General News

USA Welcomes Settlers

Two classical biological control programmes in the USA have reported progress with establishment of introduced agents this year: one is for an invasive tree threatening an important wetland habitat, the other against an insect causing significant economic damage in key grain crops.

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Florida Stripper

The broad-leaved paperbark tree, *Melaleuca quinquenervia*, was introduced to Florida at the beginning of the last century. Hopes of using the tree for timber were not fulfilled, although it did prove economical to grow for ornamental production. Unfortunately it proved an even bigger success as an invasive [See: *BNI* **18(3)**, 67N 'Melaleuca Swamping Florida' September 1997], and now infests some 200,000 ha of the Everglades and is threatening native habitat. It thrived in Florida – growing fast, flowering up to five times a year from 2 years old, and producing copious amounts of seed. A single tree can hold over 60 million seeds in the canopy, releasing them in times of stress (fire, frost, herbicide or death).

The trees were planted as a means of 'reclaiming' the Everglades. They grow densely, forming impenetrable thickets, and spread partly by adventitious roots. The thick mats of roots at the water surface cause soil accretion, and this leads to an increase in the elevation of the infested area. A few centimetres in elevation can cause big differences in the composition of plant communities here, and the spread of melaleuca is threatening to transform the Everglades from a wet prairie into a closed-canopy swamp.

A USDA-ARS (US Department of Agriculture – Agricultural Research Service) project based at its Australian Biological Control Laboratory identified some 400 species attacking this and other related *Melaleuca* species in its native range in Australia. It identified, amongst others, a leaf-feeding weevil, *Oxyops vitiosa*, as a promising potential biocontrol agent. The weevils were first released in Florida in March 1997, and between then and June 1998, some 1500 adults and 6700 larvae were released at 13 sites in six counties.

Earlier this year it was reported that populations of the weevils are now well-established, increasing, and beginning to disperse to other melaleuca infestations. The promising results show that the weevils are highly effective at defoliating existing stands of melaleuca saplings, and it seems likely that they will be able to prevent further spread of the invasive tree. Melaleuca trees shed 25-33% of their leaves each year, but *O. vitiosa* has a preference for new leaves, and attack these as they are produced. The weevils in Florida are already consuming enough new foliage that some trees are showing evidence of die-back. In time, trees may become completely defoliated. Ultimately, the weevils will contribute to stopping the problem at its source, as stressed trees no longer seem to be producing flowers or seeds. This will facilitate control by conventional means, as it overcomes the problem that has complicated herbicidal or mechanical control measures so far: the millions of seeds that trees can shed when they die.

Additional agents from Australia are in the pipeline which target the mature foliage (*Lophyrotoma zonalis*, melaleuca sawfly), saplings (*Boreioglycaspis melaleucae*, melaleuca psyllid), and bud growth (*Fergusonina* sp., melaleuca bud gall fly). Host range studies have been completed with *B. melaleucae*, and a proposal for field release has been submitted to federal authorities. Psyllids feed on the phloem and heavy nymphal feeding kills saplings. A proposal for release of *L. zonalis* is still pending. Concern about possible vertebrate toxins might prevent eventual release of this species. Australian host range studies have demonstrated the specificity of *Fergusonina* sp. This fly will be tested soon in the Florida quarantine facility with the eight native species of Myrtaceae. Both leaf bud and flower bud galls are produced by the fly and its symbiotic nematode, *Fergusobia* sp. This will further help stem flower production and enhance traditional control measures.

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Saving Dough

Russian wheat aphid (*Diuraphis noxia*) (RWA) arrived in the USA in 1986, and since then has cost more than US$1 billion in insecticide costs and related losses. Its North American range now extends through 16 US states and two Canadian provinces. It spends the winter primarily on wheat and barley, while several native and introduced grass species harbour populations during the summer. The most important non-cultivated grass hosts of *D. noxia* in North America are the wheatgrasses (genus *Agropyron*; particularly crested wheatgrass, *A. cristatum*) and wildryes (genus *Elymus*; particularly Canada wildrye, *E. canadensis*).

The US government is developing an arsenal of weapons against the aphid: conventional breeding has produced aphid-resistant varieties, which are now available to producers; microbial agents are being tested [see *BNI* **21(1)**, 8N-9N, 'Fungal solution for crop pests?' March 2000]; and insect parasitoids have also been introduced from the area of the origin of the aphid.

In 1988, USDA-ARS (US Department of Agriculture – Agricultural Research Service) began work with a consortium of federal and state scientists to release 11 species of exotic RWA parasitoids in the wheat and barley growing areas of the western USA. They released a staggering 11.8 million parasitic wasps, representing more than 80 geographic strains collected from 25 different Eurasian countries where the aphid originated.

Key to the success of the project was the collection of these exotic enemies by staff of the ARS European Biological Control Laboratory in Montpellier, France. Over 60 exploration trips (throughout the endemic range of *D. noxia*) were made between 1988 and 1994. Seventeen different countries were visited by more than 40 federal and state scientists and technicians, and that resulted in the collection (mostly from *D. noxia*-infested wheat and barley fields) of at least 29 species of natural enemies for release in North America to combat the pest.

From 1991 to 1993, ARS scientists at the Plant Sciences and Water Conservation Research Laboratory in Stillwater, Oklahoma released seven parasitoid species in wheatfields in eastern Colorado, with the aim of establishing natural enemies in the grain-growing areas there. Seven years later, John Burd (ARS) reports that four of the species have become established throughout a six-state area: Colorado, Kansas, Montana, Nebraska, Oklahoma and Wyoming. Three of the species were also found parasitizing related greenbugs (*Schizaphis graminum*) on sorghum, and two species successfully parasitized RWA on summer wild grass hosts.

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Biological Control of Water Hyacinth: the Indian Experience

Water hyacinth (*Eichhornia crassipes*), which entered the country as an ornamental, is the most serious aquatic weed in India, creating a large number of problems in the management and utilization of freshwater resources. Attempts made from 1969 by the Indian Station of the Commonwealth Institute of Biological Control (CIBC) to import exotic natural enemies were unsuccessful owing to an ongoing debate on the potential of this weed as a resource. With the inception of the All India Coordinated Research Project on Biological Control of Crop Pests and Weeds in 1976, renewed efforts were made by the Indian Council of Agricultural Research to import host-specific natural enemies. Water hyacinth creates special problems in India, because drought and associated problems are chronic features. Water hyacinth reduces the volume of available fresh water by increasing losses through evapotranspiration (up to 9.84% reduction reported). It impedes the flow of water in irrigation systems (40-90% reduction reported) and impairs the quality of water, making it unfit for human consumption. After taking into consideration these and other major disadvantages of the weed, it was finally agreed by the Indian authorities in July 1981 that some biocontrol agents should be obtained for trials.

With the assistance of CIBC (now part of CABI Bioscience) a shipment consisting of the two weevil species, *Neochetina eichhorniae* and *N. bruchi,* and the mite *Orthogalumna terebrantis* was received from the US Department of Agriculture, Fort Lauderdale, Florida. *Neochetina eichhorniae* was also imported from Long Pocket Laboratories, CSIRO, Indooroopilly, Queensland, Australia (although this culture was subsequently discarded owing to microsporidian infection).

The weevils and the mite were reared in a glasshouse under quarantine conditions. Detailed host-specificity tests, involving 76 species of plants belonging to 42 families for the weevils and 88 species of plants belonging to 42 families for the mite, confirmed their safety to cultivated plants in India. Limited field trials were then conducted with permits issued by the Plant Protection Adviser to the Government of India (PPA). Based on the results obtained during these studies the PPA gave permission for open field releases throughout the country.

Neochetina eichhorniae and *N. bruchi* established readily under field conditions in India after large-scale releases were initiated in 1983. Field studies indicated that release of a breeding population of about 1000-5000 adults, depending on the area of weed coverage, invariably resulted in establishment, irrespective of whether the initial releases were made at one spot or over a wide area. During the first year the insects were observed to multiply and spread throughout the weed mat on which they had been released. Thereafter, an increase was seen in the number of adults per plant, which in turn caused a reduction in the number of leaves and petiole lengths. Once the population of adults exceeded five individuals per plant, the leaves of the weed turned brown, starting from the tip, and ultimately the whole plant collapsed and sank to the bottom of the water body.

Successful biological control ranging from 90-98% was achieved in six tanks, with a combined total surface area of over 1000 ha, in Bangalore within 3-4 years of the release of a total of about 25,000 weevils. The tanks are manmade lakes created some four centuries ago by damming natural rainwater channels to provide water for use during the summer months, mainly for irrigation but also as a source of drinking water. The proliferation of water hyacinth in them is a symptom of the pollution afflicting these once pristine water bodies. Some have been breached, but sewage has polluted others as the city has grown. Both *N. eichhorniae* and *N. bruchi*, separately and in combination, were found to be effective in suppressing water hyacinth. However, the rate of weed suppression was found to be very slow in a partially sedimented tank, where the water hyacinth plants were anchored. This was probably due to silt coverage of root hairs of the weed, on which the insects pupated.

Interestingly, there were fluctuations in weed cover, ranging from 5-30%, in all the tanks in which the weevils had been released for 3-5 years after the initial collapse. However, residual weevil populations were found to be capable of reducing weed populations every time such an increase was observed, and no additional releases were necessary.

Studies in Bangalore indicated that *N. eichhorniae* and *N. bruchi* could be successful even in tanks that dry during the summer. In the laboratory they survived without food for as long as 48 and 28 days, respectively, in 95% humidity, and much longer in the presence of free water. They can probably survive periods of drought by remaining below plant debris or within crevices in the soil and water may be available to them in the form of dew.

More than 150,000 weevils were released at different locations in 15 states elsewhere in India. Spectacular biological control of water hyacinth was achieved in the 286 km² Loktak Lake in Manipur, 75% of which was covered by the weed. Control was achieved within 3 years of release of some 18,500 adult weevils during 1987-88. Besides the lake's importance to the local community for fishing, a hydroelectric power project set up at Loktak Lake in 1983 has an installed capacity to generate 105 MW of power and irrigate 23,000 ha of land. Control of water hyacinth by release of weevils has brought about a permanent solution to the weed problem, which in turn has benefited the economy of the entire region.

Results with *O. terebrantis* are so far more equivocal. Although it established under field conditions after releases were initiated in 1986, the mite does not appear to be capable of suppressing water hyacinth on its own. Heavy population build up was observed in all the tanks where releases had been carried out, leading to browning of leaf laminae, but promising results are yet to be achieved.

The results of the studies carried out to date clearly show that *N. eichhorniae* and *N. bruchi* are effective biological control agents, capable of bringing about a permanent solution to the problems posed by this weed in India. Hence, there is an urgent need to spread them to regions where releases are yet to be made. This objective can easily be achieved by releases of field-collected natural enemies into selected weed-infested water bodies in different parts of the country and redistribution from these spots after establishment and population build up.

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This article also appears in Water Hyacinth News *No. 2 (October 2000) with agreement of the author and the publishers.*

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IPM Systems

This section covers integrated pest management (IPM) including biological control, and techniques that are compatible with the use of biological control or have little negative impact on natural enemies.

Banana Flavouring

The articles in this section have a common ingredient in this issue: bananas and plantains. This is not a comprehensive summary, but indicates the sheer effort going into overcoming the very serious constraints to production of this key crop around the world. Bananas and plantains can be divided into those which are sweet and eaten as a dessert fruit and those that are starchy and only eaten after cooking. In many parts of the world cooking bananas and plantains are staple foods, and 90% of the total world production (some 85 million tonnes) is grown for domestic consumption. On the other hand, in the developed world dessert bananas are a favourite fruit, and this makes them the fourth most valuable food crop and the most important fruit, worth US$2.5 billion annually in export trade.

One of the most serious pests of bananas is a boring weevil, and the many promising avenues being explored for controlling it are described. There is also an array of nematode pests that infest the crop in different regions and climatic conditions, and progress against these is also reported. Above all, though, bananas are threatened by diseases. There are a host of these, and new ones are still emerging. The most serious of them, black Sigatoka was first seen (in Fiji) in 1963 but has now found its way to all the banana-growing regions, although some countries are still free of the disease. Research on management of this disease is in the early stages, and we hope to report on it in a later issue. Here we report on initiatives and progress against other diseases, both 'old' (such as yellow Sigatoka) and 'new' (such as banana leaf streak disease in Uganda). Lastly, we look at control of post-harvest diseases, which are particularly important in export bananas because they affect quality and storage.

Although wild species are seed-bearing, modern cultivars are sterile. Propagation is by vegetative means, and this has implications for the incidence of pests and diseases and how they may be managed. Vegetative propagation means that both have been passed on in planting material between and within countries, and the provision of clean planting material has been an area of intense research that is yielding dividends. To add to the problems, bananas and plantains are perennial crops, in which new plants emerge as suckers from a shared rhizome. (The rhizome and bananas/plantains attached to it are collectively called a mat.) Pest and disease problems tend to get worse with successive ratoon crops.

Two wild species (*Musa acuminata* and *M. balbisiana*) gave rise to modern commercial bananas and plantains. These diploid species have produced diploid, triploid and tetraploid offspring. The conventional way of indicating the (probable) parentage of current clones is by using 'A' and 'B' for *acuminata* and *balbisiana*, respectively (e.g. Cavendish AAA). However, the narrow genetic base of modern export, dessert bananas makes them susceptible to pest and disease attack, and a key element in banana and plantain IPM programmes is improving host plant resistance.

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IPM and INIBAP

INIBAP (the International Network for the Improvement of Banana and Plantain) was established in 1985 as an international organization with a mission to sustainably increase the productivity of banana and plantain grown on small-holdings for domestic consumption and for local and export markets. INIBAP is a programme of the International Plant Genetic Resources Institute (IPGRI). It has a small headquarters staff in Montpellier, France and regional offices in the four major banana-growing areas of the world.

IPM is a very important area of work for INIBAP, and a number of different activities are ongoing. These include supporting and carrying out research on various component parts of IPM (host plant resistance, biological control, disease management, etc.), organizing meetings and workshops, and distributing relevant information. This report provides an overview of INIBAP's different IPM-related activities. It should be noted that INIBAP is a networking organization. It does not conduct research in-house. Instead it works through out-sourcing, thus making use of and strengthening existing facilities and expertise. INIBAP also plays an important role co-ordinating and catalysing research carried out by its partners worldwide.

Host plant resistance is one of the most important components of any IPM programme. In the case of bananas, despite the fact that breeding started as long ago as the 1920s, new pest and disease resistant varieties developed by breeding programmes have only become available for distribution in the last few years. INIBAP is playing a number of different roles in helping to ensure the continual availability of improved varieties for use in IPM programmes worldwide.

Support to Breeding Research

The absence, until very recently, of improved, pest and disease resistant varieties has been attributed to the difficulties of breeding bananas at the genetic and practical levels (most important varieties are highly sterile and can only be used in conventional breeding programmes with difficulty), together with the very low levels of investment in banana breeding. In an effort to accelerate the development and release of new varieties, INIBAP works in a number of ways:

- Providing direct support to research on *Musa* improvement, with a focus on the use of biotechnology and molecular approaches to increase breeding efficiency.
- Providing the secretariat and co-ordination for PRO*MUSA*, the Global Programme for *Musa* Improvement. PRO*MUSA* brings together all the major players in *Musa* improvement worldwide, allowing researchers to develop collaborative projects and forge partnerships, thus creating synergies and avoiding unnecessary duplication of research.
- Organizing a worldwide, multi-site evaluation programme (International *Musa* Testing Programme) which allows breeders to test their materials over a wide range of environments and disease pressures, while at the same time providing national programmes early access to improved varieties.

Distribution of Germplasm

INIBAP maintains the world's largest collection of *Musa* germplasm. This material is held in trust for the global community and is freely available for distribution to *bona fide* users. The collection contains wild species of the genus *Musa*, as well as a wide diversity of cultivated varieties and improved varieties from breeding programmes. All material is introduced and distributed under the terms and conditions of Material Transfer Agreements, to ensure that the germplasm and information related to it remain in the public domain.

In the case of improved varieties, INIBAP has introduced a specific Germplasm Acquisition Agreement and a Material Transfer Agreement. These agreements provide a framework within which improved germplasm can be distributed by INIBAP, while at the same time providing breeders the opportunity to benefit from the commercial use of their material. Through this innovative approach, INIBAP has been able to acquire improved varieties from all the major banana-breeding programmes and is working to ensure that such varieties will continue to be available free-of-charge to those who need them most – small-scale farmers in developing countries.

All material is virus indexed by INIBAP before distribution. Only accessions in which no viruses have been identified are available for dissemination. As plants are distributed in the form of *in vitro* plantlets, a clean source of planting material is ensured for the end users.

Improved pest and disease resistant varieties have been distributed to over 50 countries by INIBAP, and in several countries, most notably in Cuba, Nicaragua and Tanzania, smallholder banana producers are gaining significant benefits from the use of these varieties.

Clean Planting Material against Viruses

A number of viruses affect bananas and these include Banana Bunchy Top Virus (BBTV), Cucumber Mosaic Virus (CMV), Banana Bract Mosaic Virus (BBrMV) and Banana Streak Virus (BSV). Banana viruses, especially BBTV and BBrMV (this one was only identified for the first time in 1989), have had a significant effect on the production of non-export, traditional dessert bananas in several Asian countries, including the Philippines, Sri Lanka, Bangladesh, Vietnam and Pakistan. Control measures for these viruses are based on quarantine, sanitation (use of clean planting material) and roguing. INIBAP's regional office for Asia and the Pacific has been active in helping to develop virus control programmes in several countries in Asia. Workshops and training courses on virus control, virus indexing and the use of clean planting material have been held in the Philippines (for the region) and Sri Lanka. As a result of these workshops, national banana rehabilitation programmes based on IPM, with clean planting material as the key component, have been put in place in both the Philippines and Sri Lanka.

Controlling Bacterial Diseases in Indonesia

'Blood disease', a destructive banana bacterial disease, is serious in the Sulawesi area of Indonesia and has devastated the cooking banana Kepok (Saba) in this region. In recent years severe outbreaks of this disease have also been seen on the southern tip of Sumatra, in the region of Lampung, where it is now seriously threatening the smallholder banana crop. INIBAP's Regional Office for Asia and the Pacific is working with the Research Institute for Fruits in Indonesia, to conduct demonstration trials on the management of this disease. Disease management technologies, effective in combating a similar disease known locally as 'tibaglon' or 'Bugtok', have been developed in the Philippines. A study previously carried out in Negros Oriental (Philippines) showed that an integrated disease management programme including sanitation, early debudding, disinfection of tools and fruit bagging can reduce disease incidence by up to 100% over a 12-month period. It was discovered however that farmers found bagging impractical because of the height of the local varieties of cooking bananas being cultivated. Nevertheless, the practice of sanitation and early debudding alone was shown to reduce infection from an initial incidence of 88% to 6% after 12 months. These methods were considered practical and have been well accepted by farmers. The disease management strategies developed for Bugtok in the Philippines are being tested for their effectiveness against Blood disease. It is hoped that the simple techniques, either alone or in combination with other techniques, such as the use of clean planting material, will help to solve the Blood disease problem in Indonesia.

Mobilizing IPM for Sustainable Production in Africa

An Africa-wide workshop on banana IPM was organized by INIBAP, together with the International Institute of Tropical Agriculture (IITA) and the Institute of Tropical and Subtropical Crops, South Africa (ITSC) in the framework of the Banana Research Network for Eastern and Southern Africa (BARNESA) in South Africa in November 1998. This attracted IPM researchers from across Africa and beyond. The proceedings of this meeting were published by INIBAP in 1999 and provide state-of-the-art information on banana IPM. The meeting identified technologies ready for testing in farmers' fields. Such technologies are: the use of clean planting material, host plant resistance and a range of cultural management practices. The meeting called for greater efforts in on-farm testing of banana IPM strategies. The main research gaps were identified as:

- Biological control: *Beauveria bassiana* holds promise for the control of weevil borer (*Cosmopolites sordidus*), but other predators and pathogens should also be investigated.
- Biologically-enhanced planting material: endophytes, arbuscular mycorrhizal fungi, etc. The screening and testing of organisms and formulations is required.
- Biological pesticides: the efficiency of neem needs to be tested under farmers' conditions.
- Enhanced trapping technologies for weevils should be further investigated.
- Use of semio-chemicals (kairomones and pheromones): improved efficiency and delivery mechanisms are required.
- Resistance breeding (including genetic engineering): new hybrids must be evaluated across years and environments. Decentralized breeding strategies and the use of varietal mixtures could also be investigated.
- Various aspects of cultural management (soil fertility, water management, mulches, intercrops, etc.) and their effects on pathogen levels need further study.

On-Farm Testing of IPM Strategies in East Africa

Pest and diseases have been identified as the major constraint to banana production throughout the East African region [see below]. However, options for IPM are known to be available and following the recommendations of the IPM workshop organized in South Africa in 1998, these should now be tested on-farm. A project proposal was therefore developed by INIBAP in collaboration with the national agricultural research services of Uganda, Kenya and Tanzania. The project was accepted for funding by DFID (the Department for International Development, UK) and commenced in May 2000.

The project will allow combinations of IPM options to be tested on-farm in a range of settings in benchmark sites in Kenya, Tanzania and Uganda. Such settings include agro-ecological variation in terms of varieties grown, disease/pest pressure, soil fertility levels, climatic factors, etc., in combination with the differing socio-economic situations of the participating farmers. One of the most important aspects of the IPM project will be the testing of new varieties.

One other INIBAP initiative is described later in this news section. An INIBAP Associate Expert, located at the Centre de Recherches Régionales sur Bananiers et Plantains (CRBP) in Cameroon, is working on the development of an IPM strategy against the banana weevil borer, *C. sordidus*.

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Pearls of Banana Research

Uganda is the world's largest banana producer, with a 15% share of total global yield; in 1996, it produced about 9 million tonnes of the fruit. Highland cooking banana is the most important staple in the Great Lakes region. Uganda is also a secondary centre of banana diversity and there are many locally evolved cultivars; an average of 12 different cultivars were found growing on farms surveyed by IITA. However, the many different clones of the East African highland bananas are all *Musa* (AAA) and have therefore evolved (by somatic mutations) from a relatively narrow genetic base. The ancestral cultivars that would have been introduced are unknown. There is little difference in the susceptibility of these cultivars to the more important pests and diseases that have been introduced in recent times. The Uganda highland banana cultivars have recently been taxonomically characterized by Deborah Karamura at the National Agricultural Research Station (NARO).

Since the 1970s, banana has undergone a decline in the traditional growing areas in central Uganda. During the same period, it has expanded into the southwest. The increasing importance of banana in this region has been related to (a) improved food security and (b) increasing urban market demand following rapid population growth in Kampala and Jinja. Cooking banana is the preferred urban staple, in contrast to many urban areas of the world which rely on grains. It remains, also, the preferred rural staple food throughout southern Uganda.

Partly associated with this geographical shift, there has been a major decline in production in the last 25 years. Yields have fallen to as low as 6 tonnes/ha and the longevity of banana plantations has fallen from about 50 years to only 5-10 years in some areas. The decline in productivity and plantation longevity is attributed to social, economic and biological factors. The (often quoted) decline in soil fertility can be traced to labour costs and availability associated with the traditional system of culture with organic manures and regular mulching. These practices are now less common. Land ownership is an issue as farms are divided by inheritance. Replanting bananas will be less acceptable on the smaller farms because there is a 12-15 month wait for bananas to come into production, the reason to change to short duration crops is thus compelling.

As if these problems are not great enough the arrival of alien diseases and pests like black Sigatoka (*Mycosphaerella fijiensis*), yellow Sigatoka (*M. musicola*) and the burrowing nematode (*Radopholus similis*) has accentuated the decline. The most significant pest recognized by farmers is the weevil *Cosmopolites sordidus*. When this pest was introduced is unknown but it is likely to have arrived with the newer 'exotic' cultivars in the late 19th or early 20th century. The first cited record for Uganda is 1918. The combined effects of nematodes and weevils include destruction of the root system, reducing anchorage and water and nutrient uptake, which leads to reduced bunch weight or plant toppling. Diseases reduce photosynthetic capacity and therefore fruit production and often quality, or even cause the death of the plant.

Devastating banana weevil and nematode outbreaks in the mid 1980s led to widespread crop failure in Masaka and Rakai districts. Although these outbreaks persisted for only a few years, early stages of yield decline are already in evidence in certain areas in the southwestern region. This has caused apprehension about the future of the crop in Uganda. Moreover, commercial banana production has been shifting further and further away from Kampala. Currently, much of the banana serving Kampala comes from Mbarara and Bushenyi districts (240-300 km from the capital). As a result, revitalization of banana production in the central zone and stabilizing production in the southwest became high priorities within the Uganda Ministry of Agriculture and NARO. Banana weevil is considered a priority concern. It is an important pest of highland cooking banana in East Africa, and has been implicated in the decline and disappearance of cooking banana from its traditional growing areas in central Uganda and western Tanzania. Since the 1960s, accelerated yield decline in this region has led to the replacement of cooking banana with exotic beer bananas (types AB and ABB) and annual crops.

However, Uganda is also home to exciting and innovative research into banana pest and disease control. There is an active national programme, and they have involved many international organizations, so the prospects for bananas are becoming rosier.

In 1990, the International Institute of Tropical Agriculture (IITA) and the newly formed Uganda National Banana Research Programme (UNBRP) developed a collaborative programme to address the problems of banana weevil, nematodes, diseases and other production constraints. The first activity was a rapid rural appraisal at 25 banana-producing villages across southern Uganda. Pests and soil fertility decline were ranked as key constraints in nearly all sites. Farmers ranked the banana weevil as the leading pest/disease problem at 18 sites. Within the central region, many farmers were replacing cooking banana in favour of exotic brewing bananas such as Pisang awak (ABB) and Ney poovan (AB) which are resistant to the weevil and require less management attention. In many areas, farmers have lost confidence in a crop that had long been their mainstay.

Later in this section, progress made by this programme in developing strategies to manage the constraints to banana production and to ensure that Uganda retains its place at the top of the world's banana producers is reported.

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A Cosmopolitan Weevil

The banana weevil, *Cosmopolites sordidus*, was first recorded in connection with bananas in Guadeloupe in 1889, but has been distributed throughout the tropics on banana planting material. It has no other host and all types of banana are susceptible to varying degrees. In some of the banana-growing regions it has serious impact (for example, in East Africa) but elsewhere its importance is not as great. The reasons for this are not clear but environmental factors and differences in crop growth and management could be influential. There is yet no evidence to suggest that the weevil populations vary in aggressiveness.

The first attempt at biological control of this pest was in Fiji by Frank Jepson, the Government Entomologist. In 1913 he made collections of the histerid beetle *Plaesius javanus* and other natural enemies in Java. Subsequently, this predator was released in several countries, including Uganda by C. C. Gowdey in 1918-20, but it never became established.

Biological control was forgotten during the early insecticide era. Aldrin was recommended for weevil control in Uganda during the 1950s until resistance developed. Post-colonial funding from the UK Government was for chemical control of the banana weevil which was done by Graham Mitchell of the Centre for Overseas Pest Research (COPR) in the Caribbean in 1974-78 when alternatives to the organochlorine insecticides were being sought. At this time much research was done on damage assessment, population estimation and chemical control throughout the commercial export-producing countries.

The opportunities for developing biological control have been revived over the last 10 years and the most promising biological control agent, *Beauveria bassiana*, has been isolated from weevils in many countries. This fungus has been used in banana plantations in Brazil. In Uganda, isolates of *B bassiana* have been collected by Caroline Nankinga (National Agricultural Research Organization, NARO) and significant reductions in weevil populations have been achieved with formulations of this fungus under field conditions. Another promising line of attack is with entomopathogenic nematodes (epns). These nematodes (*Steinernema* spp. and *Heterorhabditis* spp.) have also been tested successfully under field conditions in Australia and Brazil. Recently, epns have been recovered from bananas in Kenya by Charles Waturu (Kenya Agricultural Research Institute, KARI) and there is a survey planned for Uganda later this year as part of a weevil management project.

The chemical nature of the male-produced aggregation pheromones has been identified and both lures and traps have been developed commercially in Costa Rica from where there have been reports of successful reductions in weevil damage in commercial Cavendish plantations.

By: Simon Gowen

❑

Many Hands Tackle Weevil Problem

The IITA/UNBRP rapid rural appraisal described in 'Pearls of Research', above, was followed by a study on the geographic shifts of banana production, which highlighted the importance of banana weevil, *Cosmopolites sordidus*, in the decline of cooking banana in central Uganda. The study focused on villages in central Uganda in which banana had largely disappeared; such villages presented a truer picture of crop dynamics in central Uganda than those used in the initial IITA/UNBRP study (i.e. sites still considered banana-producing villages) described above. Farmers attributed increasing weevil pressure to reductions in available labour and resulting changes in management practices. For example, crop sanitation, trapping and other cultural controls have been largely abandoned. Field verification confirmed very high weevil levels in survey study sites.

Diagnostic surveys showed that the banana weevil is widespread within Uganda, but unimportant above 1600 m above sea level. Weevil pest status varied considerably across sites and among farms within sites. For example, weevil population estimates (based on mark and recapture studies) within one watershed in Ntungamo district found density to range from 1600 to 149,000 weevils/ha. These studies found only a weak relationship between adult density and damage.

Salient features of the weevil's biology include a cryptic life style, long life span, limited mobility, low fecundity and slow population build-up. The adult weevil commonly lives more than one year, while some adults have been reported to live more than 4 years. The weevil is very sensitive to desiccation but can live for several months without feeding. These factors mean that weevils are often favoured by mulches (which contribute to soil moisture retention during dry periods) and that extensive plant loss may occur when banana is planted in a previously infested field without an adequate break between the crops.

The adults are most often found in the leaf sheaths, in the soil around the base of the mat or associated with cut residues. They are nocturnally active and not casually observed. Adults are often sedentary for extended periods and most do not move more than a few metres at a time. They rarely fly. The weevils are attracted by plant volatiles (especially those emanating from cut rhizomes) and also produce a male aggregation pheromone. Under field conditions, mean oviposition may be 0.5-2 eggs per week. The eggs are inserted singly into the leaf sheaths or rhizome. The larvae feed within the rhizome cortex, central cylinder and, occasionally, the (pseudo)stem. The insect passes from egg to adult in 6-8 weeks.

With low fecundity, population build-up is slow and, following crop establishment, weevil problems are most pronounced in ratoon crops. In one trial, yield loss increased from 5% in the plant crop to 44% in the third ratoon. This loss reflects reduced bunch size, snapping, toppling and mat die off.

Current research results suggest that no single control strategy will be likely to provide complete control for banana weevil. Therefore, a broad IPM approach might provide the best chance for success. The components of such a programme include habitat management (cultural control), biological control, host plant resistance and (in some cases) chemical control. The poor relationship between weevil adult density and damage suggest that factors which target the adult stage (e.g. trapping) may be less effective than those directed at immatures. However, the immature stages are hidden within the banana plant and largely immune to many control strategies.

Cultural Control

Dispersal of the banana weevil is primarily through infested planting material, so clean planting material could protect new stands from banana weevils for at least several crop cycles, if this is planted some distance from other infested stands. However, replanting previously infested fields will only be possible after an interval of many months to allow the existing population to die out. Otherwise, these weevils will readily attack suckers (that have been detached from mother plants and have an exposed cut rhizome surface). In one field trial, more than 40% of planted suckers were killed by weevils, as were an additional 40% of the replants.

The use of clean planting material, disinfected of weevils through paring and/or hot water treatment, has been recommended as a cultural control strategy to reduce initial infestation levels and retard pest build-up. Paring of the rhizome surface exposes damaged suckers, which can then be rejected. Paring also removes most eggs and many first instar larvae. Hot-water treatment of suckers has also been recommended for both weevil and nematode control. However, hot water regimes commonly used for nematode control (i.e. 54ºC for 20 minutes) killed only 32% of weevil larvae. Therefore, paring alone is probably adequate for reducing initial weevil infestations. [The IITA/UNBRP programme initiatives against nematodes are described below.]

In field studies, weevil populations were lower in cleaned planting material plots than in controls for up to 27 months after planting. Weevil damage levels in controls were 70-200% higher than in cleaned planting material treatments for the plant crop. Plant loss to weevils and nematodes was 21-34% in controls, compared to 2-6% in treated plots. Bunch size was similar among treatments, but clean planting material plots provided higher yields resulting from the greater number of harvested bunches.

Pseudostem trapping has also been widely recommended in Uganda for weevil control. Farmer participatory research in Ntungamo district, Uganda showed that intensive pseudostem trapping (1 trap/mat/month) could substantially reduce weevil populations, while more moderate trapping (0.3-0.6 trap/mat/month) could also lower weevil numbers. However, most farmers indicated that the labour and material required for intensive trapping was beyond their resources.

IITA and the National Agricultural Research Organization (NARO) are currently investigating enhanced trapping using pheromones. The presence of a male aggregation pheromone (i.e. produced by males and attractive to both sexes) was first recognized at ICIPE (the International Centre for Insect Physiology and Ecology, Nairobi). The chemical structure of the pheromone (called sordidin) has since been identified. ChemTica in Costa Rica has synthesized and is distributing commercially a mixture of the pheromone and weevil-attractive plant volatiles in a formulation called Cosmolure+. Preliminary studies in Uganda show that Cosmolure+ can catch up to 30 times as many weevils as conventional pseudostem traps. Further work is being undertaken on field efficacy under farmer conditions in Uganda.

Crop sanitation (i.e. destruction of crop residues) is also widely recommended to control banana weevils. The supposition is that crop residues left in the ground after harvest serve as shelters and breeding grounds/oviposition sites for banana weevils, leading to population build-up and increased damage on plants. Farmers implement a range of sanitation practices including cutting and chopping of spent stems and digging out or burying old rhizomes. The intensity of sanitation practices is often greater on commercial farms. In Ntungamo district, dominated by subsistence banana production, nearly 80% of the farmers practised little or no sanitation. It is also possible that crop residues serve as 'trap crops' drawing gravid females away from growing plants. Current studies are investigating weevil oviposition preferences, larval development and the effects of sanitation on weevil populations and damage.

Prospects for Biological Control

Biological control efforts against banana weevil have included the use of exotic natural enemies (classical biological control), endemic natural enemies, secondary host associations and microbial control (e.g. entomopathogens, endophytes, entomophagous nematodes). Microbial control agents that require repeated applications may be considered as biopesticides, although they lack the toxic side effects of chemical insecticides. As such, they may entail repeated application costs on the part of the farmer.

Classical biological control of banana weevil may be possible. The banana weevil originated in South-east Asia, coincident with the centre of origin of bananas. The banana weevil is not believed to be a serious pest in most areas within its area of origin. However, searches for arthropod natural enemies of banana weevil in Asia, conducted in the first half of the 20th century, provided only generalist predators (e.g. histerids and hydrophilids) which attack the immature stages. Releases of these natural enemies in Africa and elsewhere met with little success. In collaboration with the Research Institute for Fruits in Solok, Indonesia, IITA will be undertaking further exploration for natural enemies later this year. It is hoped that such searches may reveal the presence of egg parasites.

ICIPE has conducted studies on endemic natural enemies of banana weevil in Western Kenya. These included adults of three staphylinids, three histerids, one hydrophilid, one carabid, one tenebrionid, two labiids and one carcinophorid earwig. In laboratory studies, these predators variously searched the rhizomes of living plants and crop residues. Most of the predators attacked the egg and early larval instars, although four also attacked older larvae. Some of the predators were able to reduce weevil levels in pot trials, but predator densities under field conditions suggest limited potential.

In contrast, the Cubans have employed the myrmicine ants, *Pheidole megacephala* and *Tetramorium guineense*, which they report as providing partial control. The ants can be encouraged to nest in pseudostem pieces which can then be transferred to other banana stands. IITA and NARO have surveyed ants at several sites in Uganda and found *P. megacephala*, four other species of *Pheidole* and one unidentified *Tetramorium* species. A graduate student will begin her Ph.D. research in late 2000 on the potential of controlling banana weevils with myrmicine ants.

In West Africa, IITA explored the possibility of secondary host association, by evaluating the potential of two strains of a carrot weevil parasitoid, *Anaphes victus*, for parasitizing banana weevil. These parasitoids readily oviposited in banana weevil eggs but failed to successfully complete their development or to be able to emerge from the weevil eggs due to their relatively larger size. Larvae of *A. victus* failed to consume all of the banana weevil egg contents with decomposition of unconsumed material contributing to pupal failure. Most of the few parasitoids which successfully reached the adult stage then failed to emerge through the relatively thicker chorion of banana weevil eggs.

IITA and NARO have also been collaborating on microbial control of banana weevil, using endophytes and *B. bassiana*. Endophytes are mutualistic, non-pathogenic fungi that exist within a host plant. The objective of this study was to identify endophytes within banana plants which (a) could kill weevils (and nematodes) and (b) be introduced into tissue culture plants to provide extended protection against pests. Protocols include (a) isolation of endophytes from banana plants, (b) screening against weevil immatures, (c) determination of modes of action, (d) identification and markers of candidate strains (especially important if what is subsequently isolated is the same as what had been introduced), (e) studies on distribution and persistence within the host plant, (f) pathogenicity testing, (g) efficacy in pot trials and (h) efficacy in field trials under different environmental conditions.

Surveys of highland cooking banana and Pisang awak revealed an abundance of endophytes in the central cylinder and cortex of the rhizome. In laboratory experiments, 12 of 200 strains killed a high percentage of weevil eggs. Some of these strains also produced moderate levels of larval mortality. Weevil mortality was caused by direct colonization and by fungal exudates. The most promising strains are within the genus *Fusarium*. A number of these strains have been successfully inoculated into tissue culture plants. Preliminary studies on the efficacy of the strains in controlling weevils in pot experiments have not yet produced clear trends. Currently, further work is being undertaken on endophyte persistence and efficacy against weevils.

NARO has also screened strains of *B. bassiana* for efficacy against banana weevil adults. These strains were isolated from banana weevils, *Galleria* baits placed in banana stands and from other insects. A number of isolates effected mortality of more than 95% in the laboratory. Tests on potential delivery systems revealed that maize-based substrates and oil formulations were more effective than water suspensions. In field experiments, trap captures and weevil damage were lower in plots where maize-based formulations were applied to soil at the base of banana mats than in controls. However, the quantity of substrate required was cost-ineffective. Therefore, future work will continue to address the development of more cost-effective delivery systems, as well as pathogen performance under different ecological conditions.

Host Plant Resistance

In a screening trial in Uganda, plantains and highland bananas appeared more susceptible than other groups. Cluster analysis suggested 19 clones were highly susceptible, 17 clones were intermediate in susceptibility and 9 clones were resistant. Within the highland group, 15 clones were susceptible, while 11 were intermediate in susceptibility. Resistance did not appear to be related to host plant location or acceptance (antixenosis). There was no relationship between weevil trap captures, oviposition and damage. Instead, antibiosis appears to be the predominant mechanism affording resistance to the weevil, especially as it affected larval developmental times and survivorship. For example, in one study, survivorship in susceptible highland banana clones was 16-23 times as high as in resistant Pisang awak. Current work is attempting to explore compounds conferring resistance against banana weevil.

By Cliff Gold

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Beauveria Bait for Banana Borer

Brazil has also been at the forefront of research into biocontrol of banana weevil, *Cosmopolites sordidus*. Amongst the crop protection problems faced by Brazilian banana growers, the banana weevil aptly known here as the 'banana rogue', stands out in importance. The damage caused by the insect ranges from a drop in plant productivity to plant death. The tunnels the weevil makes in the rhizome allow the entry of pathogenic microorganisms, which accelerate the decline of the plant. Research on control of this pest increased from the 1950s onwards. There was increasing use of chemical control, initially organochlorine insecticides and more recently other types of active ingredient.

Continuous and prolonged use of organochlorine insecticides led to the development of resistance in the weevil populations. Following on from this development and the withdrawal of organochlorine insecticides, banana growers resorted to using systemic compounds, but residues of these could make their way into the fruit. This fact, combined with ecological disturbances resulting from the misuse of these products, stimulated work on alternative methods for banana weevil control. The most promising avenue is the use of entomopathogenic fungi, and research began by evaluating the efficiency and potential of the fungi *Beauveria bassiana* and *Metarhizium anisopliae* as biocontrol agents for the weevil. The Instituto Biológico in São Paulo State has carried out laboratory and field studies, the latter in the Vale do Ribeira region.

The project was initiated back in 1984, when the fungi were evaluated under laboratory conditions. The pathogens were grown on two different substrates (moist autoclaved rice and sterile ground beans). Inoculations were carried out in two ways: by making the insects crawl over the culture medium containing the fungi and then transferring them to pieces of banana pseudostem, and by placing the inoculum directly onto the pseudostem so that the insects contaminated themselves as they entered. Pest mortality of more than 85% was recorded in all treatments except for *M. anisopliae* grown on bean substrate (56% mortality). Under field conditions, *B. bassiana* was found to be the most promising agent for controlling the weevil, particularly when grown on rice medium, on which it developed best and to which the pest insect was attracted as a bait.

The results of a study on the virulence of different isolates of *B. bassiana* identified the isolate, CB-66 (originally obtained from the coffee berry borer, *Hypothenemus hampei*), as most effective for banana weevil control. In field trials, isolate CB-66 was prepared as a paste which was applied to the cut surface of longitudinal sections of banana pseudostems, and these (*telha* baits) were placed cut-side down on the soil surface next to the banana plant. Evaluations over three seasons showed that *B. bassiana* could reduce the adult weevil population by up to 61% over an extended period.

Under laboratory conditions, it was found that mineral oil at 3-5% EC added to strain CB-66 in paste form reduced *C. sordidus* populations by 77.5-100%, while the fungus alone gave only 37.5% control. Tests on the compatibility of the pathogen-oil association showed that although spore germination was reduced, virulence was increased. In the field, *B. bassiana* with 3% mineral oil applied to *telha* baits reduced pest populations below economic damage levels. The timing of application of the fungus was determined by the population level of the insect. It was applied when this averaged five or more adults per bait (recorded monthly.) Other authors have found this to be the level at which action is required to control the pest.

Over the 12-month study period, four applications and 20 evaluations were undertaken. After the first application, there was a clear reduction in the population of adult weevils in the treated area, from 9.0 to 3.4 insects per bait (equivalent to a control efficiency of 46.7%). The last application reduced the pest population to a level below that necessary for control. The control population was 45.8% higher, with 7.0 adults per bait.

These results indicate that *B. bassiana* is capable of reducing weevil infestations below damaging levels and, therefore, that it should be possible to establish a programme for management of *C. sordidus* based on the use of the fungus. Currently we are looking at whether we can use pheromones in association with the fungus to further increase disease incidence and improve weevil control.

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Weevil Control a Piece of Cake!

A study conducted in West Africa complemented the work conducted by Caroline Nankinga in Uganda [described above], and may provide the basis for developing affordable biological control measures using indigenous pathogens for the banana weevil *Cosmopolites sordidus* in Africa.

Strains of *Beauveria bassiana* were isolated from a range of hosts (*C. sordidus* and *Hypothenemus hampei*) in East and West Africa by staff from IITA, IMI (now part of CABI Bioscience) and ARSEF (Agricultural Research Service Collection of Entomopathogenic Fungi), and the most virulent selected on the basis of pathogenicity tests. Mass-production techniques for them were adapted from a technique developed for *Metarhizium* production at IITA under the LUBILOSA programme.

Key to the success of a fungal biocontrol agent is ease of mass production and the development of an effective means for its application. Researchers in the University of Ghana and IITA chose to work with a virulent *B. bassiana* isolate, IMI 330194, that was also robust and able to resist invasion of three common contaminating competitor species (*Aspergillus niger, Fusarium moniliforme* and *Penicillium hir-*

sutum). They also developed a method for formulating *B. bassiana* on oil-palm kernel cake (OPKC), which it has since been shown to persist for several months in the field, and to control weevils during the first few critical months after planting. This work may be the basis for an effective management tool for banana weevil.

Plantain (*Musa* AAB) is the preferred staple food of Ghana. The principal constraints to production are declining soil fertility, black Sigatoka disease, nematodes, and banana weevils. For smallholder farmers, biological control using *Beauveria bassiana* was considered the most promising management option for the weevil.

Researchers in Ghana began by looking at the efficacy of a water-based formulation of the fungus. In laboratory studies they found that *B. bassiana* applied to corm and pseudostem pieces had the potential to control all stages of *C. sordidus*, with up to 25%, 46% and 59% of eggs, larvae and adults, respectively, showing disease symptoms. In pot experiments they began to look at other formulations and application methods. Adult mortality in pot experiments was in the range 26.4-62.0%, and best results were obtained using dry conidia in a mixture of kerosene + groundnut oil (70:30 v/v) applied to the soil surface. These encouraging results translated to the field. In preliminary trials, weevil mortality of 53-81% was recorded on suckers dusted with *B. bassiana*, compared with 7-8% in an untreated control.

However, the researchers were looking for a method that would not only control the weevil, but would do so over the critical establishment phase of young plantains. In trials to investigate how well the OPKC formulation performed in the field, they lost no plantain suckers in the OPKC-treated plot, while 17% were lost in a plot treated with dry spores of *B. bassiana* and 19% in an untreated control.

In further field trials, they looked at whether conidia or conidial powder in OPKC gave best results. Both treatments gave equivalent and high levels of weevil mortality (75.5%) in artificial infestations, compared with only 1% in an untreated control. However, with natural infestations, the conidial treatment led to 41.7% mortality, compared to only 5.7% for the conidial powder treatment (and 3.3% for the control). No suckers were lost during the 2-month study in the conidia-OPKC treatment, but 17.7% and 19.4% were lost in the conidial powder-OPKC and control treatments, respectively. A study of the spread of fungal conidia using artificially infected and uninfected adult weevils indicated that *B. bassiana* conidia might be able to spread up to 18 m from the release point.

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Pathogens for a Pair of Weevils in Peru

Laboratory and field studies have been conducted in Peru to assess the prospects for using local strains of *Beauveria bassiana* for control of not only *Cosmopolites sordidus* (known locally as black weevil) but also the streaky weevil, *Metamasius hemipterus.* The black weevil is an important economic pest of bananas in Peru, as elsewhere in the world. The larvae cause damage by eating developing stems, which can cause wilting, stunted development and reduced production in attacked plants. The streaky weevil is a secondary pest. Its larvae do not have the capacity to cause damage to healthy stems, and its presence is always associated with damage from other pests, including the black weevil.

Laboratory assays were carried out at the National Agricultural University to assess pathogenicity. A fungal strain was isolated from a natural infection of coffee berry borer (*Hypothenemus hampei)*, and this was mass produced on rice grains. Weevils were inoculated by either applying 10 g rice-fungus substrate directly, or by spraying conidia at 2×10^9 conidia/ml. Inoculation method did not affect efficacy (judged by mortality and percentage sporulation). However, streaky weevil appeared to be the more susceptible, with 100% mortality reached 10 days after inoculation, compared to 45-50% for black weevil.

Subsequently, field trials were conducted in two commercial plantations in Tingo Maria using two entomopathogenic strains (GM1 and GG1) mass produced on rice substrate. These strains were isolated from black weevil adults from banana plantations around Tingo Maria. Traps used to attract the weevils were made from two discs of plantain pseudo-steams with 10 g rice-fungus substrate sandwiched between. These were laid out at a density of 30-40/ha at the stem-base of plantain trees and were changed every 7 days. Trapped weevils were recovered every 2-3 days and subsequent mortality and sporulation were evaluated in the laboratory. Strain GM1 induced 55.3% and 86.7% mortality in black and streaky weevils, respectively; sporulation occurred in 92.4% and 98.4% of these, respectively. Strain GG1 gave lower mortality (38.6% and 78.4%, respectively) and sporulation (74.2% and 82.1%, respectively).

Work is continuing on evaluating the pathogenicity of *B. bassiana* to the larvae, and also on formulations and mass production.

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Effective and Economic Neem

Studies conducted since 1996 at the International Centre of Insect Physiology and Ecology (ICIPE) Mbita Point Field Station (MPFS) and in farmer's fields in western Kenya have been directed at finding ecologically sound and affordable technology for control of banana pests. Results indicate that neem products can give control that is not only as effective as that provided by pesticide treatment, but also far cheaper. The pests targeted were the banana weevil (*Cosmopolites sordidus*) and the parasitic nematodes *Pratylenchus goodeyi* and *Meloidogyne* spp. These are the predominant pests in the major banana-growing areas in East Africa, which are normally over 1200 m above sea level. The pests occur together in the same plant and attack both root and rhizome tissues causing severe fruit yield losses. Although effective synthetic pesticides exist, they are expensive and hazardous to use. In recent years, neem (*Azadirachta indica*) has come under close scientific scrutiny worldwide as a rich source of natural pesticides.

Neem seed powder (NSP), neem kernel powder (NKP), neem cake (NC) and neem oil (NO) containing 4000, 5500, 5800 and 850 p.p.m. of azadirachtin, respectively, were tested as such or in aqueous form. In laboratory choice tests, less than 12% of weevils had settled under neem-treated banana 48 h after release, while more than 50% had settled under untreated corms. In a feeding test, weevil larvae caused little damage to neem-treated corms, indicating a strong antifeedant effect. In addition, females laid 3-10 times fewer eggs in neem-treated than untreated corms, and only 25% of eggs laid in neem-treated corms hatched. Forty to sixty per cent of 2nd-instar larvae died within 14 days when confined to neem-treated banana pseudostems; the survivors were small in body size and weighed 4-6 times less than those in the control. The higher the concentration, the greater was the effect of neem materials.

Effective methods, frequency and rates of application of neem materials were determined at MPFS and in farmers' fields, under different levels of soil fertility and pest infestations using a highly susceptible banana cultivar (*Musa* AAA-East Africa). Results indicated that application of 100 g NSP, NKP or NC at planting around the base of pared or unpared banana suckers, planted in drums and inoculated with weevils and mixed nematodes, significantly reduced the nematode population and weevil damage, and results were on a par with Furadan treatment at 40 g/plant. In addition, 10 months after inoculation, NSP- and NC-treated unpared suckers supported eight times fewer nematodes than pared suckers treated with the same neem product. Paring is generally recommended because it reduces initial infestations, but it is labour intensive. The results of these studies indicate that NSP and NC treatment obviates the need for paring. The NKP and NO applications were phytotoxic, however.

Soil application of powdered NSP or NC was more effective than their application in aqueous forms. Application of powdered NSP or NC at planting time and then at 1- to 4-month intervals to plants grown with controlled pest infestations in drums significantly reduced nematode density and weevil damage. Their application at 5-month intervals and above was ineffective. Their application in the farmers' fields at 60-100 g/mat at planting and then at 4-month intervals significantly reduced nematode density, and weevil and nematode damage, and increased fruit yields by 30-60% in the second crop. Yields obtained with Furadan at 60 g/plant at 6-month intervals were equal or less than that in control plants. Even with low soil fertility and high pest infestation levels, the neem treatments controlled the pests and markedly increased the yield 7-10 times more than the control. However, application of NSP or NC at more than 200 g/mat at 6-month intervals was phytotoxic.

Depending on the soil fertility and doses of application, the net gain in the NSP or NC treatments was in the range US$70-800/ha while Furadan use led to a loss of $700/ha.

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Integrated Approach for Weevil in Cameroon

An integrated approach to weevil control is being pioneered in an INIBAP-CRBP (Centre de Recherches Régionales sur Bananiers et Plantains) project in Cameroon. Four species of weevil are present in smallholders' fields in southwest Cameroon: *Cosmopolites sordidus*, *Metamasius hemipterus*, *M. sericeus* and *Pollytus melleborgi*, although the most severe infestations are caused by *C. sordidus*. Plantains with the genotype AAB appear to be most susceptible. Weevil larvae bore into the corm and weaken the plant, resulting in high plant mortality, reduced bunch weight and reduced hand number.

Development of IPM strategies for *C. sordidus* for plantain production in smallholder conditions in Cameroon and West Africa involves control with botanical insecticides, biological control, genetic control and chemical control. Studies on population dynamics are on-going in order to assess the mobility of weevils in relation to the natural population build-up in plantain fields. Yield loss of plantain over different crop cycles is being assessed. Pheromone-baited traps have been tested on a small scale. Technology validation through farmer participatory trials with NGOs and extension agents is planned for 2000.

In a field trial in southwest Cameroon, neem (*Azadirachta indica*) seeds were efficient in protecting young suckers of plantain against weevil attack for 3 months when they were dipped in a 20% solution of crushed neem seeds before planting. Weevil damage was tempered and sucker mortality due to weevil attack was reduced by 25-30%. The efficiency of neem, when applied closely to the sucker using this dipping treatment, can be explained by the multiple mode of action of neem on the life cycle of *C. sordidus*, which was assessed under laboratory conditions for neem and three other substances (household ashes, coffee husk and hot pepper). Neem had a repellent effect on adult *C. sordidus* and slowed down oviposition. Fecundity of females in contact with suckers rolled in neem seed powder was affected. Hatching of eggs in contact with a 10% solution of neem seeds was blocked. The toxicity of neem seeds to adult *C. sordidus* was low compared to a classical contact insecticide, which explains why a crown application (encircling the mat) with crushed neem seeds at 40-100 g/mat did not reduce weevil damage or weevil populations. The toxicity of neem seeds varied according to their origin and storage conditions. Neem seeds did not have any nematicidal effect on *R. similis* in the field, which was abundant and caused severe damage and toppling in our field trial.

Wood ash, which is being used by more than 30% of smallholder farmers in Cameroon, because they believe it controls weevils, had a moderate repellent effect, but did not have any effect on oviposition, hatching of the eggs or adult survival. Coffee husk (*Coffea* spp.), which is reported to have an insecticidal effect, did not have any effect on weevils. Hot pepper (*Capsicum* spp.) blocked the hatching of eggs under laboratory conditions and had a moderate repellent effect on adults.

Three strains of entomopathogenic fungi have been isolated from infected adult weevils in southwest and west Cameroon. Pathogenicity and viability tests were done over various infection cycles under laboratory conditions. Germination tests have indicated that viability of the strains had diminished after multiplication and sporulation on artificial (Vegetal) media. Nevertheless, *in vitro*, one strain caused 94% mortality of weevils after 9 days in the first and second infection cycle. Strains will be re-isolated from infected adults in order to regenerate their viability and mass produce them on an adequate delivery system. Entomopathogenic nematodes have been isolated from dead *C. sordidus* larvae.

CRBP has one of the largest *Musa* collections in the world. Preliminary screening identified various genotypes with promising levels of resistance, including plantain hybrids and parents used in the CRBP breeding programme, which are being evaluated in the field. Weevil resistance will be incorporated in the CRBP plantain-breeding programme.

Several new insecticides are being tested in order to broaden the possibilities for chemical control. In Cameroon only one efficient insecticide (fipronil, as Regent) is available on the market for controlling weevils.

In a field trial in southwest Cameroon population dynamics are being assessed using mark-recapture techniques. In this trial, which had very low weevil populations at time of planting (April 1999), the population started to build up in July, with a peak in October 1999, at the end of the rainy season, after which the population dropped and remained constant for several months. Migration of weevils between plots was observed in July and August, but not later. Trapping results indicated that *C. sordidus* migrates by flight. Daily trapping and removal of weevils reduced weevil populations, but did not control them.

The trapping efficiency of a ramp trap baited with sordidin pheromone lures (commercialized by ChemTica in Costa Rica) was compared to split pseudostem or sandwich traps in a small plantain plot in terms of number of weevils per traps per week. These ramp traps were only two to three times more effective then the pseudostem traps, with the number of weevils caught being highly variable. Pheromone lures remained attractive for 3-4 weeks.

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UK Support for Bananas

The UK government has recognized the significance of bananas and plantains to the rural population of East Africa and, in a cluster of programmes funded by the Department for International Development (DFID) through their Crop Protection Programme (CPP), is providing financial support for research into sustainable solutions to pest and disease problems. Collectively these projects address the problems of banana weevil, foliar diseases, wilts, banana streak virus and nematodes. In one of these, new technologies will be incorporated into an IPM system for management of the banana weevil in Uganda. There will be close linkages in this work with the regional project concerning on-farm testing of technologies also funded by the UK government and with a project funded by the Gatsby Foundation which has similar objectives but emphasizes the large-scale introduction of new disease-free varieties to many farmers in the central region of Uganda.

The DFID Crop Protection Programme has recognized that the Uganda National Banana Research Programme (UNBRP) has the trained staff available to address the different constraints to banana productivity. With several promising techniques and practices available together with some new varieties developed by the International Institute of Tropical Agriculture (IITA) and FHIA (Fundación Hondureña de Investigación Agrícola) banana improvement programmes, work in Uganda should make significant advances in alleviating poverty and improving rural livelihoods: the major purpose of the current DFID policy.

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Managing Diseases in Uganda

Banana diseases, including wilts, leaf spots and parasitic nematodes, have been found to be major constraints to the production of both indigenous and exotic bananas in Uganda and a key contributor to a recent and significant decline in production. Management of these will be addressed in a programme for the integrated management of banana diseases funded by the DFID Crop Protection Programme. It began in January 2000, and is being led by CABI Bioscience in collaboration with the University of Reading, UK, the Uganda National Banana Research Programme (UNBRP), the International Institute of Tropical Agriculture (IITA), Uganda and the Natural Resources Institute, UK (NRI).

UNBRP have already identified or developed a number of cultural farming technologies with potential for alleviating disease constraints and, consequently, for increasing yields and reversing the downward trend in production. As part of its intervention or management phase, UNBRP is now placing emphasis on the evaluation and transfer, to farmers, of such technologies as part of an IPM approach. The DFID-funded programme will enable new technologies developed for banana disease management to be evaluated under farmer field conditions at benchmark sites in Uganda. These include banana varieties with different yield/growth characteristics and disease and nematode resistance, improved use of organic and mineral fertilizers, and related cultural treatments to improve plant vigour, clean planting material and break crops.

The project will identify technologies that are most effective in minimizing losses due to banana diseases under different agroecological and farm management conditions. Those technologies found to be most appropriate for widespread adoption in Ugandan farming systems will then be selected with a view to subsequent widespread adoption by farmers as part of an IPM approach.

A new wilt syndrome, referred to locally as 'matoke wilt', has recently been observed on highland banana types. Its development appears to be related to particular farm management practices, including the use of household refuse and manure. The project will investigate these and other factors. Options for more effective management of this newly emerged problem by farmers may then be developed.

The project aims to provide stakeholders, including farmers, with information to allow them to judge and decide on the suitability of the various disease management technologies being assessed. It will provide a better understanding of the effects of particular farm management practices on plant health and on the prevalence and significance of major banana diseases. Direct participation by farmers, extension services and national agricultural research programme staff will greatly enhance their ability to recognise banana pest and disease constraints and increase their awareness of the beneficial effects of cultural farming practices. By identifying and facilitating the uptake of practices that most effectively improve banana plant health and reduce losses due to diseases, the project will enable farmers to increase yields and produce a crop of higher quality, thereby helping to reverse the general decline in banana production in Uganda seen in recent years. This, in turn, will enhance the livelihood of smallholder banana farmers in Uganda, by providing a more reliable staple food source and by increasing farm income generated through the sale of bananas at local markets. The demonstrative and training elements of farmer participation will contribute significantly to the rapid uptake of suitable technologies to achieve early impact for improved and sustainable banana production.

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Managing Banana Streak Virus

Another of the DFID cluster of projects in Uganda is concerned with epidemiology, vector studies and control of banana streak virus in highland bananas, which is perceived as one of the major threats to this crop in the country.

Banana streak virus disease (BSV) is now a major constraint to increasing banana production in many regions of the tropics. In Uganda, and other countries of East Africa where bananas are a major component of the diet, declining yields and the abandonment of banana plantations by some growers is attributed to the effects of the virus. BSV is widely distributed in most common cultivars of banana across the country, with high incidence near the borders. The disease appears to be causing significant yield loss in certain locations, although reliable information on the relationship between disease severity and yield loss is lacking.

Because many aspects of the dynamics of BSV are poorly understood, disease management strategies are poorly developed and banana farmers in Uganda have no clear control options available. This project, which began in November 1999, is led by the Natural Resources Institute (NRI) in collaboration with the National Agricultural Research Organization in Uganda (NARO), the University of Reading and the International Institute for Tropical Agriculture (IITA) in Ibadan. It aims to gain a better understanding of the epidemiology and ecology of BSV, and its importance and effect on banana production in Uganda. The information generated will be used to provide recommendations on optimum crop and pest management practices to limit the spread of BSV and reduce its effect on crop productivity.

Many of the activities in the project will be conducted in selected 'benchmark' sites where related studies on constraints to banana production are being carried out with groups of participating farmers. One such activity is an examination of the main factors influencing the activation of the virus, the expression of disease symptoms and the damage caused to the plant. The interaction of the virus with the host plant is complex; symptoms can be very variable, often being similar to symptoms of nutrient or water stress, and there can be periods of symptom remission. Most, if not all, *Musa* species and varieties tested to date have BSV-like sequences integrated into their genomes, which cause no symptoms in the host. However, it is suspected that some of the integrated forms can be activated under certain conditions. This may be influenced by climatic factors, plant nutrient status, and crop management. For example, water stress and cool temperatures are suspected to be the cause of localized outbreaks of BSV.

Spread of BSV will be examined through field experiments at the benchmark sites to monitor the natural spread of BSV in blocks of 'trap plants' of virus-indexed Cavendish 'Williams'. The experimental plots will be monitored visually for symptom expression and by enzyme-linked immunosorbent assay for the presence of BSV. In a related study, researchers at the John Innes Institute, UK are investigating the possibility that BSV is present in different strains in Uganda.

The role of insect vectors in the spread of the virus in the field is being assessed. BSV is a badnavirus, most of which occur in clonally-propagated tropical crops. In natural systems, the most important means of spread for badnaviruses is probably by vegetative propagation, but transmission by mealybug vectors has been demonstrated. Indeed BSV has been transmitted to banana under experimental conditions by three species, although not by African mealybugs nor in the field. An identification key to banana mealybugs is being developed by Jerome Kubiriba (NARO) and Gillian Watson (CABI Bioscience).

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Forecasting Less Fungicide for Sigatoka Disease in Guadeloupe

Yellow Sigatoka disease caused by *Mycosphaerella musicola* (anamorph *Pseudocercospora musae*) is one of the most important threats the banana industry has to face in Guadeloupe. The disease causes leaf spot, and heavy attacks can reduce considerably the number of leaves and, ultimately, bunch weight. Nevertheless the most important effect of this disease is indirect. Heavy spotting results in a reduction in the greenlife of the fruit, which considerably depreciates its export marketability. At least ten viable leaves at harvest are necessary for good fruit marketability and therefore excellent control of this disease is essential.

From 1937, when yellow Sigatoka disease was first reported in Guadeloupe, 40-50 fungicide treatments per year have been used to control the disease, and treatments have been applied systematically according to a pre-established 'calendar' programme. The main objective of CIRAD-FLHOR (Centre de Coopération Internationale en Recherche Agronomique pour le Développement – Département Productions Fruitières et Horticoles) (ex-IFAC, ex-IRFA) research has been to reduce the number of treatments to the minimum necessary for ensuring good fruit quality, so decreasing the cost of control, as well as minimizing risks of fungicide resistance and environmental effects. Key to this was gaining a better knowledge of the disease, so that a forecasting system could be developed for optimizing fungicide applications.

Disease Epidemiology and Disease Control

Germination and stomatal penetration by the fungal agent of Sigatoka disease are impeded by fungal antagonism in old leaves. Stomatal penetration only occurs on the unfurled leaf (cigar) or on the first full leaf (leaf 1). Bananas produce new leaves at a rate of about one per week. Under climatic conditions most favourable to disease development, first symptoms are observed after 12 days on leaf 2. In less favourable conditions, the disease first appears on leaf 3 or older leaves, or not at all. There is a gradient of evolution of the disease from the top to the bottom of the banana tree, and fungicide applications should be aimed at the top of banana trees to control new infections.

The incubation period (from stomatal penetration to first symptom of disease) and the transition period (from stage 1 (minute yellow point) to stage 5 (necrotic grey spot), according to Brun's scale) vary widely with climatic conditions, and can be up to 100 days. Several steps of the disease cycle are highly dependent on the water status at the leaf surface. With such variability in the development of the disease, a forecasting system has real potential to reduce fungicide applications.

In the field, it is essential to control the disease before necrotic formation, as sporulation occurs in stages 4 (waterborne conidia) and 5 (airborne ascospores). Where leaves are heavily spotted they should be removed since they can produce ascospores for many months. Contact fungicides are not curative and are effective only before fungal penetration, so they are useless in forecasting strategies that rely on symptom observations. Systemic fungicides have a curative effect on streaks (stages 1, 2, 3), but not on necrotic lesions (stages 4, 5), although sporulation is temporarily decreased.

Area-wide control is important, as wind-transported ascospores can disseminate the disease over long distances, and failure of control in one area can affect neighbouring areas.

Four Keys to Successful Forecasting

The forecasting system relies on the timing of decisions and applications, treatment efficacy, and organization of control.

1. Decision Making. In Guadeloupe, both biological and climatic data recorded every week are used to decide on the application timing. The information they give is complementary. Climatic information is predictive and is useful in preventing spread of the disease. However, more importance is attributed to biological data, since they represent the real status of the disease. Comparison of theoretical and observed data is also essential to detect any disruption in the control strategy.

The biological forecasting system is based on early detection of new attacks by continuous monitoring. The stage of evolution of the disease (SED) is calculated as the product of the rate of new leaf production (foliar emission rate) and the speed of development of the disease. The speed of disease development is monitored continuously by inspecting the youngest five leaves on ten plants in a plot each week. The most advanced stage of the disease (according to Brun's scale) is scored for each leaf. A coefficient for each leaf number/disease stage association (which increases with disease severity and decreases with leaf age) has been calculated, and these are summed to provide an estimate of the speed of disease development. The foliar emission rate is an indicator of plant vigour, and the more vigorous the growth of the banana trees, the faster the disease develops.

SED is an indicator of the potential of development of the disease and graphic representation of its weekly value is used for decision timing. There is a threshold value for spraying, but attention is also paid to the slope of the graph of SED against time. Experience has also shown the level of SED up to which fungicide efficacy is maintained.

Climatic information identifies periods when conditions are not favourable to disease development. As thermal conditions are always favourable to disease development in Guadeloupe, temperature is not used for forecasting. On the other hand, Piche evaporation, assessed under an open-air station, represents well the water status at the leaf surface, taking into account global radiation, air saturation, wind and temperature. A relationship found between Piche evaporation and duration of treatment efficacy is used in decision timing.

2. Spray Timing. The time between decision and execution of one application should not exceed 7 days and the whole spraying area should be sprayed on the same day. Treatments are made by aeroplane, which facilitates a swift operation, but good logistics are essential. The climatic conditions required for aerial spraying are limiting, and the 'windows' are small: only in the early morning and late afternoon do thermal inversion and air turbulence not interfere with spray deposition. Aerial application is not possible at all on rainy and windy days. Miss a 'window' and control may break down.

3. Effective Treatment. This is dependent on the quality of the foliar application and good coverage is essential. Bad weather conditions on the day of application, irregular topography in the spray zone or the presence of obstacles can alter its uniformity. The use of mineral oil carriers has considerably improved the quality of coverage through aerial spraying with low volumes (at 12-15 litres/ha).

Efficacy relies also on a strong curative effect and systemic fungicides are thus preferred to contact fungicides. The systemic fungicides used for yellow Sigatoka control have an antimitotic mode of action or are ergosterol biosynthesis inhibitors of group 1 (DMI group) and 2. Oil carriers strengthen the curative effect because mineral oils have a fungistatic effect.

It is important to manage development of fungicide resistance, and alternation of groups of fungicides with different sites of action is essential. Regular monitoring of resistant strains using a methodology based on a germination test of conidia determines any changes in sensitivity.

Keeping the sources of inoculum at a very low level is also important. Chemical sprays do not eliminate the disease from spotted leaves, so where extensive spotting is present, new infections will develop quickly and the only solution is to remove leaves mechanically from the banana tree.

4. Organization. Since ascospores are transported by wind over long distances, the control strategy should be the same in all banana plantations. Organization is more efficient if centralized under a single technical service operating according to rational guidelines, rather than each grower implementing his own strategy, often with short-term objectives. Banana growers are grouped in an association that performs the control strategy. The cost of the phytosanitary campaign is covered by a tax on exported bananas.

Progress and Prospects

In Guadeloupe, the forecasting system has been operating for 25 years and consequently the control has been centralized over 6000-7000 ha of bananas. Disease assessment is done and meteorological records are recorded by a technical team from the banana growers association, and treatments are applied by the banana growers association or by a private company. An equilibrium of six treatments/year has been achieved since 1973 through a control strategy including timing of decisions and the use of a systemic fungicide in pure oil, compared with 10-20 treatments/year in other countries (Ecuador, Surinam, Dominican Republic, Jamaica, Windward Islands) where fungicides are applied on a calendar basis.

However, forecasting did not eliminate all problems. The exclusive use of benomyl from 1973-1982 led to the build-up of fungicide resistance. Fortunately, fungicides with novel modes of action were available at that time and their introduction in an alternation strategy enabled us to return to equilibrium.

Today, yellow Sigatoka disease is under effective control and is not affecting the quality of export fruit. The cost of control (0.08FF/kg) represents less than 3% of the production costs. The number of treatments and the quantity of pesticides discharged in the environment have been reduced 8-10 fold by the forecasting system. Nevertheless, we should not be complacent, for new fungicide resistance may develop. There is a need for more new fungicides with more novel modes of action, especially since antimitotic fungicide resistance is widespread in banana plantations. Products belonging to the strobilurin family are still under evaluation.

The problems faced by the banana industry are quite different to those for other crops, because only one group of cultivars (the Cavendish group) with low genetic variability is grown for export. A new approach to yellow Sigatoka disease control should combine genetic resistance or tolerance with a rational use of fungicides. It is vital to begin to look at these options because another important curse of bananas, black Sigatoka (or black leaf streak disease) (*Mycosphaerella fijiensis*), which is similar to yellow Sigatoka disease but more difficult to control, is now a serious threat for the Caribbean banana industry.

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Integrated Action against Nematodes in Uganda

Plant parasitic nematodes are a major constraint to sustainable *Musa* production. In Uganda, which is the world's largest producer of East African highland bananas (*Musa* spp., AAA group), nematodes have been identified as a major factor contributing to declining production. The major nematode species affecting banana in Uganda are *Radopholus similis* and *Helicotylenchus multicinctus* at an elevation of between 1000-1300 m above sea level. At higher elevations, the most common nematode species is *Pratylenchus goodeyi*. At Sendusu, near Kampala (1120 m), production losses in the commonly grown cultivar, Mbwazirume, from *R. similis* and *H. multicinctus* were 30-38% under a variety of management regimes. Damage is characterized by reduced flower production and bunch weight, and an increase in plant toppling because of poor root development.

Nematodes can be controlled with chemicals, but these may have adverse environmental effects and the use of nematicides is too expensive and the products too dangerous for subsistence farmers. An integrated strategy (cultural, biological, cultivar selection) may be the best solution for nematode control, and this is being developed by staff at IITA-ESARC (the International Institute of Tropical Agriculture – Eastern and Southern Africa Regional Centre).

Diagnostic survey activities in Uganda were carried out in representative banana-growing villages. Data were collected on pest and disease incidence and severity and current pest management methods. In collaboration with the Uganda National Banana Research Programme (UNBRP), four benchmark sites have been selected for in-depth research and farmer participatory research. Currently work is focusing on three control strategies: host plant resistance, biological control by the use of endophytes and clean planting material. At the moment, most of our work is concentrated on *R. similis*, as this is the most damaging nematode species.

Host Plant Resistance

Research is directed at identification of durable nematode resistance sources and genetic analysis of nematode resistance. Screening for resistance to nematodes using field trials is a very time and labour-consuming effort. To screen the large available *Musa* germplasm, including landraces, commonly used exotic bananas and the IITA hybrids, a fast and reliable screening protocol is needed.

The method of single root inoculation was initiated in 1998, and improvements since have meant that the protocol is now fully standardized and can be used as a routine screening method. Four weeks after planting, three roots are selected from each plant and a cup is placed around them. Fifty females of *R. similis* in suspension are placed directly on the selected root. Evaluation 8 weeks later includes root health assessment and nematode counts. For each genotype the reproduction ratio is calculated. The advantages of this method are that a lower nematode inoculum and fewer plants per genotype are needed (since more roots per plant can be inoculated) and more hybrids can be screened at the same time. In each experiment, *R. similis* susceptible (Valery) and resistant (Yangambi-km 5) cultivars are included. Valery shows a high reproduction ratio with this protocol, while very low or no reproduction ratio is found in Yangambi-km 5.

Using this method, a number of promising hybrids have been identified in Uganda. These have low reproduction ratios, that are not significant different from Yangambi-km 5, indicating that they support low nematode densities, and these will be screened further for possible inclusion in the breeding programme and eventual release.

Currently, representatives of each clone set from the East African highland bananas are being screened. Hybrids derived from the East African highland bananas are also being evaluated. Progeny of the cross TMB2x 6142 × TMB2x 8075 look particularly promising. Both parents are also being screened against banana weevil, and first results indicate that they are resistant to the pest. They are also resistant to black Sigatoka and fusarium wilt. TMB2x 8075 has Pisang Jari Buaya (PJB) in its pedigree, which is highly resistant to *R. similis*.

Fungal Endophytes

Investigation of the potential of endophytic isolates of *Fusarium oxysporum* from banana for the control of plant parasitic nematodes began in 1997. The fungal cultures used in screenings for nematode control were isolated from Ugandan banana roots, cv. Mbwazirume, at the University of Bonn. Selection of candidate isolates was based on the nematode inactivating effects of their culture filtrates. None of the isolates screened to date were vegetatively compatible with the tester strain of the wilt fungus, *Fusarium oxysporum* f. sp. *cubense*, indicating that they are non-pathogenic. The fungal cultures were re-imported into Uganda through quarantine.

Standard protocols for screening fungal endophytes against the most damaging nematode, *R. similis*, have been established. Preliminary results of pot trials show that certain endophytic isolates reduced both nematode damage and reproduction in some banana clones. Plant growth-promoting effects have also been observed. Pot trials are on-going to determine the optimal combination of banana cultivar and fungal endophyte. The most promising endophyte, V5w2, is currently being tested in the field.

Clean Planting Material

Using pest- and disease-free planting material can reduce the spread of both plant parasitic nematodes and banana weevils. The objective of this technology-transfer project is the delivery of healthy banana planting material to farmer communities. In May 1999, a workshop was organized in Namulonge, Uganda to give training in hot water technology and to provide basic understanding of banana and yam pests and diseases.

Before planting, suckers are pared (to remove roots and infested rhizome tissue), after which they are hot-water treated (for 20 minutes at 53-55ºC). The use of clean planting material can increase production by 30-50% per cycle for at least four cycles compared with standard farmers' material in Uganda.

In Uganda, the project is carried out in four districts. The NGO Environmental Alert was involved in the mobilization and supervision of the farmers' activities and extension contact in Mpigi, while district agricultural officers performed these functions in Luwero, Masaka and Ntungamo. Baseline data were collected to establish initial damage and production levels. In total 1713 farmers were trained and 4487 suckers were treated and planted. Monitoring and data collection will be carried out in the areas where the planting has been done. A hot water tank has been constructed and the Minister of Agriculture for Buganda handed it over to farmers in that region. Similar projects are in operation in Rwanda and in Zanzibar.

Nematode-Root System Interactions

The spatial distribution of nematode population densities and damage in roots of the varieties Pisang Awak, Sukali Ndizi and Nabusa were investigated at three localities in Uganda, each with a distinctive nematode population composition. At Namulonge *R. similis* dominates, at Ntungamo the dominant species is *P. goodeyi*, while at Mbarara the two species coexist. At all three sites, suckers were removed from mats and assessed for nematode reproduction and damage. Nematode population densities were randomly distributed along the primary roots while nematode damage was significantly higher close to the corm than further along the primary roots, independent of cultivar and location. It was also observed that *R. similis*-infected banana mats had weaker plants and a reduced root system compared with those infected by *P. goodeyi*. The total length of dead roots was significantly higher when *R. similis* was present.

A study was also conducted on the relationship between banana nutritional status and nematode infection and damage. Nematode infection impairs nutrient absorption and distribution in the banana tissues. Potassium was shown to be the most impeded. When 'complete' nutrients were supplied to nematode inoculated plants, it was observed that nematode populations and damage in roots were reduced. Excess or deficient nutrient supply resulted in increased nematode population and damage.

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Soil Suppression and Nematode Biocontrol in Australia

The Australian banana industry produces approximately 250,000 tonnes of bananas for Australian domestic consumption. The most damaging nematode to banana production in Australia and worldwide is the burrowing nematode (*Radopholus similis*). The nematode causes toppling of bunched pseudostems, reduced bunch weight and increased cycling time. Nematode damage on bananas has been managed by the routine use of chemical nematicides which are expensive and hazardous. Some nematicides are becoming less effective due to the development of enhanced biodegradation, reducing the chemical's efficacy.

However, the incidence of burrowing nematode attack in Queensland is patchy. Some farms have been producing bananas for up to 30 years with little loss to nematode damage, and they have no need for nematicides. We investigated some of these farms to see if their soil naturally suppressed burrowing nematodes and, if so, whether this could provide a basis for a biological control method. Burrowing nematodes feed and reproduce within the root cortex of banana plants, and this does not make them particularly amenable to biological or other any other form of control.

Glasshouse trials were conducted by Julie Stanton and Jenny Cobon (Queensland Department of Primary Industries (QDPI), Indooroopilly) and Tony Pattison and Caroline Versteeg (Centre for Wet Tropics Agriculture) to assess soil from ten banana crops in southeast Queensland and six in north Queensland, respectively, for natural suppression of burrowing nematodes. Banana cv. Williams were planted in either sterilized or unsterilized soil from each site, and three weeks later were inoculated with nematodes. Any biological effects in the soil were assessed by counting nematodes extracted from the banana root system in a misting chamber ten weeks after inoculation.

More nematodes were recovered from sterilized than unsterilized soil in eight of the ten soils from southeast Queensland, which indicated some kind of natural suppression due to a biological factor. However, only one soil from north Queensland showed similar suppression. Work is continuing to determine whether soil can be induced to become suppressive by the addition of organic amendments such as chitin and ash, and whether indigenous antagonistic organisms present in these soils may be encouraged to reduce nematode damage in bananas.

Seeking the Root Cause

The next stage in developing a successful biological control is to identify candidate organisms that are antagonistic to burrowing nematodes. Various microorganisms may be responsible, and the Queensland team have been looking at the range that may be involved.

Julie Stanton and Jenny Cobon conducted glasshouse trials with a number of fungi (all *Fusarium oxysporum*) they isolated from the cortex and the stele of surface-sterilized banana roots. The isolates included three from naturally suppressive sites and four from non-suppressive sites in southeast Queensland. Three more isolates were supplied by Kendle Gerlach of the University of Queensland. Banana cv. Williams plants were inoculated with fungi at repotting by placing inoculated grain sorghum under the roots. The plants were inoculated with nematodes 3, 6 and 9 weeks later. Ten weeks after inoculation, nematodes were extracted from the roots for 7 days in a misting chamber, counted and the fungi reisolated from the banana roots.

There was a reduced recovery of nematodes from a fungal isolate taken from a suppressive soil site in plants inoculated with nematodes 3 weeks after inoculation with fungus, but there was no reduction with the later inoculation dates.

Caroline Versteeg investigated endophytic actinomycetes she isolated from surface-sterilized banana roots taken from a site which showed suppression of burrowing nematode in north Queensland. The actinomycetes were obtained as pure cultures and initially tested for their ability to reduce nematode motility. Three isolates were found to significantly reduce nematode motility. These isolates were grown on sterilized wheat bran, which was then mixed with sterilized soil, in which a tissue-cultured banana plant, cv. Williams was grown. The banana plants were inoculated with motile burrowing nematode 7 days after inoculation with the actinomycetes.

In the pot trials no actinomycete isolates significantly reduced the number of burrowing nematode in the roots of the banana plants relative to an untreated control. However, more endophytic bacteria isolated from suppressive soils are currently being evaluated in pot trials. Modification of the screening procedures may be needed to determine the biocontrol potential of the candidate organisms.

Rhizobacterial isolates collected from banana fields in north and southeast Queensland are being investigated by Linda Smith (QDPI, Indooroopilly) for their role in suppression of *Fusarium oxysporum* f. sp. *cubense*. The isolates are also being assessed for their antagonistic potential toward burrowing nematode in bananas. Screening of isolates by Tony Pattison and Caroline Versteeg has commenced in north Queensland. Initial results suggest some suppression of *R. similis* by ten rhizobacterial isolates, and further screening is continuing.

Finally, Tony Pattison and Caroline Versteeg have been conducting pot trials to look at the antagonistic potential of mycorrhiza isolated from banana-growing soil in north Queensland. They found that the presence of *R. similis* appeared to reduce mycorrhizal colonization within banana roots. Conversely, there were significantly fewer nematodes in plants colonized by mycorrhiza, but there was no growth improvement in plants colonized by mycorrhiza. The use of mycorrhiza as a treatment to reduce *R. similis* infection for tissue-cultured banana plants is a good avenue worthy of further investigation.

Aiming for Suite Success

By conducting this research we hope to identify organisms that are antagonistic to burrowing nematodes and can be developed for biological control. Such organisms could be introduced to banana plants either at the repotting stage in a tissue culture nursery, as a dip for vegetative planting material prior to planting in the ground, or by injection into an established plant. The endoparasitic behaviour of burrowing nematode means that no single inundative organism is likely to provide the solution to nematode problems in bananas. By developing a suite of organisms with different niches on the banana root system, the chances of successful biocontrol of burrowing nematodes on bananas should be increased.

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IPM Leads to Increased and Sustained Yields in Ghana

Plantain is a primary staple food in Ghana, providing a source of food and cash income for resource-poor farmers throughout the year, thus contributing to national food security. In recent years, there has been a substantial decline and reduction in plantation life (<3 years) within the country. Severe plant toppling in the first season and rapidly diminishing yields in ratoon cycles mean that plantain is commonly treated as an annual rather than a perennial crop. This situation necessitates frequent land clearing which is costly to the farmer and the environment. The decline in plantain production is attributed to high levels of nematodes, banana weevils and foliar disease (black Sigatoka) together with poor soil fertility (resulting from shortened fallows) and the high cost of crop management. Plantain damage due to nematodes and weevils is frequently compounded by the use of infested planting material since farmers are usually unaware that suckers are the main source of inoculum for these pests. Lack of healthy planting material represents a major constraint to plantain farmers in Ghana. Suckers are costly, they are often infested with nematodes and weevils, and may not be available when the farmer is ready to plant.

Raising Clean Planting Material

These pest and disease problems have been addressed through farmer-participatory research. The development of a simple scheme for the production and rapid multiplication of healthy planting material in community nurseries has provided the foundation for improved plantain production. Plantain suckers collected from a healthy plantation are pared (roots and corm outer layers removed) with a cutlass to remove nematodes, and weevil eggs and larvae. The pared suckers are then multiplied using a 'split-corm' technique, whereby they are split into several setts (4-10 depending on sucker size) which are germinated for 4-6 weeks in seed beds or boxes containing sawdust or other locally available sprouting media. The sprouted suckers are transferred to a field nursery at a spacing of 60 × 60 cm where they are maintained for 4-6 months before transfer to the farmers' fields. The advantage of the field nursery is that plants can be carefully maintained in a relatively small area at a stage when they are particularly susceptible to environmental stress. Prior to transplanting to the farmers' fields, suckers are pruned (pseudostem cut back to a height of 10 cm) and pared. If equipment is available, pared suckers are hot water-treated (53-55ºC for 20 minutes) before planting, as this is a highly efficient method for eliminating nematode inoculum in the suckers.

Farmer-Participatory Trials

On-farm trials were established in 1995 and 1997 to study the influence of planting material treatment (hot water treatment) and improved crop management (regular weeding) on pest and disease dynamics, growth and yield of plantain. At flowering, the density of *Pratylenchus coffeae* (the most damaging nematode on plantain in Ghana) in roots, was significantly lower in plants grown from hot-water treated suckers. The percentage of bunches lost prior to maturity (due to toppling, stem breakage, failure to flower or premature death) exceeded 75% for untreated materials under traditional management, compared with 43% for hot water-treated materials under improved management. The yield from hot water-treated materials that had regular weeding was more than trebled compared with untreated materials. Moreover, it was observed from the 1995 trial that planting material treatment, in combination with regular weeding, substantially lengthened plantation longevity. Farmer-managed plots with untreated materials were largely abandoned after the first season due to the high incidence of plant toppling. In contrast, hot water-treated materials that were well-managed continued to yield for 4 years.

Farmers' Perceptions

In 1999, Farmers' Fora held at three pilot sites gave farmers an opportunity to discuss and evaluate the technologies tested. Farmers stated that nursery production provided a means to generate and multiply clean suckers as required. Moreover, nursery-derived materials performed better than untreated suckers and could also be sold at a higher price than untreated suckers when required. The major constraints in nursery production were the need for watering during the dry season and the cost of labour for regular weeding. In addition, it was realized that use of the hot water tank for sucker treatment would be more feasible for farmers' groups than for individuals.

When asked to discus the performance of treated suckers, farmers' perceptions closely reflected the results of both agronomic and economic analyses. They observed that plots with hot water-treated materials under improved management (optimum plant spacing and regular weeding), required more labour but that this disadvantage was outweighed by better plant establishment, higher numbers of suckers, a shorter time to maturity, a higher number of bunches, longer plantation life and higher cash returns. 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 had been adopted by at least 40% of the plantain farmers at three pilot sites, representing good progress since a participatory rural appraisal in 1993 when farmers were unaware of the need for planting material treatment.

Economic Feasibility

Financial appraisal of plantain nursery production at three villages in Ghana showed clearly that the production and rapid multiplication of clean planting materials can be profitable even when there are adverse price fluctuations. Farmers producing clean suckers can benefit both through the use of their own clean planting material to produce improved yields and also by diversifying their farm income through the sale of clean suckers to other farmers.

Cost/benefit analyses showed that the use of clean planting material and improved management practices for plantain production was profitable compared with traditional practices. For example, hot water-treated suckers under improved crop management (optimum plant spacing and regular weeding) gave an economic return of US$800/ha over a 2-year period, representing net additional returns of $300/ha compared with traditional practices.

Dissemination

Technologies developed for the production and rapid multiplication of clean plantain planting material formed the basis of the curriculum for a plantain IPM Farmer Field School in Ghana (1997-1999). Twelve extension agents (from six major plantain-growing regions) were trained in methods for improved plantain production. Techniques learned were transferred to plantain farmers' groups in each of the officers' districts.

By: Kim R. Green, Project Coordinator

Research was funded by BMZ, Germany and executed by the International Institute of Tropical Agriculture (IITA) in collaboration with the Ministry of Food and Agriculture, Ghana (MoFA) and the Agricultural Research Station of the University of Ghana at Kade. The Plantain Farmer Field School was funded by the UN Development Programme (UNDP) (through FAO) with assistance from MoFA and GTZ (Gesellschaft für Technische Zusammenarbeit).

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Post-Harvest Diseases of Banana

Diseases of Economic Importance

The most important post-harvest disease of banana is crown rot, which is caused by a complex of fungi with *Colletotrichum* *musae* being the main pathogen. Additionally, *Fusarium* spp. are ubiquitous secondary invaders and *Acremonium* sp., *Botryodiplodia theobromae*, *Fusarium moniliforme*, *Fusarium pallidoroseum* (formerly *F. semitectum*), *Nigrospora sphaerica*, *Penicillium* spp. and *Verticillium* spp. are of regional importance. These secondary invaders are often isolated from severely diseased fruit in higher frequencies than *C. musae* and therefore blamed as the causal agent. However, whenever quantitative inoculation studies were carried out in order to fulfil Koch's postulates, *C. musae* required at least one log unit less inoculum than the other fungi to evoke symptoms.

Colletotrichum musae establishes a latent infection in the field at early stages of fruit development. When the banana hands are severed from the rachis during harvest, spores of fungal inoculum enter the wound and initiate disease development at this window of opportunity. Crown rot symptoms usually only become visible during fruit ripening in the countries of destination. Then, however, the disease can progress rapidly and, in severe cases, the rot penetrates the pulp which renders the fruit unmarketable. Crown rot causes losses of 2-10% in all banana-exporting countries. Its incidence rises periodically in the rainy season.

Other post-harvest diseases include anthracnose, also caused by *C. musae*, cigar-end rot caused by *Trachysphaera* and *Verticillium* spp., finger rots caused mainly by *B. theobromae, Ceratocystis paradoxa, Pestalozzia leprogena, Phomopsis* sp. and *Sclerotina sclerotiorum,* and squirter disease associated with *N. sphaerica* in combination with physiological stress factors. Other fruit spots caused by *Cercospora hayi* and *Deightoniella torulosa*, and pitting disease caused by *Pyricularia grisae* are more accurately regarded as field diseases but symptoms exacerbate after harvest. Also, the boundary between field and post-harvest diseases is gradual because many post-harvest pathogens can establish asymptomatic infections in the field.

Crown Rot Control

Crown rot is commercially controlled by the fungicides thiabendazole (TBZ) and imazalil, alone or in combination, applied as a post-harvest dip or spray. Cross-resistance to benomyl, formerly used in Sigatoka control, renders TBZ relatively ineffective in many traditional banana areas. Other fungicides have been tested on an experimental scale but are not registered for use on export bananas. Several projects have addressed non-chemical control options for environmental concerns as well as the health of banana workers and consumers.

Breeding programmes, most notably at FHIA (Fundación Hondureña de Investigación Agrícola) in Honduras, have produced crown rot-resistant hybrids but these have different organoleptic characteristics from Cavendish clones and are not well accepted by the mainstream customer.

Cultural management options include reduction of inoculum and earlier harvesting which is sometimes combined with techniques that accelerate fruit development in order to minimize yield loss. Physical approaches require first and foremost a rapid cooling of the fruit after harvest and a continuous cooling chain throughout transit which should be of minimum duration. Due to the highly perishable nature of banana fruit, the chain of operations has to be well organized at all levels. Smooth crown cuts and immediate transfer of fruit into an alum solution for delatexing also reduces crown rot. During shipment, modified and controlled atmospheres have shown promise but many of them either proved too expensive for routine use or had negative side effects on other fruit quality characteristics. Natural and non-synthetic chemicals have been investigated, among them calcium preparations, plant extracts, organic acids and waxes. One of the most promising compounds, a citrus seed extract, is now rarely used because of its inconsistent effect, possibly due to the low shelf-life of the product. Alginate-calcium gels reduced crown rot under experimental conditions. They are likely to form part of an integrated approach with biological control rather than on their own.

Among the biological options, induced systemic resistance and antagonists have been tried. Induced systemic resistance is operational in a wide range of crops but has not yet been exploited in any post-harvest situation. However, culture filtrates or cell wall fragments of *C. musae* induce the production of antifungal components in the peel of green banana fruit. As a result, conidial germination of *C. musae* was inhibited on treated skins. Subsequent attempts to employ the more easily obtainable dead conidia of *C. musae* as a resistance-inducing post-harvest treatment were unsuccessful. However, as a pre-harvest treatment (injection of the rachis 1-2 weeks before harvest) high crown rot levels could be reduced to *ca* 70% of control. More data, however, are required to substantiate and quantify these tendencies.

A programme funded by ODA (the UK Overseas Development Administration, now DFID, the Department for International Development) and managed by NRI (Natural Resources Institute, UK) in the Windward Islands identified several indigenous organisms with potential for biological or integrated disease control. Whereas only few bacteria appeared effective, mycoparasites (fungi parasitizing other fungi) showed great promise. Some of them attacked the whole range of fungi involved in the disease complex, including structures which are very resistant to fungicidal attack such as conidia and haustoria. Others showed great tolerance to fungicides themselves and could thus be combined with reduced concentrations of fungicide in an integrated disease management system. The highly diverse population structure of *C. musae* renders a single-strain biocontrol agent unlikely to provide consistent crown rot control. However, mixtures of strains could overcome this problem. Each mycoparasite was found to act via a different main mechanism, i.e. parasitism, antibiosis, competition. Combinations of up to four strains of mycoparasites belonging to different species (mostly *Gliocladium* spp. and *Paecilomyces* spp.) complemented each other and progressively increased the biocontrol efficacy against mixed infection. Preliminary studies suggest that incompatibility is not a problem. Future research should thus focus on mycoparasite mixtures in compatible formulations such as alginate-calcium gels.

Further information: Krauss, U., Bidwell, R.; Ince, J. (1998) Isolation and preliminary evaluation of mycoparasites as biocontrol agents against crown rot of banana. *Biological Control – Theory and Application* **13**, 111-119.

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Alternatives to Chemical Control for Anthracnose in Guadeloupe

Anthracnose of bananas, caused by *Colletotrichum musae*, is the most important postharvest disease affecting the quality of exported fruits from the French West Indies. This disease develops during fruit conservation and ripening and it depreciates the fruit marketability. Anthracnose is in practice controlled by a postharvest fungicide. However, under Guadeloupe conditions, this chemical control has now reached deadlock for three main reasons:

(a) aerial fungicidal sprays to control Sigatoka disease have resulted in the appearance of strains resistant to the active ingredients used for anthracnose postharvest control; (b) fungicidal treatments are not effective in all production zones, quite apart from the appearance of resistance; (c) consumer demand is for a reduction in pesticide use, especially those applied postharvest. So, there is a need for new control strategies, and these could be developed from a better knowledge of the bioecology of the pathogens.

Disease expression is dependent on a number of factors present at different steps in banana production, from fruit production in the field, to fruit packing, transport and conservation, maturation in ripening rooms, and marketing. Of these, the variation in potential fruit quality at the field level is particularly important, since it is responsible for seasonal (disease is more severe from September to January) and spatial (disease is more severe in low altitude lands of Guadeloupe) variations. Potential fruit quality is governed by a physiological (fruit susceptibility) and a phytopathological (level of fruit contamination) component. Recent work has been carried out in Guadeloupe on these two components in order to propose alternative strategies to chemical postharvest control.

The Physiology of Fruit Susceptibility

A diagnostic survey was conducted on 106 banana plots in order to identify the factors which might explain variation in fruit susceptibility to wound anthracnose as measured through artificial inoculation at flowering and wounding the fruit at harvest. This study showed that fruit susceptibility varies widely with pedoclimatic conditions and farming practices.

In the pedoclimatic area of halloysitic and ferralitic (low altitude) soils, where fruit anthracnose lesions developed most (54 plots), a relationship was found between the manganese (Mn) content of fruit and susceptibility to anthracnose: the plants producing the most susceptible fruit had higher foliar Mn concentrations and lower calcium (Ca) concentrations, and had grown on rather acid soils.

It is possible that the high Mn content of the fruit could have arisen from stress situations which could reinforce the ability of the fruit to synthesize ethylene, a hormone that can play a very important role at different levels in the host-pathogen interaction. It has been shown that ethylene activates germination, formation of appressoria and lesion extension. Anoxic conditions resulting from soil compaction or bad drainage can lead to a reduction of different forms of manganese into Mn^{2+} in the soil, and to a massive absorption of Mn^{2+} by the plant, accompanied by a lowering of the leaf Ca^{2+} content. For many plants, it has been shown that root anoxia causes ethylene synthesis by the plant shoots. It is then possible that the fruit from banana plants subjected to anoxic conditions may have a greater ability to synthesize ethylene. Work is still in progress to test this hypothesis experimentally in order to manage fruit susceptibility to anthracnose through optimized farming practices.

The Phytopathology of Fruit Contamination

Fruit pollution occurs in the field. Conidia germinate rapidly and form a melanized appressorium which remains inactive until the fruit ripens. A penetration hypha then develops and the mycelium enters the skin and later the fruit pulp, forming brown lesions. Once quiescent infections are formed, the pathogen is permanently installed on the host because dark appressoria can survive very adverse environmental conditions. So, potential fruit quality depends on the quantity of conidia that reach the fruit surface (fruit pollution) and the quantity of conidia that form a dark appressorium (fruit contamination).

Fruit Pollution

Colletotrichum musae does not sporulate on the green parts of the banana plant but only on senescent organs. We have conducted studies in order to (a) identify the inoculum sources contributing mostly to fruit pollution; (b) determine the dynamics of fruit pollution from flowering to harvest; (c) establish the mode of transport of this inoculum to the surface of the fruit; and (d) evaluate the effect of covering the bunches with a plastic sleeve on fruit pollution.

Fruit pollution occurs mainly from inoculum produced on the floral parts and the last bunch bract. Because they are closest to the fruit, the floral parts are the most effective inoculum source for fruit pollution. The elimination of the floral parts and of the last bunch bract at the flowering stage reduces considerably the quantity of conidia trapped, from flowering to harvest, in rainwater run-off under the bunches, and the level of fruit contamination measured at harvest. Moreover, *C. musae* is readily isolated from floral parts.

Fruit pollution occurs mostly during the first month after bunch emergence (the critical period) and strongly decreases thereafter. Most conidia were trapped in rainwater run-off under the bunches during this critical period. Most inoculum was isolated from the floral parts during this period. Lastly, the climatic conditions prevailing during this critical period were related to the levels of fruit contamination observed at harvest and to the cumulative number of conidia trapped in rainwater run-off from flowering to harvest.

In the absence of rainwater, inoculum is not dispersed and does not reach the fruit surface. All the floral parts of bunches from plants grown under rain-out shelters were inoculated with *C. musae* conidia and a large amount of inoculum was isolated from them. No anthracnose lesions were observed on the fruit at harvest.

Sleeving of bunches limits rainwater runoff and inoculum dispersal to the fruit surface. A reduction of more than 80% in the level of fruit contamination is observed on sleeved bunches compared with unsleeved bunches, even though there is no effect on inoculum production by the floral parts.

Fruit Contamination

We developed a methodology to assess the level of fruit contamination through the number of anthracnose lesions that develop on fruit (the technique is applicable to immature fruits aged 4 weeks). A good correlation between the number of anthracnose lesions and the quantity of appressoria is achieved when the fruit are conserved at high temperatures with elevated levels of ethylene.

The formation of melanized appressoria was evaluated, with a constant inoculum concentration, in controlled temperature and humidity conditions close to the natural contamination. The presence of free water is essential and appressoria formation does not occur within six hours. This indicates again the importance of rain or long dew periods for contamination.

Alternatives to Chemical Control

The above results suggest there are a number of strategies for managing anthracnose at various stages in the production system that could be investigated as alternatives to chemical postharvest control.

1. At the Field Level. Fruit pollution can be reduced by removing the floral parts and the last bunch bract. The operation must be carried out as soon as possible to minimize inoculum development. This practice, combined with sleeving bunches, gives a very significant reduction in the level of contamination of the fruit. Particular attention must be paid to early sleeving, which should be done before the fingers reach a horizontal position (or before all bracts have fallen). A better knowledge of the regulation of ethylene biosynthesis would allow farming practices to be developed which could improve fruit resistance to anthracnose.

2. In the Packing Station. Fruit must be handled carefully during transport to the packing station and packaging in order to avoid bruising, as this enhances disease expression. Maintaining good quality for the water used in de-handing and in the washing tanks is also important to avoid contamination of crowns. Lastly, packing the fruit in polybags allows the formation of a modified atmosphere (higher CO_2 and lower O_2 content), which is important to improve fruit conservation and slow down fungal development.

3. In Ripening Rooms. The quantity of ethylene used in the ripening rooms, as well as the time of ethylene contact and the temperature of fruit conservation can increase disease development during fruit maturation. Present practices should be reconsidered: high ethylene rates (>1000 p.p.m.) are used even though small rates (1 p.p.m.) can induce the climacteric rise.

Testing the Alternatives

The possibility of eliminating postharvest treatment through these different non-chemical measures will be evaluated in a trial on pilot farms. The level of fruit contamination at harvest will be forecast using the assessment test on 6-week-old fruits, and actual contamination will then be assessed. These results will provide useful feedback on the performance of the new measures.

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Training News

In this section we welcome all your experiences in working directly with the end-users of arthropod and microbial biocontrol agents, or in educational activities on natural enemies aimed at students, farmers, extension staff or policymakers.

Feedback on Farmer Field Schools

Since 1998, we have reported on many participatory training and research initiatives around the world. In this issue, we are revisiting two programmes based on the Farmer Field School (FFS) approach, to report on what has happened since, and see if there are any general lessons to be learned. A message that comes through clearly in both these studies is that farmer commitment to biocontrol and IPM remains high, but follow-up training is crucial (for both trainers and farmers) to reinforce understanding of IPM and fill in the inevitable gaps in knowledge.

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Keeping off the Treadmill

We begin with an update to the first article to be published in 'Training News' [*BNI* **19(2)**, 41N-42N, 'Stepping off the cotton pesticide treadmill']. The article described how, in 1997, a farmer participatory training programme involving Training of Trainers (TOT) and Farmer Field School (FFS) approaches had enabled cotton farmers from Vehari District of Punjab Province in Pakistan to become IPM practitioners. The trained farmers made decisions that lowered their input costs by 68% while maintaining or even increasing crop yield and quality.

The continuing impact of the programme was assessed at the beginning of the 1999 growing season. The aim was to find out what the FFS graduates were doing 2 years on – what aspects of training they were confident in and what needed reinforcing. A survey revealed that of the ten FFS farmer groups trained in 1997, five were still very active. At least 80% of the graduates were still involved in active FFS groups and the most visible effect of the training was that they were familiar with various stages of pests and beneficials and many were conducting agro-ecosystem analysis (AESA) in their own fields, outside the group sessions. At the five other sites, FFS groups were less active but insecticide application remained much reduced compared with before the training.

There was evidence for limited spread of IPM concepts and practices to farmers in districts neighbouring those targeted by the participatory research programme, although not sufficient to enable new farmers to carry out IPM in practice. Some of the farmers in adjacent districts who were interviewed were familiar with some beneficials, and even more were familiar with IPM terminology. But they had no understanding of the concepts, or how to practise IPM. It was concluded that insufficient dissemination of IPM technology had taken place to give untrained farmers a sound basis for changing their management practices.

Interviews were conducted with 15 FFS graduates from 1997 and 15 untrained farmers in each of the five localities where the FFS groups were still most active to assess farmer perceptions of the effectiveness of FFS training and IPM. The findings were used to revise the curriculum for 1999.

FFS training in 1999 was carried out in close collaboration with five community-based organizations (CBOs) coordinated by the NGO Catholic Relief Service. Five trainers from each CBO, many of whom are cotton farmers themselves, were trained as FFS facilitators, each taking responsibility for facilitating activities with five farmers in each FFS group. Good local networks have been built up as a result of this community-level participation and their effectiveness was demonstrated by the fact that over 90% of non-participating farmers in the five FFS communities also reduced or eliminated insecticide application on their cotton in 1999.

During the 1999 season, FFS groups again avoided early season insecticide application in all plots and were able to eliminate chemical control altogether in some of the IPM plots. Net profits for IPM and farmers' practice plots averaged 16,451 and 11,413 Rupees/ha, respectively, confirming again the economic benefits of IPM for a second season. In the Punjab context it is critical for FFS projects to convince farmers and extension staff that IPM can be viable over a range of pest pressure, climate and economic variability. However, there is now acceptance in wider circles in Pakistan of the FFS approach, and this recognition will help to facilitate implementation of future cotton IPM programmes.

When farmers were questioned about current problems in cotton production, high price of cottonseed was identified as the most severe constraint at all five sites, and at three sites pest control came second. However, at the other two, pest control was not considered a main issue, and most FFS-trained farmers said that the presence of beneficials meant that there was no need to apply insecticides. Most trained farmers at all sites were familiar with various, if not all, stages of pests and beneficials, while untrained farmers were overwhelmingly not. At one locality, most trained farmers had also retained an understanding of IPM terminology, its philosophy and importance. At other localities, the farmers' level of familiarity had dropped considerably, although it still greatly exceeded that of untrained farmers. However, when asked to assess, on a five-point scale, their confidence at making IPM decisions without back-stopping, one-third of all trained farmers expressed no confidence at all, and the median level of confidence was 50%.

The reasons for this lack of confidence may lie at least in part in the arsenal of pests that attacks cotton in the Punjab: pest status and levels can differ hugely between seasons. The 1997 season, for example, was marked by low *Helicoverpa* pressure in some areas while whitefly and associated viral disease was critical. Farmers who trained during that year will have had ample reinforcement during the season of IPM practices appropriate for whitefly outbreaks. However, in 1998 *Helicoverpa* bollworm caused havoc in most areas, but FFS-trained farmers had had little experience of this pest in the IPM context. Insecticide application frequency increased but in many cases failed to control the problem. Then in 1999, spotted bollworm (*Earias* spp.) was identified by many farmers as the major production constraint. Yields have also fluctuated considerably over the last 3 years. It is evident that one season's training alone is not sufficient to prepare farmers or facilitators to manage the variation. Follow-up and post-training support are therefore particularly important to help FFS graduates, farmer groups and facilitators cope with the huge variability in pest dynamics.

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Extending Vegetable IPM

This second update is for a much more recent report [*BNI* **20(4)**, 119N-120N, 'Vegetable IPM gains ground in Ghana'], which described the detailed planning that had gone into designing a season-long 'Training of Trainers' (TOT) course in Weija in 1998. Since then, the trainers (as FFS facilitators) and master trainers have been developing and executing FFS activities in their respective districts of Ghana. In a more recent survey, IPM FFS graduates and their facilitators were asked what they felt they had gained from the training experience. Here we are able not only to describe farm-based results and on-going activities, but also to report the facilitators' and farmers' views.

Crops targeted by FFSs were mainly the TOT crops (tomato and cabbage), but validation trials and/or FFSs have been undertaken on other crops at other sites, for example, onion, hot pepper, aubergine [eggplant], okra and lettuce. In many locations, although tomato was a familiar crop, cabbage was rare if not completely new.

Farmers reported learning about a range of new or modified practices and ideas: about insect pests and beneficials, use of neem, mulching, regular monitoring through agro-ecosystem analysis (AESA), regular planting schemes, and nursery practices. Many also talked about learning to work together as a team. However, some techniques were mentioned less often, including balancing organic and inorganic fertilizers, composting, staking for tomatoes, how diseases spread, and the importance of good seed.

Benefits farmers reported were varied and many. There has been a significant cut in input costs because of reduced pesticide use combined with the switch to locally produced and cheaper neem-based products. Labour inputs have been cut because there are fewer pesticide applications, and time savings are also made through mulching (less watering and weeding). Farmers report improved health from less pesticide use and better working practices, but also from the addition of cabbage to the family diet. The training has enabled them to plan their work better, and they report better and more sustainable production from relatively small areas of land. Better crop sanitation has led to a reduction in disease and grasshopper attack. Overall, adoption of IPM has meant better quality produce with less rejected by the market, and farmers feel they have benefited by working together to solve problems.

Yields and farmer incomes both improved dramatically post-FFS. In most locations, farmers experienced a two- to three-fold increase in tomato production, and at one location the increase was four-fold. Cabbage production changed from none or hardly any to good (for example, 80% of plants producing marketable heads). Farmers' incomes also increased by up to four times, and this has meant not only an improvement in their living standards, but also further investment and diversification in their farms.

There are a few thorns in this otherwise rosy picture. The marketing situation (fluctuating prices and buyers monopolies) is not favourable, and credit is hard to come by. Farmers are perhaps currently over-reliant on neem, which they have tended to adopt as the answer to all pest (and disease!) problems. Whether this will lead to new problems remains to be seen. In some locations there are specific problems, and lack of irrigation facilities, access to land, or good quality seed were cited as impediments in various places. On the whole, though, farmers felt they had benefited greatly from FFSs, and agreed that more farmers should be exposed to its methods. But they stressed that it was important for trained farmers to continue to meet for discussion and information exchange.

Facilitators also felt their FFSs had been a success. They cited the information offered, training methods used and willingness of the farmers to learn as the key factors. Master trainers provided good back up during first FFSs, but there has been no refresher training. Facilitators also stressed the need for continuing learning for themselves, and suggested that they should meet once or twice a year for additional information and exchange of experiences. A more integrated approach to all pest management and improved facilitation of farmer decision-making could be addressed in workshops, which could focus on gaps in the current FFS curriculum.

Farmers, post-FFS, have adopted a wide range of practices, indicating that the FFS facilitators successfully addressed a wide range of topics. Not only have FFS-trained farmers gained economically from improvements in the target crops (tomato and cabbage) by adopting a wide range of practices learned in FFSs, but there has also been a clear adaptation of the cabbage and tomato IPM curricula to other crops (and this includes staples and cocoa, as well as other vegetables). If farmers are focusing now on some components of IPM and neglecting others, this can be addressed by appropriate follow-up activities.

All it takes is time, and particularly facilitators with more time on the ground and able to travel around their districts. If, as seems likely, the FFS approach is adopted as the common extension methodology in Ghana (a process that has already been initiated by the central Ministry of Food and Agriculture office), resources and time will be less tautly stretched between conventional extension and participatory approaches.

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Internet Round-up

By: Tony Little, Technical Support Group to the Global IPM Facility, CABI Bioscience.

This quarter Internet Roundup virtually goes bananas. I was delighted to discover that The Consortium for International Crop Protection (CICP) <**http://ipmwww.ncsu.edu/cicp/about.html**> had already made a start for me, by compiling a list of internet IPM resources on banana, covering a wide range of banana IPM issues, including biological control at:

http://www.ippc.orst.edu/cicp/fruit/banana.html

The International Network for the Improvement of Banana and Plantain (INIBAP) at:

http://www.cgiar.org/ipgri/inibap/

is also good source of information on pest management, and is also very well linked.

The Department of Primary Industries, Queensland <**http://www.dpi.qld.gov.au/Welcome.html**> produces DPI notes giving pest management advice, and practical information on managing various pest and disease problem in a range of crops, including bananas can be found at:

http://www.dpi.qld.gov.au/dpinotes/hortic/tropfruit/h00059.html

Banana link at:

http://www.geocities.com/NapaValley/1702/

is definitely worth a visit, although it deals more with the political issues of bananas. It has a section on organic bananas, and a list of documents available on line. The Australian Banana Growers Council (ABCG) <**http://www.abgc.org.au/default.htm**> is a good site too. Details of current activities, research programmes and banana links are at:

http://www.abgc.org.au/

There is a number of project reports and summaries available online, for instance, as part of the CGIAR's Systemwide Programme for IPM <**http://www.cgiar.org/spipm/index.htm**>, the International Institute of Tropical Agriculture (IITA) is managing a project, 'Improving plantain- and banana-based systems', a summary of which is posted at:

http://www.cgiar.org/spipm/dbase/projects/iitaipd.html

DfID's Crop Protection Programme <**http://vwww.netcom.net.uk/~n/nri/cpp1.htm**> also has a summary of a project on development of nematode resistance in bananas and plantain, with further details at:

http://vwww.netcom.net.uk/~n/nri/pcpp/r6391.htm

Details of CABI Bioscience's work on adapting novel techniques for detection and characterization of fungi causing fusarium wilt and sigatoka leaf spots of banana and plantain are at:

http://www.cabi.org/bioscience/annualreport_projects_egham.htm#pdn

There are a range of on-line papers and news items dotted around. For example, Florida Entomologist <**http://www.fcla.edu/FlaEnt/**> has 'Timing and distribution of attack by the banana weevil (Coleoptera: Curculionidae) in East African highland banana (*Musa* spp.) at:

http://www.fcla.edu/FlaEnt/fe82p631.htm

There is a paper on the banana moth from Hort Digest <**http://www.hortdigest.com/archives/2-2000/default.html**> at:

http://www.hortdigest.com/archives/2-2000/bananamoth.htm

And another from Agropolis at:

http://www.agropolis.fr/actualiteevenements/lettre/spe1099gb/integraprotec.html

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Announcements

Are you producing a newsletter, holding a meeting, running an organization or rearing a natural enemy that you want other biocontrol workers to know about? Send us the details and we will announce it in BNI.

VII SICONBIOL

The VII Symposium on Biological Control (SICONBIOL) will be held in Poços de Caldas, Minas Gerais, Brazil on 3-7 June 2001. Themes for the symposium include: ecology and biological control, taxonomic identification and selection of natural enemies, attributes of a good natural enemy, improving the efficiency of natural enemies, commercial production of biological control agents, risk analysis and environmental impact evaluation in the introduction of natural enemies, quality control of natural enemies, and case studies of success in biological control. Application forms and instructions for the submission of abstracts will become available on the website:
http://www2.ufla.br/~siconbio
The deadline for submission of abstracts is likely to be 16 March 2001.

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FEROBIO Website

Brazil is virtual home to a new website, FEROBIO – a platform for the development and use of biological control and pheromones in pest control at:
http://www.ferobio.ufv.br/

The aim of this initiative is to promote interaction among researchers and private companies involved in the production and commercialization of biological products, and growers interested in the development of cooperative projects based on biological products in agriculture pest control in Brazil. It will bring together many different stakeholders to develop and conduct projects in biological pest control in its widest sense. The site covers a range of biological products, including pheromones and biopesticides, and also legislation relating to them in Brazil. The site (only in Portuguese at present) is hosted by the Universidade Federal de Viçosa and coordinated by Professor Evaldo Ferreira Vilela.

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Landcare News on the Web

Landcare Research/Manaaki Whenua, New Zealand now posts some of its newsletters on its website at:
http://www.landcare.cri.nz/information_services/publications/#news

Amongst them is 'What's New in Biological Control of Weeds?', an informative and entertaining newsletter (with three issues per year) about weed biocontrol in New Zealand, and well worth reading even if you aren't a weed biocontrol person, because it's so well written.

This issue includes an in-depth account of the programme against Californian thistle (*Cirsium arvense*) in New Zealand, and also summarizes what agents have been introduced against the weed elsewhere in the world.

There is also a new variant of the board game 'snakes and ladders', which was developed to enhance the understanding amongst stakeholders of why biological control projects succeed or fail. The game progresses through each stage in the biocontrol process, from getting started and finding suitable agents, to monitoring establishment success of the agents and evaluation of the programme. The 'snakes' and 'ladders' in this version are based on real events that happened to biological control researchers in New Zealand.

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Lost the Midwest But Going Strong!

After 5 years of providing biological control news for the US Midwest, the 'Midwest Biological Control News' has undergone a change of name and face, and re-emerged as 'Biological Control News'. It is no longer appearing in printed form, but on the Internet, and its new home is at:
http://www.entomology.wisc.edu/mbcn/mbcn.html

It is being published on an irregular basis (approximately quarterly), but readers can sign up for email notification of new issues being posted.

The paper version may have died, but the objectives remain the same: to provide practical information regarding beneficial organisms and their use in the control of pest organisms that include insects and mites, weeds, nematodes, and plant pathogens. The target audience was formerly university (state and local) and extension personnel in the midwest states of the USA. However, it is now expanding coverage to include all geographical regions and all crops and other applications of biological control in the USA.

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Water Hyacinth Newsletter Re-surfaces

The CABI Bioscience IMPECCA programme (International Mycoherbicide Programme for *Eichhornia crassipes* Control in Africa) and the Plant Protection Research Institute, South Africa (PPRI) have re-launched the IOBC water hyacinth newsletter, with funding from Danida (Danish International Development Assistance) through the Environment, Peace and Stability Facility (EPSF). *Water Hyacinth News* will appear twice a year, and will cover biological and integrated control of water hyacinth. Contributions are welcome. The first issue, published midyear, dealt principally with recent developments in Africa. The second issue is scheduled to appear in time for the October 2000 meeting in Beijing of the IOBC Global Working Group on Water Hyacinth.

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Conference Reports

Weedy Types Converge on Brazil

The III International Weed Science Congress (IWSC), held at Foz do Iguaçu, Brazil on 6-11 June 2000 was attended by 600-700 scientists. There were 53 scientific sessions and 16 specialist workshops. Of these, six were devoted to biocontrol and three to invasive weeds; in addition, one of the five all-Congress lectures had invasive weeds as the theme.

There were two sessions on classical biological control of weeds. One, chaired by L. Morin, reviewed the issues and provided an update on actual and potential classical biocontrol projects, particularly relating to pathogens, and how to create a framework for their implementation based on Australian experiences. The second session, chaired by J. Hoffmann, concentrated on 'The impacts of classical biocontrol', especially the economic as well as the ecological benefits, with biocontrol of ragweed (*Senecio jacobea*) in the USA being used as an example (15:1 benefit cost ratio). Of all the projects analysed, 25% were regarded as successful with benefit cost ratios varying from 112:1 to 2:1. The negative impacts of classical biocontrol were also addressed.

There followed sessions on 'Inundative biocontrol using fungal pathogens' (chaired by B. Auld), which involved an overview of bioherbicide research developments, with specific papers on *Striga* biocontrol, phytotoxins and formulation; and 'Promising developments in bioherbicide research' (D. Sands), which covered novel formulations to enhance efficiency and also risk analysis relating to broad spectrum pathogens. A final session was devoted to 'Synergy and the interaction of biocontrol agents with other methods' (C. Quimby), which concentrated on the integration of biological control and management systems using leafy spurge (*Euphorbia esula*) control in the USA as a model system. Earlier, a specialist session on 'Modelling biocontrol effects' (M. Smith) had included presentations on the use of models for problem solving and assessing the impact of biocontrol, as well as in the dynamics of weed populations.

Weeders in Waders

A workshop on invasive species in aquatic ecosystems held during the Congress on 6 June, was attended by approximately 25 people from institutes, universities, governmental and non-governmental agencies from countries all over the world, including Brazil, Argentina, the USA, Italy, New Zealand, the UK and South Africa. The meeting was chaired by Dr. R. Charudattan from the University of Florida, USA, and two formal presentations were given. R. Pitelli (University of Sao Paulo, Jaboticabal) discussed the impact of native aquatic plant species, in particular submerged species, on hydroelectric power generation schemes in Brazil. H. Evans (CABI Bioscience) introduced a new project to identify pathogens from water hyacinth which are native to Africa for development into a mycoherbicide. He also presented data on a recent survey trip to the Upper Amazon River in Peru which, based on the diversity of insect natural enemies collected there, appears to be the centre of origin of the weed, from where the plant radiated throughout South America initially and then to the rest of the world. However, the diversity of pathogen species was poor in this area.

These papers were followed by an informal discussion on a range of topics, which included: the role of eutrophication in a aquatic weed problems; the role of changes in hydrology in aquatic weed problems; the success of biological control of water hyacinth on Lake Victoria; the need for new natural enemy species; sometimes weeds escape their natural enemies even in their region of origin and there might be a need to introduce natural enemies from another area; and the need for better integration of biological and other control options for aquatic plant species.

While water hyacinth formed the major topic of discussion at this workshop, other aquatic were also discussed, including *Salvinia molesta, Myriophyllum aquaticum,* several submerged aquatic plants and algae.

Pathological Weeders

The Congress was preceded by the V International Bioherbicide Group (IBG) Workshop on 5-6 June. Sixteen papers were presented during this 2-day workshop, which was attended by 35-40 scientists and organized by R. Barreto (Federal University of Viçosa). Encouraging advances in weed-pathogen targeting and product development were reported, ranging from new pathogens of rice weeds in the Philippines and Vietnam, to the potential commercialization of *Fusarium tumidum* as a bioherbicide against gorse and broom in New Zealand and *Ralstonia solanacearum* against tropical soda apple in Florida, USA, to the relaunch of BioMal (under the new name Mallet) against malvaceous weeds in North America. Canada, in particular, seems to be putting considerably more resources into bioherbicide research, especially as new weed problems arise and old ones are exacerbated by herbicide resistance and changing agricultural practices (e.g. zero tillage). A further stimulus is the government policy to ban all chemical herbicides from amenity areas, public rights-of-way and forestry. At the Agriculture and Agri-Food Canada Research Centre at Saskatoon, research is focusing on trying to exploit indigenous pathogens, even for alien weeds, but collaboration is also being sought in Europe for certain weed species against which no local pathogens have been found.

Several bioherbicide projects under development were discussed including those targeting *Alternanthera philoxeroides, Amaranthus* spp., *Cyperus rotundus*, *Eichhornia crassipes* (in USA and African countries), *Matricaria perforata*, *Prosopis* spp. and *Striga hermonthica*.

Of particular interest is the on-going research of A. Watson's group at McGill University, which is developing a 'low-tech' product for use against *Striga* in Mali. Based on a strain of *Fusarium oxysporum*, chlamydospore powder formulations applied to the soil at sowing or to the seed completely inhibit weed emergence. The control strategy is geared to local needs and operates at a cottage industry level, utilizing a simple liquid fermentation process and cheap, easily available substrates such as sorghum straw. Women prepare the starter cultures in traditional cooking pots, using centrally produced primary inoculum (as gelatine capsules) to assure quality control, and then harvest, dry and store the powder. Prior to planting, the crop seeds are covered with an arabic gum-spore coating. This is being linked with a tree planting programme not only to provide arabic gum locally, but also to address the regional deforestation problem. This will give women in rural communities more socio-economic power. After further testing and refining, it is planned to transfer this technology to other countries in Africa affected by *Striga* weed.

J. Gressel (Israel) discussed some novel approaches to improve the efficacy and safety of bioherbicide agents by physiological and transgenic methods. M. Vurro (Italy) reviewed the prospects for using phytotoxins produced by fungi to improve the efficacy of bioherbicide agents through additive or synergistic effects.

The abstracts of the Congress have been published*. The next International Weed Science Congress will be held in Durban, South Africa in 2004. The next meeting of the International Bioherbicide Group will be held in 2003 in conjunction with either the International Symposium on Biological Control of Weeds in Canberra, Australia or the International Congress of Plant Pathology in Christchurch, New Zealand (to be decided).

*Anon. (2000) Abstracts of the III International Weed Science Congress, Foz do Iguaçu, Brazil, June 2000. Corvallis, OR, USA; International Weed Science Society, 301 pp. ISBN 1 891276 16 6.
Contact: International Weed Science Society, 107 Crop Science Building, Oregon State University, Corvallis, OR 97331-3002, USA.

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Challenges for Augmentative Biological Control

Understanding constraints to the adoption of augmentative biological control is a key issue in making it a success. The Indian Council of Agricultural Research (ICAR) and CAB International (CABI) Workshop on Augmentative Biocontrol, held in Bangalore from 29 June to 1 July 2000, addressed the problem by tackling a wide range of issues in depth. Discussions ranged from policy matters to details of research and production, to constraints in quality control and distribution and through to extension issues.

The workshop was funded by the Partnership Facility of CABI, organized by the Project Directorate of Biological Control (PDBC – Director, Dr S. P. Singh), jointly with CABI Bioscience, UK and was facilitated by Mans Lanting of Agriculture Man Ecology, (AME, Bangalore; AME is a bilateral programme between the governments of the Netherlands and India and works on sustainable livelihoods in the southern states). 'Macrobials' and microbials (insect and pathogen biocontrol agents, respectively) were covered and the main purpose was to assess opportunities and constraints in the development of implementation. Thus a broad spectrum of stakeholders attended including government and university research staff, government extension staff, biocontrol specialists, commercial producers and NGO and government biocontrol laboratory representatives. The workshop consisted of day and a half of presentations and nearly the same on working groups for the production of recommendations.

An overview on the Indian scenario for augmentative biocontrol was given by S. P. Singh, and covered aspects relating to selection of superior strains, economical methods of mass production and application of bioagents, quality control, storage, shipment, safety issues, registration and identification of niche markets. Overviews of the global situation for augmentation, quality control and regulations were given for macrobials by S. Murphy, and for microbials by N. Jenkins, both of CABI Bioscience. Further presentations were grouped under sessions on: augmentation within the BIPM (Bio-Intensive Pest Management) system (with models from cotton, rice and vegetables), the role of extension, quality control, registration procedures, the role of NGOs, and commercial production.

In general, apart from the sugarcane industry, uptake of augmentative biocontrol in India is patchy. There is, however, good general support and in a few areas/ crops, good demonstration (e.g. cotton in Andhra Pradesh and Gujarat; tobacco in Andhra Pradesh; and tomato and cabbage in Karnataka). The extent of uptake was found to be related to major factors such as extent of linkages (between research, extension and NGOs, for example), extent of government infrastructure, effectiveness of distribution, lack of biocontrol knowledge of farmers, and variability in the quality of products between commercial and also government producers. Attempts are now being made to address the last of these points: all the major microbials are now gazetted, and PDBC has begun to assess the quality of *Trichogramma* spp. used for the management of *Helicoverpa* in cotton. Despite these moves there is still need for methodology. Another major constraint identified was the availability of funding at the farm and village levels. Securing this for either purchase or production is frequently a problem. It was agreed that the relationships between, and importance of, all these issues is far from clear and needs further analysis.

A series of recommendations was drawn up by the working groups. These covered: policy matters; research and production (priority crops and research priorities); quality control (both general recommendations and specific ones for microbials and macrobials); industrial production (product quality, staff competence, extension and training, distribution and product availability, cost effectiveness of production, storage and shelf-life, packaging, simplification of registration regulations, the interface between research and commercialization, the government purchase system, tax exemption, health and safety in production, and patenting); and extension (production of biocontrol agents at different levels, distribution and promotional activities, hygiene, and impact assessment).

Although there is clearly much work still needed, this workshop was a landmark. Its real strength lay in the fact that it happened and that all sectors are beginning to speak with one voice. This was the first formal interaction between all the different parties involved in augmentative biocontrol in India, and the significance of this was acknowledged during the workshop.

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Proceedings

Production of Biocontrol Agents and Transgenics

Critical issues in the production of bioagents and transgenics were the subject of a brainstorming session held at PDBC (the Project Directorate of Biological Control) in Bangalore on 13 May 1999. The outcome of this meeting has now been published as a book of the same name*, and provides a thoughtful summary of important issues in this field.

S. P. Singh highlights in the Introduction the importance of mass production for biocontrol. He notes that although biocontrol has been identified as an important tool in pest management, its uptake in India is constrained by an inadequate mass production capability – although India has a far greater capability than many developed and developing countries. Singh identifies commercial production of reasonably priced bioagents as the great challenge. He argues the need for a code of conduct to help regulate the production of good quality biocontrol agents. He also highlights the importance of generating data for registration of bioagents, particularly pathogens, and identifies other constraints currently faced in culturing and mass production, shipment and marketing.

In the first paper, Chandish R. Ballal & S. P. Singh reiterate the message that progress in biological control depends on the ability to develop successful mass production systems for parasitoids and predators. They argue that the ultimate success of any programme will be dependent on the quality and performance of laboratory reared insects. They identify eight elements in insect rearing system management: objectives for the system, colony establishment, the rearing laboratory, research and development of techniques, resources, quality control, production, and supply. They provide a guide to the kinds of problems that can be encountered, and the questions that need to be answered. They stress the importance of genetic issues that should be tackled to avoid inbreeding and genetic drift. They also make the important point that host plant, host and natural enemy rearing need to be simultaneous, and look at key factors and constraints in each of these.

Next, H. Nagaraja & B. Ramesh look specifically at mass production of trichogrammatids, and discuss host culturing, the importance of the source colony, and mass culturing for field release or commercial sale. In particular, they suggest improved methods for culturing *Corcyra cephalonica* as a host for both trichogrammatids and other natural enemies. Then K. P. Jayanth discusses critical issues in mass production of insect biocontrol agents for weeds. He discusses ways of tackling problems posed by the necessity of large-scale raising of host plants. He considers redistribution of natural enemies within a specified action plan, and suggests that this could help overcome many problems of laboratory-based mass rearing, He ends by stressing the importance of monitoring results.

S. S. Hussaini tackles a wide range of issues concerning the use of entomopathogenic nematodes in biocontrol. He compares conventional and newer, molecular, methods for identification and selection of suitable nematode strains. Amongst issues in mass production, he tackles pilot scale liquid culture, the economics of product development, formulation and storage, application technology and transport.

R. D. Prasad deals with mass production of microbials. He looks for reasons for the scarcity of commercially available products, despite a preponderance of microbial biocontrol demonstrations at the laboratory level. Amongst pre-production issues, he discusses limitations in screening and strain selection, and strain improvement. He also discusses advantages and disadvantages of solid-state fermentation, and lists the advantages of liquid fermentation. He examines key factors in adopting liquid fermentation for mass production, including the post-production phase.

Finally, there are two interesting papers dealing with transgenic crops. T. M. Manjunath & Farah Deeba argue that transgenic (*Bt*) cotton could play a major role in combating *Helicoverpa armigera* in the crop in India. They look at the status of transgenic crops in other countries, and of current research in India, and point to the better suppression of the pest in transgenic crop trials. However, they say that transgenic technology has created new social and regulatory challenges, and they highlight some concerns, including those related to toxicity, cross pollination and sustainability. They discuss the benefits and safety of insect-resistant cotton, and outline measures to limit resistance development. They call for concerns to be addressed openly and debated logically. K. S. Mohan & K. C. Ravi look at factors affecting the performance of *Bt* cotton in the field. They summarize the ideal situation as proper expression of the transgene to yield a biologically active molecule in the right amount and at the right time. They argue that transgenic crops that are developed and used wisely can be very helpful, and may be essential, to world food and fibre production, agricultural sustainability and preserving the environment. However, they say that the technology is new, and for *Bt* cotton the relative importance of various factors affecting its performance is still unclear. More research and more data are called for. All these authors are confident that transgenic crops have great promise, but agree that the technology is in its infancy and much more research is needed. They also stress the importance of more openness, better information and greater education for the public to overcome what they describe as 'fear of the unknown'.

*Singh, S.P.; Ballal, C.R. (*eds*) (2000) Critical issues in production of bioagents and transgenics. Bangalore, India; PDBC, 66 pp.
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