborne nature of the spores provide a means of rapid spread between farms and the disease can cause complete crop failure if no control measures are used. From surveys in Uganda, all highland banana cultivars appear susceptible to the disease.

Banana is a staple food for over 7 million people in Uganda, including about two-thirds of the urban population. Uganda produces around 9 million tonnes of the crop annually, making it the world's biggest producer and consumer of banana. However, in recent decades, highland banana production has declined in traditional areas and has gradually shifted westwards, with concomitantly increased transport and storage costs in accessing the main markets in Kampala and other large towns. The reasons for this decline are complex, including pests and diseases (Sigatoka and '*Periconiella*' leaf spots, Panama wilt, weevils and nematodes), soil nutrient deficiencies and a range of socioeconomic constraints and postharvest handling problems. As a result of concerns regarding the threat this decline posed to staple foods, an extensive coordinated survey and research effort has been underway in Uganda since 1990 to address this complex problem.

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Interacting agronomic factors

In considering the cultural management of banana diseases, it is necessary to examine the whole range of agronomic factors that may influence disease. In Uganda, declining soil fertility is considered a primary production constraint for highland banana (Rubahaiyo 1992), as is the case also in Burundi, Rwanda and Tanzania. Soil qualities vary widely on even a local basis, so it is difficult to determine the real extent and speed of the decline. However, in a participatory rural appraisal survey (PRA) of Ugandan banana farmers carried out in 1991 (Rubahaiyo 1992), most farmers (18 out of 25 villages surveyed) reported declining soil fertility and concomitant declines in productivity. Farm size has shrunk as population pressure increases and this decline was largely attributable to continuous cultivation of the same land with banana. Imbalanced nutrition causing excessive vegetative growth rather than fruit production was also reported in some recently cleared forest soils. In Iganga, yield decline had been attributed to a combination of weevils and declining soil fertility, but yields of cassava planted to replace banana also declined after only a single cycle of production.

In areas such as Hoima, where land is still available and farmers are able to practice shifting cultivation, productivity and soil fertility levels appear to remain stable over time. However, even in these areas, smaller farmers who did not have sufficient land for shifting rotation still reported yield declines. By contrast, richer farmers in areas of depleted soils such as Kapchorwa, were still able to practice rotations or fallowing on a systematic basis and their soils remained productive. Obviously, the socioeconomic status of the farmer and pressures on land usage will be key factors in determining productivity declines and the farmers recognize these as the cause of the problem. Farmers reported soil fertility to be further reduced where annual crops were harvested under banana in mixed systems, thus removing more nutrients from the field. The capacity of farmers to redress this decline is constrained by a lack of financial resources to purchase soil amendments and other inputs, including both inorganic and organic fertilizers, and to hire labour to apply these. Fallows are often only used by smaller farmers only where the soils have become so exhausted that they could not sustain production of any crop.

Soil acidity is a further problem recognized by many farmers, particularly after excessive land use. Unlike depleted soils, this problem is not resolved by use of fallow periods. The problem is recognized as poor production with little yield, stunting, leaf yellowing from the edge inwards and a failure to flower. Farmers were sometimes unable to distinguish the effects of acid soils from those of foliar pathogens.

Use of mulches varies widely between farmers (Bekunda and Woomer 1996); the main types used are banana trash, grasses, coffee husks and residues from annual crops. However, many farmers had little interest in mulching other than leaving trash haphazardly on the ground and composts were used by only around 16% of farmers. Nonetheless, there was a clear relationship between use of mulches and reported yields. Greater use of such organic mulches is often constrained by problems in transporting such bulky materials to the field and the extent to which mulches are used largely

reflects the value placed on banana production in a particular area. Where banana productivity and importance had decreased, farmers had switched their attentions to other crops and the crop management inputs devoted to banana had correspondingly further declined. In such areas, traditional highland bananas (AAA-EA) have often been replaced by the introduced 'beer' bananas, which generally require lower levels of management inputs. Other pests, particularly weevils (*Cosmopolites sordidus*) and nematodes (*Radopholus similis* and *Pratylenchus goodeyi*) are also significant production constraints in Uganda and these have also been considered key causes of the decline of banana production in traditional areas of central Uganda.

In summary, under current management practices, decreasing soil fertility and soil erosion pose serious constraints to banana production in much of Uganda. Following the PRA, a two-year diagnostic survey was undertaken across a series of representative sites in Uganda, to elucidate *inter alia* the nature of the interaction between environmental stress and physiological stress factors and foliar diseases in the country.

Diagnostic survey: interactions between leaf spots and other factors

It was clear from the results of the diagnostic survey that the principal leaf spots of highland banana occurred as a complex in Uganda; where not constrained by temperature severity of black Sigatoka was highest at sites where *Periconiella sapientumicola* (cladosporium) speckle was also most prevalent. The trend was that black Sigatoka caused most damage, followed by *Periconiella*, with yellow Sigatoka the least damaging and largely insignificant. The extent of *Periconiella* damage was a cause for some concern, as this pathogen had not been previously considered to be particularly severe in Uganda or elsewhere and no specific control measures had been developed for this pathogen.

The diagnostic survey also showed a clear relationship between leaf spot severity and various environmental factors. The influence of minimum temperature was most profound; the highland areas of Uganda are generally too cool to allow black Sigatoka to become severe. Only *M. musicola* and *P. sapientumicola* were found in areas where the mean minimum temperature was less than 15°C. These observations accord with the findings of Gauhl (1994) in Costa Rica and with threshold altitudes for infection observed in Cameroon and Central America (Mouliom-Pefoura and Mourichon 1990, Fouré and Lescot 1988).

Principal components analysis (Table 1) established that both major leaf spots increased with increase in root damage and with increasing corm damage, but that leaf spots were reduced with a higher ratio of K:Ca+Mg and by an increase in soil organic matter.

Plant growth was found to be closely correlated with root damage and also with corm damage, both of which reduced pseudostem girth in conjunction with the leaf spots. Soil fertility and plant vigour, as determined by other pests, thus strongly influenced susceptibility to the leaf spot complex, which may in turn influence attack by weevils and nematodes.

Table 1. Regression equations of leaf spot variables on principal components of factors affecting productivity of highland bananas.

Mean position youngest leaf with Sigatoka = 7.1 + 0.4K + 0.3M - 0.5T - 0.4R - 0.3X r2= 0.74***
Mean position youngest leaf with *Periconiella* = 6.8 + 0.3K + 0.3M - 0.4T - 0.4R - 0.3X r2= 0.69***
Number of leaves at flowering = 7.8 + 0.2K + 0.2M - 0.3T - 0.3R - 0.2X r2 = 0.62***

K = ratio Potassium:Calcium+Magnesium
M = organic matter in top soil
T = mean minimum annual temperature
R = ratio of dead:functional roots
X = percentage weevil damage in corm cross section

Similar results were found through surveys of black Sigatoka disease of plantain in Nigeria (Mobambo *et al.* 1994). BLS incidence was greatest where soils had lower levels of major nutrients, were acid and had low levels of organic matter. These authors considered that soil fertility was the dominant factor determining differences in disease severity between the Meander Belts zone and the Coastal Plain Sands of that country. Soil fertility was also considered the critical factor determining differences in disease severity between homestead gardens and field plantations, a difference explained by the greater use of organic matter in homestead gardens.

It is apparent from these results that it is necessary to consider management of leaf spot diseases within the context of integrated management of the banana crop; both agronomic stresses and the internal stresses created by attack from other pests have influenced the plants susceptibility to leaf spot diseases. Furthermore, the reverse mechanism may also occur, whereby heavy leaf spot damage predisposes the plant to attack by weevils and nematodes.

Analysis of the diagnostic survey utilized variables (position of youngest leaf with mature leaf spot lesions and number of photosynthesizing leaves) that were also growth-dependent, so it was not possible to distinguish host growth and yield responses due to the leaf spots from those due to reduced plant growth as a result of the other stresses. More detailed experiments were thus established on station, to study the interactions of physiological (farming system-induced) stress factors with susceptibility to leaf spot diseases, using regularly monitored parameters of rates of disease development and leaf drying that could not be utilized during the field surveys.

Differing levels of agronomic/physiological stresses were created in these experiments by:

a) adding farmyard manure (20 kg/plant) and mulch (grass and plant residues) to provide a supply of nutrients,
b) adding no soil amendments and removing crop trash,
c) additional nutrient stress created by growing a dense millet intercrop and removing crop residues from the field (some form of intercropping is practised by around 2/3 of Ugandan farmers).

The stresses imposed, combined with the effects of the leaf spots, caused a significant reduction in banana plant growth (Table 2). The plant growth and development parameters studied show a marked depression of plant vegetative growth as a result of the effects of nutrient stresses and associated leaf spot prevalence. Well-fertilized plants were taller, with a more rapid rate of leaf emergence and shorter crop cycle than those for which no soil amendments were provided. Stressed plants had lower concentrations of potassium and phosphorus in their leaves and the plants receiving manure and mulch had a higher ratio of K:Ca+Mg than the stressed plants, as was found in the farmers fields where leaf spots were less prevalent.

Table 2. Growth and development of highland banana plants under different levels of farming system-induced stresses and leaf spots (mean values over three successive ratoons, 1993-1995).

Treatment	Mean plant height (cm)	Mean leaf emergence time (days)	Mean time to flowering (days)
Manure/mulch	353.3	12.3	482
No additions	297.6	12.7	519
Millet intercrop	288.4	13.4	517
SED (42 d.f.)	2.9	0.2	12.9

The different agronomic stresses imposed had clear effects on the severity and prevalence of leaf spot diseases (Table 3). The immature candela is the main site of infection by these fungi, which colonize the unhardened tissues. Both the position of the youngest leaf with leaf spots (for both black Sigatoka and *Periconiella*), and the total number of functional leaves (those with some green areas remaining), decreased with increased physiological stress. Taken together, these results indicate that more functional leaves were present on well-fertilized plants than on those where nutrients were less available and that reduced plant vigour and growth were compounded by a loss of photosynthetic area to the foliar diseases.

Table 3. Influence of farming system-induced stresses on impact of leaf spot diseases on highland banana.

Treatment	Youngest leaf with Sigatoka spots	Youngest leaf with *Periconiella* speckle	Number of undried leaves on plant
Manure/mulch	5.1	4.7	8.4
No additions	4.8	4.5	7.6
Millet intercrop	4.3	4.0	6.9
SED (21 d.f.)	0.1	0.1	0.1

The stresses did not influence the time to appearance of mature black Sigatoka lesions in the rainy season, indicating that the physiological processes of colonization and sporulation were unaffected by the treatments under conditions favourable to infection. However, in the dry season the rate of disease development was significantly

faster in the severely stressed treatment (millet intercrop). A similar trend was found with *Periconiella* speckle. This may be due to greater water stress in unmulched plots.

The longevity of leaves (i.e. duration of the period from leaf emergence to leaf drying) was markedly greater in plants receiving nutrient amendments than in those grown under nutrient-deficient systems (Table 4). Thus the combined effect of reduced growth rates and relatively increased leaf spot severity on the leaves of stressed plants resulted in such plants having a lower number of actively photosynthesizing leaves, despite being exposed to the same airborne inoculum as those grown with soil amendments.

Table 4. Leaf area available for photosynthesis in highland bananas over wet and dry seasons in three successive ratoon crops.

Treatment	Days from emergence to total loss of green tissue	No. of functional leaves	Mean leaf length (cm)	Mean leaf width (cm)
Manure/mulch	137.0	7.9	225.5	77.2
No additions	126.1	6.3	171.3	62.4
Millet intercrop	114.2	4.5	95.5	35.4
SED (63 d.f.)	4.3	0.4	9.4	4.9

A combination of leaf spots and the complex of nutrient stresses (and probably moisture stress in unmulched plots) caused a marked reduction in plant growth under conditions similar to many farms in Uganda where soil amendments are not applied. This was also expressed in plant height, rates of leaf emergence and leaf size. Depressed plant height and reduced rate of leaf emergence were also found by Fox *et al.* (1979) in nutrient-stressed Cavendish banana. By suppressing rates of leaf emergence, photosynthesis and hence plant growth would presumably be further reduced. Plants grown with soil amendments thus had more functioning leaves, which were also considerably larger and more widely-spaced than those of plants grown under stress, enabling a closed canopy to be formed, unlike the more open canopy in stressed plants. Effects of treatments on disease could not be attributed to differences in microclimate under the different treatments as the canopies in plants receiving soil amendments were denser than those under stress and so the relative humidity in such canopies was higher than in the stressed plants. Higher relative humidity is normally considered to favour infection processes. In these systems, the tissues of stressed plants were apparently not more susceptible to infection *per se*, yet well-fertilized plants were clearly more tolerant of disease and had a markedly greater yield potential despite infection.

The treatments also affected nutrient availability and uptake. Potassium is the most important mineral element to the banana plant and applying manure and mulch raised the concentration of potassium and phosphorus in the plant tissues and the total amount taken up given the larger size of the plants in such treatments. However, a millet intercrop reduced the amount of nitrogen available to the banana plant. The results of

this experiment confirm the significance of declining soil fertility as one of the causes of banana production decline in Uganda. Successive ratoon crops grown where nutrients were not replenished were progressively less vigorous in this experiment, which would ultimately make fields unproductive, an effect exacerbated by damage to roots and corms by other pests.

Leaf pruning

The influence of leaf spots on fruit yields were determined in a separate experiment that also examined the impact of leaf removal on disease and yields in Ugandan highland bananas. Leaf pruning is a common cultural technique in Uganda, often thought to be used by farmers to avoid bananas toppling over in strong winds as they near maturity. However, the surveys undertaken in Uganda have shown that farmers also undertake the practice to provide mulch, to reduce shading and to clean the plant of senescent and diseased leaves. The highland bananas are normally considered able to be pruned without reduction in yield. However, the arrival of the more aggressive black Sigatoka has changed the basis for this assumption, as a considerably greater leaf area may be lost to disease than was previously the case.

To examine this interaction, plants were pruned to varying extents (>4, 4 or 2 leaves left and either protected by use of triadimenol drenches or left unprotected). Triadimenol controlled all the leaf spot pathogens effectively, while in untreated plots overall leaf damage at flowering was 45% of the photosynthetic leaf area, even in these fertilized plants. *Periconiella* speckle, although considered a minor disease in many countries, was here as damaging to functional leaves as black Sigatoka. The youngest leaf with mature lesions in unprotected plants was at position 5 on the plant, whereas in protected plants the youngest infected leaf was in position 10. The leaf spot complex progressively reduced the number of leaves on unprotected plants, so that by the flowering stage, they had six leaves compared with the ten remaining on protected plants and at harvest had one or no functional leaves left.

Leaf spots also reduced the life span of leaves, leaf drying and senescence in unprotected plants being hastened by about 30 days. Plant height was again depressed by the leaf spot complex, but leaves were produced more frequently in unprotected plants, presumably as a measure to replace lost photosynthetic area. As a result of the increased rate of leaf emergence, the crop cycle was significantly accelerated in unprotected plants, with both flowering time and fruit maturity being hastened although a similar number of fruit were developed. The net effect of less photosynthetic area and a shorter plant maturation period was that the leaf spot complex significantly reduced fruit yield (Table 5). Bunch weight was markedly reduced (by 37%), the yield losses resulting from leaf pruning and the leaf spot complex being mediated through reductions in both finger girth and length.

Table 5. Effect of the leaf spot complex on yield of highland banana.

Plants	Bunch weight (kg)	Fruit per bunch	Fruit length (cm)	Fruit girth (cm)
Protected	27.3	135.8	21.4	15.5
Unprotected	17.1	132.8	19.0	13.7
SED (5 d.f.)	1.3	1.0	1.0	0.2

Leaf pruning did not affect the rate of leaf spot development on an individual leaf or the rate of leaf collapse. However, pruning did cause a highly significant reduction in the yield of protected plants (Table 6). This was particularly apparent in plants protected from leaf spots. Where no fungicides were applied, yields were comparable to treated plants with only 2 leaves remaining. Where pruning further reduced leaf area of unprotected plants, yields were minimal and many fruit would be unmarketable.

Table 6. Effect of leaf pruning at flowering on yield of highland banana.

Number of leaves remaining	Protected plants (kg/bunch)	Unprotected plants (kg/bunch)
>4	27.3	17.1
4	23.4	15.7
2	17.2	14.7

In this study, leaf life was shortened by premature senescence and drying, with a reduction of around 30 days compared with protected plants. This is comparable with the effects of Sigatoka leaf spots on Cavendish bananas reported by Stover (1974). Photosynthetic leaf area is undoubtedly reduced, although the effects of this will be to some extent offset by photosynthetic compensation in surviving leaves and fruit. The results suggest that although leaf spots did not adversely affect fruit development, they did affect fruit growth and yield. By defoliating the flowered plants, leaf spots and cultural pruning progressively remove the assimilate source without prospect of replacement, at a time when the fruits form a powerful assimilate sink.

The data also suggested that leaf spot defoliation enhanced fruit ripening, shortening fruit maturity time. Defoliation accelerates physiological maturity of fruits both in the field and after harvest and the effect increases with severity of defoliation (Meredith 1970, Stover 1972). Premature fruit ripening in the field or in transit to market, because of leaf spots, is a major cause of quality loss and field-ripe bananas cannot be marketed. Fruit from diseased plants also tend to have inferior cooking qualities.

Severe pruning at flowering does not affect tissue susceptibility to infection, but leaf pruning did have a marked effect upon yield, particularly in protected plants. The smaller relative decline in unprotected plants may have been because such fruit were barely filled at all and also suggest that photosynthate that would normally go towards corm development and sustaining young shoots has been diverted towards the fruit, with a net loss in corm quality. Therefore further seasons of leaf pruning and leaf spots may

well have very detrimental effects on plant growth and may predispose corms and roots to attack by other pests such as weevils.

It is concluded that leaf spot defoliation depresses plant growth, but that the effect is checked by more rapid leaf emergence to maintain photosynthesis. However, after flowering, when the plant stops producing new leaves, it becomes overwhelmed by leaf spots with consequent effects on bunch filling.

Stover (1974) and Ramsey *et al.* (1990) reported that when leaf spots appear on leaves younger than the tenth from the shoot they affect fruit physiology and result in losses. By extrapolation from the diagnostic survey data described earlier, it can be estimated that around 60% of Ugandan banana growing areas are liable to yield losses exceeding 30% as a result of the leaf spot complex. The net effect of leaf spots on yield was seen even in well-managed plots, indicating that very many farmers, lacking the means or the information to provide appropriate agronomic inputs, will lose much of their crop in years to come.

Available leaf spot management strategies

The effects of soil fertility on yield and black Sigatoka severity reported here are similar to those reported on plantain in Zaire (Mobambo and Naku 1993) and Nigeria (Mobambo *et al.* 1994), where soil fertility again declined rapidly from the plant crop through to the first ratoon crop. Soil fertility degrades very rapidly under continuous cropping, together with a decline in soil organic matter. Mobambo *et al.* (1996) also found that with the rapid decline in fertility (and presumably also available stored assimilate from the previous crop) into the first ratoon, leaf spot severity increased and yields declined. Yield losses were 33 and 76% in the plant crop and ratoon crop, respectively. BLS is a major constraint to plantain production in central and west Africa, but control strategies are again constrained by the socioeconomic circumstances of most farmers. The phenomenon of rapid yield decline due to loss of soil fertility and organic matter is common in subsistence banana systems (Robinson 1995). Yields in the highland banana systems of East Africa are clearly far below the potential for such types, and improvements in management across a range of factors would be expected to give increased yields, if socioeconomic circumstances can enable this change.

Although they are aware of the necessity of maintaining soil fertility, Ugandan farmers are often unable to undertake even basic measures due to a lack of land or of access to the traditionally-used animal manure and mulches. It is generally considered that earlier farmers had a good understanding of soil conservation practices, but that this information has been lost over time. Soil conservation practices were at one time mandatory in some areas, which would help to explain this finding. Inorganic fertilizers have been little used by Ugandan farmers, due to reasons of cost and lack of information regarding appropriate regimes.

These problems are compounded by a lack of information about soil nutrient deficiencies and their remedy. Without access to soil analyses or knowledge of deficiency symptoms, farmers felt they were not able to address the problem and take

appropriate corrective action. In some cases, environmental stresses become compounded and some farmers reported that nutrient deficiencies first became apparent after a period of prolonged drought.

The two main leaf spot management strategies used by banana farmers in intensive industries elsewhere, fungicide sprays and deployment of resistant material, are at present of limited value in East Africa. Fungicides are expensive and may be beyond the reach of many farmers, without assistance through some form of credit scheme. Other concerns are:

- Availability of product
- Labour availability
- Operator and environmental safety
- Access to equipment
- Farmer awareness of appropriate products, application rates and frequencies.

Such practices should not necessarily be dismissed out of hand. At present, it is probably economically worthwhile to spray many of the bananas produced specifically for market, in order to protect the crop. However, the above concerns need to be addressed through appropriate research and farmer training and a more rational approach to fungicide use before fungicide-based management is considered. Development of integrated management strategies and systems making use of meteorologically-based warning systems rather than calendar-based spraying has been successfully put into place in Cuba and may not be inconceivable in East Africa.

One alternative may be the use of drenches or granulated fungicides; in Brazil, triadimenol at 0.75 g a.i./mat was applied to the root zone during the rainy season to control yellow Sigatoka (*Mycosphaerella musicola*), application being based on a disease development-based schedule (Ventura *et al.* 1994). Triadimenol applied >3 times over the season gave good disease control and resulted in the best bunch weight and number of commercial hands. However, soil application may carry inherent risks of more rapid development of resistance due to sub-optimal concentrations in tissues.

Effective resistance is not as yet available within East African Highland banana germplasm collections. Deployment of more resistant material may therefore ultimately require import of more resistant types such as hybrid plantains, with potential problems of consumer resistance to the different flavours and cooking qualities entailed. However, in West Africa, some black Sigatoka-resistant hybrids developed by IITA, including the new selections TMPx7152-2 and TMPx7356-1 have shown similar yields to Obino l'Ewai under low external inputs and so may be of value in rehabilitating the industry in areas of depleted soils. Similarly the black Sigatoka-resistant hybrid cooking bananas developed from cv. Cardaba by FHIA (Rowe and Rosales 1993) may also be appropriate for depleted soils, but require evaluation under Ugandan conditions. Alternative approaches such as the development of genetically-modified banana and plantain may offer a solution in the longer term, but these are as yet a long way from field implementation.

Other aspects of integrated disease management schemes developed elsewhere which may have value in east/southern Africa are:

- **Plant density** - under the same soil conditions, black Sigatoka disease development is more intense under dessert banana spacings of 2000 plants/ha than 1850 plants/ha (Vicente 1998). Spacing and pruning regimes used by Ugandan farmers are highly variable, ranging from 2.5 to 5.0 m spacing and from 1 to 8 production units per mat. The implications of a higher production unit number are that smaller bunches are produced, an effect which would be exacerbated by both low fertility and leaf spot stresses.
- **Sanitation** - the systematic (every 7-10 days) pruning of leaves or leaf parts with mature lesions reduces the period of inoculum production and so the number of ascospores reaching new infection sites. In Cuba, a reduction of 6-8 weeks in the total period of ascospore production was obtained in this manner (Perez 1996).

It is clear from the studies reported here and the work of others in the region, that yield decline in cooking banana is a very serious problem in eastern Africa and that the management of leaf spot diseases cannot be considered in isolation from other agronomic and pest constraints. Soil fertility plays a vital role in determining yield and disease is markedly more prevalent in areas of depleted soils. It is likely that reductions in plant vigour caused by nematodes and weevils will also predispose plants to disease. A truly integrated approach to crop management, rather than just pest management is required and this must be sufficiently flexible to respond to the circumstances and constraints of farmers in the region.

Addressing constraints to leaf disease management within an integrated crop management context

It is clear from the above studies that, although past research has established the significance of leaf spot diseases, other pests and agronomic factors in Uganda, it is no longer appropriate to consider these production constraints in isolation. Furthermore, the development and validation of appropriate technologies cannot be based on studies on-station, as farmer's needs vary greatly depending on the agroecosystems involved and socioeconomic constraints to adoption of alternative practices.

In the case of leaf spot diseases, a number of interacting constraints thus require farmer-participatory research under the farmers own conditions (obviously, a number of these would also apply for other production constraints):

1. Farmers own pest management technologies
2. Evaluation of resistant germplasm
3. Appropriate spacing and pruning regimes
4. Validation of sanitation measures
5. Impact of managing other pests and pest interaction effects under farmer's conditions
6. Knowledge of soil nutrient requirements
7. Value of low-cost soil amendments (green manures, composts etc.)

8. Value of chemical control and treatment thresholds
9. Impact of cropping practices, intercrops and crop duration.

In order that research and extension may be effectively combined to better address these needs with resource-poor farmers, some basic tenets must be recognized:

1. Constraints and their relative significance differ according to farmers agroecosystem and socioeconomic status; there is no single 'right package'.
2. Production constraints interact, particularly in low-input systems, thus a multidisciplinary approach is required.
3. The research agenda should be driven by both farmers and researchers (participatory technology development rather than technology transfer).
4. Farmers should not be provided with a set 'researched' package, but be empowered through a participatory technology development process to decide and evaluate for themselves from a 'basket' of technologies.

It is clear that farmers must now become more directly involved as partners in the research process, in order that disease management practices may become relevant and appropriate to use in the integrated management of the crop. For a successful process of participatory technology development, the potential constraints to farmer's adoption of technologies and problems in technology transfer must be recognized and acknowledged. These include:

1. A lack of understanding of the biology underlying the system and the potential value of introduced management technologies.
2. Access to, or availability of inputs, e.g. labour, time, soil amendments, fertilizers, resistant germplasm, irrigation, fungicide suitability, safety and delivery systems, control measures for other pests, land availability for rotations/fallows, cash or credit for inputs.
3. Competing demands on time or resources from other activities.
4. Unclear cost:benefit relationships for inputs (these may not be directly financial).
5. Perceived relative value of banana crop compared with alternatives.

Past development of extension recommendations has generally occurred through a process of on-station technology development, followed by a phase of on-farm technology transfer or refinement, the so-called 'top-down' research and extension approach. The advantages and disadvantages of this approach can be summarized as:

On-station technology development

- Researcher owns the objectives of the experiment,
- Very complex trial designs are possible,
- Allows investigation of the fundamental biology underlying the system,
- Allows testing of 'risky' interventions,
- Provides technologies for evaluation on-farm,
- Farmers indirectly informed of results,
- No direct link to farmer's circumstances.

On-farm technology development/transfer

- Researcher owns the objectives,
- Treatments are developed from researchers' own knowledge,
- Moderately complex, replicated trial designs are possible, extrapolated to other sites,
- Provides technologies for recommendation to farmers via extension through top-down process,
- Farmer acts as paid/unpaid research assistant/labourer, +/- informed as to purpose of study,
- High risks if treatments fail,
- Value as demonstration plots,
- Tend to be single discipline studies,
- Subsequent adoption is often limited, other than for 'clear winner' technologies.

This can be contrasted with a farmer-participatory technology development approach, in which the **farmers themselves become the experimenters**.

Farmer-participatory technology development

- Farmers and researchers own the objectives of an experiment in an open and informed partnership,
- Treatments developed from interactive discussion on appropriate measures, drawing on the knowledge of both farmers and researchers,
- Farmers experiment on a scale (and level of risk) with which they are comfortable (and can say no!),
- Measures are evaluated under farmer's own specific conditions and circumstances, so confidence in subsequent uptake,
- Simple trial designs only, but can be replicated between farmers; conventional analyses can be difficult,
- Treatments can be combined across disciplines,
- Research outputs appropriate to farmer's circumstances and constraints; adoption of integrated measures more likely,
- Problem matrix identified drives agenda for more 'upstream' research on underlying mechanisms.

In order that participatory technology development processes may be successfully implemented, experience elsewhere has shown that an appropriate 'enabling' environment is required, viz.:

1. Close linkages with farmers,
2. Farmer-to-farmer interaction and group dynamics,
3. Associated discovery-based learning programmes (e.g. farmer-field-schools, guided experiential learning etc.),
4. Credit schemes for inputs and/or direct external provision of initial 'start-up' inputs,
5. Farmer/group savings schemes for sustainability of inputs.

It is now timely to move towards a participatory technology development phase, drawing on the outputs from past research in Uganda and elsewhere, but developing baskets of technologies that farmers can draw from with the confidence borne of their own experience and knowledge. This will require a shift in research approach and emphasis and closer integration of research and extension programmes and may require changes at policy level as well as in the field.

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Advances in breeding for host plant resistance to banana diseases

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Introduction

Banana[2] (*Musa* spp. L.) is a vegetatively propagated crop that is widely cultivated for its fruit. In Africa and elsewhere, banana is not only consumed as fresh fruit, but more importantly provides a starchy staple that is the mainstay in many local food economies (Vuylsteke *et al.* 1993a). As one might expect with a giant monocotyledonous herb, banana has many parasites and the danger of epidemics is aggravated in several ways (Robinson 1996). Banana is an evergreen perennial plant, so its epidemics may be continuous. Also, the tropical environment in which it is usually grown is frequently warm and wet, giving rise to regular explosions of pests and diseases. Nevertheless, many ancient banana clones are still being cultivated by smallholder farmers in homestead gardens or small- to medium-sized fields throughout the tropics, without any crop protection chemicals, and producing some 70 million tons (FAO 1997) of delicious and nutritious fruit and food each year. In contrast, modern European potato clones cannot be cultivated without the use of expensive, certified pathogen-free seed combined with routine application of insecticides and fungicides (Robinson 1996).

It is particularly interesting that many of the serious epidemics affecting banana this century were the result of encounters with new diseases or new (more virulent) forms of old ones (Buddenhagen 1987, Robinson 1996), sometimes involving the widespread cultivation of "new" clones that were relatively recent introductions in a particular region. Examples of the latter are the Panama disease (fusarium wilt caused by the fungus *Fusarium oxysporum* f.sp. *cubense* (E.F. Smith) Snyder & Hansen)), epidemic that decimated the Gros Michel dessert banana plantations of Central America in the 1910–1950s (Stover 1962), and the fusarium wilt currently affecting the Pisang awak (Kayinja) cooking/beer banana cultivar in eastern, central and southern Africa (Sebasigari and Stover 1988, Ploetz 1994). Another dramatic case of a new encounter disease epidemic, this time on ancient *Musa* landraces, is the black Sigatoka leaf spot disease (caused by the fungus *Mycosphaerella fijiensis* Morelet) epidemic, which

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[2] The term banana is used here in a generic sense, encompassing all edible bananas, such as dessert and cooking banana cultivars, including the plantains.

entered the African continent only in the late 1970s (Frossard 1980, Craenen 1999). Black Sigatoka can cause yield losses of up to 50% in plantain (Mobambo *et al.* 1993) and highland banana ('matooke') (Tushemereirwe *et al.* 1996). All landraces of plantain and highland banana are quite uniformly susceptible to this leaf spot. In addition to fusarium wilt and black Sigatoka, viruses cause important diseases of bananas in Africa. Cucumber mosaic cucumovirus, banana bunchy top virus and banana streak badnavirus can cause serious damage in localized situations and may be more widespread than presently known (Sebasigari and Stover 1988, Dahal *et al.* 1998). Bacterial rots and other fungal diseases occur throughout Africa, but rarely reach epidemic proportions.

Thus, the recent history of banana has been greatly influenced by the diseases that have afflicted and continue to afflict this major commodity and food crop. Recent reviews of the main banana diseases include papers on fusarium wilt (Ploetz 1990, 1994), black Sigatoka (Fullerton and Stover 1990, Craenen 1999), and BSV (Frison and Sharrock 1998). The evolving disease situation on the crop, particularly the expanding threat of new and more virulent forms of the major fungal pathogens, has spurred increased interest in the genetic improvement of banana (Persley and De Langhe 1987, Rowe and Rosales 1996a, Vuylsteke *et al.* 1993a,b, 1997).

Banana disease management through host plant resistance

Disease control in banana can be achieved by quarantine, sanitation, eradication, enhanced cultural practices, pesticides, biological control, and host plant resistance (Jeger *et al.* 1995). Within an integrated disease management strategy, host plant resistance appears to be the most convenient and effective component intervention to reduce yield losses from banana diseases at low cost to the farmer (Simmonds 1962, Ploetz *et al.* 1994, Jeger *et al.* 1995). It is generally assumed that improved, disease-resistant genotypes would be readily adopted by farmers as new cultivars. The overall appropriateness of host plant resistance is due to its lower cost relative to other interventions (e.g. less external inputs, labour and/or technical expertise required). Better adapted varieties with improved yields and disease resistance have proven to be the cheapest, most reliable and environmentally safest way to increase productivity of most of the world's important food crops (Simmonds 1994, Robinson 1996).

Unlike the major cereals, most of the production gains in banana obtained during the past two decades have resulted from expansion of the cultivated area (CGIAR 1997). This observation seems to indicate that the crop has not yet benefited from scientific advances in genetic improvement and cultural practice, despite the suggestion 30 years ago, based on empirical physiological estimates of yield potentials (de Vries *et al.* 1967), that banana should receive much more attention in breeding and selection. This apparent lack of progress (through breeding) in banana productivity statistics is largely due to the fact that *Musa* genetic improvement by conventional hybridization is complex and difficult. Banana breeding is burdened with obstacles typical of polyploid,

vegetatively propagated crops. Among the more substantial impediments are the trisomic pattern of gene inheritance, low seed fertility, and slow propagation (Vuylsteke *et al.* 1997). Hence, though banana breeding started nearly 80 years ago, no new banana cultivar that was acceptable to farmers and consumers had been bred until recently (Rowe and Rosales 1996a). However, recent advances in banana breeding hold great promise for future production gains through the cultivation of improved, disease-resistant hybrids by smallholder and commercial farmers. Indeed, several breeding programmes have made significant progress in the development and selection of disease-resistant and high-yielding banana hybrids. Such hybrids are now available from the Fundacion Hondurena de Investigacion Agricola (FHIA) in Honduras (Rowe and Rosales 1996a), the International Institute of Tropical Agriculture (IITA) in Nigeria (Vuylsteke *et al.* 1993a,b, 1997), the Centre Régional de Recherche sur Bananiers et Plantains (CRBP) in Cameroon (Tomekpe 1996), the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) in Guadeloupe and France (Bakry *et al.* 1997), and the Brazilian Agricultural Research Corporation (EMBRAPA) (Silva *et al.* 1997b). An overview of these advances is provided in the disease-specific sections below.

Breeding banana for disease resistance

Host plant resistance to diseases has always been a major objective in banana breeding programmes. Susceptibility of Gros Michel to fusarium wilt was the driving force for beginning banana breeding in 1922 in Trinidad, in 1924 in Jamaica, and in 1959 in Honduras (Rowe and Rosales 1996a). During the past two decades, the appearance and spread of new fusarium races and of more virulent forms of Sigatoka leaf spot, to which many of the major banana cultivars are susceptible, has revitalized interest in banana breeding (Buddenhagen 1987, Ganry 1993, Jones 1994, Ortiz *et al.* 1995).

Once a pest or pathogen has been identified as a problem that requires a resistant cultivar(s), scientific breeding can be divided into five basic activities (Hartman and Vuylsteke 1999):

1. Characterize the host/pathogen interaction.
2. Develop screening procedures.
3. Identify sources of resistance.
4. Determine the inheritance of resistance genes.
5. Design and implement breeding strategies based on the results of steps 1 through 4.

In a practical breeding programme much of the research is concurrent, and steps 4 and 5 are usually combined, with breeding and selection commencing prior to a full understanding of inheritance. An ongoing breeding programme is then modified to fit new information as it is obtained.

Fusarium wilt resistance

Fusarium wilt is a soilborne fungal pathogen that can devastate plantations of susceptible genotypes. Four races of *Fusarium oxysporum* f.sp. *cubense* have been identified by host differential testing (Ploetz 1994). Races 1, 2 and 4 are important to production of edible bananas, while race 3 attacks Heliconia species. Gros Michel (*Musa* AAA) and Pisang awak (ABB) are susceptible to race 1, Bluggoe (ABB) to race 2, while race 4 affects Cavendish (AAA) cultivars as well as all genotypes susceptible to races 1 and 2. Recently, Panama disease was observed on the highland banana (AAA) landraces of Uganda (Tushemereirwe and Ploetz 1993). Plantains (*Musa* AAB) are resistant to races 1 and 2 (Ploetz 1994), but there are indications that race 4 will attack these cultivars.

Clones to be screened are generally planted in an infested field, in which susceptible plants have succumbed to fusarium wilt. Clones can also be planted into holes in which chopped corm material from heavily infested plants has been placed (Rowe and Rosales 1996a). Disease severity is assessed by scoring outward symptoms (e.g. yellowing of leaves) and evaluating the degree of discoloration of vascular bundles in the corm and pseudostem (Stover 1962, Orjeda 1998). Field screening for fusarium response is relatively expensive in both time and resources due to the large size and long life cycle of banana. Susceptible clones may also escape disease challenge due to edaphic variation in the field.

Large numbers of clones have been screened for resistance to fusarium wilt (e.g. Vakili 1965). Resistance to races 1 and 2 is remarkably common among the wild and cultivated *Musa* species, but surprisingly few sources of resistance have been used in breeding programmes. The wild diploids *M. acuminata* ssp. *malaccensis* and *M. a.* ssp. *burmannica* (primarily Calcutta 4), and the edible AA diploid Pisang lilin have shown resistance to races 1 and 2, and have been widely used (Shepherd *et al.* 1994, Rowe and Rosales 1996a). FHIA has developed the superior diploids SH-3142, SH-3362 and SH-3437 with resistance to races 1 and 2, and SH-3362 is also resistant to race 4 (Rowe and Rosales 1996a). Resistance to race 1 derived from Pisang lilin and Calcutta 4 is believed to be controlled by a single dominant gene (Vakili 1965).

Breeding for Fusarium wilt resistance at FHIA has yielded two outstanding Gros Michel-derived hybrids with resistance to race 1. The tetraploid hybrids FHIA-17 and FHIA-23 also produce high yields and have good fruit quality, and are being widely tested in several countries for potential release as dessert bananas. FHIA-23 is already grown commercially in Cuba (FHIA 1999). In addition, FHIA-01 (or Goldfinger), a tetraploid derived from the sweet-acid dessert banana Dwarf Prata (AAB), has shown to be resistant to races 1 and 4 and was the first man-bred banana to reach relatively widespread evaluation and release. EMBRAPA also selected tetraploid Prata hybrids with fusarium resistance, i.e. PV03-44 and PA03-22 (Shepherd *et al.* 1994), and these have been tested in several countries. Hybrids from crosses on Pisang awak with the resistant diploids Pisang lilin and SH-3437 have recently been developed at FHIA (FHIA 1999) and IITA (IITA 1999), but their Fusarium wilt resistance remains to be tested.

Black Sigatoka resistance

Black Sigatoka is an airborne fungal leaf spot disease that causes severe leaf necrosis on susceptible cultivars (Stover 1980). In Africa, black Sigatoka attacks plantains and East African highland bananas, but the ABB cv. Kayinja (Pisang awak) is resistant. The widely grown dessert bananas (Cavendish, Gros Michel and AB cv. Sukali Ndizi) are very susceptible.

Most screening for Sigatoka leaf spot resistance has been done using natural infestations in field tests (Vakili 1968, Fouré *et al.* 1990, Vuylsteke *et al.* 1997). Several methods of scoring Sigatoka resistance in the field have been proposed, but for purposes of selection for resistance, Craenen and Ortiz (1998) found that the youngest leaf spotted at flowering sufficed to distinguish black Sigatoka resistant hybrids, whereas other measurements are likely more important for screening pathogen variation or characterizing the nature of host plant response (Fouré *et al.* 1990). Experimental designs for field testing for Sigatoka leaf spot resistance have been highly developed (Gauhl *et al.* 1995, Nokoe and Ortiz 1998, Orjeda 1998). Field screening for Sigatoka resistance is relatively expensive in terms of time and resources, hence nursery and *in vitro* screening have been used, yet with varying success.

Several authors have screened large numbers of clones for resistance to black Sigatoka (e.g. Fouré *et al.* 1990, Vuylsteke *et al.* 1997). Resistance is readily found among the wild and cultivated *Musa* species, yet few resistance sources have been used in breeding programmes. A model for black Sigatoka resistance was proposed by Ortiz and Vuylsteke (1994), consisting of a major recessive allele and another two independent loci with favorable additive effects. Pedigree analysis of released hybrids identifies Pisang lilin and Calcutta 4 as the primary sources of black Sigatoka resistance in IITA, EMBRAPA, CIRAD-FHLOR, CRBP and most FHIA-released hybrids (Rowe 1984, Vuylsteke *et al.* 1993b,c, 1997, Shepherd *et al.* 1994, Rowe and Rosales 1996a, Tomekpe 1996). The use of the same few sources of resistance has contributed to high levels of relatedness between clones from the various breeding programmes (Hartman and Vuylsteke 1999). At FHIA, SH-3437 was selected as an outstanding diploid hybrid with a high level of resistance to black Sigatoka and it is used extensively in breeding black Sigatoka-resistant tetraploid hybrids (Rowe and Rosales 1996a). At IITA, several diploid plantain-derived hybrids were selected for their black Sigatoka resistance and good bunch and horticultural traits (Vuylsteke and Ortiz 1995), of which TMP2x 1297-3 and TMP2x 2829-62 are proving to be superior paternal genotypes for breeding high-yielding and black Sigatoka-resistant hybrids (Tenkouano *et al.* 1998).

The intensive efforts during the past 10-20 years by several breeding programmes to incorporate Sigatoka resistance into different banana genepools have been fruitful in terms of producing a range of high-yielding, black Sigatoka-resistant (BSR) hybrids with good horticultural qualities. These polyploid hybrids are all potential new cultivars for release. FHIA has selected SH-3436 as a BSR tetraploid (AAAA) hybrid from the Gros Michel dessert banana pool, but its stature is too high and its fruit flavor lacks in fruitiness (Rowe and Rosales 1996b). BSR hybrids of the sweet-acid dessert bananas

Prata and Silk (AAB) have been developed at FHIA [FHIA-01, FHIA-18 and SH-3640] (Rowe and Rosales 1996a, INIBAP 1998), EMBRAPA [PV03-44] (Shepherd *et al.* 1994), and CIRAD [IRFA 909 and 910] (Bakry *et al.* 1997). Plantain breeding has produced many tetraploid BSR hybrids at IITA [TMPx 548-9, TMPx 1658-4, TMPx 2796-5, TMPx 5511-2, TMPx 6930-1, TMPx 7002-1, etc.] (Vuylsteke *et al.* 1993b,c), CRBP [CRBP 037, 039, etc.] and CIRAD [IRFA 904, IRFA 911] (Tomekpe 1996), and FHIA [FHIA-20, FHIA-21] (FHIA 1999). Some of these BSR plantain hybrids have been widely distributed and are entering commercial production, e.g. FHIA-20 and 21 in Cuba and Honduras (FHIA 1999), although many of these plantain hybrids suffer from streak virus infection (see below). Tetraploid BSR hybrids of AAB and ABB cooking bananas have also been developed, e.g. FHIA-03 derived from Cardaba (see Ortiz *et al.* 1995) and BITA-3 from Laknau (Ortiz and Vuylsteke 1998a).

A second generation of improved triploid hybrids is becoming available from FHIA and IITA. These hybrids were developed from tetraploid by diploid crosses and are considered as superior cooking banana hybrids, because of their black Sigatoka resistance, high yield and other desirable attributes. It concerns the hybrids FHIA-25 from FHIA (FHIA 1999) and PITA-16 from IITA (Ortiz *et al.* 1998).

Virus resistance

Cucumber mosaic cucumovirus (CMV), banana bunchy top virus (BBTV) and banana streak badnavirus (BSV) are the viruses currently known to occur in Africa (Ploetz *et al.* 1994). CMV and BBTV are transmitted by aphids, while mealybugs are vectors of BSV. Banana viruses also readily spread through the dissemination of infected propagules, either suckers or tissue culture plants. All banana species and cultivars are generally believed to be susceptible to viruses (Ploetz *et al.* 1994), but this view is probably based on the inadequate screening of *Musa* germplasm. Some symptoms are specific to each virus, but symptoms can be variable and confusing (Ploetz *et al.* 1994, Diekman and Putter 1996). Bananas with severe CMV and BSV infections may die through top dieback and internal pseudostem necrosis. It has also been demonstrated recently that BSV DNA sequences are integrated in the host genome of many, if not all, *Musa* genotypes. These integrated viral sequences may be activated by a number of environmental stresses, including tissue culture and perhaps the breeding process itself, to produce episomal BSV and cause streak disease (Frison and Sharrock 1998). Viruses have also become a major threat for international germplasm distribution (Diekman and Putter 1996).

Procedures to screen for virus resistance are not well developed, which accounts for conflicting results (Ortiz 1996). Methods for inoculation or transmission and for scoring disease severity are not yet robust, although virus diagnosis techniques have been improved recently. The limited work on germplasm screening relied on field scoring of virus incidence based on visual virus-like symptoms, occasionally supplemented with virus titer measurements. Ortiz (1996) reported significant differences among genotypes in host response to BSV and/or CMV. Bananas with AA (wild and cultivated) and AAA genomes, and ABB cooking bananas showed no or few virus-like symptoms in several

diverse environments, suggesting virus resistance. Conversely, plantain landraces were ranked as susceptible or less susceptible. Epistatic gene interactions have been suggested to control virus susceptibility in hybrid germplasm (Ortiz 1996).

Most breeding programmes have not yet added virus resistance as a specific improvement objective. However, host plant resistance may be considered as a feasible approach to control BSV, since natural variation has been observed for BSV incidence and severity in *Musa* cultivars and hybrids. At IITA, BSV symptom incidence, relative concentration of BSV antigens in banana leaf tissue, and yield loss from BSV were used to evaluate genotypic response to the virus. Considerable differences were observed for symptom expression among accessions that had similar relative concentration of BSV antigens, suggesting that specific genetic factors and ploidy level may be key factors in the expression of BSV symptoms (Tenkouano, Dahal and Vuylsteke, IITA, unpublished results).

Some IITA plantain hybrids that were selected for black Sigatoka resistance (TMPx 7002-1, TMPx 2637-49 and TMPx 548-4) showed negligible loss in bunch weight despite high symptom incidence and high concentration of BSV antigens, suggesting BSV tolerance. TMPx 1658-4 and TMPx 2796-5 had lower symptom incidence and non-significant yield loss, suggesting even better tolerance. PITA-14 (TMPx 7152-2) was also found to be virus-tolerant at the IITA-Onne breeding station in Nigeria (Ortiz and Vuylsteke 1998b), but this tolerance was not stable across environments (Tenkouano *et al.* unpublished). BITA-3 was registered as an AAB cooking banana hybrid with BSV tolerance, exhibiting few and mild symptoms in some environments and no significant yield loss (Ortiz and Vuylsteke 1998a). The BSR tetraploid plantain hybrid PITA-12 (TMPx 6930-1) and the BSR secondary triploid hybrid PITA-16 (TM3x 15108-6) had very low BSV incidence with very mild symptoms, low virus titer and suffered no yield loss, and thus may posses "resistance"[3] to BSV (Ortiz 1996, Ortiz *et al.* 1998, Tenkouano *et al.* unpublished). The ABB cooking banana hybrids FHIA-03 (from FHIA), TMBx 612-74 and TMBx 1378 (from IITA) had low or nil incidence of BSV and low virus titer, also suggesting some form of resistance. However, genotypes showing tolerance or resistance to BSV, but which are infected with BSV, may still be limited in their international movement.

Durability of host plant resistance

In host plant resistance breeding, the aim generally is to select for horizontal resistance, which is more durable. The main features of horizontal resistance are (Simmonds 1991): it shows polygenic inheritance; it shows continuous distributions from very susceptible to varying degree of resistance; it exhibits resistance (less disease) rather than immunity; it is pathotype (strain) non-specific; it is durable over time, and has several diverse components as mechanisms of resistance. Ortiz and Vuylsteke (1994) suggested that the (partial) black Sigatoka resistance in the TMPx germplasm (hybrids derived

[3] The term resistance is to be used cautiously in the case of host response to BSV, because of this virus specific biology. Resistance to BSV could be due to a low propensity to activate integrated BSV DNA.

from plantains crossed with Calcutta 4 and Pisang lilin) was typical of horizontal resistance. This germplasm has been grown for more than a decade in the high disease pressure environment of the IITA breeding station in Nigeria, as well as in multilocational trials across diverse African locations, and its resistance was found to be stable (Ortiz *et al.* 1997) and has remained intact, which seems to suggest that this resistance may be durable. A similar tentative conclusion can be drawn for the FHIA hybrids that have been evaluated in many locations over several years. Conversely, an example of the non-durability of vertical resistance is the immunity exhibited by the AAA banana cv. Yangambi Km5, which resistance was recently observed to have broken down in Cameroon (Mouliom-Pefoura 1999). *Musa* breeders should thus continue to select for partial resistance (less disease) instead of complete resistance (immunity), while also intensifying efforts to broaden sources of resistance.

Much has been gained in the past few years in our knowledge of pathogen diversity and its implications for the durability of resistance (for review, see Hartman and Vuylsteke 1999). However, a clear understanding of the nature of the interactions between *Musa* and its major fungal pathogens is still lacking. The effect of host plant resistance in *Musa* on pathogen populations will greatly influence the durability of resistance, but little is as yet known about this interaction.

Conclusion

Breeding for host plant resistance to the most important banana diseases in Africa (black Sigatoka, fusarium wilt, and viruses) has recently been relatively successful. Various breeding programmes have developed several banana hybrids with good resistance to one or more of the diseases. These hybrids are finally reaching farmers' fields in a number of countries. Multiple disease resistance is found in a number of these hybrids, such as FHIA-01, FHIA-23, SH-3640, PITA-12 and PITA-16 (Rowe and Rosales 1996a, Ortiz *et al.* 1998, and various unpublished results). The pedigree of PITA-16, which is a selection from a cross between the IITA tetraploid hybrid TMPx 4479-1 and the FHIA diploid hybrid SH-3362, underscores the importance of free availability of *Musa* genetic resources for the genetic improvement of the banana crop.

Breeding for host plant resistance to diseases is a multidisciplinary effort, involving plant breeding and genetics, plant pathology and virology, and other disciplines depending on the particular constraints, therefore integrated banana breeding programmes should be fostered. In addition, conventional banana breeding is unlikely to resolve all the pest and disease challenges to increase banana production in the tropics, hence other available tools must be employed. Plant biotechnology is a powerful tool of modern science that should be used appropriately and realistically in banana improvement (Vuylsteke *et al.* 1998). In the next few years, transgenic bananas with fungal and viral resistance are likely to be tested, and the initiation of molecular marker-assisted selection for fungal resistance should enhance breeding efficiency.

Musa improvement requires a holistic approach if it is to be successful (Vuylsteke *et al.* 1997). Host plant resistance to diseases, the focus of this paper, is only one, albeit

major, component of improved cultivars. Better cultivars must have not only multiple disease and pest resistance, but also high and stable yield, improved plant habit, and desirable fruit quality. This can be achieved by crossbreeding and selection to increase the frequency of favorable alleles in populations, which should eventually result in the production of improved genotypes for farmers and consumers.

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Prospects for the management of Fusarium wilt of banana (Panama disease) in Africa

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Introduction

In many parts of the world bananas are produced as a primary staple food crop, and in Africa the crop provides more than 25% of the total food energy requirements for around 70 million people. Uganda is currently the world's largest producer (ca. 8.5 million tonnes per annuum), accounting for approximately 15% of total global yield (Karamura 1993) (Table 1).

Table 1. Banana production in East Africa.

Country	Annual production (metric tons)	Acreage	Number of endemic cultivars[1]	Number of exotic cultivars[1]
Uganda	8,500,000	1,499,999	150	40
Tanzania	2,870,000	324,000	NA	NA
Kenya	1,097,539	88,989	15	12
Malawi	704,216	135,000	NA	NA

[1] Information not available
Source: Rutherford and Lamboll (1998)

In eastern and southern Africa bananas are produced under systems of shifting cultivation or in permanent farming systems, often in association with crops such as coffee, or in more intensive, well-managed homegarden systems. However, production levels have fallen to such an extent in many areas over the last few decades that these systems are no longer able to meet the demands of rapidly increasing populations. In response to this decline, a number of national and international organizations such as the International Network for the Improvement of Banana and Plantain (INIBAP) and the International Institute of Tropical Agriculture (IITA) have made considerable efforts to identify and prioritize constraints to banana production in the region. Their findings have formed the basis for reversing the recent reductions in yield through more

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appropriate allocation of available funding and resources. Among the major constraints identified were declining soil fertility resulting, primarily, from increasing population pressure on available land and shortened fallow periods (Gold *et al.* 1993, INIBAP 1986). Key pest and disease constraints included banana weevil, parasitic nematodes, Fusarium wilt, Sigatoka leaf spots and viruses. Fusarium wilt is a highly destructive disease that has, and continues to, cause major losses in many parts of Africa (see below and Figure 1). Recent surveys undertaken in Kenya have shown that incidence of Fusarium wilt in some areas is as high as 80%, due to extensive cultivation of the highly susceptible clone Gros Michel (J.N. Kung'u, personal communication).

Panama disease: causal agent, symptoms, disease spread and yield loss

Causal agent

Fusarium wilt, or vascular wilt, is caused by the soilborne fungus *Fusarium oxysporum*, an extremely diverse species that comprises both saprobic and pathogenic forms. Although the latter are collectively capable of affecting a wide range of plant hosts, individual strains may exhibit considerable host specificity, facilitating their delineation into special pathogenic forms (formae speciales) and races. Special form *cubense*, which comprises strains pathogenic to banana, exhibits extensive pathogenic and genetic variability and comprises, for example, four races as well as a large number of genetically distinct vegetative compatibility groups (VCG). Strains of races 1, 2 and 4 exhibit specificity to, and may be highly virulent on, Gros Michel (AAA), Bluggoe (ABB) and Cavendish (AAA) types such as Williams, Grand Nain and Dwarf Cavendish which are of major importance to the international export trade. Races 1 and 4 previously caused considerable losses to the banana export market throughout the world. Races 1 and 2 are widespread throughout tropical and subtropical banana-producing regions. Race 4 is generally confined to subtropical areas and, within the African continent, is only problematic in South Africa and the Canary Islands (Ploetz 1990a). All three races continue to present a major threat to global banana production.

Symptoms

Fusarium wilt of banana can usually be readily diagnosed by the appearance of a number of typical symptoms. These include gradual yellowing, wilting and drying of the leaves, commencing with the older, outermost leaves. Petioles of affected leaves may snap, resulting in the leaves drooping downwards. The outer leaf sheaths may split longitudinally at the base of the pseudostem, although this may be caused by other factors such as environmental conditions and infestation by banana weevil. Internally, infestation by the fungus results in black/purple discolouration of the vascular system of the corm and/or pseudostem that may extend into developing suckers. The rate and extent of external and internal symptom development depends on a number of factors,

including host susceptibility, strain virulence and environmental conditions and, if initial infestation is localized within the corm or pseudostem, may only be apparent on one side of the plant. In highly susceptible cultivars and the latter stages of infection, the entire foliage may be yellowed or destroyed, and all vessels and surrounding tissues of the corm and pseudostem discoloured. Pseudostem splitting, leaf yellowing and leaf wilting tend to be more pronounced in drier climates, when plants may already be suffering from water stress, and should be taken into account when disease assessments, particularly diagnostic surveys, are being considered.

Disease spread

On entering the host, the pathogen eventually spreads throughout the entire banana mat, including daughter suckers that may otherwise appear symptomless. Use of such suckers as planting material is one of the primary means by which the disease is inadvertently disseminated on-farm and to neighbouring farms, and is probably the key reason for Fusarium wilt developing in localized patches. Propagules of the pathogen may also be disseminated effectively in water, on farm implements such as machetes and hoes and through the accumulation and distribution of infested plant material and soil.

Yield loss

The rate of pathogen spread within the banana plant, and hence symptom development, may vary considerably. Nevertheless, in most cases infested plants will not develop sufficiently for a mature bunch to form and the entire plant will ultimately be destroyed.

Panama disease in Africa and recent research

Until recently, much of the research undertaken on bananas in eastern and southern Africa has involved short-term surveys and has concentrated on crop taxonomy and, to some extent, pest control. Research undertaken over the last decade has focused on three main areas: national and regional disease surveys to accurately assess the occurrence and distribution of Fusarium wilt; studies of pathogenic and genetic variability within *F. oxysporum* f.sp. *cubense*; efforts to identify and develop host resistance to the disease. Reports of Fusarium wilt and results of surveys undertaken across Africa by a number of workers have confirmed the presence of the disease in Burundi, Democratic Republic of Congo, Malawi, Rwanda, Tanzania, Uganda (East Africa), Cameroon, Canary Islands, Ghana, Guinea, Madagascar, Mauritius, Nigeria, Sierra Leone (West Africa) and South Africa (Sebasigari and Stover 1988, Stover 1990, Ploetz 1990a, Lodwig *et al.* 1999, Kangire 1998, Rutherford 1998) (see Figure 1).

While some information has been accquired with respect to the prevalence of wilt and susceptibility of local cultivars to the disease, this is by no means comprehensive. Ploetz (1990b, 1993) obtained strains of *F. oxysporum* from wilted plants during surveys undertaken in many parts of Africa in the late 1980s and early 1990s. He successfully identified a number of VCG among representative strains, some of which have

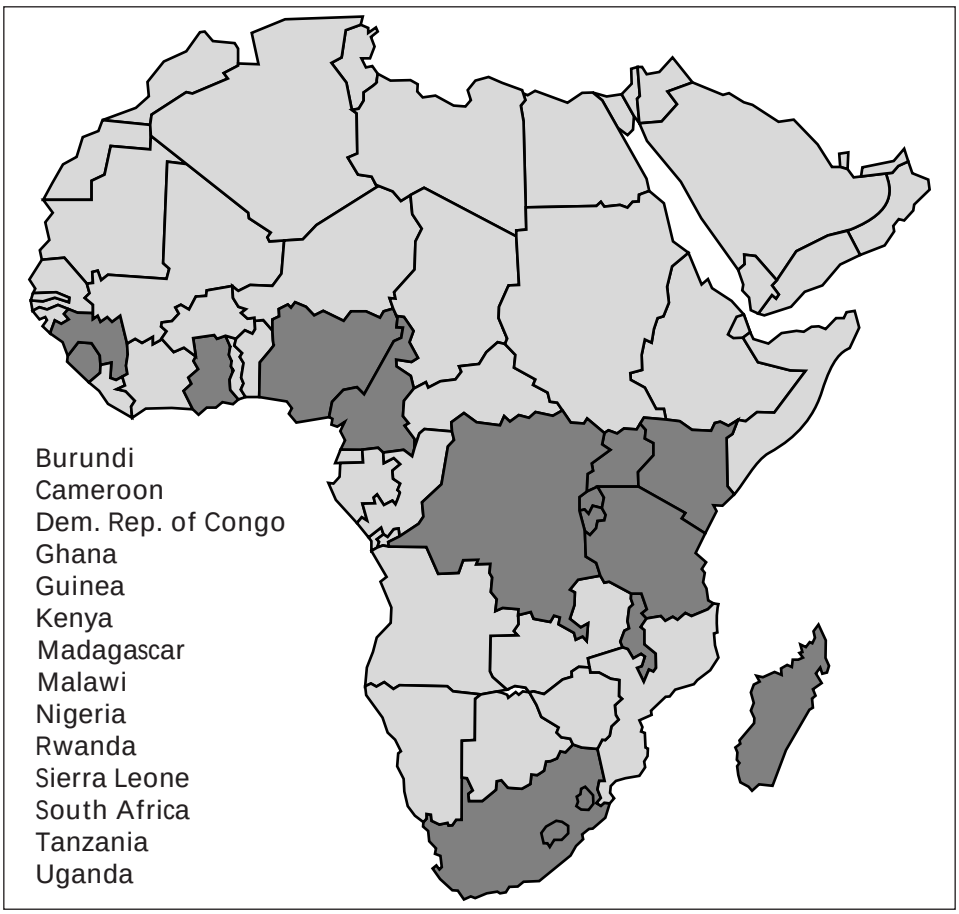

Figure 1. Countries in Africa affected by Fusarium wilt of banana.

subsequently been correlated with genetic lineages determined by RFLP analysis (Ploetz 1997). Other research initiatives undertaken since 1990 have provided important information on the distribution of wilt, relative susceptibility of economically important cultivars and the occurrence, distribution and relationship between pathogenic and/or genetic variants of the fungus, including races, in Uganda, Kenya and Tanzania (Rutherford *et al.* 1995, Rutherford 1998, Kangire 1998, Kung'u and Jeffries 1998, Lodwig *et al.* 1999). The findings of some of this work are summarized in Table 2.

The evaluation of banana germplasm for resistance to Fusarium wilt forms a major component of ongoing research and efforts in this area are increasing. Germplasm indigenous to parts of Africa as well as that developed through international breeding programmes (e.g. *Fundación Hondureña de Investigación Agrícola* (FHIA) and IITA) is currently being evaluated at a number of sites in Africa where Fusarium wilt is endemic as part of an INIBAP global initiative. Countries in Africa where evaluation sites have been established to date include Uganda, Kenya, Malawi and South Africa. Accessions

Table 2. Fusarium wilt of banana in East Africa.

Country	Major banana-producing areas affected	Economically important cultivars affected	VCG identified	Pathogenic races identified
Uganda	All (Western Uganda represents 75% of total production)	Bogoya[1] (AAA) Kisubi/Sukari Ndizi[2] (AB) Kayinja[3] (ABB)	0124, 0124/5 01212, 01222	1 **
Kenya	Busia, Coastal Region, Embu, Homa Bay, Kakamega, Kisii, Kisumu, Meru, Migori, Murang'a, Taita-Taveta	Kampala[1] (AAA) Muraru (AA?) Wang'ae[2] (AB) Bokoboko[4] (ABB)	0124, 0125, 0128, 01212, 01220	1 & 2 **
Tanzania (mainland only)	All (widespread – Mbeya, Mara, Kagera, Morogoro, Kilimanjaro, Arusha, Tanga)	Kijoge[1] (AAA) Kisukari[6] (AB) Bokoboko[4] (ABB) Halale[5] (ABB)	0124, 01212	1 & 2 ***

* Cause as yet unidentified
** Based on pathogenicity testing
*** Based on field surveys only

1 = Gros Michel
2 = Ney Poovan
3 = Pisang Awak
4 = Bluggoe
5 = Also known as Harare, Zambia, Gurutu or Haladoni
6 = Ney Poovan, also known locally as Kambani

showing promise with respect to resistance to Panama disease and that may be suitable replacements for Cavendish types in some areas include FHIA-01 (AAAB, also referred to as Goldfinger) and FHIA-03.

Approaches and prospects for managing Fusarium wilt of banana

Chemical control

The use of chemical pesticides has been, and will continue to be, an extremely effective means of managing Fusarium wilt on many crops in temperate and tropical regions. However, the use of pesticides in developing countries, including those in Africa, is greatly restricted by their availability and cost, and is usually limited to soil fumigation and seed treatment (e.g. oil palm, Flood *et al.* 1994) or to high value cash crops grown under controlled conditions (e.g. glasshouse carnation production). Fumigation of soil with methylbromide have been shown to effectively reduce levels of Panama disease in South Africa for a period of 26 months, but the pathogen successfully recolonized the treated soils within another 2-3 years (Herbert and Marx 1990). Reductions in Fusarium wilt have been reported following application of chemical pesticides to control root-knot

nematode in a number of crops, including cotton (Jorgenson *et al.* 1978), and it is conceivable that similar effects may occur in banana. Overall the sheer size and perennial nature of the banana plant and the mode of infection and spread by *F. oxysporum* f.sp. *cubense* (FOC) unfortunately suggest that effective management by fungicide application may be an extremely difficult and expensive task.

Biological control

The use of naturally occurring predators, parasites and pathogens for pest management has obvious advantages over chemical pesticide application but, in comparison, the technology is still in its infancy. To date most success has been achieved for the control of insect pests and weeds, although the successful use of microbial control agents for controlling fungal plant pathogens has increased. Fungi and bacteria within the genera *Gliocladium*, *Verticillium*, *Trichoderma* and *Pseudomonas* have been highly effective in reducing losses attributed to a number of soilborne pathogens, including Fusarium and verticillium wilts (Yamaguchi *et al.* 1992). The strategies employed vary depending on the nature of the host crop (e.g. annual or perennial, seed or vegetatively propagated), the farming system and agronomic factors, but the conventional approach involves pre-planting application of a biocontrol agent (BCA) formulation to protect the host against initial infection. Unfortunately microorganisms alien to the environment into which they are introduced are often used, and a rapid decline in their numbers has frequently been responsible for the ultimate failure of many attempts at biological control. Given the perennial nature of banana, and therefore the need to provide protection for prolonged periods, and the practical difficulties associated with BCA application (particularly post-planting), such an approach may prove unsuitable for control of Panama disease (for a comprehensive discussion on practical applications of biological control, see Alabouvette *et al.* 1993).

Successful BCA may reduce pathogen populations and disease levels through direct competition (for nutrients etc.), parasitism, cross protection or, indirectly, through induction of a resistant response within the host (Marois 1991). The latter is often the mechanism operating where disease control is achieved using microorganisms that are similar in nature to the pathogen but non-pathogenic to the host, an approach that may be more suitable for control of Panama disease, particularly as the induced resistance may extend to daughter suckers. Microorganisms occurring naturally within the rhizosphere of the host or as fungal endophytes are prime candidates as they are also well adapted to the environment in which they must survive and exert their effect. Non-pathogenic strains of *F. oxysporum* have already been used successfully for the control of Fusarium wilt on a range of crops including sweet potato, tomato and flax (Komada 1975, Lemanceau and Alabouvette 1991, Yamaguchi *et al.* 1992). In some instances it may be possible to manipulate the soil environment to the advantage of such microorganisms. The role of suppressive soils in controlling *Fusarium* spp. has long been recognized (Louvet *et al.* 1981, Alabouvette and Horby 1990), and soils which suppress the development of Panama disease have been noted in a number of areas (Stover 1990). Suppressiveness may be related to chemical, physical or microbiological factors, is not considered to be a static phenomenon and can be enhanced, reduced or

even nullified by changes in the environment (Stover 1990, Alabouvette *et al.* 1993). Manipulation of the soil environment through implementation of specific cropping practices has resulted in soils becoming more suppressive to soilborne diseases, including those caused by *F. oxysporum* (Louvet *et al.* 1981), and the application of ash and molasses (see below) may be examples with respect to bananas.

The recent advances and emerging possibilities with respect to biological control are certainly encouraging. However, extensive research is required in several areas before effective biological control of Fusarium wilt of banana becomes a practical and economic option. Obtaining a better understanding of the complexities of the soil environment and factors that affect microbial populations would go some way in accelerating our progress in developing of more appropriate biological, and indeed cultural, management practices.

Cultural practices

On-farm cultural practices may be effective in reducing crop losses by reducing pathogen survival and transmission in soil, on plant debris and on farm implements, and by reducing spread of inoculum within and between mats and to daughter suckers. These may also be readily integrated with other approaches, particularly longer-term measures such as the utilization of host resistance. Sanitary practices, such as the removal and destruction of plant debris, cleansing and sterilization of farm implements and the use of 'clean' (i.e. non-infested) planting material are relatively simple to implement and could reduce spread of the disease not only on-farm but also between farms. Removal and destruction of wilted plants (including corms) may be beneficial in preventing disease spread, particularly if outbreaks are confined to one or a few plants. However, it must be accepted that in many instances this may be impractical and pathogen inoculum may remain in surrounding soil. The use of disease-free planting material may be very effective in wilt-free areas. Plantlets derived from tissue-culture material and multiplied in nurseries established on wilt-free sites are available in some areas, although purchase costs are relatively high. Soil solarization has also been effective in eliminating soil inoculum and hence reducing Fusarium wilt in a number of crops (Katan *et al.* 1983), but again practicalities and costs may preclude its application by small-scale farmers and recolonization of soil by the pathogen may be rapid. Addition of ash and molasses has been reported to reduce wilt severity and to enable adequate formation of the first bunch in affected plants in Kenya and South Africa (J.N. Kung'u, R. Hearn, personal communication). However, any measure that will extend the lifetime of an infested plant, and hence increase the potential for on-farm disease spread, requires careful consideration before being employed.

The widespread use of cultural practices for managing Panama disease is currently restricted, firstly, by a lack of awareness, particularly among growers and extension services, of the nature of the problem and of how specific practices may be of benefit. Secondly, the practicalities, costs and perceived benefits associated with the various approaches preclude their use in many circumstances. In-depth research is also required to determine the relative effects, in differing cropping systems and environments, of

potentially beneficial practices, to facilitate identification and adoption of the most appropriate technologies and their effective integration with other approaches.

Host resistance

The use of plant resistance is generally considered to be the most important approach to future plant disease control in the tropics, and is certainly the most effective, economic and practical long-term option for small-scale farmers in developing countries. Tropical regions, including those in Africa where bananas are cultivated and Panama disease is prevalent, often have an immensely rich plant flora, providing enormous scope for searching for, and utilizing, naturally occurring resistance. In East Africa, for example, literally hundreds of genetically distinct banana types have been identified. Ultimately the strategy employed for utilizing resistance will depend on, among other factors, the banana clones cultivated, the current status with regard to wilt and future needs. Conventional breeding at FHIA and IITA (see also Vuylsteke, previous communication, this volume) has resulted in a number of clones that exhibit resistance to Panama disease being released for further evaluation within Africa as part of the International *Musa* Testing Programme (IMTP) (Orjeda 1998). These include FHIA-01 and FHIA-03, which show resistance to FOC races 1 and 4 and which have potential for replacing susceptible varieties in some areas. Unfortunately conventional breeding methods are not well suited for bananas, and the process can be extremely complex, time-consuming and expensive. One alternative approach is to identify and appropriately deploy naturally occurring germplasm exhibiting resistance to wilt, as this may be more acceptable to growers with regard to other characters such as marketability.

Whatever approach is employed, many factors must be taken into account during the development, evaluation and deployment of new germplasm if durable resistance is to be attained. Pathogen variability is one reason why resistance to wilt expressed by certain banana cultivars cultivated in some areas has broken down in others (Stover and Buddenhagen 1986). Pests too have been shown to have a considerable effect on development of Fusarium wilt. Infestation by the root parasitising nematodes *Radopholus similis* and *Meloidogyne incognita* has been found to increase levels of Fusarium wilt in a number of crops, including banana (Loos 1959), cotton and pigeonpea (Hillocks and Bridge 1992, Hillocks and Marley 1995), possibly through increased root damage resulting in an increase in the number of potential fungal entry points. Such effects may not only lead to a breakdown in resistance to wilt but may also limit the effectiveness of some cultural and biological management practices.

Movement of germplasm

It is generally accepted that the movement of planting material infested with *F. oxysporum* f.sp. *cubense*, not only on-farm but on a local, national and regional scale, is one of the primary means by which Fusarium wilt is spread and introduced to disease-free areas. Quarantine measures involving restrictions on the movement of germplasm may therefore, theoretically, be very effective in preventing spread of Fusarium wilt to,

and within, Africa. Research on VCG has indicated that, for example, the disease was originally introduced to East Africa through the introduction of contaminated germplasm from South-East Asia (Stover 1962, Ploetz 1992). Of FOC races 1 and 2, both of which are known to exist in Kenya and Tanzania, only race 1 has been detected in neighbouring Uganda (Kangire 1998, Kung'u 1998). Similarly, while FOC race 4 is causing serious losses to producers of Cavendish clones in South Africa, these remain wilt-free in tropical Africa. The success of quarantine restrictions is heavily dependent on, firstly, knowledge of geographic areas and banana types already affected by wilt, the occurrence and distribution of differing forms of the fungus in differing regions and the relative susceptibility of cultivars being produced (particularly in relation to pathogen variability). As indicated, extensive research has already been initiated in East Africa to obtain such information. Secondly, close liaison is required between those countries under threat to ensure that appropriate measures are agreed, introduced and implemented effectively to restrict the movement of germplasm where necessary. Failure to adequately address both aspects have to date restricted progress with regard to restrictions on movement of potential infested banana germplasm within Africa.

Pathogen variability

In general, the development, introduction and impact of management practices that have potential for reducing losses resulting from Panama disease, particularly if implemented as part of an integrated pest management strategy, are dependent on in-depth knowledge of pathogenic and genetic variability that exists within FOC. Considerable research has already been undertaken elsewhere in the world on strains of FOC that those cultivars of major importance to the export trade, namely Gros Michel and Cavendish types. However, our understanding of variability within FOC affecting these and the many other clones produced for local use in Africa, particularly as staple sources of food, remains limited. Enhancing our knowledge of variability may facilitate more accurate disease diagnosis, the identification and monitoring of pathogen populations (e.g. races, VCG), in-depth epidemiological and ecological studies and the development, evaluation and implementation of cultural and biological management control practices. It will also assist in the development and implementation of appropriate quarantine measures and will permit the enormous pool of banana germplasm to be screened for resistance with confidence and for material to be selected and distributed appropriately.

Dissemination of information and networking

Considerable information relating to Fusarium wilt of banana and its management is generated through the many diagnostic surveys, laboratory studies, germplasm evaluation trials and so forth undertaken worldwide. While much of this information is effectively disseminated across the developed world, much of it never reaches developing nations such as those in Africa where it may have the greatest impact. This is particularly true for efforts to identify sources of resistance to wilt, and inclusion of African nations in large-

scale evaluation trials, such as the IMTP coordinated by INIBAP (Orjeda 1998), is vital in this regard. Distribution of information leaflets and bulletins, such as Fact Sheet No.5 produced by INIBAP for global use (Moore *et al.* 1995) and that currently being prepared by CAB International with East African growers in mind (Rutherford *et al.* 1999), is a relatively simple but effective means of conveying important information to those who are in greatest need. Regional and international networks such as INIBAP, the Banana Research Network for Eastern and Southern Africa (BARNESA) and the *Musa* Network for Central and West Africa (*MUSA*CO), can play extremely important roles not only in facilitating widespread dissemination of information, but in promoting, strengthening and coordinating regional and international research efforts that utilize the capacity of individual nations to the full. BARNESA, which was initiated in 1994, now comprises representatives of banana research programmes from 11 countries/regions in Africa (Uganda, Kenya, Malawi, Rwanda, Tanzania, Democratic Republic of Congo, South Africa, Burundi, Madagascar, Zanzibar and Ethiopia) as well as International Agricultural Research Centres (IARC) and donors.

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Integrated management of viruses infecting *Musa* spp.

J. d'Arros Hughes[1]

Virus diseases

Viruses are infectious agents consisting of nucleic acid (ribonucleic acid or deoxynucleic acid) and a protein coat. Some virus groups additionally have a phospholipid membrane. Viruses are inert outside a living organism but once they infect a living cell, the infected cell replicates the viral nucleic acid and coat protein that is then assembled into infectious viral particles.

Unlike animals, plants do not possess an immune system and therefore, once a plant is infected it remains infected. The viruses are then transmitted through vegetative propagules (including micropropagation). Viruses can also be transmitted through true seed and by vectors (usually insects, but also nematodes and fungi).

Virus diseases usually induce conspicuous foliar symptoms and usually reduce the vigour of the plant. This results in stunting and often an increased susceptibility to other pests and diseases. Virus diseases lead to reduced yields, in terms of both quantity and quality.

Virus diseases can usually be controlled by using healthy planting material, eliminating vectors (insects, nematodes, fungi), removing sources of infection or alternative hosts and through the use of resistant cultivars or varieties. Development of integrated control strategies for virus diseases requires a thorough understanding of the viruses, their field transmission and their epidemiology.

Virus diseases of *Musa* spp.

Virus diseases are a major constraint to banana and plantain production. Four virus diseases of *Musa* spp. are known to occur in Africa: banana bunchy top, banana mosaic, banana streak and banana die-back. Banana bunchy top causes severe disease outbreaks where the vector is present (Diekmann and Putter 1996). Banana mosaic can cause losses if severe strains of the causal agent, cucumber mosaic virus (CMV), are present (Jones 1994) and banana streak may cause severe losses where severe strains occur (Lockhart 1994) and susceptible cultivars are grown. The significance of banana

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die-back (Hughes *et al.* 1998) is not known, but as with almost all virus diseases, any infection can cause yield losses due to diversion of plant resources to virus replication. In addition to effects on growth and yield, viruses are a constraint to international germplasm distribution because, for quarantine reasons, only pathogen-free vegetative material of banana and plantain can be distributed. All the viruses infecting *Musa* spp. are transmitted vegetatively and through tissue culture or micropropagation.

The virus diseases of *Musa* spp. occurring outside Africa, abaca mosaic and banana bract mosaic, will be described as they remain potential quarantine issues. The causal agents of these two diseases are 'conventional' potyviruses. The other viruses known to infect *Musa* spp. occur in Africa. The distribution of the viruses is given in Table 1. The viruses that are found in Africa fall into the potyvirus, cucumovirus, badnavirus and nanavirus groups. With the exception of the badnavirus, the viruses are 'conventional' and control methods for each of them are similar. The badnavirus, banana streak badnavirus (BSV), is a pararetrovirus and it has been shown that BSV sequences are integrated into the host chromosomes. The potential control measures for the disease caused by this virus will be discussed separately.

Table 1. Geographical distribution of viruses infecting *Musa* spp.

Disease	Causal virus	Distribution[1]	Distribution in sub-Saharan Africa[1]
Abaca mosaic	Abaca mosaic potyvirus (possibly a strain of sugarcane mosaic potyvirus)	Asia (Philippines)	Not reported
Banana bract mosaic	Banana bract mosaic potyvirus	Asia (Philippines, India, Sri Lanka)	Not reported
Banana bunchy top	Banana bunchy top nanavirus	Africa, Asia, Australia and Pacific Islands	Burundi, Central African Republic, Congo, Egypt, Gabon, Rwanda and Zaire
Banana mosaic	Cucumber mosaic cucumovirus	All continents	The virus is found continent-wide
Banana streak	Banana streak badnavirus	Europe, Africa, Asia and Oceania	Benin, Cameroon, Cape, Verde, Côte d'Ivoire, Ghana, Guinea, Kenya, Madagascar, Malawi, Mauritius, Morocco, Nigeria, Rwanda, South Africa, Tanzania, Uganda and Zanzibar[2]
Banana die-back	Banana die-back virus	Africa	Nigeria[3]

[1] Distribution data from Diekmann and Putter (1996)
[2] Vuylsteke *et al.* (1998)
[3] Hughes *et al.* (1998)

Abaca mosaic

The natural hosts of abaca mosaic, caused by abaca mosaic potyvirus (possibly a strain of sugarcane mosaic potyvirus, SCMV), are *Musa textilis*, *Marantha arundinacea* and

Canna indica. Banana is an experimental host. Leaves of infected plants may have yellow or light green streaks and the petioles may be mottled dark green with yellowish streaks. In addition to vegetative transmission, aphids (*Rhopalosiphum maidis* and *Aphis gossypii*) transmit abaca mosaic potyvirus in a non-persistent manner. Diagnosis of abaca mosaic potyvirus is by enzyme-linked immunosorbent assay (ELISA) (Diekmann and Putter 1996).

Banana bract mosaic

Banana bract mosaic potyvirus (BBrMV) infects *Musa* spp. and cultivars. The virus causes dark streaks on the bracts of the inflorescence (Ploetz 1994). Streaks may also occur on the petioles and spindle-shaped chlorotic streaks may occur on the laminae. Vector transmission is by aphids (*R. maidis*, *A. gossypii* and *Pentalonia nigronervosa*). The virus is transmitted vegetatively. Detection of BBrMV is by ELISA (Diekmann and Putter 1996) using monoclonal or polyclonal antibodies.

Banana bunchy top

Musa spp. and cultivars are naturally infected by banana bunchy top nanavirus (BBTV). *C. indica* and *Hedychium coronarium* may be alternative hosts and the virus has been transmitted experimentally to *Ensete ventricosum* (Diekmann and Putter 1996). Infected plants may exhibit dark green streaks on the petioles and typically exhibit 'bunching' of the leaves due to progressive shortening of leaves and internodes. The leaves tend to develop chlorotic margins. Symptomless plants and attenuated symptoms have also been observed. Transmission is vegetative and by the aphid *P. nigronervosa*. Detection is by ELISA using monoclonal and polyclonal antibodies as well as by using DNA probes (Wu and Su 1990, Burns *et al.* 1995).

Banana mosaic

The causal agent of banana mosaic, CMV, is distributed worldwide and is found in many dicotyledon and monocotyledon families (Brunt *et al.* 1990). Infected *Musa* spp. exhibit chlorotic streaking or flecking, mosaics and leaf distortion. Severe strains can cause severe symptoms including cigar leaf and pseudostem necrosis. Transmission is by aphids (*A. gossypii*, *R. maidis*, *R. prunifoliae* and *Myzus persicae*) in a non-persistent manner and also by true seed. Detection of this virus is by ELISA using polyclonal or monoclonal antibodies, by mechanical inoculation to diagnostic herbaceous indicator plant species (Francki *et al.* 1979) and polymerase chain reaction (Singh *et al.* 1995).

Banana streak

The natural hosts of banana streak badnavirus (BSV) are *Musa* spp. and cultivars. A bacilliform virus likely to be BSV has been found in *Ensete ventricosum* (Mesfin *et al.* 1995). *Ensete* spp. are also experimental hosts for BSV. The symptoms vary between cultivars, but generally consist of chlorotic streaks or spindle-shaped lesions that may turn necrotic. Cigar leaf necrosis may occur and lead to death of the plant (Dahal *et al.* 1998a). Symptoms are sporadic and appear to be environment dependent. There is a

correlation between ambient temperatures and symptom expression (Dahal *et al.* 1998b). In addition to vegetative transmission, the virus is reported to be transmitted through true seed (Daniells *et al.* 1995) as well as by the citrus mealybug (*Planococcus citri*) (Lockhart and Autrey 1991). The virus particles can be detected by several means: by ELISA using polyclonal antibodies (Thottappilly *et al.* 1997, 1998), by immunosorbent electron microscopy (ISEM) (Diekmann and Putter 1996) and by immunocapture (IC-) polymerase chain reaction (PCR) (Hull and Harper 1998). The viral nucleic acid sequences that are integrated into the *Musa* spp. genome can be identified using direct PCR (Hull and Harper 1998).

Banana die-back

Banana die-back infects banana plants causing symptoms of leaf necrosis and die-back of the plant. Subsequent suckers that develop are progressively more stunted until the entire mat is dead (Hughes *et al.* 1998). The mechanism of transmission of banana die-back virus (BDBV) is not known although some limited field spread has been observed. Diagnosis of this virus is at present through the use of ELISA using polyclonal antibodies and mechanical inoculation of herbaceous indicator plants.

Control of virus diseases

Healthy planting material

Healthy planting material is a very important starting point for the control of plant virus diseases. Virus-infected plants are unable to eliminate the virus and therefore remain infected throughout their life and, in the case of vegetatively propagated crops such as *Musa* spp. and *E. ventricosum*, throughout the lives of subsequent generations that were taken as suckers from the infected mother plants. Healthy planting material therefore at least allows the chance of preventing infection from outside occurring and therefore maintaining healthy crops in the field.

In crops propagated through true seed, 'virus-free' seeds are often used. These are seeds collected from virus-tested mother plants. In reality the term 'virus-free' is rarely used, as it is not possible to test a whole plant or seed in its entirety in a non-destructive way. Theoretically, even one virus particle can cause virus infection of the whole plant. The term 'virus-tested' is usually used, indicating that the plant has been tested for viruses and the tests were negative. Seeds can be obtained from *Musa* spp., but these are not used for multiplication of planting material. However, where it is intended that seeds will be used, for example in breeding programmes, the female and male parents should be indexed for viruses. If one or other of the parents is virus-infected, the seedling(s) may also be virus-infected (Daniells *et al.* 1995, Gold 1972).

The use of virus-tested vegetative propagules (micropropagated plantlets) are the most effective means of ensuring that new planting material is free from virus diseases at planting. Specific guidelines are followed for the testing procedures (Diekmann and

Putter 1996) and the plantlets are certified that they tested negative for viruses. A Germplasm Health Statement is usually issued but this does not substitute for a phytosanitary certificate from the exporting country. Micropropagated plantlets are the only accepted means of distributing *Musa* spp. germplasm internationally. Where micropropagated plantlets are not available, multiplication of suckers from virus-tested mother plants may be done, preferably in an insect-proofed screenhouse. These suckers will not have virus-tested status unless re-testing is done, but they do provide some likelihood that the propagules will be healthy. In cases where even virus indexing is not available, at the very least, vegetative propagules should be taken from mother plants that have never expressed virus-like symptoms.

It is possible to use virus-tested planting material to saturate an area with healthy plants. Provided all the infected plants are first removed from the site, this will remove sources of infection within the area (with the possible exception of alternative host plants for the virus) and may delay re-infection. This technique is however ineffective with vector transmitted viruses if the replanting is done on a small scale, as the vectors will come in to the replanted area from the surrounding infected areas (Ollennu and Hughes 1991). The efficacy of this method of treatment of virus-infected areas is dependent on the policy-makers being effective in the rigorous implementation of the introduction of the healthy material and a thorough knowledge of the means of spread of the disease so that natural barriers can be used to prevent vector spread.

Vector control

The vectors of virus diseases of *Musa* spp. are aphids (*R. maidis*, *R. prunifoliae*, *A. gossypii*, *P. nigronervosa* and *M. persicae*) and mealybugs (*P. citri*). Two main types of vector control would normally be considered: biological control and vector control.

Biological control is not normally considered effective for aphids out of a controlled environment, although it can be effective in glasshouse conditions (Hall 1985). Biological control of mealybugs has been achieved (Neuenschwander 1996), but is not applicable at the present time for the control of the putative vector of BSV, *P. citri*.

The use of insecticides to control these vectors of virus diseases is not economically feasible for subsistence agriculture although they can be used in commercial plantations to control aphids. Control of mealybugs through insecticides is not practical on *Musa* spp. Mealybug colonies have been found on different sites on the plant: under the leaf sheaths of the pseudostem, just under the soil surface on the roots and on the inflorescence (Hughes 1998). Due to the cryptic nature of the mealybugs, contact insecticides do not find their targets and systemic insecticides may have toxicity problems and taint fruit (Thorold 1975).

Removal of sources of infection

In the case of vegetatively propagated crops such as *Musa* spp., ratoon crops can be a source of virus for the next planting season. Infected crop plants that perennate from one growing season to another can provide a significant source of inoculum. For

example, if a single *Musa* spp. sucker infected with BBTV is left in a field, it can serve as a source of inoculum for the vector aphids when the new healthy material is planted. Ideally all material infected with viruses should be removed from the farm or plantation and burnt to prevent it being a source of infection and also to prevent any vectors which may be on the removed plant material from migrating to adjacent plants.

Weeds around the farm can also harbour viruses. Some of these may be transmissible to *Musa* spp. In particular, CMV has many alternative hosts in weed species. Removal of weeds is good farming practice in any case and will also serve to remove possible sources of infection. CMV is also known to infect many crops species, for example cowpea, soybean, fodder legumes, yams and many vegetable and salad crops (Brunt *et al.* 1990) that may be grown together with *Musa* spp. in subsistence agriculture.

Phytosanitation

Removal of symptomatic, virus-infected plants from within a crop reduces the chances of vector transmission within the crop. Viruses generally reduce crop yields. Even when the symptoms are not particularly severe, there may be a yield advantage to be gained by substituting a healthy plant for an infected one.

Without virus-indexing, farmers will be unable to rogue infected but symptomless plants from within the crop, and these can remain a source of inoculum for vector transmission to adjacent healthy plants.

Geographical or temporal isolation

Geographical isolation is where the crop is grown at a distance from sources of inoculum. The barrier to infection may simply be that a sufficiently large distance has been left between the plantings to preclude vector transmission. In other cases, geographic barriers such as mountain ranges or lakes can prevent or reduce spread of diseases, as the vectors are less likely to cross those natural barriers. Interestingly, geographic barriers, more than political ones, are likely to reduce the movement of people between areas, thus reducing spread of disease through infected planting material. Diseases, spread through infected planting material in this way, may initially occur along roads, and other transportation routes such as rivers, before being spread locally between farmers.

Temporal isolation requires the crop to be grown at a different time from other host plants. This is not appropriate for *Musa* spp. which are grown over more than one season.

The use of geographical or temporal isolation is not appropriate for subsistence agriculture. However, under intensively managed commercial conditions, these options should be investigated as a means of controlling the spread of vector-borne virus diseases.

Resistant cultivars or species

Breeding for resistance to virus diseases of *Musa* spp. or *E. ventricosum* has not been a significant component of breeding programmes, even though host plant resistance is probably the most effective form of virus disease control. Producing viable seeds has, however, been a

major difficulty in *Musa* spp. and there has only been limited attention given in the past to the significance of virus diseases of *Musa* spp. by the research community.

In the past there has probably been some natural selection in response to disease pressure. However many selections, even at present, are based on fortuitous observation of absence of symptoms. Some breeding programmes are now paying increased attention to breeding for virus resistance and some virus-resistant or tolerant clones are available. These include BITA-3, a starchy banana with partial resistance to black sigatoka (Ortiz and Vuylsteke 1998a), and tolerance to streak virus, and PITA-14, a black Sigatoka-resistant tetraploid hybrid plantain with virus tolerance (Ortiz and Vuylsteke 1998b).

Integrated disease management

The integrated management of plant virus diseases must be part of an integrated disease management strategy that, in turn, is part of the management of the farm and farming environment. For all of the virus diseases of *Musa* spp., except for banana streak, conventional disease management strategies apply. Therefore, for abaca mosaic, banana bract mosaic, banana bunchy top, banana mosaic and probably banana die-back, appropriate disease management strategies using healthy planting material, controlling the vectors, removal of sources of infection (whether of the crop or other species), geographic or temporal isolation and the use of resistant cultivars or species will control the diseases (Figure 1). In most subsistence farming conditions, the most appropriate means of control will be the use of healthy, resistant planting material in combination with roguing/phytosanitation.

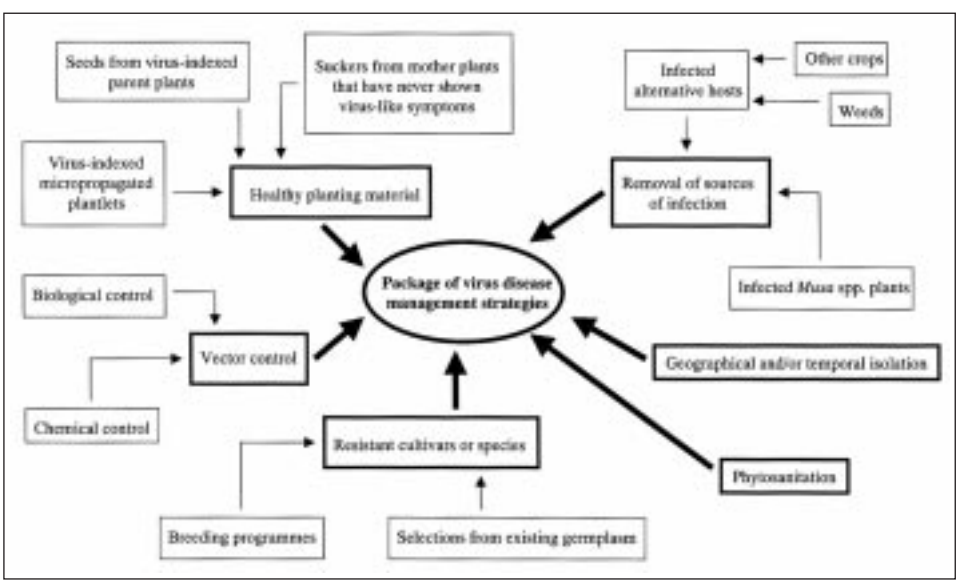

Figure 1. Components of an integrated package to manage virus diseases of *Musa* Spp.

Banana streak is, however, a non-conventional virus disease. It is known that the virus exists as infective virus particles and that virus DNA is integrated into the *Musa* spp. genome (LaFleur *et al.* 1996). It is also postulated that the virus may exist as a super-coiled DNA replicative intermediate within the host cells. In addition it appears that all *Musa* spp. and cultivars have integrated BSV sequences. Transcription of the integrated sequences, giving rise to infective virus particles (Lockhart *et al.* 1998), appears to be activated by stress. It has been suggested that the following may be considered stressful events: environmental stresses (for example drought (water stress), poor nutritional status, abnormal climatic conditions), pest and disease pressure (including weed competition) and tissue culture/micropropagation (Frison and Sharrock 1998).

While methods to control this non-conventional, potentially stress-induced disease are not obviously apparent, there are techniques that may be used to manage the disease. There is little evidence of natural transmission or field spread (Hughes 1998, Su 1998, Thomas *et al.* 1998). The major cause of spread appears to be the dissemination of highly susceptible planting material. The apparent spread of virus symptoms may be simply a 'switching-on' of symptoms by some form of stress (Dahal *et al.* 1998b), or due to an increased awareness of the disease and its symptoms by researchers and extension staff. The best form of management for banana streak seems to be to grow resistant or tolerant species or cultivars and to manage stress-induced transcription of the integrated sequences through 'good' farming practices.

In conclusion, it is clear that healthy virus-resistant or tolerant species or cultivars and 'good' farming practices are prerequisites to avoid major *Musa* spp. or *E. ventricosum* yield losses from virus infection. Both these requirements can easily be put, with recommendations to control other pathogens and pests, into a comprehensive integrated pest and disease management package for use by subsistence farmers. This package can be adapted for the commercial banana growers as the basic principles remain the same regardless of the size of the farm. The main difference between commercial and subsistence farmers, apart from the size of the farms, monoculture vs. mixed cropping and quality of the end product required, is the ability of the different growers to provide high cost inputs. With a range of options available within the integrated pest management package, the management of pests and diseases of *Musa* spp. and *E. ventricosum* should lead to improved, sustainable yields of plantain, banana and ensete in sub-Saharan Africa.

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Session 2D
Review of IPM research activities

Case studies

Plantain IPM in Ghana: a case study

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Introduction

Plantain is a major staple in Ghana, ranking only second to cassava in terms of production and consumption (PPMED 1991). In addition to its nutritional value, plantain is an important component of sustainable agricultural systems in densely populated, high rainfall zones (Gold 1993) and can provide a useful source of cash income for resource-poor farmers (IITA 1994). Despite the benefits derived from plantain cultivation in Ghana, there has been a decline in production, such that total production in 1990 was approximately 1.6 million tonnes or half that obtained in 1970 (PPMED 1996). Decreasing yields and shortened cropping cycles have been attributed to several constraints including poor crop and soil management practices, inherent low soil fertility, reduced fallows and, in particular, a complex of pests and diseases (Karikari 1970).

This paper describes research being undertaken to develop integrated pest management (IPM) strategies that are appropriate for plantain farmers in Ghana and can be applied to reverse the decline in plantain yields and plantation life. The mechanisms which are emerging to enable effective technology transfer to extension agents and farmers are also outlined.

Constraints to plantain production in Ghana

A Participatory Rural Appraisal (PRA) was conducted in 1993 to determine farmers' perceptions of constraints to plantain production in Ghana (Schill *et al.* 1997). It was found that farmers considered lack of planting material to be the most important agronomic constraint to plantain production. In addition, farmers were unaware that suckers are often infested with nematodes and weevil which results in low yields, plant toppling and reduced plantation life. Inability to weed sufficiently due to lack of finance was also identified as a major production constraint.

Subsequently, a diagnostic survey (DS) was undertaken over 3 years (1994-1996) to investigate the distribution, severity and dynamics of plantain pests and diseases in Ghana. Plant parasitic nematodes and black Sigatoka were identified as the major biotic

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constraints on new farms (Schill *et al.* 1996) but while nematode damage increased dramatically in the second and third crop cycle, Sigatoka severity decreased. The nematode species profile varied with the region, for example, *Pratylenchus coffeae* was widespread at high densities throughout the plantain production area, while Radopholus similis was found only in the western Region.

Levels of infestation by banana weevil were low in the plant crop, but became increasingly important in older plantations. However, since plantations rarely exceed 3 years in age, due to nematode attack, weevil populations seldom reached damaging levels.

IPM research

On the basis of results from the PRA and DS, farmer-participatory trials were established at four 'in-depth' study sites, represented by one village in each of four plantain-producing regions (in collaboration with the Ministry of Food and Agriculture, Ghana). The key areas of research included: i) production of clean planting material by paring or hot water treatment, ii) rapid multiplication of clean planting material using a split-corm technique and nursery management, and iii) assessment of the effect of planting material treatments and improved crop management practices on pests, diseases, and plantain growth and yield. Complementary on-station research is also ongoing on the following aspects: i) yield losses due to different biotic constraints, ii) biological control of the banana weevil, iii) efficacy of planting material treatments for nematode control, and iv) effect of individual nematode species on root health and yield.

Yield loss

On-station yield loss trials showed the importance of nematodes and weevils as production constraints, particularly when in combination (Udzu 1998). Weevils alone (artificial infestation) gave a yield reduction of 35%, nematodes (natural population) reduced the yield by 64% and combined, the pests lead to a severe reduction of 85% in the plant crop. Black Sigatoka was not found to be so damaging, thus supporting survey findings. There were differences in the average leaf area damaged between sprayed and non-sprayed plots at flowering but this did not translate into yield differences (Schill 1997).

Rapid multiplication of clean planting material

On-farm trial results indicated that disinfested planting materials can be produced effectively by paring alone, or paring followed by hot water treatment. Clean suckers can be multiplied 4-10-fold by a split-corm technique, pre-germinated in cheap media such as sawdust and grown in nursery beds before transplanting to the farm. Use of clean planting material and improved management practices, such as regular weeding and optimum plant spacing, lead to increased yields and sucker production compared with the use of untreated planting material and farmers traditional management practices ($P<0.01$). The number of bunches and suckers produced more than doubled for the plant crop at one site, Nyinahin (Table 1). Plots with untreated planting material and farmer management were largely abandoned after

Table 1. Number of plantain bunches and suckers produced from treatments tested on-farm at Nyinahin in Ghana in 1996 (plant crop).

Treatment[a]	Mean no. of suckers[b]	Mean no. of bunches[b]
1	106	26
2	193	46
3	339	60
4	276	58
LSD	**132.1**	**21.6**

[a]Treatments:

1. Untreated planting material, traditional management, intercropped
2. Hot water-treated planting material, traditional management, intercropped
3. Hot water-treated planting material, researcher management, sole-cropped
4. Hot water-treated planting material, researcher management, intercropped

[b]Mean of six farms

the first year due to low yields and toppling, while plots with hot water-treated planting materials and improved management practices are still yielding three years later.

Nematodes

While on-farm trials have demonstrated the positive effects of paring and hot water treatment, more detailed experiments to determine the efficacy of planting material treatments in reducing nematode populations in suckers and reinfestation rates are ongoing. Preliminary results indicate that 9 months after planting, the density of *P. coffeae* in roots from pared suckers is >30,000/100 g root tissue, compared with <100 nematodes/100 g root tissue from hot water-treated suckers, indicating that paring alone may not be such a thorough control option as previously considered (F.C. Brentu, personal communication). The subsequent effects of the treatments on growth and yield are, however, being monitored.

Weevils

Biological control is seen as an important component of IPM for banana weevil in Ghana. Methods have been developed for the mass-production of the entomopathogenic fungus *Beauveria bassiana* at IITA, Benin. In the field, weevil mortality up to 80% has been recorded on suckers dusted with the fungus compared with 8% mortality in the untreated control, although these results are subject to seasonal variation (Godonou *et al.* 1998). Research is ongoing to develop a simple delivery system for the fungus that can be incorporated into the current nursery scheme. Promising results have been obtained using oil palm kernel cake (a byproduct of oil palm processing) as a cheap media for production of the fungus and subsequent application to the suckers. The media enhances the persistence of the fungus after application to the sucker, such that a weevil mortality of 61% is obtained, even when suckers are attacked 28 days after sucker treatment, compared with 12.3% using conidial powder alone and 3.8% in the control (Figure 1).

While methods for biological control are still under development, farmers are recommended to remove weevil eggs and larvae from planting material by paring and to use cut pseudostems to trap adult weevils in their plantations.

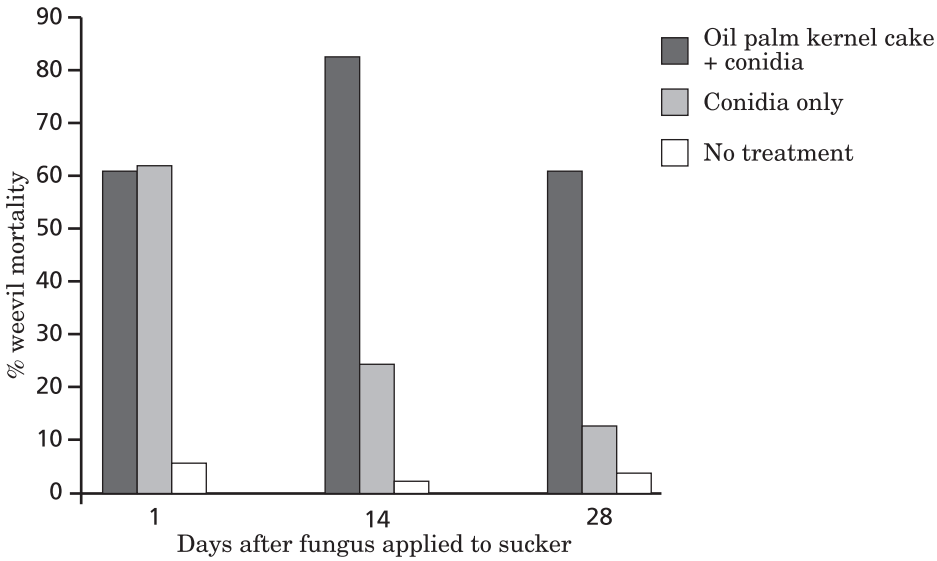

Figure 1. Persistence of *Beauveria bassiana* on plantain suckers using different fungal formulations.

Research is also underway in Ghana to develop IPM strategies for black Sigatoka, weeds and viruses:

Black Sigatoka

Multilocational trials are being undertaken by Crops Research Institute, Kumasi and Agricultural Research Station, Kade, in collaboration with IITA and the Gatsby Charitable Foundation, UK to evaluate plantain and banana hybrids for resistance to Sigatoka, and tolerance and/or resistance to banana streak virus (BSV). Three FHIA hybrids have been identified as promising (FHIA-21 FHIA-03 and FHIA-01), and were also found to have acceptable cooking qualities (O.A. Danquah, personal communication). In addition, it is hoped that newly available hybrids will soon be evaluated. Once suitable germplasm has been identified, materials will be multiplied and distributed to farmers.

Until resistant hybrids are available, farmers are recommended to use mechanical control based on eliminating necrotic leaf tissue. Research is also being planned to determine the effect of mulching on the development of black Sigatoka.

Weeds

A trial is being conducted by the Ghana Plantain Farmer Field School, to determine the optimum weeding frequency for plantain. In addition, future research will evaluate whether the use of cover crops such as *Mucuna* can reduce the need for weeding.

Viruses

The capacity for detection and diagnosis of plantain viruses including BSV is being enhanced through a collaborative project between national programmes, the Gatsby Charitable Foundation, UK and IITA.

A summary of the status of IPM practices for plantain in Ghana is shown in Table 2.

Table 2. Current status of IPM practices for plantain in Ghana.

Constraint	Management options in Ghana	Trials ongoing in Ghana	Recommended to farmers	Farmer adoption
Lack of planting material	Split-corm technique	Yes	Yes	++
	False decapitation	Yes	Yes	+
	Nursery production	Yes	Yes	+
Nematodes	Paring alone	Yes	Yes	+++
	Paring + hot water treatment	Yes	Yes	+
Weevils	Paring alone	Yes	Yes	+++
	Paring + hot water treatment	Yes	Yes	+
	Trapping	No	Yes	+
	Biological control	Yes	Not yet	–
Black Sigatoka	Resistant germplasm	Yes	Not yet	–
	Pruning	Yes	Yes	+
	Improved management e.g. mulching	Planned	Not yet	–
Weeds	Optimum timing	Yes	Not yet	–
	Cover crops	Planned	Not yet	–
Viruses	Resistant germplasm	Yes	Not yet	–

Training and technology transfer

Plantain farmers and extension agents at the IITA/MoFA in-depth study sites have been trained during participatory trials in techniques for planting material treatment and multiplication, nursery management and field maintenance. Annual farmers field days provide the opportunity for extension agents and farmers in neighbouring districts to also benefit from the technology. This year, farmers at each village successfully established their own community nurseries with technical backstopping from IITA and MoFA.

In October 1997, a scheme was initiated by the National IPM Secretariat in Ghana to coordinate the research outputs from different institutions engaged in plantain research in the country and to harmonize them for the purpose of training extension agents and farmers, using the IPM-farmer field school training methodology. After curriculum development and a baseline survey, monthly meetings attended by 12 extension agents (from six major plantain-growing regions) were initiated in January 1998. The trainees carry out field experiments, and learn to grow and monitor the crop. Regular agroecosystem analysis is undertaken, in which trainees observe host-pest interactions and learn to make

recommendations based on their observations. Each trainee is expected to mobilize at least 20 farmers in their communities and run a simultaneous FFS in plantain production. A total of 200 farmers are currently being trained using this methodology throughout the country.

Impact assessment

Plantain farmers at the three in-depth study sites have given positive feedback with respect to the techniques introduced for the production and multiplication of clean planting material (Green *et al.* 1998). For example, one farmer stated that "Plantain can survive on the farm for several years before dying off, unlike previous years where the plant dies off after one harvest". Paring of suckers, which is a simple, low-cost technique, has been adopted by at least 40% of farmers in each of the villages studied. This represents good progress since the PRA in 1993 when farmers were unaware of the importance of planting material treatment. In addition, all plantain farmers in these villages now have access to the use of a hot water tank for planting material disinfestation, and many understand the benefits that can result in terms of yield and plantation life. One or two farmers in each village have also adopted the nursery scheme to multiply clean material. In Gyedu, two farmers produced nurseries of 1200 and 600 suckers respectively (sufficient to plant 1 ha and 0.5 ha of farm land).

Analysis was undertaken to determine the economic feasibility of using planting material treatment and improved crop management practices compared with the use of untreated planting material and farmers traditional practices (Mensah-Bonsu *et al.* 1998). The new strategy was found to be profitable over a 3-year period and adoption resulted in a return of approximately $1295/ha, representing a compensation of $475/ha compared with traditional practices. Further analysis is being conducted to determine the costs and benefits of nursery production.

Lessons learned

Research findings have demonstrated that integrated management of different biotic constraints cannot be considered in isolation. For example, while hot water-treated suckers perform substantially better than untreated planting material, the plants do not reach their full yield potential if weed competition is also present. In addition, weevil infestation is currently a relatively minor problem perhaps due to short plantation life, but consideration needs to be given to the possible effect on weevil population dynamics if planting material treatment leads to a prolongation of plantation life.

Bridging the gap between research outputs and actual adoption by farmers can be problematic because in general the mandate of the institutes involved in technology generation is for research rather than extension. In addition, the impact of the extension services is limited due to lack of funds. The Plantain Farmer Field School, however, is now providing an effective link between the two domains.

When resources are limited, farmers are understandably suspicious of new technologies. It was found, however, that if farmers are given the opportunity to test a technology and observe the results for themselves in a low-risk situation (e.g. farmer-participatory trials), then subsequent adoption is more probable. Moreover, farmers are more likely to adopt a technology if they can be convinced of the advantages by neighbouring farmers in addition to researchers and extension staff. For this reason, cooperation from the chief farmer or other respected farmer in a district is vital.

Conclusions

Strategies for the production and multiplication of clean planting material have been successful in Ghana, leading to an increase in plantain yields. Analysis has shown that these techniques are economically feasible and that farmers' perceptions of the techniques are favourable. Widespread adoption of the technology, together with other methods for improved plantain production, is being encouraged through a Plantain Farmer Field School.

While the use of disinfested planting materials is an important step towards improved plantain production, further work is necessary to provide farmers with a wider range of options for pest and disease management. Moreover, strategies are now needed to enable yields to be sustained over several years. It is therefore envisaged that future IPM research for plantain in Ghana will be closely linked with efforts to enhance and conserve soil fertility.

Acknowledgements

Travel funds for K. A-N. were provided by the Workshop Organizing Committee. Funding for the IITA plantain IPM project is provided by BMZ, Germany. Funding for the Plantain Farmer Field School in Ghana is provided by UNDP through FAO with assistance from GTZ ICP/MoFA, Ghana.

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Banana and plantain in IPM Zanzibar

K. Rajab and H. Fundi[1]

Introduction

Banana and plantain are important staple food crops in Zanzibar, ranking third in preference after rice and cassava. The estimated annual production is 10.5 tons per hectare (Ministry of Agriculture, Livestock and Natural Resources 1997). They are usually intercropped with cocoyams, pineapples, coconuts etc. or used as nurse crops for clove seedlings. It is a common practice to grow this crop round homesteads. These homestead gardens usually thrive better than the field-planted crop as they receive organic inputs from the kitchen refuse that is thrown between them. They seem to have greener leaves and produce better yields because of the inputs. The crop is grown by smallholder farmers with little or no inputs and poor management practices. These smallholder farmers fall into two groups, subsistence farmers and small-scale commercial farmers. The former are concerned with ensuring a food supply and the latter with profit. They usually differ in tenure of land farmed, cropping systems, farming objectives and wealth.

Throughout the islands, bananas and plantains are used both as dessert and for cooking when still green or in the case of the *Musa* genomes ABBs and AABs also when ripe. A total of 22 varieties are known in Zanzibar (Fundi 1990). The names of some of the varieties vary with location, but the most predominant are those of AAA and AAB subgroups with seven and eight varieties respectively, the AA subgroup with three varieties, the ABB subgroup with three varieties and the AB with one variety.

At present, the overriding constraint to banana/plantain production as revealed by a Participatory Rural Appraisal (PRA) and a diagnostic survey is poor soil fertility followed by nematodes (*Radopholus similis*, *Helicotylenchus multicinctus* and *Pratylenchus coffeae*), the disease black Sigatoka caused by the fungus *Mycosphaerella fijiensis* Morelet, which attacks the leaves thereby reducing the photosynthetic area and hence the yield. Other constraints are Panama disease *Fusarium oxysporum* f.sp. *cubense* (much more prevalent in the coral rag area) and to a much lesser extent the crop is attacked by weevils Cosmopolites sordidus. The situation is aggravated by lack of proper management.

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The extent of damage caused by nematodes, weevils and black Sigatoka has been assessed during the *Musa* diagnostic survey of the islands.

Due to the complexity of the pest problems, isolated control measures for combating individual pests is not seen as the best option. What is required is a holistic approach, whereby the crop is managed within its cropping system. Such an approach is called integrated pest management (IPM). Many definitions of IPM exist, one of these is as follows: "A pest management system that in the socioeconomic context of farming systems, the associated environment and the population dynamics of the pest species, utilizes all suitable techniques in as compatible a manner as possible and maintains the pest population levels below those causing economic injury" (Smith and Reynolds 1996, Dent 1991). Some definitions emphasize the use of non-chemical control methods, others mention damage threshold levels, but all definitions point to a set of common characteristics. Characteristics of an IPM approach are the use of all available, suitable methods of prevention and control, including resistant varieties, cultural methods such as planting time, the use of sword suckers, hole size and spacing, desuckering, deleafing, intercropping and crop rotation, biological control, and pesticide only as the last resort, but preferably selective ones, or used in a selective way to prevent detrimental effects on natural enemies and other non-target organisms. This will conserve the ecosystem and stimulate the presence of natural enemies. No total eradication of all noxious organisms is aimed, but keeping them at a low level. Technology is developed by farmers in close cooperation with researchers and extensionists. Farmers make their own decisions and carry them out.

In Zanzibar, an IPM system is not prompted by problems of over-use of pesticides, nor by resurgence because of pesticide use. Nevertheless, pesticides are being used, notably on vegetables and posing hazards of poisoning by high residues. With increased market potentials, the demand for pesticides will increase, and negative effects will become more pronounced. Thus there is a need to demonstrate that IPM is a reliable and economic alternative to an over-reliance on pesticides. Unfortunately, this can most convincingly be demonstrated in cases where there is already an over-use of pesticides. In such situations, the effectiveness of the IPM strategy can be proven quantitatively by a reduction in pesticide use, a reduction of costs to the farmer, increased yields etc. Besides being of direct benefit to the farmer, such a situation contributes much to creating awareness of IPM among politicians, administrators and the general public.

Banana/plantain IPM activities

Activities executed by the banana/plantain IPM group of the Plant Protection Division are as follows:

- Formation of farmers' groups (following PRA)
- Training of Trainers (TOT)
- Establishment of plots to serve as Farmer Field Schools (FFS)
- Establishment of Participatory Action Research (PAR) plots
- Fortnightly meetings with farmers.

Formation of farmers' groups

Farmers' groups of between 4 and 29 were formed following PRAs. The criterion for selecting the farmers was those growing bananas/plantains either for subsistence only or also for sale. The farmers were identified by the District Plant Protection Officers (DPPOs) and Block Extension Officers (BEOs) and invited to take part in PRAs. Farmers were asked of their willingness to form a group during the PRAs. By using PRAs, baseline information was collected. This included passport details of the farmers, banana/plantain varieties grown, preference and reason for preference of the different varieties, cropping systems, crop husbandry, pest problems, pest control practices costs involved and other constraints to banana/plantain production. This allowed the IPM system to take into account the farmers circumstances in terms of their perception, needs, objectives and constraints including resources, thus placing the IPM system in the context of the overall farming system and the social and political forces acting on it.

Training of Trainers (TOT)

A total of six trainees (from the PPD and other sections of the Ministry) were trained on IPM methodologies and good banana husbandry.

These trainees serve as facilitators in the Farmer Field Schools.

Special topics taught during the TOT were:

- Growing a healthy banana/plantain crop
- Crop growth stages
- Pests and diseases identification and management
- Identification of beneficial insects
- Insect zoo establishment
- Weevil trapping
- Intercropping.

Establishment of Farmer Field Schools (FFS)

Farmer Field Schools are basically schools without walls. These are fields established whereby farmers and facilitators learn how to grow a healthy crop. The fields are divided into plots in half of which the crop is grown following IPM recommendations, and in the other half following farmers' practice (FP). A number of such fields were established in both the islands of Zanzibar (Unguja and Pemba) (Table 1). From the onset of land preparation, special topics on hole size, spacing, selection and treatment of planting material were delivered to the farmers. In addition, farmers and facilitators conduct Agro-Ecosystems Analysis (AESA) of the plots whereby they assess the crop's growth and disease/pest pressure within its ecosystem. This is the first activity carried out early in the morning during meeting days. The growth measurements taken are plant height and girth. Number of standing leaves (Sigatoka pressure) and presence of pest and beneficial insects is also recorded. A comparison of the IPM plots and FP plots are made at the end of the AESA. This is carried out under a shade where the participants and

farmers sit and do the analysis of the day's work. During such sessions, data is processed, presented, discussed and, where possible, recommendations given.

Alongside the IPM and FP plots, Participatory Action Research (PAR) is carried out whereby farmers do small experiments besides the FFS plots to evaluate matters that interest them. For example with some of the groups farmers decided to look at the effects of intercropping bananas with cocoyam and to assess the difference between hoe weeding and slashing.

Table 1. Components considered in FFS plots.

Components	Packages	
	IPM	FP
Variety	Mkono wa tembo	Mkono wa tembo
Selection of planting material	Good	No selection
Manuring	Use of manure	No manure
Paring of corms	Paring of the corm	No paring
Spacing	2.5 x 2.5	Irregular
Desuckering (hill capacity)	3	No desuckering
Hole size	60 x 60 x 60 cm	Irregular
Weeding	Time specific	No weeding
Mulching	Yes	No

Fortnightly meetings with farmers

Facilitators and farmers meet once every fortnight to carry out the above activities from 8.00 am to 12.30 pm, and the TOT is carried out from 2.00 pm to 5.00 pm. Schedule of a full day's activity is given as Annex 1.

Conclusion

The PRA at the beginning of the programme aims at documenting farmers' perception of the problems facing banana/plantain production in Zanzibar and identify some of the major constraints that the farmers in Zanzibar will need to address in implementing IPM, for example, land tenure, lack of capital, lack of knowledge and agroecosystem complexity.

The approach taken will look at the economics and social benefits of banana/plantain IPM programme. It will make the farmer an active participant and not a passive receiver of recommendations. He/she will be able to :

- grow a healthy crop,
- recognize pests, diseases and beneficial insects (potential natural enemies),
- carry out regular observations on components of the package,
- make the right crop protection decision, through discussion with other farmers and facilitators,
- carry out his/her own experiments.

The above will in the long run empower the farmers by making them aware of IPM problems facing banana/plantain production, make them better managers of their crop, and consequently bring about an increase in production, thereby alleviating the shortage of bananas/plantains, and increase food security as a whole.

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Annex 1. Schedule of full day's activities at Farmer Field School.

Time	Activity
8.00-8.45	Prayers, roll call and briefing
8.45-10.00	Agroecological System Analysis (AESA) data collection, Participatory Action Research (PAR) data collection
10.00-10.45	AESA data processing
10.45-11.30	AESA data presentation, discussion and decision-making
11.30-11.45	Ice breaking/Group dynamics
11.45-12.15	Special topic
12.15-12.45	Evaluation and planning for next FFS
12.45-1.00	Prayers and closing

Management of pests and diseases of banana in Kenya: a status report

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Introduction

Bananas have played and continue to play a major role in the diets of the people and the economy of Kenya. It is an important food crop providing carbohydrates for both rural and urban households. They are a source of income for the majority of smallholder growers. The year-round fruiting habit of the crop ensures food security at household level with a potential of sustaining food supply to urban markets especially in periods between cereal crop harvests. This potential coupled with the environmental conservation attributes of the plant makes banana an ideal crop for economic growth and sustainability of the agricultural resource base.

Banana production and area

The area under banana and plantain cultivation in Kenya was 115 500 ha in 1989 and this has increased to 125 000 ha in 1997 with a corresponding production of 520 000 and 595 000 metric tonnes, respectively. This gives only a production output of between 4.5 to 4.8 tons/ha which is quite low (Wabule 1998). In the highlands of the central, eastern and coastal regions, dessert cultivars are very popular, especially Cavendish and Gros Michel while in the higher, western regions, the East Africa highland bananas (*Musa* AAA, Matooke and Mbidde cultivars) are very common.

Cropping patterns

In Kenya, bananas are grown mostly by small-scale farmers. However, there are very few commercial farms which produce bananas for export or consumption in big hotels. In

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[5] MOALDM, Kisii, Kenya

the commercial farms, preferred cultivars are grown in defined rows and spacing. Farmers like intercropping a variety of crops with bananas which include cereals, legumes, root crops, plantation crops, tree crops, fruit trees and vegetables. Twelve percent of the farmers were observed to grow bananas as monocrop, 60% as mixed crop and 28% adopted monocrops in the rest of the land (Prasad *et al.* 1999).

Management practices

In a survey, it was found that only 14% of the farmers followed good management practices, 52% average and 34% of the farms were neglected.

Farmers' perceptions

All the banana-growing farmers interviewed were unanimous in agreeing that banana is an important crop for them and it provides food and economic security. Ninety percent of their knowledge on the banana farming comes from relatives, neighbours, parents, and friends and 7% from government extension services. Only 15% of the farmers had knowledge on the damage caused by the weevils and they had no knowledge on the nematodes or the damage caused by them.

However, in a survey conducted in Rachuonyo district in 1996, farmers' ranking of constraints to banana production revealed a large (14) number of bottlenecks but the two single most important ones are diseases and labour. Insect pests were rated very low due to poor understanding of weevils and nematodes but pests and diseases as a syndrome have the highest share, 34% of weighted scores.

Production constraints

In Kenya constraints affecting banana production have been identified based on surveys and rapid rural appraisal studies. This has been necessary to understand production constraints as perceived by both farmers and researchers. From this, it has been clear that constraints are both abiotic and biotic in nature. They include the banana pests (banana weevil *Cosmopolites sordidus* Germar, a complex of nematodes and thrips) and diseases (black Sigatoka, yellow Sigatoka, *Cladosporium* freckle, Panama, cigar-end rot and viral diseases), declining soil fertility, poor crop management, lack of clean planting material, poor marketing infrastructure, postharvest losses, competition with other crops for land, labour and capital, genetic erosion and lack of inputs/credit facilities. In order to address some of these constraints, efforts have been made by the NARES and IARCs, especially ICIPE, to develop and transfer appropriate technologies to the farming communities and extension personnel.

Distribution of banana pests

The banana weevil *Cosmopolites sordidus* infestation was recorded in all the banana-growing areas in Kenya and the percentage coefficient of infestation (PCI) was more

than 20% in all the 22 districts surveyed. In Kwale and Embu districts, upto 100% PCI was recorded. In coastal and central provinces, silver corky scab caused by thrips on the raw fruits was observed (Prasad *et al.* 1999). On the shores of lake Victoria, weevils such as *Temnoschoita nigroplagiata*, *T. erudita* and *T. basipennis* were observed feeding on the decaying banana plant material.

A complex of banana nematodes (*Pratylenchus goodeyi*, *P. coffeae*, *Radopholus similis*, *Helicotylenchus multicinctus*, *Meloidogyne* spp.) were common in many banana fields in Kenya. At the coast, up to 200 masl, *H. multicinctus*, *Meloidogyne* spp. were observed in high densities. In the western region, *H. multicinctus* was common, although generally in moderate densities. *Radopholus similis* was observed in central and western regions. In the central and western regions, higher than 1000 masl, the lesion nematode, *P. goodeyi* was the dominant species and it was also observed on a Matooke cultivar grown at Kilifi, coast region. In the central region, in Muranga district, where coffee is being replaced with banana, *P. coffeae* is commonly found. In addition, *Rotylenchus clavicaudatus* (in high numbers in Homa Bay district), *Scutellonema* spp., *Criconema* spp., *Xiphinema* spp., *Hemicycliophora* spp., and a new *Trophurus* sp. were recorded (Seshu Reddy *et al.* 1997).

Management options for the pests of banana

Habitat management

Habitat management is the only available control option for the small-scale growers for the banana pests and diseases. In subsistence production systems common in Kenya, the returns are too low to allow meaningful investment into pest and disease control measures. IPM opportunities that offer less capital investment therefore offer long-term sustainable control practices particularly for the small-scale farmers.

Use of clean planting material

Banana pests (weevils and nematodes) are dispersed mainly through infested planting material. Since these pests, especially the weevils, rarely move far, the adoption of clean planting material reduces infestation to new plantations and therefore delay pest population buildup. The process of selection and cleaning through paring and hot water treatment should be encouraged among the small-scale farmers. In western Kenya where the Ministry of Agriculture, Livestock Development and Marketing has been working with ICIPE on banana research, the indications are that farmers are taking up these IPM practices.

Improved agronomic practices

The adoption of practices that encourage vigorous crop growth leads to less attack and losses caused by the banana pests. These practices include deep planting, weeding, mulching, the application of organic manure. It has been shown that the use of guano manure in particular leads to reduction of banana nematodes. The use of mulches has been shown to result into better bunch weight as a result of improved plant vigour. The depth of planting particularly leads to good plant anchorage and discourages the weevil

attack as the corm remains buried deep. This leads to delayed attack. Good weeding also reduces weed competition and further removes some weeds such as *Commelina bengalensis* L. and couch grass which are alternate hosts of the banana nematodes.

Management of crop residues and trapping

Destruction of crop residues of the harvested plants reduces breeding sites for the weevils near the mats and reduces subsequently the damage. The crop residues can then be used as mulch or for traps. The use of pseudostem traps continuously leads to low weevil population and reduced damage to the banana. Trapping can be intensified during the rainy seasons when trap catches are improved by the moisture. Trapping requires labour and pseudostems which at times may be in short supply.

Cropping systems to reduce pests' attack

In Kenya, the small-scale farmers grow banana in association with other crops, thus leguminous crops which do not compete with banana are desirable. Most of the intercrops however have limited direct effect on the weevil due to weevil specificity to the banana. Thus, the use of intercrop combinations that may reduce banana yield, such as sweet potato, may be discouraged. In addition, the farmers often grow more than one variety of banana, hence tolerant varieties (dessert types) are often found together on the same homestead or farm with the susceptible cultivars.

The perennial nature of banana makes short-term rotation not possible in the small-scale subsistence sector. Plantations are often many years old and still in production even where pest and disease pressures have increased. In order to do a rotation, then sequential rotation is advised depending on the land holding and the circumstances of the farmer. A section of the farm can be uprooted of banana and rotated with another crop and then banana reintroduced later on.

Host plant resistance to weevil and nematodes

Among many pest management technologies, improved banana cultivars with high levels of resistance/tolerance could offer one of the solutions to weevil and nematodes. Fox example, in the studies conducted in Kenya with eight banana cultivars, Seshu Reddy and Lubega (1993) found Nakyetengu (AAA-EA) and Gonja (AAB) to have a higher level of survival rate of the weevil in both field and laboratory tests than the sweet type Sukali ndisi (AB). In another study, 48 banana cultivars with diversified traits were evaluated for the weevil development, survival and extent of damage caused to the rhizome and pseudostem. Among these, several dessert types including white Muraru (AA), Kamara Masenge (AB), Gabon (AAA) were found to be tolerant. In general, beer, roasting and cooking type bananas were found to be more susceptible to the weevil. However, there were significant differences in the number of weevils survived/developed and damage caused between and within genome groups (Seshu Reddy 1996).

Musabyimana *et al.* (1996) evaluated 19 diversified banana cultivars (6 AAA-EA, 3 AAA, 3 AA, 2 AB, 3ABB and 2 AAB) and found that they differed significantly for *C. sordidus* damage and their ability to support nematodes. The highland cultivars (AAA-EA) were more susceptible than other genome groups. The diploids, Njuru (AA) and Muraru

(AA) were found to be tolerant to both weevil and nematodes. However, their potential productivity is relatively low (7-11 kg/bunch) compared to AAA-EA (more than 25 kg/bunch).

Natural enemies of the weevil

In western Kenya, 12 predators of the weevil have been identified and their potential impact on banana weevil populations has been studied by Koppenhoffer (1993). He found that three predators viz. *Dactylosternum abdominale*, *Euborellia annulipes* and *Eutochia* spp. significantly reduced the weevil egg and larval populations on 6-month-old banana suckers under controlled conditions. The adult weevil has been observed to have no predators or parasitoids in Kenya.

Isolates of *Beauveria bassiana* and *Metarrhizium anisopliae* were pathogenic to the third instar larvae causing 98-100% mortality after nine days, whereas *B. bassiana* was also pathogenic to adults causing from 63-97% mortality by 35 days (Kaaya *et al.* 1993). A bacterium, *Serratia marcescens* was found to be less effective against the weevil (Kaaya *et al.* 1993).

Semiochemicals for weevil management

Semiochemicals have been found to play a role in the attraction and orientation of the weevils to the host plant. At ICIPE, the evidence for volatile male-produced aggregation pheromone was found and pheromone components were identified and synthesized. In addition, a strong response of the banana weevils to kairomone components with high attractivity to the weevil has been identified (Budenberg *et al.* 1993a,b, Ndiege *et al.* 1991, 1996).

ICIPE is exploring the potential of a combined use of the existing trapping technology as a mass trapping and/or pathogen dissemination vehicle to control the banana weevil and to exploit the crude kairomone extracts from the most susceptible banana varieties and/or semiochemicals already identified.

Use of neem in banana pest management

The use of neem as a repellent is being explored at ICIPE. Treatment of pseudostem traps with neem oil (1-5%) has been found to inhibit the growth of weevil larvae up to 14 days. Neem repels the insects and treated corms show less weevil damage. Preliminary field trials suggest that three applications per annum are sufficient to protect bananas from weevil and nematodes attack (ICIPE 1997).

Use of insecticides

The application of insecticides for the control of banana pests among the small-scale farmers in Kenya is negligible. Limited use of insecticides is however now practiced by a few commercial farmers growing dessert-type bananas mainly for the urban markets. These farmers should be exposed to IPM to strengthen their knowledge, practice and decision making.

Management options for the diseases of banana

The main foliar diseases of banana in Kenya are black Sigatoka *Mycosphaerella fijiensis*, yellow Sigatoka *Mycosphaerella musicola* and *Cladosporium* freckle. Black Sigatoka has been severe in the Coastal, Central (except around Mt. Kenya) and Eastern Provinces. Symptoms related to *M. fijiensis* are not observed at elevations above 1300 masl. Although severe damage is caused to the banana by the foliar diseases, they are not usually killed unless infection is very heavy on a susceptible cultivar. Yellow Sigatoka is present in all banana-growing areas in Kenya. Mixed infections of black/yellow Sigatoka and other foliar diseases do occur, making it difficult to distinguish in the field. These diseases are particularly serious during the dry months. The leaf spot disease caused by *Cladosporium musae* is common on the East African highland banana (AAA-EA). It tends to be abundant on older leaves. Symptoms consist of patches of yellow orange discolouration producing mosaic-like symptoms. The disease can be serious if younger leaves are affected. However, if older leaves are affected, and the plant is well managed, then there is no economic loss caused.

The control of these foliar diseases are mainly through culturally-based practices. Good drainage and even spacing of plants in the field giving a closed canopy and application of organic manures result into a vigorous sturdy plant. The affected leaves should be chopped and burnt. The use of sytemic fungicides has been recommened but is not applicable to the small-scale growers due to costs involved. Resistant cultivars can also be planted. For eradication purposes where the diseases occur, quarantine can be imposed to limit the spread of the diseases. This is not easy to achieve since a lot of planting material changes hands from farmer to farmer.

Panama disease, a fungal disease caused by *Fusarium oxysporum* f.sp. *cubense* was observed in Kenya for the first time in 1952 in Malindi and Muranga on a cultivar suspected to be Bluggoe (ABB), locally called Bokoboko. In the mid-1990s the disease has been reported in other banana-growing areas in Kenya. The affected varieties include the Gros Michel (AAA), Sukari (AB), Bluggoe (ABB) and Pisang awak (ABB) and Muraru (AA). The pathogen spreads between areas mainly through affected planting material. Movement of banana trash and contaminated soil by man and agricultural implements, surface flood waters and irrigation also aid in the transfer of the pathogen.

The disease can be prevented through adoption of clean planting material, improved crop hygiene and good soil fertility. Flood fallowing to a depth of 30 cm for four months has also been recommended though not easy to practice under small-scale farmer setting. The resistant varieties can be planted like the Cavendish group and the cooking banana cultivars. Quarantine can also be imposed in the movement of planting material from affected areas, though not easy to implement (Onyango 1998).

The fruit fungal disease cigar-end rot caused by *Verticillium theobromae* and *Trachysphaera fructigena* attacks the fruits of cultivars such as Muraru (AAA), Cavendish group (AA) and Gros Michel (AAA). The disease development is encouraged by damp weather. The East African highland bananas and the Sukali ndisi are not affected by the disease. It is managed by good bunch prooning.

The viral diseases of *Musa* in Kenya include Banana Streak Virus (BSV) and Cucumber Mosaic Virus (CMV). The control of viral diseases is mainly through sanitation where affected plants are destroyed. Methods such as cultivar resistance and vector control and phytosanitation have been advocated. Some of these methods are expensive and not yet being practiced.

Socioeconomic aspects

In Kenya, socioeconomic research on banana production has just started and on a very limited scale, mainly at ICIPE where only nine months of a scientist's time has been allocated to a project aiming to disseminate banana IPM technologies. There is therefore urgent need to design and implement a national socioeconomic research programme which is also integrated into the regional (BARNESA) and global (INIBAP) programmes. Two key components of the proposed research programme deserve mention. First, it should develop a three-tier methodology. It should start with participatory rapid appraisals to gain an understanding of end-users' perspectives and develop hypotheses for further testing. This should be followed by formal surveys in several zones representing various banana production systems. Since surveys largely rely on farmers' responses and, as a result, portray "reported behaviour", complementary data should also be recorded over time to portray "observed behaviour" and baseline productivity.

The second task is to determine the types of information to be generated. In this regard, key issues to be addressed are outlined and illustrated with results from the ICIPE's banana IPM project.

a. The role and importance of bananas in the production and cropping systems. The importance should be determined in terms of contribution to food security, cash income, resource allocation, etc. For example, whereas bananas are allocated only 14.3% of arable land in Oyugis, western Kenya, they are the most important source (42%) of cash income.
b. Characterization of banana production systems. There is need to determine the types of bananas grown, whether as single stands or intercrops, the scale and objectives of producers (sale, brewing, etc.).
c. Knowledge and control of major constraints. Pests and diseases, soil degradation and other constraints should be investigated. For example, farmers' assessment of damage due to banana weevils may differ from that of researchers; furthermore, farmers' assessment may not be commensurate with the measures they take to manage the damage.
d. Farmers' production resources. These include capital, labour, implements, credit, inputs and extension services available to banana producers. Studies carried out in western Kenya and elsewhere point to a general situation of severe constraints in available resources.
e. Banana production costs. Banana production is rated as labour-intensive; because of this, it is important to estimate additional labour and material (purchase of grass mulch) costs of, say, controlling banana weevils. This task has not yet been performed in Kenya.

f. Perceived and real benefits of pest and disease control. This is the cutting edge of banana pest control. Though necessary, it is not sufficient to merely determine the benefits, farmers should feel they are better off using the controls.
g. Cost/benefit analysis and impact assessment of pest and disease control. Reduction of pests and diseases and the attendant yield increases are achieved at a cost. Net benefits and overall impact of the interventions must be determined.
h. Determination of the factors influencing farmers' decision-making and use of pests and disease controls. Current work at ICIPE will soon throw light on this issue but nationwide studies still have to be done.
i. Postharvest and marketing. There is hardly any information on these two parameters in Kenya. Baseline information at ICIPE shows that farmers complain of poor marketing infrastructure. Unlike in neighbouring countries, there is no traditional or modern banana-based beer brewing industry in the country. Processing banana products into handicrafts is just starting in western Kenya, but no research has been undertaken on these aspects.
j. Approaches to dissemination of the banana IPM technologies. Research carried out at ICIPE shows that conventional extension approaches have failed to disseminate banana IPM technologies even after extension workers were trained by a combined team of ICIPE and KARI researchers. Research should be undertaken to determine the viability of alternative approaches, including farmer-to-farmer extension, to the dissemination of banana IPM technologies.
k. Decision-making tools for policy makers. In the absence of reliable research-generated information, policy makers are unable to make informed decisions. Research findings have to be transformed into decision-making tools for policy makers.

Enhancement of capacities in banana IPM for NARS, NGOs and farmers

There is still a knowledge gap particularly on banana IPM among the various farming communities and extension personnel in Kenya. In order to increase banana production, the transfer of knowlege must be well managed and the farmer-research-extension linkage strengthened. The production-to-consumer channel must also be improved to avail the relevant market information so that farmers become conscious of the market demands and produce good quality products. The decision-making process by the farming communities in adopting new techniques must be well understood, bearing in mind that in many cases farm operations are performed by women. In order to address some of these problems, the Ministry of Agriculture, Livestock Development and Marketing, the Kenya Agricultural Reseach Institute and ICIPE have organized joint banana IPM training courses in 1996, 1997 and 1998. The District Agricultural and Horticultural Crops Officers as well as NGOs from the main banana-growing districts have been trained on banana IPM. Farmers' mobile training workshops were initiated on trial basis and they are popular and very effective in banana IPM information dissemination (Seshu Reddy *et al.* 1998).

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Banana IPM in Uganda

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Introduction

Banana is the leading staple food as well as second commercial crop in some areas in Uganda. It is believed that banana was brought into the country by legendary Baganda predecessor, Kintu, and planted at Magonga in Busuju in Mpigi (Haig 1940). Apparently it is around this area that the first outbreak of banana weevil was recorded in 1918 (Hargreaves 1940). Banana in Uganda is grown as a perennial crop and plantations have been reported to remain productive for over 50 years (Haig 1940, Davidson 1940, Mukasa 1970). This practice of growing banana as a perennial crop for over 10 years has a bearing on its relationship with the soil and pests since there is no rotation to break off the pest cycle. By 1940, it had been observed that standard of banana husbandry in Buganda had deteriorated and yields were decreasing (Haig 1940). However, the period between 1952-1961 recorded considerable expansion of plantations in southwestern Uganda, Busoga in the East and Teso, Lango and Acholi in the North. For the same period Buganda registered very little change (Mukasa 1970). The expansion trend continued between 1970 and 1988 but with declining yields in the same period (Table 1) to the extent that some of the original major producing areas like Buganda are now importing banana (Karamura 1992). The reported decline in yield is attributed to poor management aggravated by decline in soil fertility and increasing pests (weevils and nematodes) and diseases (fusarium wilt) (Dungu 1987). New diseases (black Sigatoka and banana streak virus) have also contributed to the decline. The problem has caused geographical shifts and further expansion of plantations to areas which traditionally used to be pastoral in the southwestern part of the country (Gold *et al.* 1998).

Table 1. Banana production trends in Uganda from 1970 to 1988.

Year	1970	1980	1985	1986	1987	1988
Hectares (x 000)	909	1170	1209	1210	1336	1396
Production (tons)	7657	5699	5552	6660	7398	8440
Yield (t/ha)	8.42	4.86	4.59	5.50	5.54	6.26

Source: Ministry of Agriculture, Planning Division (1992)

[1] AHI/IITA, Mbarara, Uganda
[2] INIBAP, Kampala, Uganda
[3] IITA/ESARC, Kampala, Uganda

Historical records of IPM

During colonial to early independence period (1920s to 1960s), banana weevil and weeds were ranked top among the banana pest problems in Uganda (Haig 1940, Hargreaves 1940, Harris 1947, Whalley 1957, McNutt 1974) and diseases were categorized as non-epidemic which could cause severe losses only in localized areas from time to time. These included *Fusarium oxysporum* f.sp. *cubense* and Sigatoka (*Cercospora musae*). Observations on nematodes were very limited and their importance was not mentioned. IPM activities during this period were therefore only directed towards banana weevils and weed control. Records show that three components of IPM, cultural control methods, biological and chemical control, were introduced with very little or no research backing.

Cultural control

Cultural control measures for weevils were recommended without data on weevil ecology. The recommendations were based on reports from other countries (Jamaica and Australia) and were vigorously disseminated through leaflets, extension service and administration (Hargreaves 1940).

The recommendations were (Harris 1947):

- use of clean planting suckers;
- maintenance of complete cover of mulch in the banana garden;
- splitting the pseudostems and corms lengthwise into thin strips after harvesting. This action denies the weevils their breeding sites and at the same time provides mulch cover;
- cutting old shoots at ground level so as to leave no above-ground stumps that encourage the beetle oviposition;
- compacting soil over the cut rhizome to prevent access by the ovipositing weevil;
- trapping adults using pieces of rhizome or fresh pseudostems. However, the author thought that this measure required more constant attention than may be expected from African peasants and was only suitable for badly infested and isolated areas;
- executing all the above measures uniformly over a given area to avoid problem of migration and reinfestation.

These are the recommendations still being preached to farmers to date by extension agents and NGOs in Uganda. It was understood that their adoption would help to maintain soil fertility, suppress weeds and keep away the banana weevil (Harris 1947).

Biological control

Attempts at biological control took place in 1934 and 1935. A predatory beetle, *Plaesius javanus* Erichs. (Histeridae) from Java was released on Kibibi island in Lake Victoria where bananas were heavily infested with borers (Greathead 1971). Surveys conducted in 1944 did not record any living *Plaesius* and the weevil damage had increased. Like in

the case of cultural control, the predator was introduced without prior tests on its predatory capacity and survival ability in the new environment.

Release of *Plaesius javanus* in Tanzania in 1948 and in Mauritius in 1959 did not succeed either in controlling banana weevil (Greathead 1971). Two other beetle predators, *Hololepta* (*Leionata*) *quadridentata* (F) (Histeridae) and *Dactylosterum subdepressum* (Lap.) (Hydrophilidae) were also introduced against the banana weevil in Tanzania, Mauritius and Seychelles but did not succeed (Greathead 1971).

Chemical control

Dieldrin was recommended and used from the late 1950s to early 1980s (Whalley 1957, McNutt 1974, Sengoba 1986). However, dieldrin is now banned from the world market. Weevil resistance to dieldrin has also been reported from other countries and in Uganda (Gold *et al.* unpublished). Chemicals currently on the Ugandan market (furadan and dursban) have not undergone proper evaluation test and recommended dosage rates can not be relied upon (Tushemereirwe, personal communication).

Farmers' pest control measures

Major action against banana pests by farmers is directed towards weevils because most of them categorize weevils as their number one pest. The actions differ from place to place. However, destruction of spent corm and pseudostem (sanitation) is the most widely adopted compared to other cultural weevil control measures (Bananuka and Rubaihayo 1994). The methods of destruction/handling of the plant residues also vary among farmers and regions. The origin of sanitation practice is understood by the farmers to be the agricultural extension officers and NGOs who may have adopted it from the recommendations of the Agriculture Department during colonial era.

Other control options which are gaining popularity with the farmers include use of cattle urine (a few cases have been reported where human urine is being used), kitchen ash, a mixture of herbs like chillies. However, their origin and efficacy are not established. Farmers who have adopted these practices believe that they are effective, but it is hard to ascertain this fact because they are used in combination with other practices. Use of chemicals against weevils has been extensive in Masaka and Rakai Districts but not in southwestern Uganda. Some of those who use chemicals do not know details of the chemicals they have used. Apparently the weevil outbreak which was reported in Masaka in 1986 (Sengoba 1986) followed the use of 2.5% dieldrin which was suspected to be adulterated. Farmers who employ chemicals have since changed from dieldrin to furadan. A few of them use pseudostem traps laced with chemicals. An important observation in Sengoba's survey report (1986) was that most farms in which cultural practices were observed were less affected by weevils compared to those where dieldrin was used. Some farmers using dieldrin did not destroy harvested corms on belief that it feeds the younger suckers (Wortman *et al.* 1994).

Farmers' knowledge of nematodes is limited. However, they do report and describe toppling in their gardens. Toppling is a symptom of nematode problem in bananas.

Weed control is largely done manually by hand, but a few commercial farmers (especially in Masaka) have adopted herbicides. By far most farmers use mulch at varying intensity to provide nutrients and suppress weed growth.

The effectiveness of farmers' practices is yet to be determined. There is a need to establish the effects of cultural methods on target pests on the long term and to do cost-benefit analyses in order to compare them with other recommendations.

Recent advances (1990-1998)

Vigorous research on banana was initiated in the early 1990s with the establishment of the Uganda National Banana Research Programme (UNBRP) in December 1988 (Mukibi 1994) and of the Eastern and Southern Regional Centre by IITA in Uganda. The UNBRP phased its research agenda to run consecutively as follows: Rapid Rural Appraisal, diagnostic survey and on-farm/on-station research (Karamura *et al.* 1994).

Rapid rural appraisal and diagnostic survey

Surveys (starting with Rapid Rural Appraisal followed by diagnostic survey) were conducted between 1991 and 1994 by a multidisciplinary team of researchers from UNBRP in collaboration with IITA/ESARC, NRI and Makerere University to generate baseline information on socioeconomics, soils and agronomy, pests, diseases, germplasm and postharvest. Notable information from the survey were (Karamura *et al.* 1994):

- Uganda has about 120 highland banana cultivars (AAA subgroup). However, there is a high frequency of somatic mutations in the subgroup. Distribution of these cultivars within the surveyed sites was influenced by agronomic characteristics, pests and diseases, economic uses of cultivars and population movements.
- The banana weevil, *Cosmopolites sordidus*, was a key pest at all surveyed sites. However, highest densities were observed below 1400 masl, weevil populations being influenced by cultivar and type among other things. The highland group also exhibited differences in response to weevil attack.
- Although farmers did not know nematodes, the survey team observed the problem and identified various species of nematodes associated with bananas. *Pratylenchus goodeyi* (Cobb) Sher and Allen, *Helicotylenchus multicinctus* (Codd) Golden and *Radopholus similis* (Cobb) Thorne were the most widely distributed and abundant. Species composition and distribution showed some relationship with elevation and cultivars.
- Black Sigatoka, presumed to have arrived in the country in 1988, was observed at all sites below 1400 masl. A few highland cultivars were tolerant to the disease.
- A condition exhibiting symptoms resembling Fusarium wilt was observed on the highland banana but was limited to the highland districts of Kabale,

Bushenyi and Mbarara in the southwest. The disease has now been named 'Matoke wilt' (Kangire, unpublished).

- Low potassium and phosphorus levels was noted as the major soil fertility constraint in most sites in Central Uganda.

Banana cultivar collection

- A checklist of cultivars found in Uganda has been compiled and published (Karamura and Karamura 1994). This has solved the longstanding problem of synonymous nomenclature and paved way for characterization studies.
- Cultivar collections totalling 300 local and 35 exotic entries (from INIBAP, IITA and FHIA genebanks) have been established at Kabanyolo, Kawanda and Mbarara.

The survey studies identified the key constraints, leading to their prioritization and to the initiation of research intervention. Pests, diseases and associated agronomic factors were identified as key constraints requiring urgent research attention.

On-station research

On-station strategic research activities were initiated in 1991 and have continued to expand at Kawanda, Kabanyolo and Namulonge research stations. Highlights of some of the achievements are presented in this volume: biology, dynamics and pest status of banana weevil (Gold *et al.*); microbial control (Nankinga *et al.*); host plant resistance to weevils (Kiggundu *et al.*); biology, dynamics and pest status of nematodes (Speijer and Fogain); habitat management and cultural control of nematodes (Kashaija *et al.*); banana diseases (Tushemereirwe and Bagabe, Holderness *et al.*); breeding for resistance to diseases (Vuylsteke and Hartman); fusarium wilt distribution and control (Rutherford and Kangire).

Banana weevil

- Basic information on methods of assessing banana infestation by weevils have been tested and adopted (Ogenga-Latigo and Bakyalire 1993, Gold *et al.* 1994a).
- Weevil oviposition behaviour in relation to plant age has been studied and elucidated (Abera *et al.* 1997). Weevils prefer older plants to young suckers for oviposition.
- Studies on integration of pseudostem trapping with chemical control tested at Kabanyolo Research Station revealed that contact insecticides, primicid and dursban were more efficient than systemic (furadan) for use with trapping. Saturated trapping (one trap on every mat) without chemical use reduced weevil population from 3.8 to 0.6 per trap in 10 weeks (Massanza 1995).
- Potential for biological control using locally extracted soilborne fungus (*Beauveria bassiana*) has been demonstrated in the laboratory and field cases (Nankinga 1994, Nankinga *et al.* 1996, Nankinga and Ogenga-Latigo 1996). Suitable formulation methods for large-scale on-farm testing are being investigated.

Adaptive research

Banana weevil

Pilot sites for on-farm trials have been selected for validation of technologies. These sites also provide ground for researcher-extension-farmer interactions and bases for technology transfer.

Work on one of these sites in Ntungamo District has gone on for three years (since December 1995) under the sponsorship of African Highlands Initiative (AHI) and joint implementation by NARO, IITA and Ntungamo District Agricultural Extension Department. Highlights of this work are presented below.

The study looked at interactions between weevils and nematodes on one hand and soils on the other, with a view to developing IPM strategies. Pests and soil fertility are the key constraints identified as the causes for decline and shifts in banana production. It is important to note that cultural recommendations by Hargreaves (1940) and Harris (1947) were adopted without empirical data backing the basis on which they were made. The recommendations have also been variably adopted, thereby raising queries on their effectiveness. For example some farmers have reported complete loss of banana plantations despite adopting mulch and manure. These amendments are good for soil fertility maintenance and banana yield, but their effects on the pests are not known. Previous recommendations only looked at the yield without looking at what happened at the base of the plant and pest populations, and comparative data on yield loss was lacking. Besides there is a need to identify the key actions that will suppress weevil and nematode populations and hence be emphasized in an IPM strategy.

Banana weevil populations were estimated from the farms following the mark-and-recapture method described by Southwood (1978). Corm damage (cross-section) from weevils were estimated from newly harvested plants (i.e. <14 days after harvesting) using the scoring system used by Taylor (1971) and modified by Gold *et al.* (1994b).

The participatory rural appraisal revealed that the community depended heavily on banana for food and cash income but the plantations were declining due to lack of proper management, declining soil fertility and weevils. Diagnostic survey results showed that all the farms had weevils but population densities differed among villages and among farms (ranging from 1600 to 150,000 per ha). The density was however not correlated to corm damage. Agronomic practices varied a lot among farms but crop sanitation (removal, shredding and spreading spent corm and pseudostem) was the only practice which suppressed weevil population and damage (Table 2). The soils were not very poor but were low in organic matter and potassium.

Studies were undertaken on the effects of cultural soil fertility management practices (soil conservation bunds, grass mulch and farmyard manure) on plant nutritional status, sucker growth/vigour, yield, and extent of corm damage by weevils. Sucker growth was faster and more vigorous on sections of farms where farmers constructed soil conservation bunds, applied mulches or farmyard manure compared to control (Fig. 1). Yields of the first cycle crop were higher in the mulched plots (Table 3). However, weevil damage after one year under mulch and/or soil conservation bunds

(improved soil management practices) was not significantly different from control (2.6, 2.1 and 2.0% respectively) (Fig. 2).

Table 2. Adult weevil population and corm damage under none/light and moderate/heavy sanitation management in Kikoni Parish, Ntungamo District in Uganda (1996).

Level of sanitation	No. of farms	Weevils per ha (x 000)[1]		Corm damage[2]	
		Mean	Range	Mean	Range
None/light	26	25.1	1.6-149.4	7.6	1.8-19.0
Moderate/heavy	24	11.8	2.5-32.8	3.2	0.8-6.0

[1] Weevil population significantly different (t = 2.29)
[2] Corm damage significantly different (t = 3.41)

Table 3. Banana yield from farmers plots with mulch and soil conservation bunds in Kikoni Parish, Ntungamo district (1997).

Treatment	No. of bunches	Mean bunch weight (kg)	Yield per plot1 (kg)
Mulch + contour bunds	27.3 + 2.1	25.1 + 1.4	661.7 + 44.4
Contour bunds only	21.8 + 0.7	24.3 + 0.7	523.0 + 23.0
Control	17.8 + 1.0	22.6 + 1.3	398.8 + 29.7
LSD 0.05	8.3	ns	220.1
CV	21.5%	12.9%	24.10%

[1] Plot size = 12 m x 36 m

Weevil trapping was evaluated under controlled conditions to dispel the controversy of its efficacy. Farms were stratified on the basis of weevil density per ha (determined by mark-and-recapture method) and grouped into three treatments: (i) control - no trapping; (ii) farmer-managed trapping (trapping at the farmer's capability – often carried out piecemeal); and (iii) researcher-managed trapping (involved trapping from all the mats in the farm using one trap per mat once every month). Trapped weevils were collected, counted and killed. Weevil damage was assessed every three months. The trial lasted from June 1996 to September 19997.

Weevil populations were significantly reduced under researcher-managed conditions (which were regular and intensive) (Table 4). Although weevil population in farmer-managed farms also decreased, relatively to control, the reduction was less than that achieved under researcher-managed farms. A decline in weevil damage was noted during the trapping period, but differences were not significant among treatments.

Discussions during periodic researcher/farmer/extension staff meetings to review the results concluded that although trapping reduces weevil population, it has serious limitations: (a) trapping is laborious; (b) trapping materials are limited at certain times of the year; and (c) weevil migration from neighbouring farms without weevil control measures can affect the achievements from trapping. Trapping should therefore be used in conjunction with other control measures at community level.

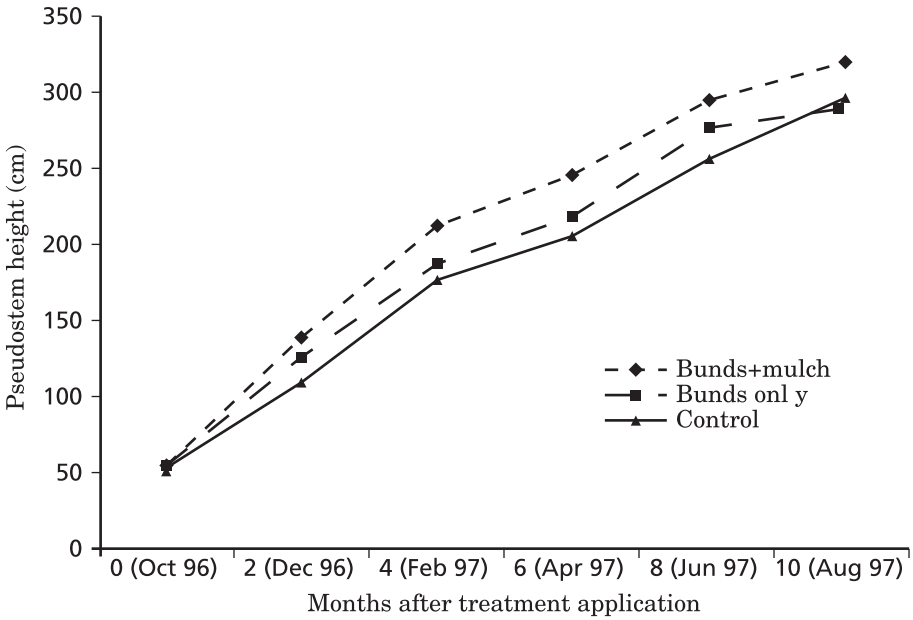

Figure 1. Sucker height (cm) in plots with different soil fertility/conservation management.

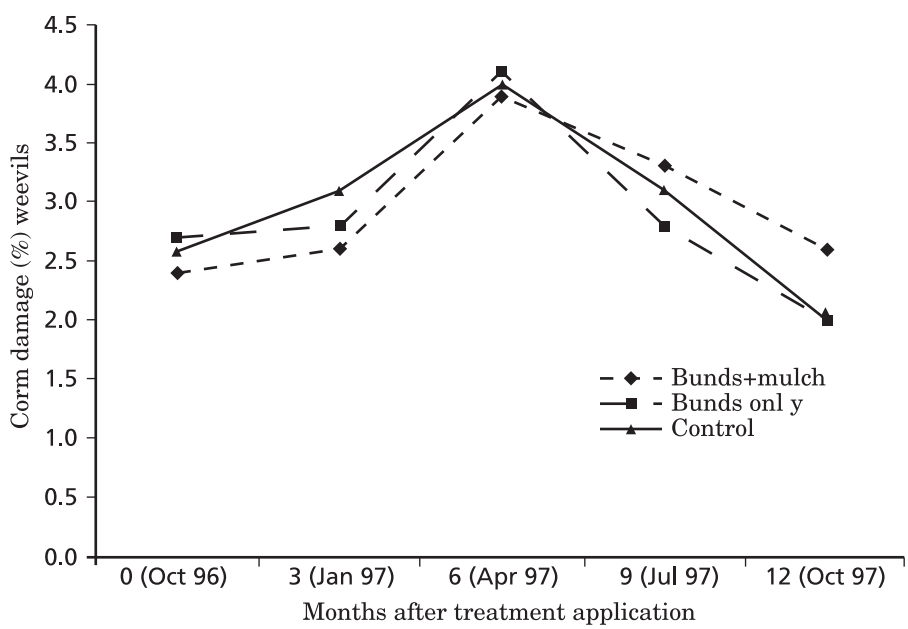

Figure 2. Corm damage (%) by weevils in plots with different soil fertility/conservation management practices in Ntungamo.

Table 4. Weevil adult population and corm damage increase/decrease between June 1996 and 1997 in the 27 trapping study farms at Ntungamo.

Trapping management	No. of farms showing				Mean reduction (%) under each management
	Increase (>+10%)	No change (+10 to -15%)	Medium reduction (>-15 to -50%)	Major reduction (>-50%)	
Weevil adult population					
Researcher	0	1	1	7	62
Farmer	0	1	3	5	48
Control (no trapping)	2	3	2	2	21
Corm damage					
Researcher	0	1	3	5	45
Farmer	1	2	3	3	30
Control	1	2	4	2	23

(N = 9)

Table 5. Number of farmers implementing different banana production technologies before and after farmer-to-farmer exchange tour.

Technology	No. of farmers implementing the technology*			
	Before the tour	Soon after the tour	Six months later	Total
Banana husbandry	1	4	15	20
Compost manure	0	4	11	15
Mulching	1	2	12	15
Soil and water conservation	0	11	8	19

*Number of interviewed = 20

Nematode control

In general there are no cultural practices that target nematode pests specifically. Survey studies have been carried out in Uganda. These studies revealed the presence of eight parasitic nematodes associated with bananas, including *Pratylenchus goodeyi* (Sher and Allen), *Helycotylenchus multicinctus* (Cobb) Golden, *Radopholus similis* (Cobb) Thorne which are associated with banana root necrosis worldwide (Kashaija 1996). The use of clean planting material to control nematode pest damage and spread has been recommended (Speijer *et al.* 1994). A few farmers have tried the use of pesticide such as furadan (carbofuran) to control the pests but the associated costs and health hazards have limited widespread use.

A few exotic cultivars such as Pisang awak, Yangambi Km5 and Gros Michel have been identified as tolerant to resistant to nematodes but these together constitute less

than 1% of the cultivars grown (D. Karamura, personal communication). No resistance has been identified in East African highland bananas although damage can be variable accross cultivars. Current studies by IITA and NARO are focusing on identifying host plant resistance to weevils and nematodes and on understanding the mechanisms involved as a basis for developing resistant cultivars through conventional and non-conventional breeding.

The use of non-host crops such as cassava and sweet potatoes in rotation with banana crops is reportedly promising. Nematode densities are drastically dropping following two seasons of root crop cultivation. However the effects on soil fertility following the cultivation of soil-mining root crops vis-à-vis banana yields have not been elucidated. Furthermore, there is a need to study the socioeconomics associated with the rotation system (banana/root crops) and to determine the duration required before rotating to the next crop.

Issues/questions

- Adoption of permanent production plots without rotation provides a stable habitat for pests. Is it logical to recommend rotation practice for farmers with large pieces of land?
- Chemical control is being discouraged and hence not looked at by the research programme, yet some farmers insist on use of chemicals. Lack of proper information and advice on use of chemicals is one of the causes for their misuse.
- Farmers are trying various control measures which require validation and standardization by researchers before their dissemination.
- Current IPM recommendations were not validated with the involvement of farmers and extension service. This has resulted in wide variability in adoption of the methods.
- Several problems are encountered in conducting on-farm IPM research:
  - small farm holdings restrict experimental layouts and hence validity;
  - variability in farmers' management causes high data variability;
  - patience and/or interest of farmers decline over a period (farmer incentive);
  - conflicts of agronomic and IPM advantages of the recommendations.

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Banana IPM in Tanzania

A.S.S. Mbwana and N.D.T.M. Rukazambuga

Importance of banana

Banana is a staple food to 20–30% of the population in Tanzania. It is produced mainly by subsistence farmers in kitchen gardens and small plots in many parts of the country, from seal level to the slopes of mount Kilimanjaro and all highland areas. The cooking banana in particular is an important staple crop in Kagera, Kilimanjaro, Arusha and Mbeya regions and is the preferred food for most local communities. Bananas have been grown in the area for long period and as a result have become an integral part of people's culture and diet.

Tanzania mainland produces 2.6 million tonnes of banana annually on 0.35 million hectares. In areas where management is good and pest pressure low, bananas are available throughout the year. The continuous availability makes banana an important food security crop in Tanzania. In addition to food security and fruit, the crop brings a steady income, complementing cash crops such as coffee. It is the most profitable crop with maximum rate of return for investment (labour, land and cost) in the region (J. Nkuba, unpublished data).

With mulching and weeding, farmers were able to maintain relatively high nutrient levels in their soils, allowing banana fields to last for up to 100 years. However, since the 1970s, production has been on decline, and highland bananas have almost disappeared from some areas (e.g. parts of Bukoba District in Kagera Region on the littoral zone). The severity varies from field to field and the fields are therefore categorized in four groups with different recommendations (Table 1).

However, production of banana in Karagwe District of Kagera Region, in the western part of the region bordering Mbarara and Ntungamo District of Uganda, has been increasing. This increase may be attributed to the good soil type coupled with less weevil and nematode pressure. Shifts of highland bananas from traditional production areas was also reported in Uganda (Gold *et al.* 1998), where weevils, nematodes and soil degradation are the major causes (Gold *et al.* 1993, 1998).

ARI-Maruku, Bukoba, Tanzania

Table 1. Banana field categories in Kagera Region of Tanzania.

Category	Description
A	Tall, healthy plants with big bunch throughout. Forms a complete cover. No fall down. No nematode root necroses and no weevil damage (field cleanness).
B	Generally healthy plants with big bunches, but occasional stunted plants are observed, bearing small bunches with or without fall down (less than 10% with root necrosis and/or 25% with substantial weevil damage) (spot control).
C	Reasonable plant growth but with small or moderate bunches; stunting slight or obvious and yield in general noticeable decline; poor plant cover; fall downs common (10-50%) associated with moderate to severe nematode root necrosis, more than 25% and or serious weevil corm damage; otherwise no other observable constraints to production (general control).
D	Banana in serious decline to the point of non-productivity. Small or no bunches, very weak or non-existent flowers. Very poor plant covers. Fall downs very common (more than 50%) and associated with severe root necrosis (more than 75%) and/or weevil corm damage; often occurring in areas of poor soil fertility (uprooting).

Source: Walker *et al.* (1983)

Production constraints

Banana weevil

Banana weevil is an important pest on highland bananas in the Great Lakes region (INIBAP 1986, Gold 1998, Rukazambuga 1996, Gold *et al.* 1998, Rukazambuga *et al.* 1998, Walker *et al.* 1983, Mbwana 1985, Sikora *et al.* 1989, Rukazambuga 1993, Gold *et al.* 1994b, Bosch *et al.* 1996). In Kagera region, banana weevil was found in all villages around Mtukula border with Uganda in 1939, and by 1941 it was found in all villages in Misenyi division (Anonymous 1941). The weevil is now present in all districts of Kagera region but most severe in Bukoba District where it has caused disappearance of highland cooking banana on the littoral zone (such as Bugabo Division). In this area, the highland cultivars have declined and are being replaced by the exotic types (less preferred for food), some of which are susceptible to fusarium wilt. It is believed that the shift of highland bananas from Bukoba to Karagwe District was caused by banana weevil, nematode and soil degradation (Bosch 1996). A similar pest–soil complex was observed in central Uganda (e.g. Iganga and Mukono Districts), where both banana weevil and nematode damage are very high (Gold *et al.* 1994b, Speijer *et al.* 1994b) and soil fertility is low. Yield loss studies are yet to be conducted in Tanzania.

Nematodes

The incidence of nematodes on bananas was first recorded in Tanzania in 1959 in an *ad hoc* nationwide survey (Whitehead 1959). The species recorded then included *Radopholus similis*, *Meloidogyne* spp., *Hoplolaimus* sp. and *Helicotynchus multicinctus*. Later in 1973, nematodes were associated with banana damage which was

reported in Bukoba District of Kagera Region in the early 1970s (Mbati 1974), and this was attributed partly to plant parasitic nematodes, in particular *Pratylenchus goodeyi* (Mbwana 1981) and *Radopholus similis*. Nationwide yield loss assessments have not been conducted, although losses are estimated to be more than 50% (Walker *et al.* 1983). Nematicide screening experiments at ARI-Makuru have given yield increases of up to 90% (Mbwana 1985), indicating that actual losses suffered may be higher than the estimates.

Nematodes are the most intricate and indeed most difficult banana pests for the farmers to appreciate. In this respect nematodes remain a very important production constraint of banana in Tanzania.

Nematodes damage was found to be exacerbated by presence of weevils, low soil fertility and poor crop management in the highland areas of Tanzania (Sikora *et al.* 1989). The combined effect has disrupted permanent nature of homesteads in Kagera region and caused emigration from villages on shores of lake Victoria westwards to Karagwe District where the soils are still fertile and the pest problem still minimal (A.S Mbwana and N.D. Rukazambuga, personal observation). In general, farmers moved with infested planting materials of their preferred highland varieties. Currently, nematodes are emerging as a constraint to banana production in these new areas.

Diseases

The leaf spot diseases in Tanzania include black Sigatoka (*Mycosphaerella fijiensis*), yellow Sigatoka (*Mycosphaerella musicola*) and *Cladosporium* spp. Black Sigatoka was first reported in Tanzania in 1987, and by 1990 it had been reported on all Cavendish cultivars in the regions along the Indian Ocean, in particular the Coast Region, Tanga and a part of Morogoro Region. The disease has not been reported in the high altitude regions of Mbeya and Iringa (> 1700 masl) (Bujuru, Nsemwa and Rukazambuga, unpublished data).

Fusarium wilt (*Fusarium oxysporum* f.sp. *cubense*) (FOC) is a serious disease and widely distributed in the whole country. In places where highland bananas are disappearing, they are being replaced with exotic bananas such as Gros Michel. Some of these cultivars are known to be susceptible to Fusarium wilt. It is therefore necessary to screen all imported banana planting material against FOC races 1 and 2.

Banana steak virus is the only disease reported in many banana-growing areas in Tanzania. However its distribution and severity among different banana genomes and agroecological zones is not known. A nationwide survey is required to establish its status in the country.

Soil fertility decline

Banana is normally planted on the best part of land in the homestead in Tanzania. At planting time every effort and resource is spent to ensure good establishment of the banana fields. However, at harvest individual fields support soil fertility depletion through harvested bunches (export of nutrients from the field). In highlands where banana is the prime staple crop, population pressure coupled with high rates of soil erosion necessitate continuous nutrient replenishment to maintain high productivity. The most common form

of fertilization is the farm manure from the farmer's own kraal. Cattle ownership in Kagera region stands at only 18% (Tibaijuka 1985, Bosch *et al.* 1996). Getting manure would mean very high costs to the farmers, many of whom could not afford it on a continuous basis. This has resulted into gradual decline of soil fertility, leading to banana production decline.

Poor agronomic practices

Banana management is variable from place to place, and in Kagera Region where highland bananas are staple crop, management practices such as mulching and weeding are done before short rains annually. These practices normally improve plant vigour and resistance/tolerance to pests and diseases. However when not applied properly they can lead to serious crop losses. For instance, many farmers mulch their crops with uncomposted organic material such as cow dung and coffee husks, which damages the root system, leading to yield loss. Other farmers intercrop bananas with beans (*Phaseolus* sp.) that are also alternate hosts of banana nematodes, thereby helping the buildup of nematode pests in banana crops.

IPM strategies for pests and diseases in mainland Tanzania

In Tanzania, much efforts have been made to develop intervention strategies against banana production constraints. Initially more emphasis was put on pesticide use and cultural practices. Each method had its deficiencies. The use of any control method depended largely on a combination of factors, including efficiency, price, safety to humans, animals and environment. Dieldrin was the first chemical in the 1970s, and its side effects on soil might probably have led to the widely toppling of bananas in the high rainfall zone of Bukoba District, leading to negative attitude towards chemical control among villages communities in Kagera region. This situation opened up for the search for alternative controls and the development of IPM strategies. To fit in the framework of IPM, chemicals were de-emphasized.

Chemical control

Use of insecticide was the first control strategy recommended to farmers in an attempt to supress banana weevils. During the 1970s dieldrin was the only available insecticide recommended against the weevil (McNut 19974) and therefore was imported and distributed to farmers free. In the 1980s farmers were advised to use carbofuran against nematodes and weevils. Many farmers seemed to be willing to use the chemical, but the prices were prohibiting to the small banana subsistence farmers (Table 2).

Table 2. Trend of the cost of Carbofuran 5G and revenue from banana sales in Tanzania during the 15-year period since 1982.

Item	1982	1984	1987	1990	1992	1994	1997
Furadan (Tshs/kg)	-	30	122	1060	1500	3000	4500
Furadan cost/ha (x 000)	-	5.4	22	200	270	541	810
Price (Tshs) of bunch (50 kg)	150	350	600	700	900	1200	2000
Price (Tsh) of bunch (50kg)	12	17	23	200	250	510	60

Cultural control

The difficulties of using chemical control as a strategy led to the development of cultural methods at ARI-Makuru in collaboration with ICIPE and the University of Bonn in Germany. After a series of verification trials, a number of cultural strategies were recommended for nematodes and banana weevil control.

Nematode control

Due to their microscopic nature, nematodes have always escaped notice by farmers. Hence farmers usually collect infected planting materials and plant them in new fields or in their already infested fields (Mbwana 1992). This system constituted a major means of nematode transmission from farm to farm. The following cultural practices are recommended:

1. Following of the field for 15 months (without bananas).
2. Clean planting materials obtained by
   i. corm paring,
   ii. hot water treatment of pared corms at 55°C for 20 minutes,
   iii. chemical dip of pared corm in suspension of Furadan for 24 hours (rate: 1 kg Furadan in 20 L water).
3. Manuring to
   i. improve plant vigour,
   ii. promote anti-nematode practices such as use of coffee husks, cow dung, compost etc.
4. Use of resistant varieties like some FHIA hybrids which are resistant (Table 3).

Table 3. Interim resistance characteristics of some banana varieties (from INIBAP Transit Centre at Leuven, Belgium) against major pests of bananas in Tanzania.

Variety	Resistance1				
	Use2	Weevil	Nematode	Panama	Leaf spot
FHIA-01	C,D	S	S	S	X
FHIA-02	C,D	S	S	S	X
FHIA-03	C	S	X	X	X
Cardaba	C,B	X	X	X	X
Pilipita	C,R	X	X	S	X
Km5	B,D	X	X	X	X
Saba	C,R	X	X	S	X
Pisang mas	D	X	X	S	X
IC2	M,D	X	X	S	X
K'masenge	D	X	X	S	X
Mysore	D,B	X	X	S	X
Pisang lilin	R	X	X	X	X
612	C,D	X	X	X	X
Pisang awak	C,B	X	X	X	X
IITA Hybrid	R	X	X	X	X

[1] Resistance: X: resistant; S: susceptible

[2] Uses: C: cooking; B: brewing; R: roasting; D: dessert

An *ad hoc* countrywide survey was conducted in 1959, however nematode species and severity distribution were not established. Such information would provide the current status of nematode and set the future course of action towards increasing and stabilizing banana production. Baseline information on species and damage severity distribution and mapping is wanting. Cultivar response to nematode damage is also yet to be established in the whole country.

Banana weevil control

As recounted earlier, many farmers were enable to use carbofuran for the control of banana weevil. A number of cultural control methods were developed or validated for use by our farmers. Those recommended include:

1. Clean planting materials by
   i. corm paring,
   ii. hot water treatment of pared corm at 55°C for 20 minutes,
   iii. chemical dip of pared corm in asuspension of Furadan for 24 hours (rate: 1 kg Furadan in 20 L Water).
2. Field hygiene (removal of dead leaves, chopping of harvested stems and regular continuous trapping using pseudostem/corm traps.
3. Resistant varieties (Table 3).

These strategies work in combination and require the devotion of the farmer. The merits of these strategies were observed at a contact farmer's field in Bukoba District, Kagera region (Table 4). The field had a pest complex of weevil/nematode, low fertility and poor management. The farmer was advised to uproot and replant using clean planting material followed by compost making and application, regular weeding, continuous trapping and removal of harvested pseudostems. The results are presented in Table 4. The number of weevils caught in the trap decreased with time. At the same time the number of flowered plants increased proportionally with decline in weevil population, indicating that a combination of weevil population control and improved agronomic management increased the proportion of flowering plants. The number of plants in the plots which were not attended declined and remained low throughout the study period.

Table 4. The effect of practicing trapping, field hygiene, clean replanting and manuring on weevil population and plant flowering during the first seven months.

Date	No. weevils caught	Flowered plants	
		Treated	Untreated
28/2/94	11 930	12	8
31/3/94	8579	19	4
30/4/94	3077	27	4
31/5/94	1776	22	2
30/6/94	2643	21	4
31/7/94	1530	31	5
31/7/94	-	65	5

Cultural disease control

Based on the experience with Furadan effectiveness and associate costs, chemical control of bananas diseases has been ruled out for Tanzania. Thus for banana disease control the following cultural practices are recommended.

- Field hygiene including
  - regular deleafing and burning affected leaves,
  - weeding as necessary,
  - desuckering to the right plant population.
- Use of resistant varieties such as FHIA hybrids which are mostly resistant to leaf spot diseases (Table 3).

Other control measures

Apart from the formal recommendations, farmers in Tanzania (especially in the highlands) practice certain operations which contribute directly or indirectly to banana improvement and are indeed some form of IPM. These are:

1. intercropping with beans to improve soil fertility in areas where nematodes are not prevalent,
2. crop sanitation e.g. desuckering and detrashing to reduce leaf spot diseases,
3. application of ashes to regulate soil acidity and improve soil fertility,
4. application of mulch to conserve soil moisture, increase organic matter and suppress weeds,
5. compost making and application to improve soil fertility,
6. removal of pseudostems of harvested bananas may reduce egg laying sites for weevils,
7. uprooting old tree stumps in banana fields to minimize armilaria rots,
8. selecting their best land for banana fields,
9. propping/guying to reduce wind damage.

   The frequency of application of these practices and the size of population using them is not known. There is an urgent need to quantify their importance and incorporate them into in IPM package.

Conclusion

Although banana production in the world has been increasing at an average of some 10% annually, that of Tanzania has stagnated over the same period in spite of increasing areas put under the crop every year. This is a testimony that productivity is decreasing.

In conclusion, the authors would like to stress that the lessons learnt in Tanzania strongly suggest that unless and until a sequential and holistic approach is developed and instituted, banana and plantain improvement will remain a paradox for a great many decades. Banana is a perennial crop and the probability of uprooting and fallowing the whole field is not likely, therefore the available option is to get clean sites for planting materials planted sequentially, followed by weevil management and regular trapping.

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IPM for nematodes on bananas in South Africa

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Introduction

Nematodes can cause considerable losses to banana crops (Keetch 1989), and therefore nematode control is of utmost importance. Until now, the only treatments available were class I pesticides which are expensive and very toxic. Other problems related to the use of these products are advanced microbial degradation, pH and temperature change sensitivity, persistence in the soil and contamination of ground water (Peoples *et al.* 1980, Zaki *et al.* 1982, Wixted *et al.* 1987, Davies *et al.* 1991). It is thus important to evaluate nematode control methods which are cheaper and/or less detrimental to the environment.

The scope of this study was to investigate the potential of several microbial or plant-based nematode control products to improve crop yield and quality (Table 1). In addition, the use of mulches, mycorrhizae and the potential of resistant plants was tested. Most of the commercial products tested originate from organisms which are normally present in the soil and exhibit nematode control activities. Mulches, tillage and mycorrhyzae are ways of promoting plant and root growth, thereby rendering a plant more tolerant to nematodes.

Material and methods

Nematode control

Some of the products tested, the active ingredient, the organism from which it is derived and its mode of action are given in Table 1. Products have been tested in the glasshouse and in field trials. The products tested were compared with an untreated control and a registered chemical. A mixed population consisting of *Radopholus similis*, *Meloidogyne* spp. and *Helicotylenchus multicinctus* was used in all glasshouse trials and the same populations were present in the field trials. Nematicides were applied at the registered dose which is 30 g fenamiphos per mat, 15 g cadusaphos per mat, 5 g fenamiphos in the plant bag and 2.5 g cadusaphos in the plant bag. Nematode extraction was done with the sugar-flotation technique of Jenkins (1964).

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Table 1. Summary of microbial or plant-based products tested for nematode control on bananas.

Product	Origin	Active ingredient	Mode of action
PL Plus	*Paecilomyces lilacinus* (fungus)	Spores of the fungus	Infests eggs and larvae
Biostart	*Bacillus* (bacteria)	Bacteria	Breaks down chitin
Agrimec	*Streptomyces avermirtilis* (fungus)	Abamectin	Paralyzes insects and pest organisms
Furfural	sugarcane	Furfuraldehyde	toxic to organisms - induces better microclimate around roots
Ditera	*Myrothecium* (bacteria)	Fermentation product	Infest eggs and larvae

Mycorrhizae

Arbuscular Mycorrhizal Fungi (AMF) are obligate symbiotic microorganisms that interact with the root system of the host plant. AMF were found to play an important role in the survival and growth of various micropropagated fruit crops like apple (Morin *et al.* 1994), pear and peach (Rapparini *et al.* 1994), because they render plants more effective in nutrient uptake (Berta *et al.* 1990), more resistant to transplant stress nematodes (Sikora 1992) and root pathogens (Dehne 1982), and improve plant growth (Gianinazzi *et al.* 1989). It is envisaged that these fungi be applied in the nursery to enhance the establishment of the small plantlets in the soil. The plantlets are seldom planted in virgin soil and therefore nematodes are most probably present. Soil fumigation is expensive and very toxic and therefore other options have to be found. If these fungi could also protect

Table 2. Cultivars and selections included in the cultivar and selection trials for nematode resistance.

AAAB	AAAA	AAA	AAB	AA	Selection Chinese Cavendish
FHIA 1-Goldfinger	FHIA 2	Yangambi	Prata Ana	Pisang mas	FBR
SH 3640	FHIA 17	Gros Michel			KBC1
SH 3641					KBC2
SH 3656					KBC6
FHIA 18					KBC7
					KBC8
					KBC9
					B45
					Eibelie

plantlets from being infested by nematodes during the first few weeks after planting, it would give the plantlet the opportunity to grow faster and establish properly.

Soil and roots have been collected in the banana-producing areas for identification and isolation of the AMF species present. This was done according to the technique of Morton *et al.* (1993). AMF-infested soil was also used to infest small tissue culture banana plants. These plants were left for 4 months to allow AMF establishment before nematodes were added.

In the first trial, nematodes were added as a mixed population on different species. In a following trial, *R. similis* obtained from carrot discs and *Meloidogyne* were used singly to infest the plants.

Selections and cultivars

In the past, several selections of Cavendish-type bananas have been produced by the local farmers; these plants, together with new cultivars are now being tested in all banana-producing areas for crop properties, fusarium resistance and resistance to nematodes. Nematode resistance was tested according to Speijer and De Waele (1997).

A glasshouse trial and two field trials were conducted to investigate the tolerance of Goldfinger to several nematode species, *R. similis* included. Tissue culture banana plants, 25-cm-high, of the cultivars Goldfinger and Williams were infested with a mixed nematode population collected in the field consisting of *R. similis*, *Meloidogyne* spp. and *H. multicinctus*. The plants were inoculated and differences in populations determined 2 months later.

Selection Dwarf Cavendish	Selection Williams	Selection Grand Nain	Selection Giant Cavendish
RS3	JBW	GN B/5/2	GCTCV 44A
RSS3	CRT	GN A/4/4	PK3
KBC4	Woelfe	GN A/5/9	PK4
KBC5	D5	Zelig	
Lancefield	EA1		
DC A/2/1	Take two		
DC C/3/4			
DC A/5/9			
Buena Vista			
R3			
B15			

Results

Microbial or plant-based products

PL Plus

Four doses of PL Plus were used and compared with an untreated control and cadusaphos at 15 g/mat. Results showed a reduction of nematodes comparable to cadusaphos (Fig. 1). PL3 at the highest dose was most effective in reducing nematodes in the roots. Figure 2 shows the decrease of nematodes caused by the PL products. Control was calculated by comparing the data in the treatments to natural seasonal fluctuations of nematode numbers in the control treatment. By calculating the factor with which the numbers vary, the effective change in numbers caused by the product can be determined. In the root samples, PL3 showed the best results followed by PL1, PL2, cadusaphos and PL4. In the soil samples, PL1 and PL2 followed by PL4 and PL3 were also more effective than cadusaphos.

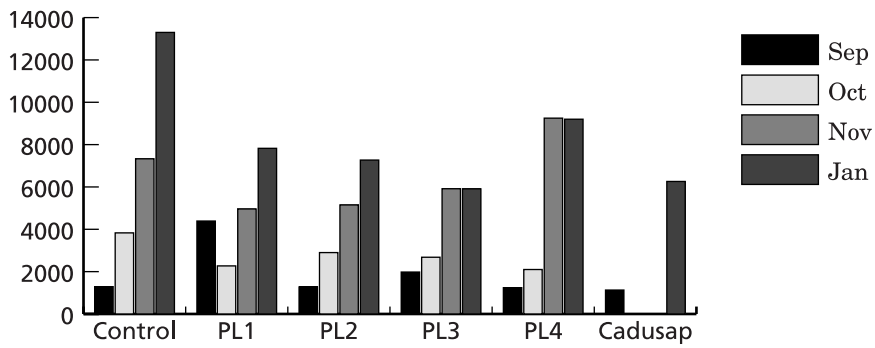

Figure 1. Number of nematodes in 30 g roots in the different treatments from September 1996 to January 1997, sampled monthly except for cadusaphos which was sampled only in September and January.

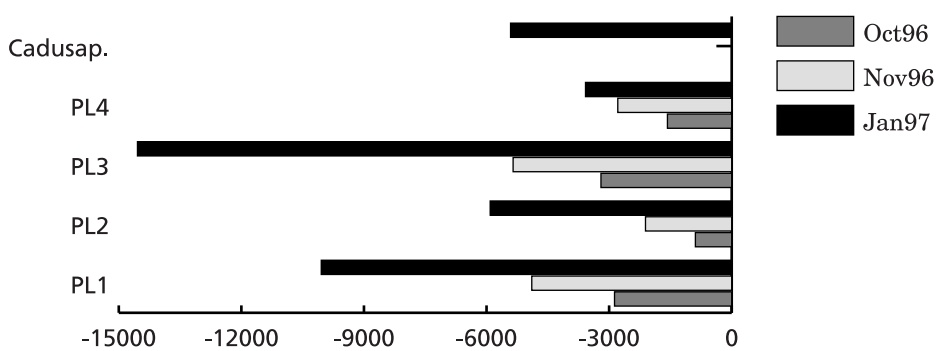

Figure 2. Effective decrease in nematode in number in 30 g roots with different PL Plus treatment relative to control numbers.

Biostart

Some of the bacteria induce root growth while others attack the chitin of the nematode egg shell, which inhibits egg development. Results showed that nematode numbers in the soil were reduced compared to the control and cadusaphos treatments. However, due to natural microbial competition in the soil, there was no long-lasting effect and nematode numbers increased steadily (Fig. 3).

Endoparasites like burrowing nematodes, which are present in the roots for most of their life cycle, cannot be reached by the bacteria and are therefore not greatly affected by this product. Since the product can break down the chitin in nematode eggs, this product will probably be more effective in plantations with only spiral and root-knot nematode infestations.

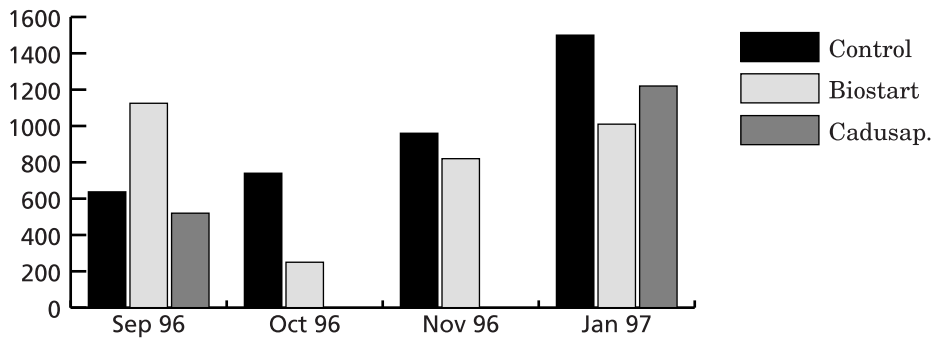

Figure 3. Number of nematodes in 250 ml soil of the different treatments from September 1996 to January 1997, sampled monthly except for cadusaphos which was sampled only in September and January.

Agrimec

In the glasshouse trial, Agrimec at 0.1 ml injection gave the best result regarding nematode numbers and root mass. Agrimec 0.1 ml and fenamiphos both caused an increase in root mass (Fig. 4). Agrimec at 0.1 ml per plant gave the best control of *R. similis*. All treatments did however reduce *R. similis* numbers in comparison with the control (Fig. 5). Clearly, however, the 0.5 ml Agrimec was less effective than the 0.1 ml

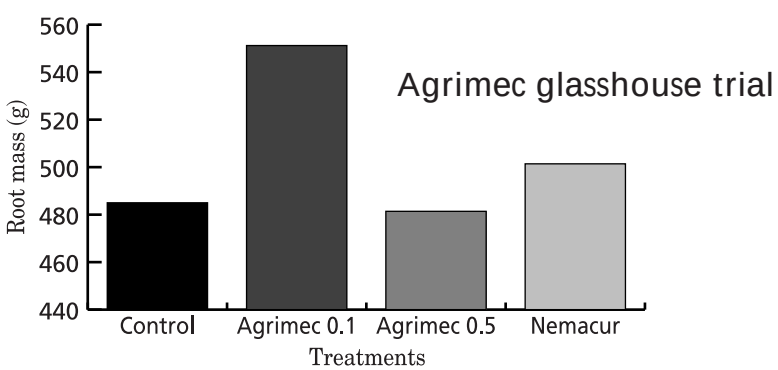

Figure 4. Root mass of the different treatments six weeks after application.

treatment. This is possibly due to the 0.5 ml dose being higher than the optimum. Some phytotoxicity was also observed in the plants. Phytotoxicity combined with damage caused by the injection needle lead to the differences observed.

Results obtained with Agrimec pseudostem injections in the field are shown in Figure 5. The 2 ml injection gave fairly good results and no phytotoxicity was observed on any plants. However the variation in numbers in the treatment itself shows some shortcomings in the injection method used for the trial.

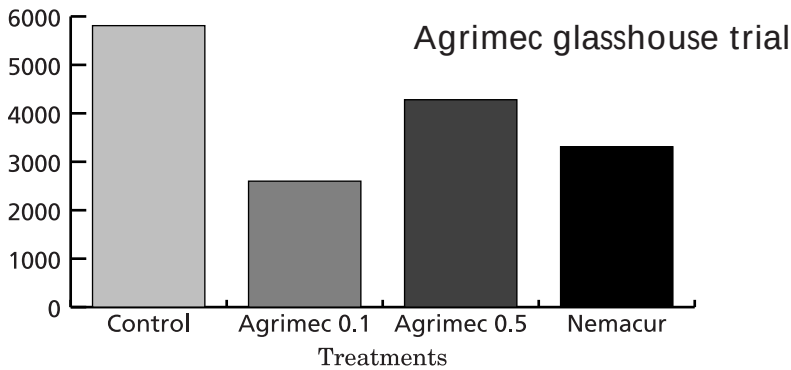

Figure 5. Number of burrowing nematodes in 30 g roots in the different treatments six weeks after treatment.

Furfural

Results of the glasshouse trial indicated that plants were not able to absorb Furfural (Fig. 6) because large differences could be found in nematode numbers between cadusaphos and a soil drench of Furfural. However, when Furfural was injected into the pseudostem, better nematode control was obtained, as shown in Figure 7.

Furfuraldehyde is a large molecule which is probably too large to be absorbed by the plant. However, when injected into the plant, the compound may come into contact with the nematodes.

Ditera

Ditera was tested in the glasshouse with very good results. Nematode numbers were reduced in all treatments compared to the control, and the Ditera 10 g compared well with the fenamiphos treatment (Fig. 8). Mean root mass was also determined and both Ditera 7.5 and 10 g per plant gave excellent results followed by fenamiphos, Ditera 5 g and control (Fig. 9).

The product is being tested in the field at two doses, 50 kg and 100 kg per hectare, and at a reduced rate of 25 and 50 kg per hectare. The amount of product was reduced because of the small difference in results between both initial doses and the lower price. Although the number of nematodes varied considerably in the treatments, preliminary results showed the highest yields for Ditera 50 kg/ha (Table 3), followed by fenamiphos and Ditera 100 kg/ha. There was little difference in the number of hands. The control and Ditera 100 kg/ha gave the shortest cycle. However, these are preliminary results and more data need to be collected before conclusions can be drawn.

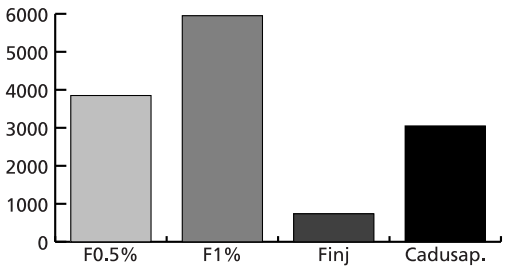

Figure 6. Number of nematodes per 30 g roots in the different treatments of furfural compared with cadusaphos.

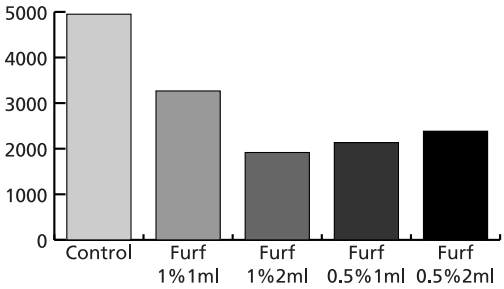

Figure 7. Number of nematodes per 30 g roots in the injected plants compared with a control.

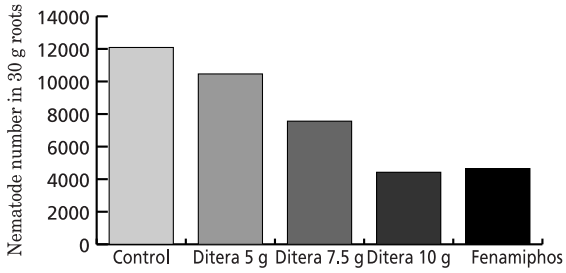

Figure 8. Number of *Radopholus similis* in 30 g roots in the different treatments six weeks after application.

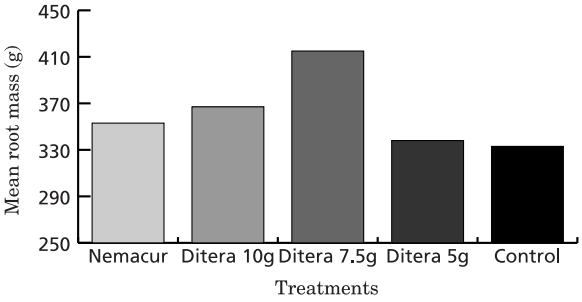

Figure 9. Mean root mass of the different treatment six weekx after application.

Table 3. Influence of Ditera on yield at Dennekruin, Mpumalanga, South Africa.

Treatments	n	Bunch weight (kg)	Number of hands	Days flower/harvest
Control	16	27.2	11.17	174.5
Ditera 50 kg/ha	18	32.6	11.24	179.7
Ditera 100 kg/ha	21	28.2	11.27	174.5
Fenamiphos	15	28.8	10.9	181.1

AMF

Although it was possible to obtain a high level of colonization with AMF in the different cultivars, the levels fluctuated greatly. Nematode infestation also fluctuated greatly and together these factors prevented clear assessment of the effect of mycorrhizae on nematode populations. More tests are being carried out.

Selections and cultivars

Most of the field trials have been planted recently and not enough data have been collected to date to give indications of tolerance.

The glasshouse trials with Goldfinger and Williams indicate differences in infection towards *R. similis*. However, although Goldfinger showed much lower numbers of *R. similis*, the numbers of *H. multicinctus* were much higher (Table 4).

Table 4. Number of nematodes in 250 ml soil and 100 g roots in Williams and Goldfinger plants infested in the glasshouse with different numbers of nematodes.

Cultivars	Number of nematodes					
	250 ml soil			100 g roots		
	Spiral	Root-knot	Burrow	Spiral	Root-knot	Burrow
Will 0	0	0	0	0	0	167
Will 1000	0	100	0	333	2667	4167
Will 10000	1100	450	0	9167	18000	24333
Gold 0	0	0	0	0	167	0
Gold 1000	400	650	200	1167	12500	5833
Gold 10000	400	850	250	8667	15333	21833

Spiral = *Helicotylenchus multicinctus*; Root-knot = *Meloidogyne* spp.; Burrow = *Radopholus similis*

In two field trials (Tables 5 and 6), Goldfinger was compared with several other cultivars. Species present in the field trials were *H. multicinctus*, *Meloidogyne* spp., *Pratylenchus coffeae*, but *R. similis* was absent from these two fields. Numbers of nematodes varied widely between the different cultivars and locations. Whereas 44A showed the lowest number of nematodes at Minnaar, it had the highest number in the Burgershall trial. However, it must be noted that this cultivar is highly sensitive to cold and therefore was more stressed than the other cultivars in the Burgershall trial.

Again it can be seen that although Goldfinger is resistant to *R. similis*, it is not resistant to other species, especially Helicotylenchus. Although *R. similis* is a severe

pest to bananas, it is absent from many farms in South Africa and its spread is limited to the use of tissue culture plants. It is therefore important to look for a selection that is more tolerant to both ecto- and endoparasitic nematodes. Another problem observed with the new cultivar, even if it is resistant to nematodes, is that it must be an edible, good yielding banana to be acceptable to the farmer and consumer. This is a problem with Goldfinger.

Table 5. Numbers of nematodes in 250 ml soil and 100 g roots of four cultivars at Minnaar in the Kiepersol area, Mpumalanga, South Africa.

Cultivars	Number of nematodes					
	250 ml soil			100 g roots		
	Spiral	Root-knot	Burrow	Spiral	Root-knot	Burrow
CC	225	260	75	6166	3867	5880
44A	325	175	100	2567	2133	3800
GP	510	275	40	16466	13083	8800
G	210	112	0	6533	1800	5533

CC = Chinese Cavendish; 44A = ???; GP = Giant Parfitt; G = Goldfinger

Spirals = *Helicotylenchus multicinctus*; Root-knot = *Meloidogyne* spp.; Lesion = *Pratylenchus coffeae*

Table 6. Numbers of nematodes in 250 ml soil and 100 g roots in six cultivars at Burgershall in the Kiepersol area, Mpumalanga, South Africa.

Cultivars	Number of nematodes					
	250 ml soil			100 g roots		
	Spiral	Root-knot	Lesion	Spiral	Root-knot	Lesion
GNnov	1237.5	87.5	0	26401	1092	1267
GNIsr	987.5	175	12.5	25650	801	350
GN	887.5	75	0	22742	2212	0
44A	850	87.5	25	36893	408	1476
G	762.5	87.5	0	31242	1593	931
CC	1062.5	50	37.5	14483	850	508

GN = Grand Nain conventional; GNIsr = Grand Nain Israeli; GNNov = Grand Nain Novartis; 44A = ???; G = Goldfinger; CC = Chinese Cavendish

Spiral = *Helicotylenchus multicinctus*; Root-knot = *Meloidogyne* spp.; Lesion = *Pratylenchus coffeae*

Discussion

In the IPM Strategy on bananas in South Africa, several aspects are being investigated to reduce nematode numbers.

Research on microbial and plant-based substitutes as environmentally-friendly alternatives to pesticides is vitally important because until now, banana producers were forced to use extremely toxic nematicides to control nematodes in their plantations. The

latter are applied twice a year as registered, but display decreasing effectiveness. Initially, both types of products should be used together in an IPM programme.

Some of the products have delivered very good results and producers will have the opportunity to use these in the near future. The products all have their specific mode of action and some will be more effective on different kinds of nematode species in certain areas. It is anticipated that in the future, a producer will be able to select between different biorational based products for control purposes, depending on the specific environmental conditions under which the crop is cultivated. However, one must accept that in the case of severe infestations, conventional nematicides will still be used to initially suppress the number of nematodes.

The use of mulches will also add to the benefits of an IPM programme as it will render stronger and healthier plants which are indirectly more tolerant to nematodes and other stress factors. It will also help in rebuilding a natural environment for the plant. Bhattacharyya and Madhava Rao (1984) stated that some mulches can effectively reduce numbers of nematodes.

Mycorrhizae will mainly be used in the initial stage where plants are transported from the nursery to the field, where they can be of great importance in very poor soils. They can also reduce the need for nematicide use if nematode penetration can be effectively reduced in the very first weeks after planting.

Resistant or tolerant cultivars are important because their use will drastically reduce nematicide applications. It must however be noted that if a banana cultivar resistant to a certain species is identified, it may not be resistant to all species, and that the impact of the other species must also be investigated as a banana plantation very seldom is infested with only one species.

Acknowledgements

The authors wish to express their most sincere thanks to Mss. C. Neethling and S. Dreyer.

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Novel techniques for the control of the banana weevil, *Cosmopolites sordidus*, in South Africa

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Introduction

The banana weevil *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae) is one of the most serious constraints to banana production worldwide (Ostmark 1974). Larvae of the weevil tunnel into the rhizome and occasionally into pseudostem tissue of banana plants. Apart from a general decline in plant vigour, pseudostems of infested plants tend to break just above soil level which normally results in the loss of the entire bunch in windy conditions. Damage ranging up to 100% has been reported by Koppenhofer *et al.* (1994) in Central and East Africa. Damage of this nature is, however, seldom experienced in South Africa. The banana weevil is only of economic importance in the South Coast region of KwaZulu/Natal. Approximately 2200-2600 ha of bananas are commercially produced in this region and it constitutes ±25% of the total hectarage of bananas in South Africa.

Although the weevil has been recorded at several isolated locations in the Mpumalanga Province over the past 25 years, its population remains small and no significant damage has been observed.

Until recently farmers were aware of the weevil problem but not concerned. Infestation in some areas in Kwazulu/Natal is severe and snapping and lodging of plants is very common. Most of these bananas are exposed to strong winds and the problem is exacerbated by nematode infestations and limiting soil layers. Apart from a few farmers trying to control the weevil manually, very little chemical control was carried out prior to 1998. It is likely that farmers will treat severely infested lands with immidachloprid 350 SC and/or prothiofos 960 EC during 1999.

Since a premium is placed on environmentally safer pest control methods in banana, alternatives to hazardous chemicals need to be investigated (Daneel *et al.* 1996). Certain fungal pathogens are effective biological control agents of *C. sordidus*

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and could be compatible in an environmentally-friendly integrated pest management programme for bananas, provided these pathogens can be effectively introduced into pest populations.

Entomopathogens represent a potential strategy for control of the banana weevil. Although many strains produce high kill rates in the laboratory (Kaaya *et al.* 1993), efficacy in the field has not been clearly demonstrated. Unless the strains can be properly established or infection is passed from one insect to another, the fungi would have to be used as biopesticides and costs may be prohibitive, especially for small-scale farmers.

Banana weevils are highly thigmotaxic and tend to congregate in large numbers on the underside of traps made by placing out cut pseudostem or rhizome tissue sections in infested plantations. This behavioural pattern renders entomopathogens and particularly fungal agents a potentially viable alternative control strategy, especially if used in combination with an aggregation pheromone.

The initial aim of this investigation was to quantify transmission of *Beauveria bassiana* (Bals) Vuill from artificially infected weevils to non-infected weevils under laboratory conditions. The effect of *B. bassiana* on the banana weevil under field conditions was another important aspect studied.

Materials and methods

Laboratory trials

Banana weevils were obtained from a farm in the Sabie River Valley (24.36S-1.28E) in the Mpumalanga Province. The *B. bassiana* isolate (PPRI 5339) was obtained from the Plant Protection Research Institute (PPRI) of the Agricultural Research Council in Pretoria. The isolate was initially isolated from the leaf gold beetle, *Conchyloctenia punctata* (Coleoptera: Chrysomelidae).

Production and harvesting of conidia

The isolate of *B. bassiana* was grown on potato-dextrose agar for 30 days. Conidial suspensions were obtained by flooding the cultures with sterile distilled water, scraping the surface with a scalpel blade and filtering the suspension through cheese-cloth. Conidial concentrations were determined by using a Neubauer haemacytometer and adjusted to 1.33 x 109 ml-1.

Bioassay procedures

Adult banana weevils were kept in glass containers (300 x 300 x 300 mm) in the laboratory under ambient temperature and relative humidity (28 ± 5°C and 55 ± 5% RH). Thirty weevils were maintained in each container and the treatments were replicated four times. Natural conditions were simulated as close as possible in the containers. The floor of each container was covered with a 20 mm layer of slightly moist sand. One block of rhizome tissue (150 x 100 x 100 mm) per container was used to feed weevils for

the duration of the experiment. The tissue blocks were replaced twice during the observation period. Mortality assessment was made after 37 days.

All weevils were surface-disinfected in 30% ethyl alcohol before being placed into the containers. Fifteen weevils from each container were then marked with a scratch on the pronotum. The remaining 15 weevils from each container were inoculated with *B. bassiana* by applying 50 ml of the conidial suspension to the mouthparts and ventral surface of each weevil using a micropipette.

To quantify the transmission of the pathogen, the untreated weevils that survived after the 37-day observation period were placed separately into 90 mm Petri dishes which were lined with moist filter paper and all Petri dishes were sealed with parafilm. The weevils were then incubated at 26 ±1°C. Dead weevils without noticeable mycosis were also incubated. Incubation under the high humidity regime was carried out to enhance sporulation and growth of surface mycelia of *B. bassiana*. After a week a final assessment was made by examining all the incubated weevils for the presence of mycosis.

Field trials

Isolate PPRI 5339 was grown on millet seed. Magenta tissue culture vessels were half-filled with millet seed. The seeds were covered with water to the point just before clear water was visible. The vessels were closed and the seeds were allowed to swell for an hour. After an hour the lids were opened and if any free water was present it was discarded. The vessels containing the millet seed were then autoclaved. Each vessel contained approximately 17 149 seeds. After autoclaving the vessels were allowed to cool down and were then inoculated with the pathogen. Prior to inoculation *B. bassiana* was grown on malt extract plates for 14 days at 24°C for two months.

The contents of one container was used to treat a single mat by spreading the seeds around the mat. Field trials were conducted at two localities, namely Kiepersol in Mpumalanga and Munster in the South Coast of Kwazulu/Natal. The trials in Kiepersol were conducted during February and March 1998 and application of the pathogen took place during an overcast period with relatively high temperatures and humidities. The treatment in Munster took place during June with relative low temperatures and humidity. The treatment at Kiepersol consisted of 10 replicates with 3 plants per block while the treatment at Munster consisted of 4 replicates with 9 plants per block. Control plants received no treatment and weevil activity was measured with pseudostem traps. Weevils were collected weekly and pseudostems were replaced every 3 weeks. Tokuthion EC at 120 ml/100 L was used as a standard reference at Munster.

Results and discussion

Laboratory trial

After 37 days, 52 artificially inoculated weevils were recovered. All of these were dead and most (96.15%) were showing typical external signs of *B. bassiana* mycosis (dense

Table 1. Effect of *Beauveria bassiana* on mortality of inoculated and uninoculated individuals of the banana weevil *Cosmopolites sordidus* incubated together in humid chambers in the laboratory.

	Inoculated weevils Mycosis			Uninoculated weevils Mycosis			
	Present	**Absent**	**Total**	**Present**	**Absent**	**Alive**	**Total**
Mean mortality/container after 37 days (± S. D.)	12.5(1.66)	2 (0.5)	13(1.87)	1 (0.71)	1 (1.0)	0	8 (1.58)
Mean mortality/container after 44 days (± S. D.)	13(1.87)	0	13(1.87)	2.5 (1.12)*	0.25 (0.43)	0	2.75 (0.83)
Mean survival/container after 37 days (± S. D.)	0	0	0	0	0	8.25(1.92)	8.25 (1.92)
Mean survival/container after 44 days (± S. D.)	0	0	0	0	0	7.5 (2.29)	7.5 (2.29)
Total number of weevils recovered		**52**	**41**				

* Mycosis on one weevil was caused by an unidentified fungus

Table 2. Weekly average number of weevils collected per plant at Munster in the Natal South Coast.

Treatment	n	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Total
Beauveria	36	0.31a	0.28a	0.28a	0.25b	0.19b	0.03b	0.31a	0.42a	0.42ab	0.19a	2.67ab
Control	36	0.06a	0.11a	0.19a	0.97a	0.67a	0.19a	0.25a	0.36a	0.53a	0.39a	3.72a
Tokuthion	36	0.31a	0.08a	0.19a	0.22b	0.06b	0.06ab	0.33a	0.25a	0.19b	0.36a	2.06b
Significance		0.269	0.149	0.679	0.005	0	0.095	0.864	0.554	0.068	0.492	0.015

n: Number of plants
Level of significance: $P < 0.05$

Table 3. Weekly average number of weevils collected per plant at Kiepersol in Mpumulanga.

Treatment	n	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week1	Total
Beauveria	30	0.3a	0.067a	0.067a	0.1a	0.1a	0.067a	0.03a	0.067a	0.067a	0.867a
Control	30	0.333a	0.467b	0.167b	0.133a	0.4b	0.4b	0.067a	0.266b	0.3b	2.533b

n: Number of plants
Level of significance: $P < 0.05$

mat of white surface mycelia) (Table 1). Eight (19.52%) of the 41 uninoculated marked weevils which were recovered, were dead after 37 days and only 4 (9.76%) of these displayed visible signs of *B. bassiana* mycosis. After the weevils were incubated at a high relative humidity for a further week, three marked weevils died. In one instance, however, mortality was not caused by *B. bassiana* infection. The two unmarked weevils without mycosis displayed typical symptoms of *B. bassiana* infection after being subjected to the high humidity regime. At the termination of the trial, a total of 11 (26.83%) marked untreated weevils had died and 10 (24.39%) of these showed typical external symptoms of *B. bassiana* infection, indicating that successful transmission occurred.

Field trial

Although an analysis of variance did not reveal any significant differences between the control and *B. bassiana* treatments in the Munster in the Natal South Coast at $P<0.05$, it is evident from the trend in Table 2 that less weevils were caught at the mats treated with *B. bassiana* than in the control. The pathogen was applied under environmental conditions extremely unfavourable for the pathogen (average temperature for June 17.8°C, rainfall 1 mm). Conversely the higher temperature and humidity in the Kiepersol area led to significant reduction of the weevil population (Table 3).

The high humidities and temperatures normally experienced in the Natal South Coast region should enhance the effectiveness of Beauveria if it is applied during November (1997 average temperature: 20.5°C, rainfall: 297.2 mm) and April (1997 average temperature: 20.5°C, rainfall: 213.9 mm).

Current control practices for the banana weevil in South Africa are based on the treatment of infested plants with highly toxic chemicals. This study indicated that *B. bassiana* was transmitted from infected individuals to healthy weevils in 24% of the cases under laboratory conditions. Although natural conditions were simulated as close as possible in the laboratory, it can be expected that transmission and ultimately the infection rate of the pathogen will be lower under field conditions. More virulent strains of this pathogen are needed that lead to higher rates of transmission and infection. It was also demonstrated that *Beauveria* is able to effectively control the weevil in the field if it is applied under favourable environmental conditions.

A disadvantage of insect pathogens is an intrinsic limited longevity under conditions of low relative humidity, high temperatures and exposure to high ultraviolet radiation. The rather rapid growth and subsequent overhead covering of the banana plantation a few months after planting, in combination with the availability of plant debris in the plantation, would ensure a microclimate suitable for the survival of fungal pathogens. By inoculating the pathogen on millet seed, some of the environmental constraints were initially negated. Millet seed containing viable *B. bassiana* were recovered at the termination of the trial two months after application.

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Prospects for IPM in enset (*Ensete ventricosum*) production in Ethiopia

M. Bogale

Background

Enset is a large banana-like plant, sometimes called "false banana" (Westphal 1975). Unlike banana, however, the seedy, leathery fruits of enset are inedible. The corm, pseudostem and leaf stems are the main sources of food.

Every part of the plant is utilized, not only for food, but also for several other cultural applications. Cut leaves of enset are indispensable for wrapping, thatching, matting, making containers, shading for crops and humans, and as instant umbrella. The pseudostem yields strong fibers, even when used in unprocessed form. Most parts of the plant are good as fodder, especially in the dry season when grass is scarce.

It is estimated that about 20% of Ethiopia's population (about 15 million people) depend on enset as a staple or co-staple food crop (Bezuneh 1969). The crop is considered as a security crop for it can withstand long periods of drought, heavy rains and flooding, that ordinarily devastate other food crops.

During the last several decades, enset cultivation has evolved as one of the most stable and sustainable agricultural development systems because the system has been efficient in building and sustaining the fertility of the soil. The concurrent cultivation of crops on the same land with enset has enabled the system to intensify food production and support large densities of people. It is estimated that in some enset-growing areas the human density goes up to 500 people per square kilometer of land (Braukamper 1980, 1983 cited in Pankhrust 1993).

However, the sustainability of enset agriculture is threatened by a number of factors among which diseases are the most important ones. These are aggravated by the continuous cultivation of enset in the same location and intensification of the cropping phase in the enset agroecosystem which stems from the ever-increasing population pressure.

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Table 1. Enset-based cropping systems in the different agroecological zones of enset.

Crops	Upper high-altitude (2500-3000 m)	High altitude (2000-2400 m)	Intermediate altitude (1500-2000 m)
Cereals	Barley, wheat	Wheat, tef, sorghum	Maize, sorghum, tef
Pulses	Faba bean, peas	Faba bean, lentils, chickpea	Chickpea, beans
Horticultural crops	Cabbage, onions	Garlic, peach, onions	Tomato, papaya, citrus, banana
Cash crops			Coffee, chat, cotton, sugarcane, tobacco
Roots and tubers	Potato	Potato, Coleus edulis	Yam, taro, sweet potato
Oil crops	Bassica, niger seed	Niger seed, linseed	Castor, sunflower, safflower
Spices		Thyme, fennel, sweet basil	Black cumin, pepper, coriander, capsicum, ginger, cardamom

Adapted from Westphal (1975)

Setbacks in enset agriculture

Fungal diseases

Foliar diseaes

Fungal foliar diseases are numerous and widespread; most are undescribed and unidentified. Some are destructive on suckers, seedlings, young transplants and rapidly growing plants up to the age of 2. However, affected plants normally tolerate these diseases and recover as they grow older. Mature plants do not have serious foliar diseases (Quimio and Tessera 1993).

Leaf spot diseases which commonly affect suckers, seedlings and young plants are caused by *Phyllostica* sp., *Piricularia* sp. and *Drechslera* sp. In older plants, leaf spots are due to *Cladosporium* sp. and to some extent *Deightoniella* sp. are frequently encountered (Quimio and Tessera 1993).

Root corm and pseudostem diseases

Little is known about the fungal diseases affecting enset roots, corm and pseudostem. Quimio and Tessera (1993) reported cases of sclerotium wilt and root-rot caused by *Sclerotium rolfsi* on young seedlings and transplants.

Inflorescence and fruit diseases

Except for a minor leaf spot disease of flower bracts attributed to a species of *Cephalosporium*, nothing is known about the fungal diseases affecting enset's inflorescence and fruits (Quimio 1992).

Disease control strategies

The fungal leaf spot diseases affecting suckers, seedlings and young plants are severe during the rainy season and under humid conditions. Suckers crowded on corms planted close together and under shade of big enset plants, suckers in nurseries intercropped with tall plants such as maize, or heavily infested by weeds, are often seriously affected by these diseases. Quimio and Tessera (1993) recommend that:

- Nurseries should be established in open spaces and corms should by properly spaced and planted in well-tilled and manured soil.
- Suckers should be thinned, leaving just enough seedlings for planting.
- Old leaves should be removed and properly disposed.
- Nurseries should be regularly weeded and, if possible, should not be intercropped with tall plants.

These cultural practices are expected to promote vigorous plant growth and suppress development of leaf spot diseases in nurseries. As leaf spot diseases normally start from the nursery, healthy suckers for planting would mean a healthy start for plants in the field. Healthy plants properly spaced in deeply-tilled, well-manured and regularly weeded plots are likely to better tolerate foliar diseases.

The use of fungicides would not be consistent with the traditional methods of enset agriculture. Planting healthy seedlings whose old roots and leaf sheaths have been removed in deeply-tilled and well-manured soil is likely to minimize the damage from fungal root and corm diseases of enset. Fungicidal dips would be good for controlling fungal root pathogens, but this would not be practical under the farmers' crop management system.

In short, applying the basic principles of raising healthy seedlings, proper plot preparation, and proper crop management to maintain healthy plants in the field, coupled with general field sanitation practices, would minimize the damage due to fungal diseases. Resistant clones could also be very helpful.

Bacterial diseases

Bacterial wilt

Bacterial wilt is the most important disease of enset. It was first reported and described by Dagnachew and Bradbury who attributed the disease to *Xanthomonas musacearum* sp.n. (Yirgou and Bradbury 1968). Known to occur only in Ethiopia, the bacterium was later re-named as *X. campestris* pv. *musacearum* (Yirgou and Bradbury) Dye (*Xcm*) (Dye *et al.* 1980).

Bacterial wilt also affects the banana plant. In 1974, a natural epidemic of the disease was reported in banana cultivar Du Casse Hybrid in Kaffa province (Yirgou and Bradbury 1974). It was reported to be pathogenic on hot pepper, tobacco, sesame and *Datura stramonium* (Wondimagegn *et al.* 1987).

Based on inoculation experiments done using bacterial suspensions from infected plants on 60 clones, Ashagari (1985) showed that the clones Ado, Kembate, Hedesso, Seskila, Genticha and Abate have relatively better tolerance to bacterial wilt. Bacterial

wilt is very destructive as it kills enset plants at all growth stages. Devastated fields are sometimes abandoned and replaced with other crops. Other times farmers are forced to rotate infested fields for at least two cropping seasons with other crops such as maize.

Bacterial corm rot

Bacterial corm rot is widely distributed and kills both young and mature plants. The causative agent has not been identified so far. The disease is characterized by yellowing and wilting of the outermost leaves, which eventually die and turn brown. In large plants, the leaves may break and hang at the petiole even before they turn brown. Wilting progresses inwards until all the leaves die. In advanced stages of the disease, the plant easily topples down when pushed.

Control strategies

Moderately resistant (tolerant) varieties are available and these could be deployed in conjunction with various management practices to control the disease. Sanitary measures and cultural practices which could prevent, reduce or eliminate the spread of *Xcm* in the field include:

- Flaming of tools used in infested plots
- Preventing animals from browsing and straying into infested plots
- Rouging infested plants and burning them away from the field
- Deep tillage and turning over the soil to expose it to the sun during dry period prior to planting
- Manuring of planting holes
- Replacing wilt-susceptible banana cultivars with resistant ones
- Cultivating different clones of enset (of varying levels of resistance) in a plot as commonly practiced now by enset farmers would also prevent the rapid spread of the disease
- Using tolerant varieties.

Diseases caused by nematodes

Root nematodes

Although no study has been made so far on the effects of nematodes on growth and yield of enset, they have been found invariably associated with poorly growing, unthrifty-looking and often stunted plants (Quimio and Tessera 1993). In a diagnostic survey made recently (Bogale *et al.*, unpublished) *Pratylenchus goodeyi*, *P. zeae*, *Meloidogyne* spp. and *Ektaphelenchoides* sp. were found to be the dominant nematodes associated with the roots of enset. Although less frequent, *Helicothylenchus multicinctus*, *H. dihystera*, *P. coffeae* , *Tylenchus* sp., *Radopholus similis*, *Haplolymus* sp. and *Scutellonema bradys* were also encountered.

P. goodeyi particularly was found associated in large numbers with bacterial wilt of enset, and thus suspected to play a role in the development and severity of the latter disease (Quimio and Tessera 1993).

Foliar nematodes

Quimio (1991, 1992) reported a foliar nematode disease caused by an *Aphelenchoides* sp. affecting the succulent leaves of suckers and young seedlings. The disease is characterized by linear black leaf streaks usually occurring on leaf margins and near the base of newly expanded leaves. On very young seedlings the streaks may be found all over the leaf blade.

Control strategies

Root nematode disease control in enset may be compared with that of banana. It includes:

- The use of nematode-free planting materials
  - Dipping in nematicides
  - Packing corms in mud mixed with nematicides
  - Hot water treatment
- Reducing or eliminating nematode inocula in the soil prior to planting
  - Chemical fumigation
  - Fallowing
  - Flooding. These methods, however, even if proven successful in enset, will not be practical in the enset subsistence farming system.
- Maintaining the plant in good health during cultivation.

In the context of the enset agricultural system, a more practical method of freeing planting materials from nematodes or reducing the population of the nematodes in the roots of the planting material would be pairing of the corm, i.e. removing the outer cortical tissues of the corm which may carry the nematodes. Other cultural practices recommended for controlling nematodes include:

- Deep tillage and turning over the soil to expose it under the sun's heat during summer prior to planting
- Manuring the soil prior to planting
- Using more tolerant/resistant cultivars
- Avoiding planting nematode-susceptible crops as intercrops or rotation crops
- Eradicating alternate hosts from the field.

After planting, little could be done to combat the nematodes so far as the traditional methods of enset cultivation are concerned. The only thing that could be done is to apply animal manure to keep the plant healthy and possibly enhance activities of antagonistic microorganisms.

Viral diseases

The only known viral disease of enset is the enset BaDNA (Bacilliform DNA) Virus (Tessera *et al.* 1997). Various studies are underway by the authors regarding this virus.

Conclusions and recommendations

1. Yield loss incurred by pests and diseases in enset production has not yet been properly studied.
2. The causative agents of important diseases like bacterial corm rot have not yet been identified.
3. Most of the control strategies suggested against the various diseases and pests in the enset agricultural system are similar. Verifying and integration of these control strategies could be the first step in the development of IPM in enset production in Ethiopia.

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Banana and plantain IPM in Cameroon: progress and problems

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Introduction

Bananas and plantains are major staple foods as well as important source of revenue for a significant proportion of the Cameroonian population. About 1 700 000 tonnes are produced annually (1 000 000 tonnes plantains and 700 000 tonnes bananas). Plantains are produced by resource-poor farmers, generally in a mixed cropping system with cash crops (coffee, cocoa) or with food crops (cocoyam, cassava, maize, tania, legumes). Plantains are found throughout the southern part of the country between 0 and 2000 masl. Several plantain cultivars are grown: French types are dominant in the highland areas (>1000 masl) whereas false horn and true horn are dominant in the lowland zones. Export bananas in contrast are monocropped and are produced by large-scale growers. The total area under export banana cultivation is about 5000 ha and these plantations are located in the Fako and Moungo divisions on volcanic soils between 0 and 500 masl. Several pests and diseases are found in both cropping systems. The most important pests are the banana borer weevil (*Cosmopolites sordidus*) and the nematodes *Radopholus similis* and *Pratylenchus goodeyi* (Fogain 1994, Bridge *et al.* 1995). Black and yellow Sigatoka due respectively to *Mycosphaerella fijiensis* and *M. musicola* are the most devastating diseases (Mouliom Pefoura 1984). Other phytosanitary problems are cigar-end rot disease caused by *Trachysphaera fructigena*, weeds and thrips on fruits.

This paper gives the distribution and the importance of the major phytosanitary problems in Cameroon and IPM control measures developed or currently under investigations.

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The banana borer weevil

Distribution and importance

Three species of weevils are found in banana plantations in Cameroon: *Cosmopolites sordidus*, *Metamasius sericeus* and *Pollytus melleborgi*, but *C. sordidus* seems to be the only weevil of economic importance (Fogain 1994). *Cosmopolites sordidus* was first reported in the country in 1947 by Carayon (Mendjime 1982). The insect is found in all the banana- and plantain-producing areas in Cameroon (Fig. 1). The percentage of occurrence varies between 50 and 90% (Fogain 1998a). A survey carried out in all the banana- and plantain-producing areas showed that 82.5% of the farmers are aware of the weevil problem and are capable of recognizing damage caused by the insect. Severe damage is observed in small-scale plantain farms compared to commercial plantations of Cavendish. In some areas such as southwest Cameroon, it is difficult to grow plantain if no protection against the weevil is available. For example, investigations undertaken in a peasant plantation comparing plantains and Cavendish showed that damage due to the weevil can be up to 77% on young plants of plantains and only 20% on Cavendish clones six months after planting in a highly infested zone of Ekona.

Integrated management of *Cosmopolites sordidus*

Several control measures including cultural, mechanical and chemical methods are used by farmers. In intensive cropping systems, plantations are renewed every 5 to 6 years and control measures against the banana borer weevil include crop hygiene, propping and guying, use of clean and disinfected suckers or tissue-cultured plantlets, and chemical treatment. In small-scale farming systems, some farmers use insecticides or wood ash but propping is the most common form of control.

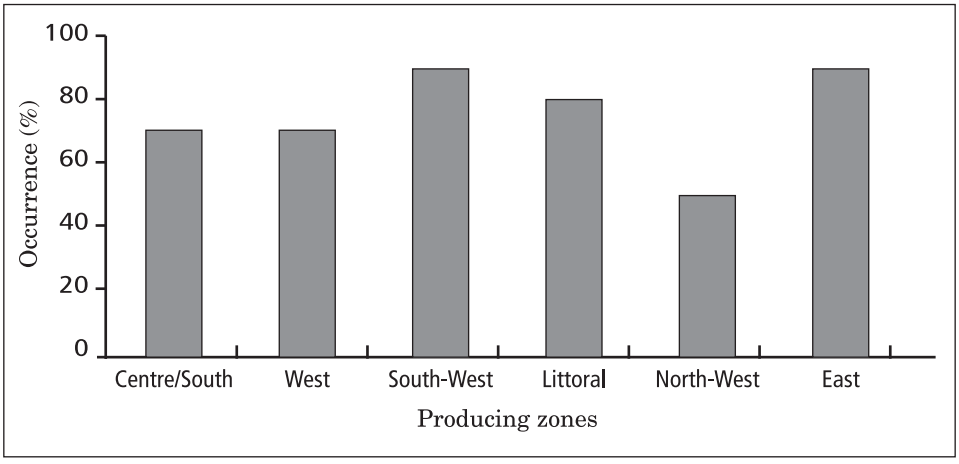

Figure 1. Occurrence of *Cosmopolites sordidus* in plantain-producing areas of Cameroon.

Cultural and mechanical control

Crop hygiene and the use of clean planting material are recommended to farmers, but only industrial growers apply these techniques. Removal of plant debris and destruction of old pseudostems to reduce breeding sites are sound techniques to reduce weevil populations. Trapping adult weevils using split pseudostems is also recommended. Propping and guying are common practices in small- and large-scale plantations to reduce toppling.

Chemical control

The use of insecticides to control weevil is the most popular control method, both in commercial and in peasant plantations. Insecticides are applied systematically 2 to 3 times a year (April, July and October) depending on the level of infestation. The insecticide Regent (fipronil) is the most commonly used. Continuous application of this compound may in the future lead to resistance as it is the only compound used by most growers. Some nematicides such as Terbuphos have insecticide activity and can therefore be used when the level of infestation is not too high.

Plant resistance

Several investigations have shown that different levels of susceptibility to *C. sordidus* exist within *Musa*. An evaluation of 52 accessions from the CRBP *Musa* germplasm revealed that most banana and plantain grown commercially are susceptible to *C. sordidus* (Fogain and Price 1994). Cavendish AAA and most of the ABB cooking bananas are however less susceptible than most of the plantain AAB clones. The triploid AAA Yangambi Km5 and the diploids Calcutta 4, *Musa balbisiana* and Truncata have a good level of resistance to the insect (Fogain and Price 1994, Mohaman 1998).

Current investigations are carried out in the following areas but most of the results obtained, however, have not yet been transferred to farmers.

Botanical insecticides

Studies on the use of neem (*Azadirachta indica*) against *C. sordidus* were initiated in 1993. *In vitro* tests showed a significant reduction of weevil population with neem powder. Under field conditions the most interesting results were obtained with a corm dipping treatment at the rate of 2 kg of neem powder in 10 litres of water (Fogain and Ysenbrandt 1998).

Use of antagonists

The banana borer weevil has several natural ennemies. Surveys in banana and plantain producing zones of Cameroon revealed the presence of entomopathogenic fungi. A local strain of the fungus *Beauveria bassiana* was isolated in the country and several investigations *in vitro* have shown that the strain is pathogenic on adults of the weevil (Fogain 1994). Several strains of entomopathogenic nematodes have also been isolated and are currently being tested for their efficacy against the weevil. The use of these

biocontrol agents will be of interest to resource-poor farmers as most of them do not apply pesticides capable of affecting the antagonists.

Nematodes

Distribution and importance

The major nematode species associated with bananas in large-scale plantations are *Radopholus similis*, *Helicotylenchus multicinctus*, *Hoplolaimus* spp. and *Meloidogyne* spp. The nematode *R. similis* is present in all plantations and is by far the most important. Population levels vary in most cases between 2000 and 200 000 individuals per 100 g of roots. In areas where bananas are alternated with fallow, large populations of *Meloidogyne* are often found on roots of young tissue-cultured plants.

In extensive cropping systems, the major crop found is plantain AAB. The dominant species vary with the region. In area at elevations below 700 m, *R. similis* is the dominant species, whereas at higher elevations (>1000 m) *Pratylenchus goodeyi* is dominant (Fig. 2). Between these two elevations, both species can be encountered. Other nematode species are *H. multicinctus*, *Hoplolaimus* spp, *Meloidogyne* spp. and P. *coffeae*. Results of a survey showed that only 22.2% of the farmers are aware of nematode problems and 5% can recognize nematode damage. Root damage is generally severe in this type of cropping system as replanting is not frequent and also because most resource-poor farmers do not apply nematicides. In the Centre and South provinces of Cameroon, more than 50% of the root samples collected showed severe root necrosis (Fogain 1998). Studies undertaken to evaluate yield loss of plantains due to the burrowing nematode showed that yield of the plantain French Sombre can be doubled when nematodes are controlled with three applications of nematicide a year (Fogain 1998a).

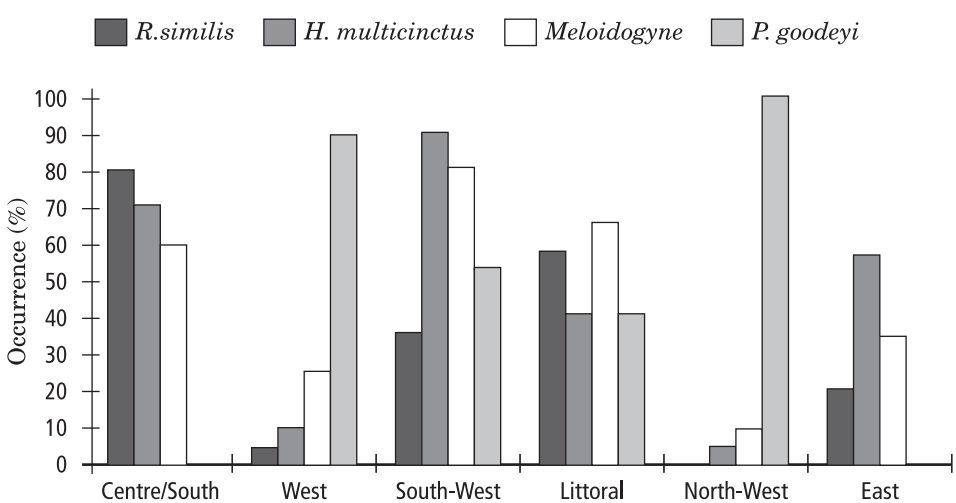

Figure 2. Occurence of major nematode species of bananas and plantains in Cameroon.

Integrated management of nematodes

Although several control measures are recommended to farmers, nematode IPM in the whole country is only done by large-scale banana growers. Most resource-poor farmers generally do not apply IPM strategies for many reasons, in particular a lack of basic information on how to apply the technology, and financial resources to use them.

Use of clean planting material

The planting material is one of the most important source of dissemination of nematodes. Clean and disinfected suckers are recommended to farmers to ensure that the nematodes do not get into the field. In commercial banana plantations suckers are pared and dipped in a nematicide mixture before planting. Other methods such as hot water treatment for disinfection of planting material are not adopted by farmers. In small-scale plantations, farmers simply clean the corms and no dipping is done before planting. Tissue culture plantlets are also widely used by industrial banana plantations.

Cultural control

Fallow and crop rotation are widely used by commercial banana plantations because replanting is frequent. Studies undertaken in Cameroon have shown that infested land fallowed for 10-12 months results in considerable reduction of *R. similis* populations (Fogain *et al.* 1998). In some commercial plantations the fallow period is extended to 15 months. When tissue-cultured plants are used after fallow, very low populations of *R. similis* are recorded two years after planting. This is due to the fact that when the initial population of a pest is very low. it takes the pest longer to increase to damage treshold levels. Crop rotation with non-host plants such as sweet potato and pineapple is also recommended to farmers.

Chemical control

In commercial banana plantations, nematicides are systematically used in old plantations. In newly established plots, nematode populations are monitored monthly and decisions to apply nematicides are taken only when populations of *R. similis* are greater than 7000 individuals per 100g of roots. Several nematicides are available to farmers (cadusaphos, carbofuran, phenamiphos, terbuphos, oxamyl, etoprophos, isazophos) (Fogain *et al.* 1996). Three applications a year of nematicides are recommended (April, July and October). In small-scale plantations of plantains, nematicides are not recommended because of their high toxicity, hazards to humans and animals and their high cost.

Botanical nematicides and biological control

Studies have been initiated on the efficacy of neem (*Azadirachta indica*), *Chromoleana odorata* and *Thitonia diversiflora* against nematodes. Collection of indigeneous strains of arbuscular mycorrhizal fungi (AMF) from Cameroon to set up *in vivo* cultures for

future studies on their possible effect to alleviate nematode constraints in banana plantations have also been initiated. Preliminary results of the survey indicates that more than 50% of roots collected in banana fields are mycorrhized (Fogain and Ngamo 1998). Trap pot cultures using leek seedlings have been set up with soil samples collected from these areas to isolate strains.

Plant resistance

As most small-scale farmers do not apply IPM strategies, host plant resistance will certainly bring them substantial benefit from little investment. Since 1989, more than 200 accessions from different genomic groups have been screened at CRBP to look for sources of resistance and for plantains with low susceptibility to *R. similis*. Results indicated that all the plantains and Cavendish are susceptible to nematodes (Fogain 1988b). Yangambi Km5 and other clones of the Ibota subgroup and a clone of the Pisang Jari Buaya subgroup are resistant to *R. similis*. Selangor, Calcutta 4 and most *Musa balbisiana* are significantly less susceptible than Cavendish, plantains and East African banana. Some of these resistant or tolerant clones are already being used in breeding programmes for resistance to black Sigatoka.

Sigatoka diseases

Distribution and importance

Two species of Sigatoka are present in Cameroon: *M. musicola* causing yellow Sigatoka and *M. fijiensis* causing black Sigatoka. These diseases are among the major constraints to banana and plantain production in Cameroon. Yield loss varies between 50 and 100% (Mouliom Pefoura and Fouré 1988). *M. fijiensis* was reported in commercial banana plantations in 1983 (Mouliom Pefoura 1984). Due to its high level of pathogenicity, it is progressively replacing *M. musicola* in areas situated at lower elevations where the later has existed for almost half a century. The disappearance process of *M. musicola* often happens after a period of coexistence with *M. fijiensis* (Mourichon and Fullerton 1990). In lowland areas, *M. fijiensis* is known to cause severe damage to cultivars which are less susceptible to *M. musicola*. *M. musicola* is more common at high altitudes with severe damage inflected on certain *Musa* subgroups such as plantains (AAB) which has been reported less susceptible at lower elevation (Fouré and Lescot 1988). Similar distribution of the two species has been reported in the coffee production zones of Colombia and Costa Rica (Martinez Figueroa 1989, Avila Adame 1991, Tapia Fernandez 1993). In Cameroon both species now exist in mixtures in the Centre, West, Littoral and South-West provinces, whereas *M. musicola* is the only species encountered in the North-West and *M. fijiensis* in the East and South provinces (Fig. 1). High infection levels are found in most of the provinces except in the West. Lower levels of damage were found to be due to low plant density and unfavourable climatic conditions.

Integrated management of *Mycosphaerella* spp.

Several control measures are recommended to smallholders. However, because resource-poor farmers lack income, *Mycosphaerella* disease IPM in Cameroon is only applied in commercial banana plantations. In these large-scale plantations, black Sigatoka is controlled primarily by fungicides, because non-chemical alternatives do not provide commercially acceptable control. Smallholders usually apply cultural practices to reduce inoculum in the field.

Cultural practices

Good agronomic practices including improved drainage, good weed control, desuckering and proper spacing are all important in reducing the spread of infection through the reduction of humidity within the plantation. Proper fertilization is also important. Current studies undertaken in coffee areas in Colombia seem to show a positive influence of proper plant nutrition on tolerance to this disease.

Planting date has been shown to reduce the disease incidence on plantain. For instance, disease incidence is reduced when planting bananas and plantains in Njombé takes place between June and October compared to the period from November to May.

Leaf pruning of highly diseased and dry leaves reduces the inoculum pressure in the plantation. The upper face of leaves must be placed on the ground. This technique is largely applied by farmers, but it is not effective during the period of high disease pressure (wet season). Current studies are focused on the impact of regular leaf pruning on disease.

Chemical control

In commercial banana plantations, black Sigatoka disease is controlled by repeated applications of fungicides. In small plantations, efficacy of chemical control has been demonstrated by applying minimum fungicide amount with knacksap sprayers combined with leaf pruning (Mouliom Pefoura and Fouré 1988). Nevertheless, financial cost of this practice did not allow adoption of this method by farmers.

Three fungicide chemical groups having different mode of action are used: triazoles (systemic IBS fungicides, e.g. active/commercial product propiconazole/Tilt), benzimidazoles (systemic antimitotic fungicides, e.g. active/commercial product benomyl/Benlate), morpholines (penetrating product, e.g. active/commercial product tridemorphe/Calixin). The choice of fungicides in an alternating scheme takes into account the registered active ingredients available locally, the parasite pressure and the structure of the pathogen population (resistance). Until 1997, the proposed fungicide application scheme in Cameroon was as follow: the alternate use of benzimidazole and morpholine during the dry season and the use of a cycle of three successive triazoles and two successive benzimidazoles during the wet season. Due to the recent appearance of cases of field resistance to benzimidazoles and triazoles, this rotation of fungicides is being modified by the use of a new compound with a novel mode of action and belonging to the b-methoxyacrylate group.

To reduce the annual number of fungicide applications, a successful forecasting system has been developed to control black Sigatoka disease in Cameroon (Mouliom Pefoura and Lassoudière 1984, Fouré 1988). This forecasting system is based on the state of disease evolution (SE) corresponding to a quantitative evaluation of symptoms on the leaves. The disease incidence is recorded once a week and fungicide application is only carried out when SE increases successively twice. This biological forecasting method has been used with success between 1984 and 1996, allowing disease control with about 20 applications instead of more than 30. It requires the use of systemic fungicides and good logistic organisation to be effective. Because of current logistic problems banana plantations apply fungicides on a temporary basis (every 10-14 days). Studies have been undertaken to improve the biological forecasting system.

(i) Detection prior to symptom development has been tested with an immunological method (ELISA) that allows application of the fungicide at an early stage in the reproduction cycle of the fungus, leading to a better efficacy and reduced fungicide applications.

(ii) A bioclimatic forecasting system combining biological and climatic parameters has been tested to decide on the date of fungicide application. This system has been recently developed in Costa Rica and is currently used with success in plantain plantations (Lescot *et al.* 1998).

The monitoring of the sensitivity of strains to fungicides has been established at CRBP as the successive applications of a fungicide may induce the selection of resistant strains of *M. fijiensis*. *M. fijiensis* populations of the two large-scale banana plantations are monitored systematically twice a year. These population studies concern both benzimidazoles and triazoles. Since 1997, a decrease in sensitivity of strains to these fungicides was shown in the laboratory. The introduction in Cameroon of a new molecule belonging to a new chemical group (beta-methoxyacrylates) is one way to overcome this problem. It allows a reduction of the number of applications of triazoles and benzimidazoles.

Plant resistance

Cavendish varieties traded internationally and all known plantain landraces are susceptible to black Sigatoka disease. The development of Sigatoka disease resistance has been a major breeding objective in banana and plantain for many years. Indeed, on the one hand smallholders cannot afford expensive fungicide applications and on the other hand commercial plantations need to increase the durability and the efficacy of fungicides. Thus genetic improvement for black Sigatoka resistance is a major component of IPM especially in the traditional farming system. This genetic improvement programme includes the search for sources of resistance to black Sigatoka and creation of new varieties resistant or tolerant to the disease. Therefore, resistance to black Sigatoka is the top priority of the CRBP breeding programme. The screening of over fifty clones belonging to various genetic subgroups under natural infection conditions in Cameroon revealed the existence of phenotypes of highly resistance (HR) and partial resistance (PR) (Fouré *et al.* 1990). All clones of the Ibota subgroup (AAA)

and clones (AAw) of the subspecies *microcarpa* (Truncata), *malaccensis* (Pahang) and *burmanicoïdes* (Calcutta 4) have a HR phenotype. The PR phenotype is found in any genomic group. No HR clone was found in genomic group with a *balbisiana* gene. Results of this screening allowed definition of two strategies: (i) short-term strategy: screening for resistant cooking bananas. Some tolerant ABB clones such as Pelipita were already tested and accepted by the farmers. (ii) medium-term strategy: screening for resistant diploids used as male parent to improve plantain landraces (Tomekpé *et al.* 1995). Multilocational evaluation of the most promising tetraploid hybrids with black Sigatoka resistance is underway in farmer fields.

Conclusions

In Cameroon, only commercial banana growers have successfully adopted IPM. In this type of cropping system, cultural practices combined with pest and disease forecast are being used to reduce the number of agrochemical treatments. In small-scale farming systems, several constraints limit the implementation of IMP strategies:

(i) lack of basic information on the pest or disease situation, on control measures and on new technologies available,
(ii) lack of finance,
(iii) area under cultivation too small.

To overcome this situation, (i) collaboration between researchers, extension workers, NGOs and farmers should be strenghtened; (ii) on-farm training programmes should be organized to bring together all the players; and (iii) farmers should be encouraged to form cooperatives.

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Session 2E
Review of IPM research activities

Farming systems socioeconomics and banana IPM

Cultural practices in relation to integrated pest management in bananas

J.C. Robinson[1], M. Daneel[1] and P.S. Schoeman[2]

Introduction

In the case of commercial banana production, chemical control measures still predominate in the elimination of biotic factors that limit or depress yields. In this group of factors, black Sigatoka, Panama disease, nematodes and the weevil borer are by far the most important. Resistance breeding remains a critically high priority, especially for controlling black Sigatoka and *Fusarium oxysporum* f. sp. *cubense* (race 4), but such resistant material is not yet available for the Cavendish group of cultivars which form the basis of world trade in bananas. For these commercial growers who apply chemicals, cultural practices play only a minor role in the context of integrated pest management (IPM).

In terms of world production, bananas are essentially a smallholder crop in which food security and a localized cash economy are the main considerations. In common with commercial banana production, breeding for resistance to pests and diseases is also critically important for small-scale rural farmers, but is even more so in this sector due to the high cost and inaccessibility of chemicals and the fact that bananas and plantains form the staple food of these people. Therefore, cultural practices are the only measures available to small-scale farmers for the control of pests and diseases. The focus of this paper therefore lies with the latter group of farmers, in relation to cultural practices and IPM.

Smallholder cultivation of *Musa* in sub-Saharan africa

In sub-Saharan Africa (SSA), *Musa* provides more than 25% of the carbohydrate requirements for about 70 million people. Bananas and plantains are an integral component of most farming systems where the emphasis is on food security for the rural

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population. In fact, in Uganda, the per capita consumption of *Musa* is in the excess of 250 kg/year (Karamura 1992).

From 1970 to 1997, cooking banana yields fell from 8 t/ha to 5 t/ha in Uganda and from 11 t/ha to 5 t/ha in Rwanda. Yield decline in new plantations is very rapid and can often be seen within two years, i.e. in the first ratoon cycle. There are many reasons for this yield decline, the most important of which are black Sigatoka, *Fusarium oxysporum* f.sp. *cubense*, weevil borer, nematodes, poor planting material, declining soil fertility and shorter fallow periods. These factors are invariably interrelated in that infected plant material causes more rapid plant decline, which necessitates more frequent replanting, which means shorter fallow periods, which in turn enhances the decline of soil fertility, especially as no inorganic fertilizers are applied. The establishment of "clean" planting material in "clean" soil would reverse this negative spiral. However, because the important role of *Musa* in food security is not fully recognized, research tends to be underfunded and the technology needs of the smallholder are not being addressed. Thus progressive yield decline remains a severe problem.

Cultural practices in relation to IPM in banana

Assuming this paper concentrates on soil pests and diseases, there are four main areas of influence on which to focus:

a. reducing pest numbers in the soil before planting,
b. reducing pest numbers in the planting material before planting,
c. promoting root health and vigour in the plantation to help the plant cope with pest pressure, and
d. reducing the chances of pest entry into the rhizome or roots.

Reducing pest numbers in the soil before planting

Use of clean virgin soil

This is the ideal scenario but such soil is becoming less and less available due to a history of shifting cultivation using infected planting material in new soil. If there is clean virgin soil still available then it is absolutely essential that clean planting material is used to establish a banana plantation.

Fallow and rotation cropping

Since increasing population pressure is reducing the availability of agricultural land, fallow periods are becoming shorter after yield decline has necessitated plantation removal. A two-year fallow is more effective than a one-year fallow, but for however long it is, old rhizomes, suckers and other banana trash must be removed to starve out nematodes. Also, alternative host crops and weeds must be avoided for at least one year. Under bare fallow in Australia, no *R. similis* was recovered from old banana roots after 8 weeks burial, but *R. similis* survived for up to 6 months in old rhizome tissue (Stanton 1998). This emphasizes the need to remove old rhizome tissue when fallowing.

Currently, however, bare fallow is not recommended in Australia due to the risk of soil erosion which would also be a problem in any high rainfall area.

In crop rotation experiments, groundnuts and maize were shown to be hosts for *R. similis*, whereas cassava, potato and cocoyam were not (Price 1994). Banana crop rotations showed that the grasses *Panicum maximum* and *Phaseolus altopurpureus* hosted no *Radopholus similis* or *Meloidogyne javanica* after 32 weeks (Colbran 1964) and sugarcane eliminated *R. similis* after 10 weeks (Loos 1961). In recent work by Stanton (1998), it was determined that sorghum was a strong host for *R. similis* in banana rotation cropping whereas sugarcane and jarra grass were excellent at controlling this nematode. From all this work, it appears that certain crops can be recommended for banana rotations such as sugarcane, various grasses, cassava, potato and cocoyam. On the other hand, groundnuts, maize, and sorghum should be avoided by small-scale banana farmers as rotation crops for bananas.

Environmentally-friendly nematicides

Preplant fumigation with EDB or methylbromide is expensive and very toxic. It is being phased out in commercial plantations and is totally unsuitable for small-scale farmers. Likewise, the use of chemical nematicides in the planting hole is expensive, toxic to humans and damaging to the environment. In addition, they are subject to advanced microbial degradation and resistance buildup of the target organism, which reduce their effectiveness. On the other hand, research being conducted at many institutions is showing that environmentally-friendly products and fungal-based bionematicides can be used to effectively control nematodes. This development fits in better with the IPM concept but currently these products are expensive and not readily available for smallholders to purchase.

Reducing pest numbers in planting material before planting

Tissue culture planting material is totally free from injurious pathogens such as *Fusarium oxysporum*, nematodes and weevil borer. However, it is essential that this material should be used in conjunction with clean soil. If the soil is infected with any of these organisms, then tissue culture material should be avoided because the plants, although very vigorous, have no reserves to withstand severe root damage soon after planting. Suckers can survive better than tissue culture plants under infected soil conditions. However, if the soil is infected with disease, nematodes or weevil borer, higher yields can be expected if suckers are treated. The options for sucker treatment are as follows.

Paring

This involves slicing off the outer layers of the rhizome and inspecting the white tissue for infections or weevil tunnels. All discoloured rhizomes are then discarded and only clean ones are used for planting. The operation is fairly easy and inexpensive although it is not a guarantee that clean looking rhizomes are in fact uninfected.

Solarization

This involves heat treatment by solar radiation. In an experiment by Mbwana and Seshu Reddy (1995), banana suckers were treated in a homemade solarization tank and planted out. After 650 days of growth, roots were inspected and analyzed for numbers of the nematode *Pratylenchus goodeyi*. From unpared suckers there were 29767 *P. goodeyi* per 100 g roots compared with 5027 *P. goodeyi* from pared suckers. With suckers that were both pared and solarized, the count was only 542 *P. goodeyi* per 100 g root. This indicates the beneficial effect of combining two treatments and also shows that paring alone does not remove all nematode infections.

Hot water treatment

This can be used to destroy nematodes and weevil borer in rhizome tissue without damaging the rhizome. In a recent experiment by Hauser (1998) at IITA, plantain suckers were treated with hot water at 52ºC for 20 minutes. Mat survival increased by 11% and plant lodging was reduced from 30% to 10% with this treatment. Yields in the plant crop also showed the interactive benefit of hot water treatment together with fertilizer use. Thus, for control (untreated), hot water-treated suckers, fertilized plots and hot water treatment together with fertilizer, plant crop yields were 10, 13, 15 and 21 t/ha, respectively. In the first ratoon, corresponding yields were 0.17, 3.06, 1.44 and 6.92 t/ha, respectively. The ratoon cycle also shows the interactive benefit of the two treatments but more importantly, it shows that severe yield decline occurred in all treatments by the second cycle, due to the rapid resurgence of pest numbers.

Treatment with neem

As an environmentally-friendly sucker treatment, the use of neem cake (*Azadirachta indica*) at 100 g per sucker at planting, then at 4 and 8 months after planting, reduced *Pratylenchus goodeyi*, *Meloidogyne javanica* and *Cosmopolites sordidus* to the same levels as with the use of Furadan nematicide. The percentage coefficient of infestation with weevils was reduced from 75% down to 5% (Musabyimana 1998).

Promoting root health and vigour in the plantation to counteract pest infestations

Various cultural aspects of *Musa* production can be used to increase root vigour, depth of rooting, survival potential and productivity of banana plants being established in infected soil. For resource-limited, small-scale farmers, some of these measures are possible whereas others are only achieved by costly management inputs.

Soil preparation

It has been widely demonstrated that a soft, easily worked soil, encourages more and longer roots in the root zone than a hard, compact soil. In a survey in Martinique, Delvaux (1995) found that as soil bulk density decreased from 1.2 to 0.6 g/cm^3 so banana root density increased from 1 to 7 roots/dm^2. He also found that certain soil types such as andisols were much less prone to compaction over time than vertisols or ferrisols.

Planting deeply in furrows or basins also encourages a deeper root profile than surface planting. It is logical that a denser and deeper root system would be able to cope better with infections from nematodes than a weak, superficial root system, and in addition, reduce the number of fallen pseudostems.

Inherent vigour of tissue culture planting material

In a comprehensive study by Eckstein and Robinson (1995), tissue culture planting material was compared physiologically with conventional suckers. For 4 months after planting, the tissue culture plants exhibited a higher rate of photosynthesis than sucker leaves. This physiological boost caused total root dry matter of the tissue culture plants to be double that of the sucker root system 4 months after planting and total plant dry matter to be double that of suckers by 5 months after planting. Once again it is emphasized that these differences are only achieved with optimum management and with no biotic constraints whatsoever.

Boosting tissue culture nursery growth with microorganisms

The enhancement of plant and root growth of young tissue culture banana plants was studied by Severn-Ellis (1998) using non-symbiotic bacteria. It was found that plant growth, dry mass and leaf area were significantly improved by a combination of *Bacillus* bacteria and fertilizer. Bacteria alone were less effective than fertilizer alone, but the strong interaction between the two showed that bacteria could play a major role in the presence of plant nutrients, probably by enhancing the availability and uptake of these nutrients. Progress has also been made in the field of using fungal endophytes for the biological control of nematodes. Niere *et al.* (this volume[1]) found that when various fungal isolates were inoculated into 19-week-old tissue culture banana plants, the rate of multiplication of *R. similis* in root segments of these plants was reduced by more than half, compared with non-inoculated plants. Plant height of the inoculated plants was also increased. These techniques may eventually play a role in protecting the root environment in smallholder banana plots.

Supplementary fertilizers

Declining soil fertility is one of the major causes of banana yield decline with smallholders. Many experiments have been conducted to show the beneficial effect of fertilizers on yield. An important finding in all this work is the strong positive interaction of fertilizer use with other inputs like hot water treatments, microorganisms in the tissue culture medium, organic amendments and mulch, on boosting root vigour and yield.

Organic amendments

Manure helps to reduce the level of nematodes in the long term but large amounts are required for direct nematicidal properties. Secondary effects result from increasing root vigour to cope better with nematodes. Chicken litter can also reduce nematode populations. The high nitrogen seems to inhibit nematodes but stimulates microflora which indirectly reduces nematodes.

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[1]Niere B.I., P.R. Speijer and R.A. Sikora. Fungal endophytes for the biological control of *Radopholus similis*.

Mulching

There are many advantages of mulching in bananas which can all play a role in promoting root health and vigour in the plantation. These are:

a. increasing and replenishing soil organic matter,
b. reducing surface temperature and temperature fluctuations,
c. reducing weed growth,
d. improving soil structure and water infiltration,
e. decreasing soil erosion by wind (less dust),
f. decreasing soil erosion by water (less runoff),
g. reduced soil compaction,
h. decreased water loss via surface evaporation, and
i. roots forage higher and grow more vigorously.

Mulching is essential in dryland banana farming and especially on resource-limited plots. In West Africa, Wilson (1987) found that cumulative plantain yield on mulched plots was fourfold higher than that on clean cultivated plots. In Brazil, Cintra and Borges (1988) found that organic mulch on bananas gave an average yield threefold higher than that on hand weeding or cover crop plots. In West Africa, Swennen (1990) increased plant crop plantain yield from 0.6 to 11.9 to 14.1 and to 18.8 t/ha for control, fertilized, mulched and fertilizer plus mulch plots respectively. Mulch therefore played a more important role than fertilizer but the interaction of mulch with fertilizer was the ideal. In the ratoon crop, yields dropped severely due to pest pressure, but the mulched plots still sustained a yield of 10 t/ha.

Reducing the chance of pathogens entering the rhizome or roots

These techniques mainly relate to plant infestation by the weevil borer, *Cosmopolites sordidus* Germar.

Trapping

Old pseudostems are cut into pieces and placed in the plantation to attract and trap adult weevils which should be regularly collected and destroyed.

Plant residue removal

This involves cutting of old pseudostems low down and chopping into small pieces for faster decomposition.

Sanitation

New suckers should not be left standing on the soil surface overnight before planting the next day.

Although these three practices can help reduce adult weevil populations, they are extremely labour-intensive operations.

Conclusions

- Cultural practices are invariably the only techniques a smallholder can use to control or live with soil pests and diseases in banana/plantain production.
- Much information is already available from experiments on smallholder plots, which relate cultural practices to increases of growth and yield under high pest pressure.
- In much of the experimental work, the inference that increased yields are due to either increased root vigour or lower pest numbers, is often speculative.
- More quantitative studies are required to relate cultural techniques to specific root measurements and/or pest counts. In this way the mode of action of these treatments would be better understood.
- There is a widespread need for better transfer of new technologies to the small-scale farmers via training, demonstration plots and participatory techniques.

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Understanding current banana production with special reference to integrated pest management in southwestern Uganda

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Background

Globally, bananas are the fourth most important food crop after rice, wheat and maize. In the Great Lakes Regions of East/Central Africa, they are the most important food staples. For Uganda, bananas is of strategic importance to food security. For example, 75% of farmers allocate 40% of cropped land to banana production, mostly for home consumption. However, productivity is decreasing due to three mutually reinforcing factors, namely (i) pests and diseases, (ii) declining soil fertility (Gold *et al.* 1993) and (iii) socioeconomic factors such as labour, infrastructure and marketing problems (Karamura 1993). There is also a high regional variability in the net impact of these constraints. For example, whereas, between 1970 and 1990, banana production declined substantially in the eastern and central traditional mainstay producer regions, it expanded appreciably in the southwestern region. In the eastern and central regions, exotic beer banana cultivars and annual crops such as cassava, maize and sweet potatoes have replaced cooking bananas (Gold *et al.* 1993). In response to these trends and constraints, a series of measures were taken, including the development of a research agenda by a consortium of international and national research institutions, namely the Uganda National Banana Research Programme of the Uganda National Agricultural Research Organisation (NARO), the International Institute of Tropical Agriculture (IITA), and the African Highland Initiative. In 1997 the collaboration was extended to the International Centre of Insect Physiology and Ecology (ICIPE) to provide an input in farmer-participatory research with special reference to IPM.

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Focus of socioeconomic investigations

Consensus among researchers was that cultural controls of pests and diseases of banana offered the best hope. In any case, farmers were widely using most of the conventional cultural controls. Against this background, socioeconomic work under the ICIPE/NARO/IITA collaboration focused on cultural controls at a benchmark site (BS) where productivity is relatively high but is beginning to decline. Specifically, the investigations sought to provide an understanding of farmers' decision-making processes regarding banana pest and disease controls (BPDC). The aim was to determine: (a) BPDC chosen, abandoned temporarily or for good, or taken up again; (b) the criteria used; (c) factors influencing the decisions; and (d) the results obtained and why.

Conceptual and methodological framework

We hypothesized that five factors are crucial for an understanding of farmers' strategies and decisions regarding banana production in general and IPM practices in particular. First, the role bananas play in the production systems and economy is of utmost importance. This role appertains to the part bananas play in farmers' production objectives and priorities, food security, and cash income. Farmers adopt different strategies depending on whether banana is principally a food staple or a commercial commodity. Second, the availability of production resources: money, land, labour, farm implements and inputs. Third, farmers' knowledge of banana pests and diseases and their controls are critically important. Fourth, economic factors, namely costs, benefits, benefit/cost ratios and affordability greatly influence farmers' production and IPM decisions. Finally, farmers' decisions are influenced by a host of institutional factors such as policy, marketing, extension, road infrastructure etc. (Fig. 1).

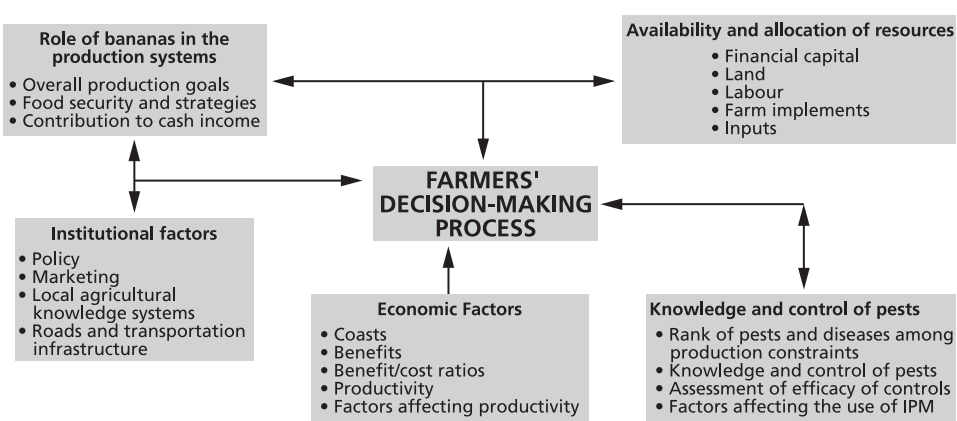

Figure 1. Framework for understanding current banana production and IPM practices.

Methodology

Sampling procedures used

A total of 65 farmers were randomly selected from four parishes. With the help of local council officials, a list of villages in each parish was obtained. In line with the accepted view that farmers in different farming systems have different technological needs, we grouped the sample farmers into three socioeconomic strata, hereafter referred to as SS. We used eight criteria suggested to us by the farmers themselves. These are: (i) quality of residential house, (ii) livestock owned, size of banana farm(s), (iv) size of coffee plantation(s), (v) off-farm employment, (vi) food security, (vii) ownership of crop-processing equipment and (viii) ownership of motor vehicle(s). The disadvantage of this approach is that it invariably entails an element of relativity, but it saved valuable time and effort. On the basis of these criteria, the 65 households were grouped into the three socioeconomic strata as shown in Table 1.

Table 1. Distribution of sample households by parish and socioeconomic stratum.

Parish	Socioeconomic stratum			
	Bottom	Middle	Top	Total
Total	33	20	12	65
Percentage	50.8	30.8	18.5	100.0

Methods of data analysis

Unstructured interviews coupled with observation were carried out in Kisekka sub-county as part of the sampling process for the formal surveys. Interpretative analysis was used for data obtained by use of unstructured interviews. Survey data were analyzed by a variety of quantitative methods. Budgeting techniques were used to measure the comparative advantage of various crops in terms of income earned and returns to family labour. Multi-regression and cross-tabulation were used for quantitative analysis. Regression analysis was used to determine factors affecting yield while cross-tabulation and χ^2 techniques were used to determine the relationships among selected variables.

Research results

The study area

The study was carried out in Kisekka sub-county, Masaka district. The district is located approximately 130 km south of Kampala and borders on Mpigi and Mubende districts to the north, Mbarara district to the southwest, Rakai district to the south and Lake Victoria to the east. Terrain is generally flat with shallow elongated valleys and flat-topped hills. Soils are mainly sandy loam. Rains are bimodal, ranging from 750 to 1200 mm annually. Vegetation is dominated by dry acacia savanna, forest and savanna

mosaics in some areas. The area falls under the banana/coffee farming systems with bananas as the major food crop and coffee the traditional cash crop. Other crops grown include cassava, sweet potatoes, maize, beans, sorghum, millet, tomatoes, onions, passion fruits, ginger, cabbage, pineapples, sugarcane, tobacco, pumpkins, yams, eggplants and field peas. The main economic activity is agriculture with a bias towards food crops. Cash crops are mainly coffee, cotton, maize and bananas. Fruits and vegetables include pineapples, tomatoes, onions and cabbage. Off-farm enterprises generate 20% of total household income.

Demographic profile of sample population

Results show two important trends. First, although women dominate (94 men per 100 women), the sex ratios in the adult age groups are balanced. Second, children below 15 years form a significant proportion of the total population (45%) while very young children (0-4 years) have a significant share of 21.4% of the population. Dependency ratio, the number of persons in the so-called economically active age group (15-64) per 100 dependents (persons aged less than 15 years plus those aged 65 years and over), was estimated at 104.3. This means that each economically active persons supports 1.04 dependants. But if we take out school-going children aged 15 and more, each economically active person supports two dependents. Women have the additional burden of caring for children aged 0-4 years. Age of household head is, on the average, 45.6 years; 71% of household heads are males, 58.3% of whom have obtained primary education. Most male farmers (65%) have part-time off-farm employment, suggesting that most of the responsibilities are left in the hands of their wives. Part-time employment puts stress on the already strained available family labour. On average, 2 persons per household are available for farm and off-farm work. Average household size is 6.71 persons. Most children (76%) are schooling which reduces family labour. All farmers have reasonably long experience in banana farming averaging 18.9 years.

Role and importance of banana in the production systems

Importance of banana

The commanding importance of bananas in the economy of the study area is shown by the data on four parameters. First, bananas are the chief food staple but there are important differences in the way farmers in the three socioeconomic strata value and consume bananas. For example, 67% of farmers in the bottom socioeconomic stratum (SS) value bananas less as the most important food staple than their counterparts in the middle (100%) and top (83%) strata. Aggregately, 73% cooking bananas are grown and consumed on the farm. Significantly, 80% of farmers regard banana as an important crop for food security. Second, on the aggregate, farmers allocate 57% of cropland to banana production and, as in the case of food consumption, farmers in the top stratum allocate a much larger percentage (60%) of cropland to banana production. Third, bananas are also the most important single source (38%) of income to the household. Bananas have a share of 68% of the income from crops. Fourth, farmers (62%) regard banana production

as a profitable enterprise. Farmers' decisions regarding banana production and pest and disease control are therefore bound to be largely influenced by the vital role bananas perform in the economy.

Sources of livelihood and household income

Agriculture is both the main occupation and major source (81%) of annual household income of which 55% and 21% come from crop and livestock production respectively. Other farm sources such as renting land and sale of trees generate 1.1% of total income. The remaining 20% comes from off-farm enterprises (mostly casual employment). Bananas contribute 46.3% and 37.5% of agricultural and total household income respectively (Table 2). The contribution of banana to cash income from crops (68%) is more than three times more than the share of the second largest contributor, coffee (21.7%). Results from PRA show that prior to the 1980s, the share of coffee was much higher. However, field observations show that farmers are replanting coffee, placing coffee seedlings at banana mats.

Table 2. Contribution (Ug. Shs.) of different enterprises to average annual household income, Kisekka sub-county, Uganda.

Enterprise	Annual cash income	Proportion of household income
Banana	390,103.0	37.46
Coffee	125,065.0	12.01
Maize	7,719.3	0.74
Beans	41,148.3	3.95
Groundnuts	1,935.4	0.19
Fruits	1,387.1	0.13
Sugarcane	5,806.5	0.55
Other crops	4,200.0	0.40
Total crops income	**577,364.6**	**55.45**
Cattle	123,943,5.00	11.90
Goats	0.00	0.00
Poultry	123,943.5	11.90
Pigs	6,419.4	0.62
Rabbit	96.7	0.01
Total livestock income	**254,403.1**	**24.43**
Trees	10,500.0	1.02
Land rented	161.29	0.02
Other farm sale	338.7	0.03
Total other farm income	**10,999.99**	**1.06**
Total farm income	**842,767.69**	**80.94**
Off-farm income	198,451.0	19.05
Total household income	**1,041,218.69**	**100.00**

Farmers' assessment of constraints to banana production

A summary of farmers' ranking of constraints to banana production in their area reveals major features. First, farmers have a heightened perception of the damage caused by pests as is reflected in the large share of scores (51%) given to pests. Farmers have vivid memories of the big decline in banana production experienced in the 1980s with which they associate large-scale pest outbreaks and the use of chemical pesticides. Second, crop resources form the second most important cluster of constraints to banana production with an aggregate score of 22%. Socioeconomic constraints (lack of labour, 7.7, and information, 1. 5) have a share of 9.2%.

Resources availability and allocation to banana production and pest management

Land tenure and use

Kibanja (tenancy), accounting for 55% of farms, is the commonest type of land tenure. Other forms of land tenure include leasehold (16%), renting (18%), and hire on a temporary basis (3%). The majority of farms surveyed (55%) are fragmented, with the number of land holdings ranging from 1 to 7 and an average of 2 plots per farm. Average total farm size is 2.9 ha, ranging from 0.001 to 69.5 ha. Crops account for the largest proportion (43%) of land (Table 3). Whereas farmers in the middle SS use 83% of their land, farmers in the top and bottom SS leave 49% and 24% of their land uncultivated. For 50% and 63% of farmers in the top and bottom SS respectively, lack of labour is the major reason for leaving large proportions of uncultivated land. Soil infertility also contributes significantly to the land being left uncultivated. Infertile soils are found mainly in the plains (*bisenyi*) which are often a source of grass mulch, water and firewood. Vegetation in the *bisenyi* comprises short grass (*Cymbopogon*), thickets and papyrus. Land use then, is an important indicator of the priority order among the different economic enterprises, banana production being the most prized crop enterprise (Table 3).

Table 3. Allocation of land to different agricultural activities by socioeconomic stratum (SS) in Kisekka sub-county, Uganda.

Activity	Area (ha)				Percentage share by land use			
	Bottom SS**	Middle SS	Top SS	Aggr.*	Bottom SS	Middle SS	Top SS	Aggr.*
Crops	0.65	1.51	2.52	1.26	74.71	67.71	26.20	43.45
Pasture	0.00	0.15	1.45	0.31	0.00	6.73	15.07	10.69
Trees	0.01	0.12	0.76	0.19	1.15	5.38	7.90	6.55
Elephant grass	0.00	0.07	0.16	0.05	0.00	3.14	1.66	1.72
Uncultivated land	0.21	0.38	4.73	1.09	24.14	17.04	49.17	37.59
Total area	0.87	2.23	9.62	2.90	100.00	100.00	100.00	100.00

* Aggregate - **SS=Socioeconomic stratum.

Major crops grown

Five crops are dominant, namely banana, coffee, maize, beans and groundnuts. The average total cropped area is 1.26 ha but varies with the SS. Farmers in the bottom SS have 0.65 ha whereas farmers in the middle and top SS have 1.56 ha and 2.52 ha, respectively. Average area under banana is 0.72 ha, 50.3% of which is cropland. Area under banana rises with socioeconomic stratum providing corroborating evidence to the findings that farmers in the bottom SS consume less bananas and value them less as the most important food staples.

Intercropping

Overall, 69% of farmers practice intercropping, a system they attribute to shortage of land and poor soils. The number of intercrops ranges from two to several in the field. However, single intercrops (31%) are the most common; while double, pure and several intercrops have equal distribution (16.9). A total of 83% of farmers intercrop bananas with other crops. For example, 66.6% of farmers intercrop bananas with either coffee or beans. Banana/coffee intercrops are very common among the top SS farmers (77.8%) while banana/beans intercrops are largely practised by farmers in the bottom SS. Banana pure stands account for 18.2% and 10% of farms belonging to the bottom and middle SS, respectively, but 25% of farms belonging to farmers in the top SS . Intercropping is highly complex in terms of types and proportion of intercrops among farmers in the bottom stratum. In this regard, results from the PRA show that farmers believe that intercropping lowers banana productivity. A final observation, the proportion of land allocated to coffee, increases with socioeconomic stratum, suggesting that as wealth increases, the behaviour of farmers also changes from subsistence to commercial orientation (Table 4).

Table 4. Cropping system by socioeconomic stratum in Kisekka sub-county, Uganda.

Cropping system	Proportion of farmers (%)			
	Bottom SS	Middle SS	Top SS	Aggregate
Pure	18.2	10.0	25.0	16.9
One intercrop	24.2	25.0	58.3	30.8
Two intercrops	18.2	25.0	00.0	16.9
Three intercrops	15.2	10.0	8.3	12.3
Four intercrops	6.1	10.0	00.0	6.2
Several intercrops	18.2	20.0	8.3	16.9
Major banana intercrops				
Coffee	14.8	38.9	77.8	33.3
Beans	44.4	27.8	11.1	33.3
Yams	29.6	5.6	11.1	18.3
Maize + bean	3.7	5.6	00.0	3.7
Ginger	0.0	5.6	00.0	1.9
Cassava	3.7	0.0	00.0	1.9
Other	3.8	16.5	-	7.6
Total	**100.0**	**100.0**	**100.0**	**100.0**

Labour availability and use

Much of the labour used in farming is family labour and farmers believe it is readily available throughout the year. However, labour demand is mainly high during the rainy seasons, September to December and March to June. During the labour peak periods, 64% of farmers hire labour on contract basis while 39% increase family working hours. But 76% of the children, including those aged over 15 years, are attending school while a large proportion of men is engaged in off-farm enterprises. Women are therefore the major source of family labour for banana production. Data presented on land use and interccropping also provide evidence of labour constraints. Other aspects of labour are examined in the section on IPM.

Farm implements

No farmer owns (though some have access to) agricultural machinery. On average, a farmer owns 4.4 hand hoes, 1.3 machetes, 1.2 sickles, 1.3 axes and 1.3 pruning knives. The reliance on human labour which is also scarce underlines the crippling technological conditions under which banana is grown.

Use of farm inputs

The overwhelming majority of farmers do not use inputs to improve soil fertility. For example, 92% and 84% of farmers are not using fertilizers and improved seed respectively. Farmers gave various reasons but the major ones were high cost and high labour required. The use of organic manure is also very low, 69% and 92% of farmers do not use either animal or compost manure, respectively largely due to high cost and inaccessibility of animal manure and labour intensity of compost manure.

Integrated pest management (IPM)

Farmers' knowledge of IPM

Farmers' knowledge of weevil biology and damage

The majority of farmers (58.2%) believe that the larva and adult weevil are distinct insects and only 26.2% of farmers know they are different stages of the banana weevil. Similarly, 64.6% of farmers believe that both larva and adult weevil are destructive stages while 13.8% of farmers know that only the larva is the destructive stage. Significant percentages of farmers (46.2% and 33.2%) believe that the larva and adult weevil damage the corm respectively. Data not presented also show that most farmers attribute both banana plant toppling and snapping to weevils. The level of understanding of weevil biology and associated damage is therefore low.

Factors influencing farmers' knowledge of the banana weevil

Factors found to be significant in influencing farmers' knowledge of the weevil were extension exposure, source of information, type of labour used (significant at 5%) and gender (significant at 13%). Farmers with thorough knowledge of the pest got their information from fellow farmers (37.5%), compared to only 12.5% who got the information from extension. Female farmers had more knowledge of the weevil, knew

one stage of the weevil (62%) and both larval and adult stages (62%) as compared to 39% and 38.5% for men respectively. Income and education were insignificant in determining farmers' knowledge of the weevil.

Knowledge of IPM practices

Practices commonly known by farmers include sheath removal (72.3%), disc trapping (75.4%), corm removal (70.8%), urine concoction (76.9%), Furadan use (81.5%), ash application (64.6%), and rouging (53.8%). At the same time, important practices like pseudostem trappping (12.3%), corm covering (26.2%), tolerant cultivars (18.5%), paring (3.1%) and hot water treatment (36.9%) are poorly known by farmers as pest controls.

Farmers' assessment of the effectiveness of IPM practices

Farmers' perceptions of the effectiveness of IPM practices were categorized as very effective, moderately effective, not effective and not sure (Table 5). Sheath removal (45%), Furadan (35%) and corm removal (35%) were evaluated as very effective. However, the effectiveness of other practices was not known by the majority of farmers. This could be attributed to the low intensity or non-use of these practices.

Table 5. Percentage of farmers evaluating the effectiveness of IPM practices.

Practice	Very effective	Moderately effective	Not effective	Not sure
Sheath removal	44.6	18.5	1.5	35.4
Splitting pseudostem	1.5	6.2	-	92.3
Chopping stem	7.7	20.0	1.5	70.7
Trapping	10.8	18.5	9.2	61.4
Corm cover	1.5	6.2	6.6	85.7
Corm removal	35.4	24.6	1.5	37.5
Urine concoction	10.8	4.6	6.1	78.4
Furadan	35.4	3.1	4.6	56.9
Mulch placement	1.5	9.2	4.6	84.6
Application of ash	6.2	20.0	15.4	58.4

Adoption of IPM practices

Use and non-use of banana IPM practices and their abandonment

Clean planting material is exclusively used for pest management and no one reported having abandoned or suspended it. The use of direct controls for the purpose of pest management is significant (37%) only for disc-on-stump trapping. But abandonment of its use is also significant (17%). Urine is used by 20% of farmers as a control of banana pests. Pesticides are used exclusively for pest control but, whereas only 17% use it, a larger proportion (20%) has abandoned it. Sanitation practices are the most widely used (71, 67 and 46% for sheath and corm removal, and rouging, in that order). Abandonment of sanitation practices is negligible.

Pest management practices by level of use intensity and socioeconomic stratum

In general, direct pest controls, such as trapping and use of chemical pesticides are not used intensively. Disc-on-stump trapping is the only direct pest control used intensively by a significant (19%) ratio of farmers. Sheath removal (49%), split pseudostem (37%) and chopping pseudostems (32%) are the most intensively used sanitation practices. For both direct pest controls and sanitation, there are important differences among farmers in the various scocioeconomic strata. Fewer farmers in the bottom stratum apply trapping (15%) and Furadan (3%) intensively compared to their counterparts in the top stratum. The same pattern is observable in the use of sanitation practices. These trends are consistent with results on incomes from banana production presented in a later section. Although overall pest control is poor if judged by the high figures of non-users of practices that require cash or labour hire, pest problems are bound to be severest among the poorest farmers.

Labour requirements for banana IPM practices

In general, banana production demands more labour than that of any other crops grown in Kisekka (Table 6). Nevertheless, banana has a lower ratio of hired to family labour than coffee. Differences in the importance attached to the various crops partly explain the differences in the labour ratios. Family labour contributes a higher proportion to the total labour budget for banana production. Coffee, being produced solely for cash, receives a higher proportion of hired labour partly because it pays for the labour input.

Table 6. Labour use (mean man-hours/ha) for banana and coffee in Kisekka sub-county, Uganda.

Crop	Family	Hired	Total
Banana	781	214.1	995.1
Coffee	460	194.0	654.4
Maize	515	-	518.1
Beans	-	-	564.6
Sweet potatoes	-	-	709.5
Cassava	-	-	708.2
Groundnuts	-	-	646.6

Factors influencing the use of IPM practices

We hypothesized that use or adoption of IPM practices would be influenced by nine factors, namely, (i) pest damage, (ii) risk, (iii) importance of pest, (iv) characteristics of the farmer (age, education, farm income, off-farm income, knowledge of the pest, distance from the tarmac road, household size, and banana farming experience), (v) yield, (vi) income from bananas, (vii) extension, (viii) gender, and (ix) socioeconomic status. A summary of the main results is presented below. Weevil damage was negatively correlated with the application of ash (-0.248), and clean planting material (-0.260), all significant at 10% (Table 7). The relationship of weevil damage with trapping (-0.133), corm covering (-0.116), corm removal (-0.064), urine concoction (-0.024), use of chemicals such as Furadan (-0.155), Dursban (-0.108) and Primcid (-0.094), mulch placement (-0.006), use

of tolerant cultivars (-0.027), and paring (-0.108) was negative but insignificant, which was expected since the control methods are designed to control the weevil, leading to the reduction of the damage. By contrast, the relationship between damage and rouging, sheath removal, stem sheath removal and split pseudostem had positive correlation with damage because these sanitation practices do not directly attack the larva and therefore contribute little to the control of damage caused by the weevil. It is also plausible that farmers who were using these sanitation practices were not using other weevil management practices. The risk of not using an IPM practice was determined in terms of farmers' estimation of the period his/her banana plantation would last if she/he was not controlling the pests. The shorter the period estimated, the more risky it would be for the farmer not to control the pest. Results show that risk was negatively correlated with mulch placement (-0.335), significant at 5%. This means that farmers using the practice estimated shorter periods. The implication is that farmers have high confidence in mulch placement for controlling the weevil damage. Furthermore, there was a positive correlation between risk and Dursban application (0.248), significant at 10%, suggesting that farmers believe that banana plantations can last without the use of Dursban. Farmers' perceptions of the major constraints was correlated with the use of IPM practices. Pests as a constraint was measured on a 5-point scale and the ranks were correlated with the use of IPM practices. Corm removal (0.542) and mulch placement (0.303) had positive correlation with the economic importance of the pest, significant at 1% (Table 7). On the other hand, rouging (-0.399) and Primcid use (-0.341) had negative correlations with the pest. This implies that farmers who were using Primcid and rouging experience less pests and hence no longer perceive pests as a major constraint.

Table 7. Correlation of use of IPM practices by economic importance of the pest.

IPM practice	Damage	Risk of not using the practice	Importance of the pest
Remove sheath	0.040	-	-
Stem sheath removal	0.275	0.023	-0.162
Split pseudostem	0.205	-0.141	-0.032
Trapping	-0.133	-0.083	0.183
Corm covering	-0.116	0.049	-0.089
Corm removal	0.064	-0.289	0.542***
Urine concoction	-0.024	-0.042	0.038
Furadan	-0.155	0.094	0.142
Dursban	-0.108	0.248*	0.129
Primcid	-0.094	-0.144	-0.341**
Mulch placement	-0.006	-0.335**	0.303**
Application of ash	-0.248*	-0.209	0.189
Tolerant cultivars	-0.027	-0.165	-0.224
Use of clean planting material	-0.260*	-0.102	-0.127
Paring	-0.108	-0.144	0.129
Rouging	0.123	-0.190	-0.399**

*, **, *** imply significant at 10%, 5% and 1% respectively.

Correlation of adoption of IPM practices with socioeconomic factors. Age of the farmer was positively correlated with rouging (0.428) (significant at 1%); use of clean planting material (0.354), ash application (0.383), split pseudostem (0.339), all significant at 5%; and mulch placement (0.256), significant at 10%. This implies that increase in age of the farmer is associated with high use of sanitation practices. However, age was negatively correlated with trapping (-0.260), significant at 10%. A negative correlation was also observed with corm covering, corm removal, Furadan use, Dursban use and paring. This means that increase in age is associated with less use of weevil management practices. Education showed a positive relationship with the use of virtually all the IPM practices. The significant ones were sheath removal (0.209), split pseudostem (0.225), significant at 10%; corm removal (0.266), urine concoction (0.304), significant at 5%; Furadan use (0.506) and mulch placement (0.365), significant at 1%. This means that education is an important factor in adoption of both sanitation and weevil management practices. Household size had a positive correlation with urine concoction (0.439) and mulch placement (0.355), significant at 1%; use of uninfected planting material (0.189), Primcid (0.195) and Furadan (0.208), significant at 10% (Table 8).

Socioeconomic factors influencing the level of weevil damage. On average, farmers who use hired labour have less weevil damage compared to those who use only family labour. This was expected since banana management is labour-intensive and family labour limited by chilren's school attendance and off-farm employment. All the low damage incidences were registered in farms with hired labour while the majority of farmers (66.7%) having high damage used only family labour. The implication of this is that family labour alone is not enough to implement practices for weevil control. Female farmers had relatively less damage than male farmers, for example, 100% of low weevil damaged farms and only 37.5% of high damaged farms were owned by females . In comparison, there were no male farmers with low damaged farms while 62.5% of highly damaged farms were owned by male farmers. This can be attributed to the fact that most male were engaged in off-farm activities. All the farms with low damage had access to a road but about 56% of highly damaged farms were inaccessible to a road, while 44.4% were accessible to a road.

Economic factors affecting IPM practices

Input/output coefficients for different banana IPM practices compared to other crops

The figures in Table 9 provide information on three case studies of farmers using three different IPM strategies. Farmers in case study 1 rely on sanitation practices only. Farmers in case study 2 combine sanitation with mulch application. Farmers in case study 3 add manure to mulching and sanitation. But as can be noted from the figures in Table 9, apart from seed, farmers exclusively allocate purchased inputs to banana and coffee plots. However, only 11% and 35% of farmers apply manure and grass mulch to their banana fields, respectively. Fertilizers and herbicides are exclusively applied to coffee. Yields, as expected, are highest by far from farms managed under the case study 3 regime.

Table 8. Correlation of adoption of IPM practice with the socioeconomic factors.

IPM practice	Age	Education	Farm income	Pest knowledge	Distance	Household size	Experience	Off-farm income
Remove sheath	-	0.209*	-	-	-	-	-	0.059
Stem sheath removal	0.109	-0.121	-0.579***	0.060	-0.071	-0.031	-0.044	0.068
Split pseudostem	0.339**	0.225*	0.121	0.164	-0.166	-0.120	0.141	0.030
Trapping	-0.260*	0.109	0.117	0.191	0.094	0.187	-0.105	-0.022
Corm covering	-0.155	0.038	0.198	-0.021	0.278*	0.034	-0.126	2-0.119
Corm removal	-0.021	0.266**	0.132	-0.039	0.021	0.215*	-0.203*	-0.004
Urine concoction	0.196	0.304**	-0.067	-0.085	-0.243*	0.439***	-0.091	0.133
Furadan use	-0.150	0.506***	0.374**	0.027	-0.251*	0.208*	-0.216*	-0.049
Dursban use	-0.174	0.107	-0.029	0.244*	-0.192	0.111	-0.141	-
Primcid	0.084	0.107	0.133	0.244*	-0.196	0.195*	-0.119	-
Mulch placement	0.256*	0.365***	0.220	0.239*	-0.041	0.355***	-0.162	0.127
Application of ash	0.383**	0.042	0.197	0.182	0.059	-0.143	0.399***	0.075
Tolerant cultivars	0.220	0.036	-0.001	0.164	-0.109	-0.118	-0.134	-0.076
Use of uninfected planting materials	-0.078	0.103	-0.053	0.059	0.061	0.198*	-0.135	-0.068
Use of cleaned planting material	0.354**	0.037	0.189	0.070	-0.128	-0.124	-0.135	-
Paring	-0.790	0.037	0.177	-0.089	-0.127	-0.119	-0.135	-
Rouging	0.428***	0.031	-0.226	0.363**	0.098	-0.118	-0.130	-0.072

*, **, *** imply significant at 10%, 5% and 1% respectively.

Table 9. Input/output coefficients for banana production under different IPM regimes compared to other crops in Kisekka sub-county,Uganda.

Crop	Input coefficients						Output coefficients		
	Herbicides (L)	Pesticides (kg)	Fertilizer (kg)	Manure (T)	Coffee husks (T)	Grass mulch (bundles)	Seed (kg)	Yield (T)	Price (U.Shs)
Bananas									
Case1	-	-	-	-	-	-	-	11.8	45000
Case2	-	-	-	-	-	12650	-	15.9	47000
Case3	-	-	-	14.0	17.2	12650	-	28.2	48500
Coffee	13.5	24	195	-	-	-	-	1.23	830600
Intercrop									
Maize	-		-	-	-	-	6.0	0.46	150000
Beans	-	-	-	-	-	-	50.0	1.10	379000
Maize	-	-	-	-	-	-	12.4	1.82	150000
Beans	-	-	-	-	-	-	66.2	1.02	379000
Sweet potato	-	-	-	-	-	-	-	48.8	80000
Cassava	-	-	-	-	-	-	-	49.4	100000
Groundnuts	-	-	-	-	-	-	49.4	0.75	600000

Unit cost (U.Shs): Herbicide=12,800; Pesticide=4,500; Fertilizer=474.9; Manure secured on-farm; Coffee husks=17,233; Grass mulch=18.8; Maize seed=1,233; Bean seed=500; Groundnut seed=600.
Case 1= Average management involving mainly sanitation practices
Case2=Sanitation+mulching;
Case3=Sanitation+grass mulch+manure.

Table 10. Benefit/cost analysis of banana production under different IPM regimes compared to other crops.

Variable	Banana			Coffee	Maize /bean	Maize	Beans	Sweet potatoes	Cassava	Groundnuts
	Case 1	Case 2	Case 3							
Gross income ('000 U.Sh ha-1)	531	747	1368	1022	485	272	386	390	494	452
Variable costs ('000 U.Sh ha-1)	73	314	741	276	100	73	85	80	80	105
Total costs ('000 U.Sh ha-1)	359	614	1104	559	349	288	325	372	397	380
Gross margin ('000 U.Sh ha-1)	458	433	627	746	385	199	301	310	414	347
Net Income ('000 U.Sh ha-1)	172	133	264	463	136	-16	61	18	97	72
Return to family labour (U.Sh hour-1)	720	654	803	1620	755	489	668	557	373	684
Benefit/cost ratio (BCR)	1.48	1.22	1.24	1.83	1.39	0.94	1.10	1.05	1.24	1.19

Benefit/cost analysis of banana production under different IPM regimes

Table 10 summarizes the results obtained from benefit/cost analysis of different banana IPM management systems compared to the crops. Net income for all the three banana production systems was positive, ranging from U. Shs 133,000 to 264,000 per ha depending on the type of management used. Net income from bananas for farmers who did not apply grass mulch or manure was U. Shs 172,000 per ha. Applying grass mulch without supplementing it with manure reduced net income by 23%. However, applying grass mulch supplemented with manure improved both gross margin and net income. Return to family labour was highest where farmers applied mulch supplemented with manure or coffee husks and lowest with mulch alone. Both applying mulch and mulch with manure had negative impact on the benefit/cost ratio (BCR). The profitability indicators show that banana had a comparative advantage over annual food crops despite the high labour and other input requirements. However, coffee was more competitive than all other crops partly due to market liberalization. Bananas and other food crops are mainly consumed in the local markets, thus affecting farm gate prices.

Factors influencing banana productivity

Socioeconomic factors affecting banana productivity

Regression analysis was carried out to show factors influencing banana productivity in Kisekka sub-county. Damage level was found to be significant at 0.01 with a coefficient of -1522.2. This means that an increase in weevil damage level by 1% reduces yield by 1522.2 kg. Similarly, damage level was negatively correlated (-0.43) with banana bunch size, significant at 0.01. Damage level and accessibility to any road were also negatively correlated (-0.35), that was significant at 0.01. Accessibility by road enables farmers to access markets which makes them more interested in higher yields and better management than those not accessible by roads. Likewise distance from the tarmac road to the farm is important in determining yield from the farm. Distance was significant at 10% with a coefficient of –279.92. The negative effect means that the further the farm is from the tarmac road, the poorer are the yields. This implies that farms far from the tarmac roads lack market incentives to manage banana plantations well. Distance from the tarmac road was negatively correlated with education level (–0.37), banana cropped area (–0.33), bunch size (–0.38) and yield (–0.36), all significant at 0.1. However, off-farm income (0.0038) was found to have a positive effect on yield and significant at 10%. A positive effect from off-farm income means that part of this income is invested in banana production. Farm income, gender, total farm area, number of cattle, age and education levels of the farmer showed positive relationship with yield as expected but insignificant. On the other hand, extension exposure indicated a negative effect on yield. This was in contrast with the expected relationship. When extension exposure was removed from equation 1 to produce equation 2, adjusted R increased from 0.387 to 0.402, implying that exposure to extension does not explain variation in yield.

Correlation of IPM practices with the productivity and income from bananas

Income from banana had a negative correlation with stem sheath removal (-0.533) and rouging (-0.278), significant at 1% and 10% respectively. Nevertheless, income from banana showed a positive correlation with the use of Furadan (0.320), significant at 5%. This means that farmers who get high income from the sale of bananas can afford to apply chemicals. Farmers with a good knowledge of banana weevils are using Dursban (0.244), Primicid (0.244), mulch placement (0.239), significant at 10% and rouging (0.363), significant at 5%. This was expected since knowledge of the destructive stage would lead to taking measures to control the weevil. Experience in banana production had a negative correlation with the use of IPM practices except the application of ash (0.399). Distance from the tarmac road showed a positive correlation with corm covering (0.278) but a negative relationship with urine concoction (-0.243) and use of Furadan (-0.251), all significant at 10%. This suggests that few farmers residing far away from the tarmac road were not using IPM practices. Distance and pest knowledge were negatively correlated but insignificant (Table 11).

Table 11. Correlation of IPM practices with the productivity and income from bananas.

IPM practice	Yield from bananas	Income from bananas
Remove sheath	-	--
Stem sheath removal	-0.304**	-0.533***
Split pseudostem	0.176	0.156
Trapping	0.174	-0.041
Corm covering	-0.026	0.198
Corm removal	0.174	0.132
Urine concoction	0.243	-0.020
Furadan use	0.057	0.320**
Dursban use	-0.017	0.030
Primcid	0.295	0.232
Mulch placement	0.251	0.187
Application of ash	0.034	0.164
Tolerant cultivars	0.154	-0.101
Use of uninfected planting material	-0.237	-0.010
Use of clean planting material	0.133	0.293*
Paring	-0.002	0.063
Rouging	-0.238	-0.278*

*, **, *** imply significant at 10%, 5% and 1% respectively.

Discussion

Importance of bananas

The vital role of bananas in the economy has been shown in five major ways. First, 57% of cropped area is under banana. Second, 75% of producers consume over 50% of the

bananas they grow on their plots. This is due not only to their preferences but also to market forces. Traders supplying bananas to urban markets do not buy small bunches. There is therefore a discernible collinearity between the proportion of land under banana and farmers' stated food preferences on the one hand, and actual consumption patterns, on the other. Third, the wide range in cultivars grown also reflects the uses to which bananas are put: food staple, beer brewing, dessert and roasting. A notable gap in the data presented is the information on processed products such as handicrafts which would increase greatly the viability of banana. Fourth, bananas contribute 68% and 38% of cash income from crops and total household income respectively. But farmers in the bottom SS attach far less significance (30.3%) to bananas as a source of cash income compared to 55 and 67% for the middle and top SS respectively.

Farmers' resource availability and allocation

Information presented on cash income, labour, land, implements and 21 inputs reveals a chain of mutually reinforcing trends. For example, cash income is critical to the purchase of inputs and farm implements, and hired labour. But whereas cash income from off-farm enterprises has the most positive relationship with banana productivity, involvement in off-farm enterprises takes especially male labour away from the farm. But labour hiring, as has been shown, is not affordable by farmers in the bottom stratum who have a ratio of hired to family labour of only 0.27 for banana IPM work. Ironically, due to labour constraints, households in this stratum, despite having a mean landholding of only 0.87 ha, are unable to put 24% of this land under cultivation. This group has also low use of labour intensive practices and as a result it has a high incidence of pest damage. Furthermore, information presented on the low level, especially of purchased inputs, highlights the dilemma for low-income banana growers. One way out of this predicament is the search for locally available sources of inputs, which is what some farmers are doing. They are experimenting with the use of urine and other concoctions but the finding that it is positively correlated with household size suggests that having a small family is a disadvantage. Entomological research should also play its part.

Knowledge issues

Farmers' heightened perceptions of banana pests and associated losses do not translate into knowledge intensity, so critical for IPM. Information presented has shown that farmers have a poor understanding of key banana weevil controls such as paring, hot water treatment, pseudostem trapping, and the use of tolerant cultivars. The biology of weevils and associated damage are also poorly understood especially by men. For example, 58% of farmers think that the larva is a different insect from the adult weevil. Farmers' assessment of the efficacy of cultural controls presents challenges to the extension. High proportions of farmers are not sure of the efficacy of most of the practices they themselves use: mulch placement, use of ash, corm covering, splitting pseudostems, among others. Only sanitation practices such as the removal of sheath and corms, together with the use of chemicals (Furadan) are rated as very effective. Information presented elsewhere in this report has shown that sanitation practices have virtually no control effect. This was why we looked into factors which shape farmers' perceptions. Farmers (albeit only 37%) with

thorough knowledge of weevils got the information from fellow farmers. Women understand weevil biology and damage better than men. However, the crux of the matter is not so much what farmers know as what they do.

IPM usage

In general, usage of pest controls is low, especially for direct weevil controls such as trapping and hot water treatment. What is more, abandonment is also relatively high due to a combination of high costs (chemicals) and labour intensity of some of the practices (trapping and use of compost). A closely related issue is the intensity with which practices are used. Here too direct pest controls such as trapping and hot water treatment are not intensively used due to costs and labour constraints. Sanitation practices, most intensively used, are not effective as controls. As expected, farmers in the bottom stratum use IPM practices at the lowest level of intensity. The major challenge is to demonstrate the efficacy of these controls to farmers so that they can address the issues of finding the labour and money to implement them. We also examined nine factors influencing the use of IPM practices. Risk was negatively correlated with mulch placement (-0.335) and corm removal (-0.289), practices that do not directly control weevils but contribute to plant vigour and productivity. Age was also associated with the use of clean planting material, use of ash, split pseudostems and mulch. In general, older farmers practice sanitation methods. Age was also negatively correlated with direct pest controls. Other important factors include education (positive for all practices) and household size. Extension agencies need to target their dissemination efforts to these social and economic factors.

Economic analysis clearly shows that whereas banana production in general and IPM practices require significant resource inputs, especially labour and farm inputs, benefit/cost ratios are higher than those estimated for any other crop grown in the area except coffee. In fact, even farmers who invest in sanitation practices alone realize a benefit/cost ratio of 1.48. This shows that banana production is, as farmers themselves confirmed, good business. More work still needs to be done to estimate the benefit/cost ratios of other IPM combinations so that several optimal options can be made available for farmers in each socioeconomic stratum. Entomological research should also focus on clusters of IPM practices rather than individual ones.

Information on productivity takes the process even further. Factors which have the strongest negative correlation with productivity (damage level, -1522.1830, distance from the tarmac road, -279.9248. and exposure to extension, -110.49) require appropriate responses from those responsible for addressing them. On the part of researchers, there is need to collect complementary information on plant population, number and weight of bunches, banana sales, labour and other costs based on observation for at least one year. This information would complement the data we have generated from farmers' estimates.

Institutional factors

Policy, extension, road and marketing infrastructures have an important bearing on banana production and IPM adoption but fall outside the competence of researchers. Nevertheless, it is worthwhile pointing out the relevance of institutional factors. For

example, improving rural road infrastructure and extension services, both of which have negative correlations with banana productivity, is best addressed at policy level. Regarding extension, it may be worth suggesting that since conventional methods have negative results, alternative approaches such as farmer-to-farmer extension, which have worked exceptionally well in Indonesia, Philippines and parts of Kenya, should be promoted.

Gender

Women provide the bulk of banana production and IPM work but information collected shows that men control most of the resources such as land, labour, inputs and cash income from bananas even though women sell 70% of the bananas. Women also have low weevil damage level in banana farms they manage, compared to men whose banana farms have high (63%) weevil damage. It has also been shown that men and women use IPM controls for different purposes and that gender is important though not significantly for banana productivity. This is yet another matter which policy-makers in collaboration with other change agents should address at the level of society. Those engaged in the R&D of IPM need to target technologies to gender differences.

Cluster analysis

We need to carry out further cluster analysis to address the fact that farmers use IPM practices in combinations. The case studies presented in this report highlight aspects of this issue. Cluster analysis will probably unravel the existence of optimal options of integrated IPM practices suitable for the different socioeconomic strata.

Integration

The information presented in this report highlights the need for integration at three levels. First, one of the objectives of benchmark sites is the generation of integrated databases. A modest start has been made at Kisekka benchmark where socioeconomic and some entomological data sets have been collected from the same farms. This has facilitated the determination of the three-way relationships between socioeconomic parameters and pest/damage levels on the one hand, and each of these and productivity, on the other. The integration can be strengthened further by collecting soil and disease data sets from the same farms. Second, integration requires the harmonization of research protocols and workplans of researchers working on the various components. This approach will also make it possible to apportion the causes of the decline in banana production among the major constraints, namely, declining soil fertility, pests, diseases and socioeconomic factors. Integration of research protocols and annual workplans will be a major objective of the second year research programme. Third, interventions will also have to be integrated and targeted to the needs of the three socioeconomic strata identified in this study. For example, a delicate balance has to be struck between considerations of the efficacy of IPM practices on the one hand, and their costs and farmers' needs for food and cash, on the other.

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Session 2F
Review of IPM research activities

Short communications

Fungal endophytes from bananas for the biocontrol of *Radopholus similis*

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Introduction

The burrowing nematode *Radopholus similis* is one of the major pathogens affecting banana production worldwide and is considered the primary pathogen of banana root rot. The nematode causes reddish brown lesions in the cortex and affected roots may finally die. The damaged root system results in reduced water and nutrient uptake and poor anchorage of the plant. Yield is reduced and the vegetative cycle is lengthened (Gowen and Quénéhérvé 1990) and severely damaged plants may finally topple. Chemical control of nematodes is environmentally unfriendly, hazardous to human health and too expensive for small-scale farmers serving local markets in Africa. Breeding for nematode resistance seems to be favourable; however, little nematode resistance within the common commercial *Musa* cultivars is known (Gowen 1995). Therefore, the development of biological control agents as an alternative for nematode control is considered a feasible alternative (Kerry 1990, Sikora 1992).

Fungal endophytes are believed to be potentially effective biological control agents for plant parasitic nematodes management (e.g. Hallmann and Sikora 1994, Schuster *et al.* 1995). Many fungi have been described to be associated with nematode lesions in banana roots mostly increasing disease severity (Stover 1966, Sikora and Schlösser 1973, Pinochet and Stover 1980, Mateille and Folkertsma 1991). Nevertheless, it has been shown that some fungi colonizing banana root tissue are inhibitory to migratory endoparasites (Sikora 1992, Schuster *et al.* 1995). Fungi from healthy banana roots have been isolated and previously tested for their nematode-controlling ability *in vitro* using culture filtrates (Schuster et al. 1995).

The objectives of the current investigation were to determine whether isolates of *Fusarium oxysporum* showing control activity *in vitro* also have antagonistic activity *in vivo* and to investigate their effect on plant growth.

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Material and methods

Isolates of *Fusarium oxysporum* selected for inoculation of banana plants were V4w5, III3w3, III4w1 and V5w2. These fungal endophytes were previously isolated from healthy banana roots and tested *in vitro* using their culture filtrates. Colonization of banana roots has been proven for these isolates in *in vitro* tests (Schuster, unpublished data). Spore suspensions of the respective fungal isolates were produced in Potato Dextrose Broth (PDB) on a rotary shaker. Banana plants (Musa AAA, cv. Gros Michel) were produced in tissue culture (Vuylsteke 1989) and dipped in spore suspensions of 1.4 – 3.2 x 106 spores/ml prior to weaning. Control plants were dipped in PDB only. Plants were potted in 100 ml cups filled with sterilized soil and hardened in a humidity chamber for two weeks. Four-week-old plants were transferred to polythene bags filled with 2 L of sterile soil. Two similar experiments with the difference being the plant age were conducted. After 13 and 32 weeks, respectively, plants were removed from the bags and the roots gently washed under the tap to remove all soil. Three equally developed roots were selected, and one segment on each intact root (approx. 1 g in fresh weight) was enclosed in a 100 ml cup, thus creating a confined compartment. These plants were then transferred to 10 L buckets filled with sterile soil. The roots in the cups were then covered with sterile sand while the rest of the root system was covered with sterile soil. The openings of the cups emerged about 2 cm from the soil level in the buckets, thereby allowing direct nematode inoculation at predetermined time periods. Ten days after transplanting, the exposed root segments in the cups were carefully inoculated with 10 *Radopholus similis* females singly picked from field populations and placed directly on the root surface. Plants used in the second experiment were inoculated with the fungal endophytes at the same time as the plants for the first experiment and kept in polythene bags until pot setting. Plants growth parameter were taken every 4 weeks and at the termination of the experiment. Beginning 6 weeks after nematode inoculation (plant age 19 and 38 weeks, respectively), the root segments inoculated with the nematode in the cup were cut free from the intact root and the nematodes extracted overnight by the extraction dish method (Oostenbrink 1960). All nematodes extracted were concentrated on a 20 µm sieve and counted. Means of the nematode counts for the 3 cups per plant were calculated, and each plant was considered a replication. The two experiments had 6 plants per treatment and each experiment was a complete randomized block design with five treatments: PDB: PDB only, Fo 1: *F. oxysporum* V4w5, Fo 2: *F. oxysporum* III3w3, Fo 3: *F. oxysporum* III4w1, and Fo 4: *F. oxysporum* V5w2. All treatments were followed by nematode challenge inoculations at plant age of 13 and 32 weeks, respectively. Nematode counts were ln (x+1) transformed prior ANOVA.

Results

Plant growth

Inoculation of tissue-cultured bananas, cv. Gros Michel, with isolates of *F. oxysporum* resulted in enhanced plant height of 19-week-old plants. All isolates significantly ($P < 0.05$) enhanced plant height by 11 to 25% compared to the control when plants were not stressed by transplanting and nematode challenge (Table 1). Under stress conditions, i.e. complete removal of soil, transplanting and nematode inoculation at week 13 (experiment 1), treatment Fo 1 promoted plant height significantly by 29% compared to the control, whereas plant height was not significantly affected by the other treatments (Table 1).

Table 1. Influence of four isolates of *Fusarium oxysporum* on the height of 19-week-old banana plants, cv. Gros Michel (*Musa* AAA).

Treatment[1]	Endophyte species	Plant height of 19-week-old Gros Michel (cm)	
		Non-stressed[2]	Stressed[3]
PDB	-	12.5 a	13.4 a
Fo 1	*F. oxysporum*	14.3 b	17.3 b
Fo 2	*F. oxysporum*	14.3 b	14.9 ab
Fo 3	*F. oxysporum*	14.4 b	15.6 ab
Fo 4	*F. oxysporum*	13.8 b	13.8 a

[1] Following treatments were applied to the plants: PDB (Potato Dextrose Broth) and spore suspensions of fungal isolates V4w5 (Fo 1), III3w3 (Fo 2), III4w1 (Fo 3), and V5w2 (Fo 4).

[2] Not stressed plants were kept in 2 L bags and were used in the second experiment.

[3] Stressed plants underwent complete removal of soil, transplanting and cup setting, and nematode inoculation at week 13. Means in columns followed by the same letter are not significantly different at $P < 0.05$ (LSD), n = 6.

The plant growth promoting effect, however, was not observed in 38-week-old plants kept in 2 L polythene bags until transplanting and pot setting. No differences in plant height could be detected between endophyte inoculated and control plants.

Nematode multiplication

Differences in nematode multiplication were detected between endophyte inoculated and control plants as well as among plants inoculated with different endophytes. The number of nematodes was not significantly altered in 19-week-old control plants when compared to the initial inoculum. Treatment Fo 4 significantly reduced the number of nematodes in the root segments compared to control plants. An alteration in nematode numbers, although not significantly different from control root segments, was observed in root segments of treatments Fo 1, Fo 2 and Fo 3. The latter reduced *R. similis* by 26% of the initial inoculum (Table 2).

Nematode numbers increased by 33% over the initial inoculum in root segments of 38-week-old control plants. All plants inoculated with fungal endophytes showed lower numbers of nematodes than initially inoculated. Nematodes in root segments of those plants were reduced by 51 to 99% of the initial inoculum. Treatments Fo 2, Fo 3, and Fo 4 significantly ($p < 0.05$) reduced *R. similis* compared to the control (Table 2).

Table 2. Multiplication of *Radopholus similis* in root segments of 19- and 38-week-old Gros Michel (*Musa* AAA) 6 weeks after nematode inoculation.

Treatment[1]	Endophyte species	Nematode multiplication in percent of initial inoculum	
		19-week-old Gros Michel	38-week-old Gros Michel
PDB	-	100.8 a	133.3 a
Fo 1	*F. oxysporum*	213.3 a	48.9 ab
Fo 2	*F. oxysporum*	128.9 a	10.7 bc
Fo 3	*F. oxysporum*	73.9 ab	1.4 c
Fo 4	*F. oxysporum*	37.8 b	32.5 b

[1] Following treatments were applied to the plants: PDB (Potato Dextrose Broth only) and spore suspensions of *Fusarium oxysporum* isolates V4w5 (Fo 1), III3w3 (Fo 2), III4w1 (Fo 3), and V5w2 (Fo 4). Means in columns followed by the same letter are not significantly different at $P < 0.05$ (LSD). Means of 3 root segments per plant, n = 6.

Discussion

Enhanced growth of plants inoculated with fungal endophytes has been reported for grasses (e.g. Clay 1988), tomato (Hallmann and Sikora 1994), and banana (Reissinger 1995). The isolates of *F. oxysporum* used for inoculation of tissue-cultured bananas in these experiments increased plant height compared to the control at an early stage of plant development (19 weeks). This growth promotion, however, was not detected in all treatments when the plants were stressed by combined transplanting and nematode inoculation, nor was it observed in 38-week-old plants.

Important was the fact that none of the fungal endophytes reduced plant growth. Beneficial effects are suspected to counterbalance for the energy costs of the plant to support a heterotrophic symbiont and that this benefit is substantial (Clay 1988). Furthermore, the isolates of *F. oxysporum* used for inoculation did not induce wilting symptoms or discolouration of the vascular strands in the fusarium wilt-susceptible cultivar Gros Michel during the course of the experiments, again demonstrating the non-pathogenic nature of these fungal isolates.

Nematode penetration or multiplication was effectively reduced in root segments of endophyte-inoculated plants. This effect occurred in one treatment at 19 weeks and in three treatments at 38 weeks. Similar results were obtained by Speijer (1993) who observed that simultaneous inoculation of bananas with *F. oxysporum* and *Pratylenchus goodeyi* resulted in reduced nematode penetration. In his tests the simultaneous inoculation indicate that there were other direct effects of the fungus on the nematode.

Our results demonstrated that the reduction in nematode numbers was not due to direct antagonistic activity of the fungi on the nematode in the soil system. Ten days before nematode inoculation, the soil was completely removed from the root system as thoroughly as possible and after setting the cups around the roots, the plants were planted in sterilized soil again. Furthermore, during the course of the experiment no additional fungus, other than the initial inoculum used, was applied. This suggests that the reduction in the nematode density was caused by endophyte activity inside the root tissue of the plant.

The application system used, dipping tissue culture plants at weaning stage in a spore suspension, can be effectively used in mass propagation of enhanced tissue culture planting material. Production of fungal spores is fairly easy and inexpensive and the weaning process is only slightly altered by the inoculation of the fungal isolates. Furthermore, only small amounts of inoculum are needed and no subsequent applications are necessary.

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Pathogenicity of *Radopholus similis* and *Helicotylenchus multicinctus* on bananas in Uganda

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Introduction

Radopholus similis and *Pratylenchus goodeyi* are known worldwide to be the major nematode parasites of banana and plantains (Bridge 1988, Gowen and Quénéhervé 1990). Nevertheless, *Radopholus similis* and *Helicotylenchus multicinctus* usually occur together in banana roots in farmers' fields (Gowen 1993). However, in places where *R. similis* is absent, *H. multicinctus* alone causes significant damage and yield losses to bananas (Gowen and Quénéhervé 1990). In addition, surveys done in East Africa (Sikora *et al.* 1989) and Uganda in particular (Kashaija *et al.* 1994) indicated that *H. multicinctus* is more abundant than *R. similis.* However, the pathogenicity of the two species in pure cultures and interactions when present together were not clear, and needed to be determined. This was considered important because in other studies, negative interactions have been reported between *Meloidogyne incognita* and *Radopholus similis* (Santor and Davide 1982) while other studies between *Pratylenchus penetrans* and *Meloidogyne incognita* indicated synergism (Karim 1994). It was not clear which of these interactions occurred between *R. similis* and *H. multicinctus.* The objectives of the study were to assess the level of root damage caused by *R. similis* and *H. multicinctus* in the plant root system at farm level and to determine the variability in pathogenicity of *R. similis* and *H. multicinctus* in pure cultures and in combination.

Materials and methods

Farm selection

The banana farms were selected in Kisekka subcounty, Masaka district, Uganda. This is an area which is experiencing decline in banana production, and plant parasitic

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nematodes are one of the causes in yield reduction in Uganda. The farms were selected based on observed root necrosis. In each farm ten mats containing a recently flowered plant were selected and marked for easy follow-up. The selected mats were of different cultivars, but all belonged to the East African highland banana group AAA-EA.

Nematode damage assessment

Nematode damage assessment was done according to Speijer and Gold (1996). Roots were collected from an excavation of 20 cm x 20 cm x 20 cm from a recently flowered plant. All roots collected were divided into dead and functional roots. The roots in each category were counted. Five functional roots were selected randomly. Their lengths were reduced to approximately 10 cm and split longitudinally. One half of each of the five roots was scored for the extent of necrosis in the root cortex. The maximum root necrosis observed per root segment was put at 20%, giving a maximum root necrosis of 100% for one sample of five root halves. Each plant assessed was marked. The assessment was repeated on the same plant at an interval of one month for a period of three months between December 1997 and February 1998.

Mass production of inoculum for the pot experiment

Nematode-infested banana roots were collected from Masaka district in Uganda. The roots were split and cut into small pieces of about 1 cm, blended and nematodes were extracted in water overnight. *Radopholus similis* and *Helicotylenchus multicinctus* were removed from the solution to raise pure cultures. The nematodes were cultured on a local banana cultivar Nakyetengu (AAA-EA) in drums containing sterilized soil. The inoculum was increased over a period of three months at Kawanda Agricultural Research Institute.

Experimental design and inoculation

Tissue culture plantlets of a local East African highland banana cultivar *Kisansa* AAA-EA from the Kawanda Agricultural Research Institute and Makerere University Agricultural Research Institute Kabanyolo were used to ensure clean planting material. These were planted in pots made of polythene at Masaka District Farm Institute between February 1998 and September 1998. The pots contained about 0.3 m^3 of sterilized soil. The soil was sterilized to kill nematodes living freely in the soil. The ground where the pots were laid was covered with polythene, to ensure that any roots that grew out of the polythene bag did not come into contact with unsterilized soil where they could be reinfested.

The pots were arranged in a completely randomized block design and each treatment contained six replicates. The treatments were 1000 *R. similis* per plant, 1000 *H. multicinctus* per plant, and a mixed population of 500 *R. similis* and 500 *H. multicinctus* per plant. Root segments containing nematodes were used for inoculation, because when nematodes are extracted, especially *R. similis*, they become less infective (Pinochet 1988). Nematode-infested roots were split longitudinally, cut into 1 cm-long pieces and were mixed thoroughly. A subsample of 5 g was extracted in three replicates. The nematodes in the subsamples were counted and the average was

computed. The average was used to estimate the amount of root tissue. The plants were allowed to stay for at least two weeks in pots after planting so that they establish. The soil was gently removed to expose the roots. The root segments containing nematodes were spread within 3 cm radius around the plant and covered with soil. Plants were inoculated in March 1998 and plants were about 30 cm tall.

Harvesting of pot experiment

The life cycle of *Radopholus similis* takes approximately 4 weeks (Sarah *et al.* 1996). Plants were harvested two months after inoculation to allow the nematode to multiply for at least two generations. Assessments were done 4 and 6 months after inoculation to monitor population and nematode damage fluctuation. At every harvest growth parameters and nematode damage indices were recorded. The plants were removed from the polythene bags with their root system still intact. Plant height, girth, number of functional leaves, shoot and root fresh weight, percent dead roots and percent root bases with lesions were recorded.

Nematode extraction and counts

The five roots scored for necrosis were taken to the laboratory at Kawanda Agricultural Research Institute. The roots were washed, chopped into 1 cm pieces and thoroughly mixed. A 5-gram subsample was taken and macerated in a kitchen blender for 15 seconds, with water just covering the contents. The nematodes were extracted according to the modified Baermann funnel technique (Hooper 1986) overnight using tap water. A solution of water containing nematodes was removed from the plates and put into vials. This was left to stand for about two hours to allow the nematodes to settle at the bottom. The water was reduced by gently decantering from the top to a volume of 25 ml. Two millilitres of this solution were removed, nematodes identified and the different species counted under a stereomicroscope. The number of nematodes reported include all life stages. These were computed to represent nematodes in 100 g of roots.

Data analysis

The means of different nematode species encountered in the survey were computed. Similarly the means of damage indices were calculated. The population of nematodes and damage indices could not be subjected to analysis of variance table, as these vary between sites and even within sites or neighbouring farms (Sebasigari and Stover 1988). This may also vary due to differences in management (Speijer *et al.* 1994). The percentage of dead roots and the percentage of root bases with lesions were computed for the pot experiment. The nematode counts were subjected to log x+1 to reduce coefficient of variation. The parameters recorded were subjected to analysis of variance using an MSTATC statistical package. Those that were significantly different were separated using the Least Significant Difference at a probability level of 0.05.

Results and discussion

Nematode occurrence at farm level

The results reported are from 9 farms, in one farm the plants were lost due to toppling. All the major banana parasitic nematodes were encountered at farm level in varying population densities (Table 1). The two species *Pratylenchus goodeyi* and *Helicotylenchus multicintus* occurred in all farms surveyed. On the other hand *Radopholus similis* and *Meloidogyne* species occurred in 44% and 22% of the farms surveyed respectively. The most abundant nematode species was *P. goodeyi* with the highest population of 17675 nematodes/100 g of roots on farm 1 (Table 1). The results also indicate that the least abundant nematode was *Meloidogyne*, occurring only in two farms with a population of 42 and 16 nematodes per 100 g of roots. The results indicated that *P. goodeyi* and *H. multicinctus* were more abundant than *R. similis*. These results agree with what was reported in Uganda (Kashaija *et al.* 1994) where *P. goodeyi* and *H. multicinctus* were more abundant and more widespread than *R. similis*. This is known to be a major banana nematode worldwide. A similar survey done in Tanzania also reported *P. goodeyi* and *H. multicinctus* as more abundant and more widespread than *R. similis* (Sikora *et al.* 1989).

Nematode species damage at farm level

Nematode damage can be related to percentage of root necrosis and percent dead roots. These two parameters ranged between 0.9%-12.3% and 10.6-23.6% respectively. The highest damage was observed in farm 3 (Table 1). This farm had a percent root necrosis index of 12.3% and a percentage of dead roots of 22.5%. The farm had a population of 3200 *P. goodeyi*/100 g of roots, 1308 *R. similis*/100 g of roots and 1302 *H. multicinctus*/ 100 g of roots (Table 1). When correlations were run between the nematode species and the damage indices (data not shown) *R. similis* was the only nematode species which correlated significantly with percent root necrosis (Corr. 0.441; P=0.021). However, *P. goodeyi* had the highest correlation with percent dead roots although it was not statistically significant (Corr. 0.228; P=0.252).

Speijer *et al.* (1994) considered damage less at farm level when the necrosis of the root cortex did not exceed 5% on primary roots of recently flowered plants. In all farms where *R. similis* occurred, percent root necrosis was greater than 5% and the percentage of dead roots was more than 20% except on one farm which had 35 *R. similis*/100 g of roots. This suggests that *R. similis* although it occurred in relatively low numbers compared to the other species contributed greatly to root damage at farm level.

Nevertheless in the absence of *R. similis* other nematode species can interact to cause substantial damage. Farm 7 (Table 1) had no *R. similis* but damage was greater than 5%. Root damage on this farm was possibly due to the combined effects of *P. goodeyi* and *H. multicinctus*. On farm 9 (Table 1) *P. goodeyi* occurred in high numbers (14829 nematodes per 100g of roots) and with *H. multicinctus* (16 nematodes per 100 g of roots) (Table 1). *Pratylenchus goodeyi* was the species which most likely contributed to the damage indices of 6.6% root necrosis and 15.8% dead roots.

Table 1. Nematode species occurrence in 100 g of roots and their damage on banana roots at farm level in Masaka district, Uganda.

Farm no.	*P. goodeyi*	R. *similis*	*H. multicinctus*	*Meloidogyne* spp.	Root necrosis (%)	Dead roots (%)
1	17675	1067	717	-	7.0	22.3
2	7747	-	1302	-	0.9	10.6
3	3200	1308	2046	-	12.3	22.5
4	1929	633	1475	-	8.3	23.6
5	4167	-	2082	42	4.2	13.8
6	9591	35	6784	-	1.3	19.2
7	9592	-	1592	-	8.3	15.3
8	2146	-	102	-	4.5	16.6
9	14825	-	33	16	6.9	15.8

Means are of nematode counts and damage indices for 3 samplings

Effect of nematodes on growth of bananas

There were no significant differences observed on plant height, girth, number of functional leaves, root and shoot fresh weights 2, 4 and 6 months after inoculation (Tables 2 and 3) except for root fresh weight 6 months after inoculation (Table 3). Plants inoculated with *R. similis* alone had significantly reduced root fresh weight. These plants had a root fresh weight of 816.6 g compared with the control of 1941 g. Also the mixed population (500 *R. similis* and 500 *H. multicinctus*) significantly reduced root fresh weight over those inoculated with *H. multicinctus* alone and the mixed population of the two nematodes. Plants inoculated with the mixed population had a root fresh weight of 1283 g. On the other hand plants inoculated with *H. multicinctus* alone did not significantly reduce root fresh weight (Table 3). In this treatment the root fresh weight was 1391 compared to the control of 1941 (Table 3). Shoot fresh weight was not significant 2, 4 and 6 months after inoculation (P=0.3702, 0.0828 and 0.4063) respectively although plants inoculated with *R. similis* alone had consistently lower shoot fresh weights than the other treatments (Table 3).

Table 2. Height (cm), girth (cm) and number of functional leaves of banana plants 2, 4 and 6 months (mo) after inoculation with *Radopholus similis* and *Helicotylenchus multicinctus* and the mixed population of the two nematodes.

Treatments	Height (cm)			Girth (cm)			Number of functional leaves		
	2 mo	4 mo	6 mo	2 mo	4 mo	6 mo	2 mo*	4 mo	6 mo
R. similis	85.5	94.2	107	13.2	19.0	17.7	-	6	6
H. multicinctus	90.7	110.2	104	15.8	20.5	21.3	-	6	6
Mixed population	88.3	106.7	103	16.8	20.0	18.7	-	5	6
Control	84.2	95.8	93	14.3	18.9	18.3	-	7	6
LSD(0.05)	ns	ns	ns	ns	ns	ns	-	ns	ns
CV(%)	16.9	6.3	11	29.5	7.6	6.9	-	10.2	15.9

* data not taken
ns = non significant at P=0.05

Table 3. Root fresh weight and shoot fresh weight of banana plants 2, 4 and 6 months (mo) after inoculation with *Radopholus similis*, *Helicotylenchus multicinctus* and the mixed population of the two nematodes.

Treatments	Root fresh weight (g)			Shoot fresh weight (kg)		
	2 mo	4 mo	6 mo	2 mo	4 mo	6 mo
R. similis	470	783	817	1.7	2.6	3.0
H. multicinctus	683	1116	1391	1.9	3.7	3.5
Mixed population	620	1433	1283	2.0	3.6	4.1
Control	678	1250	1941	2.1	3.3	3.2
LSD (0.05)	ns	ns	558	ns	ns	ns
CV(%)	16.9	21.7	20.6	34.1	14.8	11.4

ns = non significant at P=0.05

Radopholus similis caused a significant reduction in root fresh weight 6 months after inoculation. This may suggest that the nematode had multiplied and built up to populations causing substantial damage that leads to toppling (Speijer *et al.* 1994) caused by a weak root system. This implies that in selecting/breeding for nematode resistance, banana cultivars with a strong root system may have a high potential for nematode resistance. On the other hand, where *R. similis* was used, growth was more retarded than when the mixed population and *H. multicinctus* were used (Tables 2 and 3). This may suggest that the two species compete between themselves. In spite of these observations further investigations are needed which should involve varying the ratios of the two nematodes in the inoculum.

Effect of *Radopholus similis* and *Helicotylenchus multicinctus* on root damage

Radopholus similis when inoculated alone to banana plants caused a significantly greater percentage of dead roots (P=0.027) 2 months after inoculation (Table 4) but this was not significant 4 and 6 months after inoculation. Also plants inoculated with *R. similis* alone had significantly higher percentage of root bases with lesions (7.7%) than those which were inoculated with *H. multicinctus* alone (0%) (Table 4). However the percent of root bases with lesions did not differ significantly between plants inoculated with *R. similis* alone and plants inoculated with the mixed population of the two nematode species (Table 4). Similarly where plants were inoculated with *R. similis* alone there was a significantly higher percent root necrosis 2, 4 and 6 months after inoculation than for those inoculated with *H. multicinctus* alone. This was observed as 22.8%, 29.5% and 41.8% respectively. On the other hand the percent necrosis of plant inoculated with *H. multicinctus* was generally low. This was 3.0%, 1.3% and 3.8% 2, 4 and 6 months after inoculation respectively.

The percentage of dead roots of plants inoculated with *R. similis* alone was significantly higher 2 and 4 months after inoculation but was not significant 6 months after inoculation. This may reveal that other factors, e.g. plant age, contribute to percentage of dead roots. The plants which were inoculated with *R. similis* alone had a

significantly higher percentage of root bases with lesions than those inoculated with *H. multicinctus* alone. This may suggest that *R. similis* penetrates more of corm than *H. multicinctus*. Therefore it may be easy to transfer *R. similis* through suckers used as planting materials than *H. multicinctus*. *Radopholus similis* alone caused a significantly higher percentage of root necrosis compared to the other treatments. The damage caused by *R. similis* has been reported (Blake 1969, Bridge 1988) and it is the most damaging nematode of banana worldwide. This may be related to its rate of multiplication. Even when it was mixed with *H. multicinctus* in the same ratio, its population greatly exceeded that of *H. multicinctus* 2, 4 and 6 months after inoculation (data not shown).

In conclusion, *R. similis* was the nematode species which was most damaging to banana roots. However, when it was combined with *H. multicinctus*, damage was lower but not significantly lower than when R. similis was used alone. Despite the low indices recorded when *H. multicinctus* was inoculated to plants alone, it may still be an important point. This low level of damage may have been due to the low inoculum level, which could be below its damage threshold.

Table 4. Root damage on banana plants caused by *Radopholus similis, Helicotylenchus multicinctus* and the mixed population of the two nematodes 2, 4 and 6 months (mo) after inoculation.

Treatment	Percent dead roots			Percent root bases with lesions			Percent root necrosis		
	2 mo	4 mo	6 mo	2 mo*	4 mo	6 mo	2 mo	4 mo	6 mo
R. similis	6.1	1.8	21.5	-	4.1	7.7	22.8	29.5	41.8
H. multicinctus	0.0	1.0	3.1	-	1.9	0.0	3.0	1.3	3.8
Mixed population	1.1	1.0	12.9	-	3.3	6.7	13.2	19.2	36.6
Control	0.0	1.0	2.0	-	1.0	0.0	1.8	0.0	0.0
LSD(0.05)	2.5	ns	ns	-	1.9	2.5	11.9	18.9	13.3
CV(%)	69.6	57.7	77.3	-	37.4	34.8	54.9	75.5	36.9

ns = non significant at P= 0.05
* data not taken

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The potential of using pheromone traps for the control of the banana weevil *Cosmopolites sordidus* Germar in Uganda

W. Tinzaara, W. Tushemereirwe and I. Kashaija

Introduction

The banana weevil *Cosmopolites sordidus* Germar is one of the major constraints to banana production especially in small-scale farming systems (Bujulu *et al.* 1983, Stover and Simmonds 1987, Sikora *et al.* 1989). Weevil control generally relies on the application of costly agrochemicals that are beyond the reach of resource-poor farmers. Resistance towards these chemicals has recently been reported in some countries (Bujulu *et al.* 1983, Collins *et al.* 1991). Cultural control practices in use include crop sanitation and trapping but are of limited application. Integrated pest management approach (IPM) appears to be a plausible method being developed for the control of this pest. Weevil trapping using banana pseudostem traps is the commonly advocated component of the IPM options (Gold 1997). This method however has not been easily adopted in Uganda due to being labour-intensive and to the unavailability of trapping material. An easy-to-use and effective method, involving use of pheromone traps, has been identified as a plausible alternative (Alpizar and Fallas 1997). It could be used in combination with other control measures, especially those based on cultural practice, as an IPM option.

The pheromone trapping system has been reported to be safe, long-lasting, effective and reasonably priced (Alpizar and Fallas 1997). The trapping system has been reported to reduce damage and increase yields in banana and plantains (Alpizar and Fallas 1997). Pheromone lures (Cosmolure+) increased the attractiveness of stem traps by 5-10 times in Costa Rica. Cosmolure-baited buried pitfall traps containing 3% laundry detergent in water were however 2.5 times more effective than Cosmolure-baited stem traps. The capture rate of the trap was reported increased by 20% when Cosmolure-baited plastic gallons with a ramp were used as compared to baited pitfall traps (Alpizar and Fallas 1997).

KARI, Kampala, Uganda

This paper gives preliminary results of a study conducted at Kawanda Agricultural Research Institute (KARI), Uganda, to validate the efficacy of the technology under Uganda conditions.

Materials and methods

Site

The study was conducted on-station in a 4-year-old banana plantation of about 1 hectare, planted with the cultivar Mbwazirume (AAA-EA). The field consisted of 36 plots with 25 mats in each plot.

Types of traps and trapping

Four types of pheromone traps (Pitfall-Cosmolure+, Pitfall-RMD-1, Gallon-Cosmolure+ and Gallon-RMD-1) as described by Alpizar and Fallas (1997) were placed in the banana field as baits for the banana weevil. Pitfalls were prepared by cutting open 10-litre buckets at a height of 15 cm (Fig. 1a). A pheromone lure (Cosmolure+ or RMD-1) was hung from the roof of the bucket cover using a nylon string. A laundry detergent was added in the traps to reduce surface tension and therefore prohibit the weevils from climbing out. Gallon traps were made out of a 5-litre jerrycan (Fig. 1b). A "window" was cut in each side of the jerrycan and the flap folded down to make a walk-in ramp. Gallons were placed in the soil to make ramps touch on the ground. Either a Cosmolure or RMD-1 pheromone was hung from the cup of the jerrycan using a nylon string. Pseudostem pieces (5-10 cm long) soaked in a solution of Furadan (10 g Furadan to 1 litre of water) were placed at the bottom of the gallon to kill weevils whenever attracted into the trap.

The conventional split pseudostem traps were included as a check. Traps were made from 30 cm-long pieces of fresh material cut exactly in half longitudinally (Fig. 1c). The two halves were placed flat side down on the cleared soil surface close to and on opposite sides of the randomly selected mat (Mitchell 1978, Ogenga-Latigo and Bakyalire 1993). Pseudostem traps were placed at least 30 metres from the nearest pheromone trap.

Traps were checked every day for a month and the number of weevils caught in each trap recorded. Pseudostem traps were renewed every three days. Weevils caught in pheromone traps were sexed to determine sex ratios of weevils attracted to pheromone traps.

To determine the weevil attraction distance by pheromone traps (Pitfall-Cosmolure+), weevils were marked according to sex and distance of release by scratching on elytra using a dissecting blade. Weevils were released at 5, 10, 20, 30, 40, 50 and 60 metres from the Pitfall-Cosmolure+ trap. At each distance from the trap, 100 weevils (50 females and 50 males) were released. The marked weevils recaptured were recorded every day for four weeks.

The costs of pseudostem and Cosmolure+ to reduce weevil population by 50% in the trial were estimated.

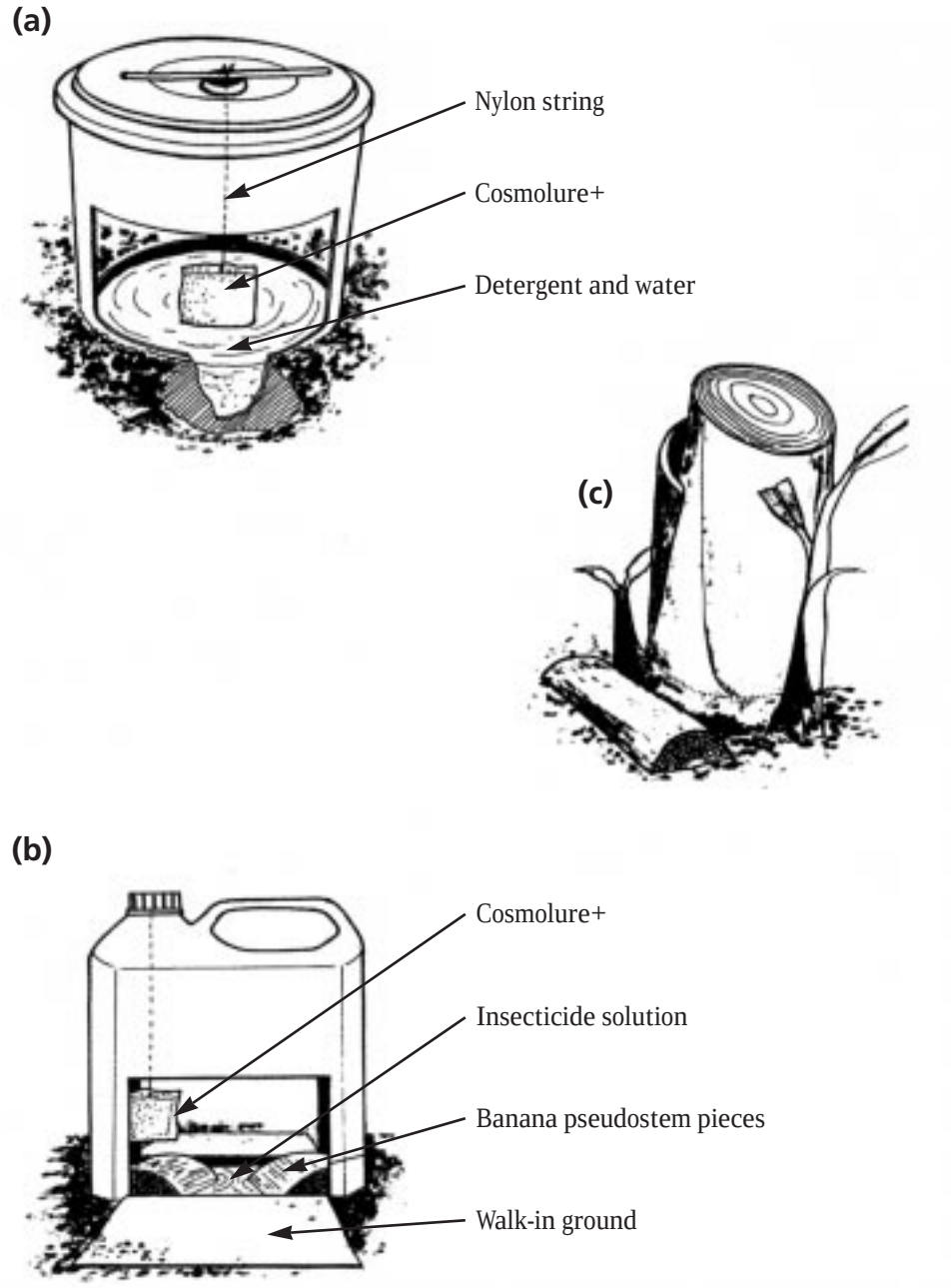

Figure 1. Trap type: (a) Pitfall trap, (b) Gallon trap with a ramp and (c) Pseudostem trap (a modified design from Alpizar and Fallas 1977).

Results and discussions

The Pitfall-Cosmolure+ traps caught 18 times the number of weevils as compared to the pseudostem traps (control), which caught a mean number of 1.3 weevils per trap per day (Fig. 2). The weevil catches of the other three pheromone traps were significantly lower than the Pitfall-Cosmolure+ trap catches and significantly (p = 0.05) higher than the pseudostem trap catches, but similar among themselves.

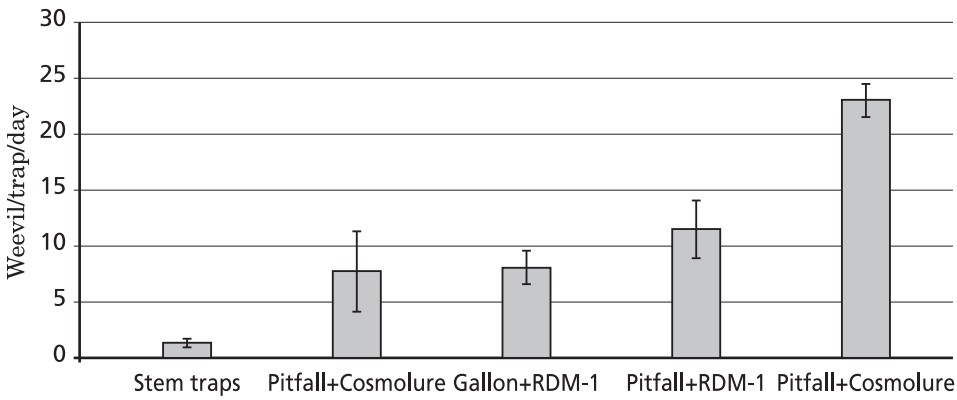

Figure 2. Mean weevil catches in different types of traps.

According to results, Pitfall-Cosmolure+ traps have the greatest potential in enhancing weevil trapping under the experimental conditions compared to other traps under study. In addition to its high weevil-capturing rate, the trap is less costly to use, as one needs only to add a laundry detergent. In contrast, the gallon with a ramp trap needs addition of banana pseudostem pieces treated with an insecticide, which are costly and may cause harm to the farmer. The weevil catches of Gallon traps baited with Cosmolure+ are not in agreement with what was reported in Costa Rica condition (Alpizar and Fallas 1997). According to the work conducted in Costa Rica, Gallon baited traps are expected to capture 20% more than pitfall traps baited with Cosmolure+. It was not clear why the Gallon-Cosmolure trap efficiency was low in Ugandan conditions.

The percentage of female and male weevils attracted by both pheromone traps and pseudostem traps were not significantly ($p<0.05$) different (Table 1). Pheromone traps equally attracted both female and male weevils ($p<0.05$).

Table 1. Sex ratios of weevils caught by pheromone traps.

Trap type	Number of weevils (n)	% weevils trapped		
		Males	Females	P-value
Pitfall + Cosmolure	274	50.9	49.1	0.838 NS
Gallon + Cosmolure	104	51.8	48.2	0.964 NS
Pitfall + RMD-1	169	54.7	45.3	0.312 NS
Gallon + RMD-1	127	45.4	54.6	0.433 NS

NS = not significant at P = 0.05

The pheromone-baited traps (Pitfall-Cosmolure trap) attracted weevils mainly from a radius of 10 metres with pheromone action decreasing greatly after 20 metres (Fig. 3). Few weevils in the distance of 60 metres from the traps were recaptured in the pheromone traps in a period of four weeks. This data suggests that 20 metres would be the optimum distance of separation between pheromone traps in case of mass trapping, which conforms to what was reported in Costa Rica (Oeschlager, personal communication). This would require at least 25 pheromone traps per hectare without changing the locations of traps in the field. The trap density of 25 traps per hectare might be more effective as compared to use of 4 traps per hectare with traps moved 20 metres along the 60 meter axis every month to cover the entire infested field (Alpizar and Fallas 1997). Using 4 traps per hectare was reported to reduce weevil population significantly within six months. The rate of reduction of the weevil population using 25 traps (non-movable) per hectare compared to 4 traps per hectare needs to be determined in Ugandan conditions.

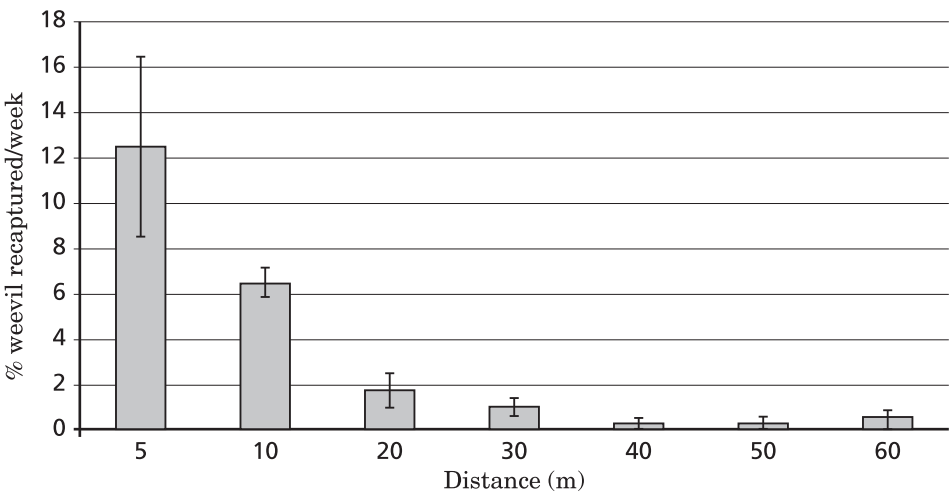

Figure 2. Mean weevil catches in different types of traps.

Compared to pseudostem trapping, the pheromone traps had a cost advantage (Table 2). The costs of pseudostem traps required to capture the same number of weevils as captured by pheromone traps in one hectare in three months was about three times. In addition to the cost advantage, pheromone traps have a simple design and are easy to use. They require little maintenance and can be used in remote locations where frequent visits are impractical. Besides, the pheromone traps are not known to have side effects on non-target organisms, and non-toxic and exhausted lures can be discarded with household garbage. The pheromone lures are however manufactured and are sold commercially in Costa Rica, and their importation and distribution may initially pose practical problems. However before large-scale application can be contemplated, their efficacy needs to be further tested on farm and under varying agroecological conditions.

Table 2. Comparative estimate costs (Ug. Shs) for using pheromone traps to reduce weevil population by 50% in 3 months per hectare.

Input	Pheromone			Pseudostems		
	quantity for 3 months	unit cost	total cost	quantity for 3 months	unit cost	total cost
Trap material						
Purchase	75	2500	187,500	13500 traps	20	270,000
Transport	-	-	-	30 trips	3000	90,000
Buckets and design	25	2200	55,000	-	-	-
Labour (laying and removing weevils)	13 man-days	3000	39,000	150 man-days	3,000	450,000
Total			**281,500**			**810,000**

* Refers to pseudostems, assuming they are obtained in a distance within 5 km of application. These are also additional to those in the farmer's own field.

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Session 3
Working groups

Working Groups

E.B. Karamura[1]

Background and methodology

In sub–Saharan Africa, a number of pest control tactics have been developed, tested and in some cases disseminated individually to farmers. The integration of tactics to address a given pest problem has received very little attention. The reason is twofold. Firstly, the training provided at graduate level emphasizes discipline specialization rather than multidisciplinary approaches. This phenomenon results into tunnel vision pest control perceptions even though at the farm level a host of production problems occur simultaneously. Moreover peer and academic recognition is possible only within disciplines. Secondly, in the policy arena, no attempts have been made to encourage the development of multidisciplinary curricula, taking into account all factors that directly or indirectly affect the pest/crop interactions and systems.

The workshop session therefore reviewed available pest control tactics with intent to develop multidisciplinary research plans for addressing IPM technology application gaps in banana production systems in Africa. The workshop also sought to establish technology pathways for the dissemination of cost-effective multidisciplinary IPM technologies at the farm level.

In short, the session activities were aimed at moving banana IPM strategies to the farm by identifying ready, compatible and cost-effective tactics and by establishing collaborative mechanisms for achieving the desired goal: banana IPM on farm. In this regard, the roles of NARS, advanced research centres, extension services, NGOs and farmers along with the need to strengthen linkages to facilitate the two-way flow of technologies and information were discussed. Also discussed were the possible financial and policy bottlenecks that would affect the implementation process.

Using the definition provided by Frison (this volume[2]) Working Groups had vertical discussions, based on the key pest/disease constraints - weevils, nematodes and diseases - in which "ready–to–go" IPM tactics were identified. In this discussion, each vertical group was assisted by cross-cutting discipline specialists in agronomy, socioeconomics and plant breeding. Subsequently multidisciplinary groups were constituted into horizontal discussion groups to review and discuss the results from vertical groups. The main task of

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multidisciplinary (= horizontal) groups were thus to remove duplications in order to integrate tactics from vertical discussions; to identify target production systems, stakeholders and associated constraints; to discuss and identify critical issues that may arise from the integration, and/or which need to be taken into account during implementation; to select/suggest appropriate titles, objectives and activities; and to discuss and develop collaboration mechanisms, partnerships and modalities for implementation.

Working Groups results and discussion

The results of vertical Working Groups are given in Appendices 1-3. The results of horizontal groups were discussed in a plenary session and are summarized in Appendix 4. In plenary participants identified "ready-to-go" packages, pointing out issues that will need to be addressed for effective execution as well as the possible partnerships and collaboration. The following were identified as " ready-to-go" IPM tactics which will need to be integrated and tested/evaluated on-farm.

Clean planting materials

This included materials produced using tissue culture, by selecting healthy mother plants (to set up mother gardens), pairing and hot water treatment, paring and solarization or paring alone.

Tissue culture

This was considered to be most effective against weevils, nematodes and diseases (particularly Fusarium wilt). However in general associated acquisition costs of tissue culture materials put the technology beyond the reach of small-scale, resource-limited farmers, unless subsidies were made available. In addition, the lack of information on the use of tissue culture materials at the farm level was cited as a major handicap. The workshop also pointed out that tissue culture technology goes hand-in-hand with optimum agronomic practices (soil fertility, adequate moisture, crop husbandry, etc.), particularly with soils with low pathogen incidence. Other limitations of clean planting materials technology included the failure to effectively control viral diseases.

Selecting healthy mother plants

This was considered an option for subsistence farmers who may not have access to planting material cleaning technology. The selected healthy mother plants could be used to establish clean mother gardens from which clean planting materials are collected for establishing plantations. While this technique was considered cheap, it is based on the ability to recognize pest attack/disease symptoms. Moreover most symptoms are not very clear, even to scientists and extension staff. The option was considered ineffective at the farm level in resource-limited and subsistence systems.

Paring and hot water treatment/solarization

These technologies are aimed at soilborne pests, i.e. weevil and nematodes. The techniques were reported to remove up to 90% of the pest population but considered more effective with nematodes than with weevils, which tend to lodge their pre-adult stages into the corm where the temperature used (52-53°C) is not effective.

The workshop identified a number of constraints associated with clean planting material tactics, including: the availability of equipment and materials for heating the water; the expense associated with tissue culture plant production; the lack of information on the use of tissue culture materials, especially the need to ensure optimum fertility and soil moisture during early field life of the plants; and the likelihood of reinfestation, especially when planted within or near existing crop stands and/or in infected/infested soils. In the case of subsistence systems the labour requirements for clean planting material are not yet determined but are expected to be high. In the rural setting where firewood is the only means for heating the water, the long-term impact of heat treatment on the environment is yet to be determined. In spite of these unresolved constraints, the workshop strongly recommended the evaluation for incorporation of clean planting material into IPM strategies.

Cultural management

Workshop discussions recognized the valuable information, technologies and experiences accumulated over a long time by banana farmers, as a result of farmer-crop interactions in diverse agroecological settings in Africa. The knowledge, experiences and the resulting technologies is what has been termed cultural management, which is aimed at improving soil fertility (use of compost manure and following), soil moisture management (e.g. through mulching) as well as avoiding soil water contamination, controlling pests and diseases (weed control, rotation, trapping, sanitation and deep planting) and increasing yield (cultivar selection).

The workshop observed that cultural management practices are effectively an IPM "package" as treatments are only effective when applied in combinations. Cultural management practices were also recognized as largely environment-friendly although the situation is rapidly changing for individual banana cropping systems. For example in highly populated banana cropping systems, land fallowing is no longer possible. Similarly, mulching materials are not in accessible distance, requiring expensive transportation costs. Moreover the long-term effects on the environment where the grass is used as mulch has yet to be assessed but is not expected to be positive. Other shortcomings of cultural management include the costs of mulch/manure application where farms are larger than one hectare; labour costs and availability (for mulch application, trapping, sanitation, weeding); land shortage; suitable rotation crops (especially as most banana cropping systems are perennial) and the problems of alternate hosts; lack of collective action (especially trapping and sanitation) encouraging fast reinfestation; and poor infrastructure, particularly for water management.

The workshop recommended that efforts should be made to collect and publish farmers' knowledge with regard to cultural management. The need to evaluate cultural management practices in terms of quantitative application was strongly recommended.

Low negative environment impact chemicals (LNEIC)

The workshop cautiously observed that although the focus on the proposed IPM technologies is the female gender and other resource-limited small-scale farmers, there is a growing number of progressing individuals trying to move into the semi-commercial sector. This group of farmers would safely use low negative environment impact chemicals (LNEIC) with the assistance of research and extension staff. The workshop did not recommend wholesale/indiscriminate use of pesticides for small-scale, resource-limited systems, citing costs of application equipment and materials, risks of poisoning and misuse, environment pollution by residues, pest resistance and the lack of education about the practices. The inavailability and high cost of chemicals in general was noted as a setback for long-term strategies based on the use of chemicals in the target systems.

Host plant resistance

The workshop observed that a number of cultivars resistant to pests, disease and/or tolerant to other stresses were available both in Africa and worldwide. In some cases these materials are a result of crossbreeding but in the majority of cases endemic materials could still be incorporated into IPM strategies. Yangambi Km5 was cited for its resistance to black Sigatoka, nematodes, weevils and Fusarium wilt. This cultivar is very prolific in diverse agroecologies in sub-Saharan Africa. Similarly the endemic East African highland bananas are resistant to Fusarium wilt, and it was felt that cultivars of this *Musa* subgroup could be targeted for agroecologies where FOC has become a major problem. The meeting noted the advantages of host plant resistance, citing sustainability, cost-effectiveness and environment-friendliness as well as income and food security. Breeding programmes were commended and encouraged to incorporate participatory methodology in their IPM strategies.

The meeting concluded that plant resistance against Fusarium wilt and Sigatoka diseases is available and that a potential exists for breakthrough resistance against banana viruses. However in all cases a lot more research will be needed before such materials can be incorporated into IPM strategies. Transgenic materials with resistance against banana bunchy top virus (BBTV), cucumber mosaic virus (CMV) and infections fungi were reported ready for field testing. The problem lies with biosafety regulations (being slow processes) and expected costs.

The meeting underlined the need to evaluate materials in the target environments where pathogen diversity is maximum and in a participatory manner with farmers. The breeders were urged to make breeding materials widely available

Quarantine

The meeting observed that indexing precedures for detecting banana diseases exist and should be used to facilitate the safe movement of clean banana planting material across borders. In this regard all banana germplasm should be moved across borders only as disease-indexed tissue culture plants. The FAO/IPGRI guidelines for the movement of plant materials (Diekmann and Putter 1996) should be followed. Participants however observed that the said guidelines were not widely available and expressed the need to have them widely distributed.

At the farm level, sanitation was recommended for the eradication of viruses and Fusarium wilt through the disinfecting of farm tools, alternate host destruction and deleafing to control Sigatoka diseases. NARS were encouraged to develop and disseminate sanitation packages to farmers.

Other technologies

The participants noted that for effective and widespread testing and adoption of IPM technologies, there would be a need for supportive collaboration mechanisms, mobilizing all partnerships including the policy makers. Quarantine was seen as critical for the safe but fast movement of clean planting materials as well as of resistant cultivars for incorporation into and adoption of IPM strategies. Research managers/administrators were challenged to involve policy makers in order to solicit their support for the adoption of IPM strategy in banana cropping systems.

Biological control

Based on the presentations made in the proceeding sessions, it was concluded that although a number of technologies were very promising indeed, they still require widespread testing/evaluation, particularly on farm and in a multidisciplinary manner.

Agronomic management

The meeting observed that effective agronomic practices by the farmers is an integral component of IPM. Extension workers including NGOs and CBOs were challenged to continue working with farmers in participatory fashion in order to support effective and sustainable adoption of IPM strategies in banana cropping systems in Africa.

Working Groups recommendations

Due to the diversity of socioeconomic and agroecological environments in banana-growing districts/regions, single tactic technologies should not be proposed for adoption by farmers.

Interventions should be developed with the farmers, selecting from the options identified in a participatory manner with farmers.

Banana IPM research gaps (Appendix 4) still exists in the areas of multiple resistance, use of genetic engineering, biologically enhanced planting material, organic amendments and mulch, and the characterization of cropping systems. Other critical

gaps exist in the areas of cost-benefit analysis and impact assessment with respect to IPM adoption on farm. At the level of implementation, the key players, especially the extension staff, NGOs and CBOs as well as farmers themselves, must be given specific training to enable them to appreciate and adopt IPM strategies. Good will from all stakeholders, particularly the donors and the policy makers, for the support of IPM strategies was noted as critical to the success of the exercise.

The meeting further suggested possible project titles, partnerships and collaborative mechanisms for the way forward (Workshop resolutions, below).

Workshop resolutions

The meeting recognized that:

- In relation to its importance as a staple food and rural cash crop, research on bananas is under-funded. The meeting participants therefore called for greater investment in banana research.
- Technologies are ready and available for testing on farm, therefore steps should be taken to implement this. A proposed project title is: "Farmer participatory testing of banana IPM options for sustainable banana production". Because of the diversity of environments and socioeconomic situations, single technology tactics cannot be proposed.
- The target group for such testing is small-scale, resource-limited farmers, taking into account the gender of these farmers.
- Baseline information is a prerequisite for impact assessment studies, both of which should be included in all project activities.
- The participation of all stakeholders – farmers, extension workers, NGOs, CBOs, and researchers – in the planning and execution of activities is essential and all work must be carried out in a multidisciplinary manner. Similarly, the implementation of projects should be through partnerships with farmers, NGOs and CBOs, making use of available methodologies for technology sharing and training, such as Farmers' Field Schools.
- Critical banana IPM research gaps have been identified as well as research partners that can contribute to address these. However, funding is essential for this research. Further research needs will be identified with the participation and input of the primary stakeholders.
- This meeting was organized with funding provided by the Swiss Agency for Development and Cooperation, the Rockefeller Foundation, the Natural Resources Institute and the Belgian Agency for Development Cooperation. The meeting acknowledged with thanks the support of these organizations.

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Appendix 1. Banana weevils

A. Available/potential IPM tactics

Tactics	Rating efficiency	
	Tech.	Cost
1. Host plant resistance	4-5	5
2. Habitat management		
Trapping	3-4	3
Clean planting material (paring, hot water, tissue culture)	4-5	2-4
Deep planting	4-5	4
Manure	2-5	?
Soil amendments	2-5	?
Urine	1-2	2-3
Ash	2-3	2-3
Crop rotation/Fallow	2-4	2-4
3. Semiochemicals		
Pheromones	2-5	2
Kairomones	1-2	2
4. Botanicals		
Neem	2-3	2
T. vogelii	2-3	2
Phytolaca	1	1
5. Biocontrol		
Arthropods		
Endemics	1-2	5
Ants	3-4	4-5
Exotics (Asia)	3-4	5
Pathogens		
B. bassiana	3-4	2-4
B. t.	1	1
Endophytes	2-4	3-4
Nematodes	3-4	2-3
6. Chemicals	4	1-4

Rating scale: 1 = lowest, 5 = highest

B. "Ready–to–go" technologies (weevils)

Technology	Suitability to multidisciplinary	Training and extension	Prospects for uptake
1. Trapping	+	+	L
2. Clean planting material	+	+	H
3. Sanitation	+	+	M
4. Deep planting	+	+	M
5. Chemicals	+	+	H

L = low, H = high, M = medium

C. Not so "ready–to-go" technologies (weevils)

Technologies	Priority	Current status	Funding needed	Research institution organization
1. Host plant resistance	H	Advanced	+	Multi-institutional, organized under PRO*MUSA*
2. Biologically enhanced planting material	H	Experimental	+	IITA, Bonn University, CRBP, ITSC
3. Genetically modified plants	M	Experimental	+	KUL, Private Sector
4. Organic amendments	H	Advanced	+	NARS, Universities, IITA
5. Intercropping/cropping systems	H	Intermediate	+	NARS, CRBP, IITA
6. Ash	L	Experimental	+	NARS, IITA
7. Rotation	L	Experimental	+	NARS
8. Biocontrol	H	Experimental	+	IITA, NARS, CRBP
9. Botanical	H	Experimental	+	NARS

Appendix 2. Available technologies (nematology)

Technology	Cost	Multi disciplinary	Suitability subsistence farmers	Low resource	Resource available
Paring	L	+	+	+	+
Paring + hot water	M	+	+	+	+
Tissue culture	M	+	+	+	
Paring +	L	+/-	+	+	+
Solarization					
Break crops	L	+/-	+	+	+
Fallow	M	+	-/+	+	+
Flood	L/M	+	+	-/+	+
Resistant cultivars	L	+	+	+	+
Mulch	M	+	+	+	+
Biocontrol	H	-	-	-	+
Nematodes	H	+	-	-/+	+

Appendix 3. Diseases

	Recommended	Research needed
Clean planting material		
Tissue culture	✔	Pilot project
Clean field planting material	✔	
Resistance		
Fusarium	✔	Evaluation
Sigatoka	✔	
Viruses	✔	
Transgenics	-	Potential
Quarantine	✔	Information flow
Sanitation		
Eradication	✔	
Disinfection	✔	
Alternate host destruction	✔	
Innoculum reduction	✔	
Biological control		Research
Chemical control		
Sigatoka	Only large-scale	Research
Cultural management		Adaptive research
Soil fertility	✔	
Water management	✔	
Weed control	✔	
Plant in ‘clean’ soil	✔	
Control other pests	✔	

Appendix 4. Research needs to complement "ready–to–go" packages

Technology	Upstream	On-station	On-farm	Demonstration
1. Biological control	—	—	—	
2. Endophytes	—	—		
3. Host plant resistance				
Breeding	—	—		
Evaluation		—	—	
4. GMOs	—			
5. Clean planting material				—
6. Sanitation				—
7. Break crops		—		
8. Enhance trapping		—		
9. Organic amendments		—		
10. Weeding				—
11. Fertilizers				—

Annexes

Annex 1

Acronyms and abbreviations

ACMV	African cassava mosaic virus
AHI	African Highlands Alternative, Uganda
AMF	arbuscular mycorrhizal fungi
ARI	Agricultural Research Institute, Tanzania
BARNESA	Banana Research Network for East and South Africa
BBrMV	banana bract mosaic potyvirus
BBTV	banana bunchy top virus
BDBV	banana die-back virus
BSV	banana streak virus
CABI	Center for Agriculture and Biosciences International, UK
CBO	community-based organization
CGIAR	Consultative Group on International Agricultural Research
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement, France
CMV	cucumber mosaic cucumovirus
CNRA	Centre national de recherche agronomique, Côte d'Ivoire
CRBP	Centre de recherches régionales sur bananiers et plantains, Cameroon
DS	diagnostic survey
EANET	INIBAP Eastern and Southern Africa Network
EARO	Ethiopian Agricultural Research Organization, Ethiopia
ELISA	enzyme-linked immunosorbent assay
EMBRAPA	Brazilian Agricultural Research Corporation
ESARC	East and Southern Africa Regional Centre (IITA), Uganda
FAO	Food and Agriculture Organization of the United Nations
FFS	farmer field school
FHIA	Fundación Hondureña de Investigación Agrícola, Honduras
FOC	*Fusarium oxysporum* f.sp. *cubense*
FOFIFA	Centre national de recherche appliquée au développement rural, Madagascar

IARC	International Agricultural Research Centre
ICIPE	International Centre of Insect Physiology and Ecology, Kenya
IITA	International Institute of Tropical Agriculture, Nigeria
IMTP	International *Musa* Testing Programme, INIBAP
INERA	Institut national pour l'étude et la recherche agronomiques, Rep. du Congo
INIBAP	International Network for the Improvement of Banana and Plantain
IPM	integrated pest management
ISABU	Institut des Sciences Agronomiques du Burundi
ISAR	Institut des Sciences Agronomiques du Rwanda
ISEM	immunosorbent electron microscopy
ITSC	Institute for Tropical and Subtropical Crops, South Africa
KARI	Kenya Agricultural Research Institute, Kenya
KARI	Kawanda Agricultural Research Institute, NARO, Uganda
KUL	Katholieke Universiteit Leuven, Belgium
MOA	Ministry of Agriculture, Zanzibar, Tanzania
MoFA	Ministry of Food and Agriculture, Ghana
*MUSA*CO	*Musa* Network for Central and West Africa
NARO	National Agricultural Research Organization, Uganda
NARS	National Agricultural Research Systems
NGO	non-governmental organization
NRI	Natural Resources Institute, UK
PCI	percentage coefficient of infestation
PCR	polymerase chain reaction
PHMD	Plant Health Management Division (IITA)
PRA	participatory rural appraisal
R&D	research and development
RF	Rockefeller Foundation
RFLP	restriction fragment length polymorphism
SCMV	sugarcane mosaic potyvirus
SSA	Sub-Saharan Africa
TT&TU	Technology Testing and Transfer Unit (IITA)
UNBRP	Uganda National Banana Research Programme
VCG	vegetative compatibility group

Annex 2

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