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Farmer-participatory testing of integrated pest management options for sustainable banana production in Eastern Africa

Proceedings of the workshop on Farmer-participatory testing of IPM options for sustainable banana production in Eastern Africa, held in Seeta, Uganda, 8-9 December 2003.

G. Blomme, C. Gold and E. Karamura, editors



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The mission of the **International Network for the Improvement of Banana and Plantain** (INIBAP) is to enhance the livelihoods of small-scale Musa producers by working with partners to:

- Conserve, characterize and disseminate genetic diversity;
- Develop (by conventional and molecular methods) superior cultivars and test them with farmers;
- Develop sustainable production systems and identify opportunities for adding post-harvest value;
- Support research-and-development efforts by disseminating information and raising awareness of key issues;
- Assess regional and national needs, develop a coordinated response and encourage the adoption of promising solutions.

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Cover illustration: Kenyan farmers visiting Ugandan farmers as part of the IPM project. (photo: G. Blomme, INIBAP).

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Foreword

The project “Farmer participatory testing of banana IPM-options for sustainable banana production in Eastern Africa” was developed on the basis of an INIBAP-organized integrated pest management (IPM) workshop held in Nelspruit, South Africa in November 1998. The workshop advocated the on-farm evaluation of cost-effective IPM options in the form of “integrated packages”. The project obtained funds through the Competitive Research Facility of the DFID. IPM options were subsequently tested in benchmark sites in Kenya, Tanzania and Uganda. These benchmark sites encompass a wide variability in terms of varieties grown, disease and pest pressure, soil fertility levels, climatic factors and the socio-economic reality of the participating farmers.

The project had linkages with other ongoing initiatives in the region, particularly those with an interest in the multiplication, distribution and evaluation of improved banana varieties and the use of tissue-culture as a means of obtaining clean planting materials. The project put special emphasis on participatory methods (annual stakeholders meetings, bi-monthly farmer field days), farmer training, exchange visits and assessing the economic viability of each tested IPM option. The end-of-project workshop was conducted on 8-9 December 2003 and brought together collaborators (farmers, scientists, extension officers and NGO representatives) to discuss the results obtained during the three and a half years of the project. Presentations were made on the importance of bananas in the project regions and results/outputs of activities carried out in the framework of this project were presented. In addition, some related and highly relevant IPM work conducted in the eastern and southern Africa region was presented. Subsequent working group discussions focused on remaining gaps, and activities and partners needed for the scaling-up of the project.

Farmer-participatory testing of integrated pest management options for sustainable banana production in Eastern Africa: a chronological overview of project activities

G. Blomme[1], E. B. Karamura[1] and S. Sharrock[2]

Background

In the East African Great Lakes region, bananas provide the staple food for over 20 million people in both rural and urban areas. Annual per capita consumption of bananas reaches 660 kg in some parts of the region, which is the highest in the world (FAO, 1998). Yet, bananas are mainly produced in low-input systems on small farms and provide one of the main sources of income, as excess production is sold in urban centres through local traders. In order of importance, the groups grown in the region are: East African highland bananas (AAA-EAHB) and other brewing (AB, ABB) and cooking bananas (ABB), dessert bananas (AAA, AAB) and plantains (AAB). Most banana plots consist of highly complex cultivar mixtures. However, each of the banana groups suffers from its own pest and disease constraints. For example, banana weevils and nematodes are highly damaging to highland cooking banana and plantain production, while Fusarium wilt is the key constraint to dessert bananas and ABB and AAB brewing bananas (Sengooba, 1986; Sebasigari and Stover, 1988). Soil degradation, due to increasing pressure on the land, associated with socio-economic factors, also reduces production. A combination of these factors has been blamed for the "banana decline"; mean production in this region has dropped steadily, from 10 t/ha (1970) to 4.5 t/ha on subsistence farms (Gold *et al*., 1999; Karamura *et al*., 1999). This has had a negative effect on both food and household income security for local populations. Yet, research results in the region indicate that 30-40 t/ha can be obtained.

Between 1995 and 2005, extensive research and development activities have been undertaken in the region by the International Network for the Improvement of Banana and Plantain (INIBAP), the International Institute of Tropical Agriculture (IITA), the International Centre of Insect Physiology and Ecology (ICIPE) and the national programmes of Uganda, Tanzania and Kenya. On-station and on-farm research have suggested that cultural, botanical and biological controls, as well as host plant resistance may offer possibilities for reducing banana weevil and nematode damage levels.

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Integrated pest management (IPM) strategies offer the most suitable and efficient means by which small-scale farmers can control pests and diseases. IPM is also environmentally friendly and provides a highly desirable alternative to pesticide application in high-population density areas. In November 1998, a workshop on IPM for banana was organized in the framework of the Banana Research Network for Eastern and Southern Africa (BARNESA). This workshop was attended by African National Agricultural Research System (NARS) and International Agricultural Research Centers (IARC) scientists from both East and West Africa. During the meeting it was noted that a number of banana pest/disease management options have been developed, tested and found to be effective. The meeting also noted that, so far, these technologies have largely been applied separately and tested against single constraints. IPM "packages" using a combination of methods have yet to be developed and tried out. Such experiments are required to identify the interactive effects of the combined applied strategies in a range of diverse agro-ecological situations.

Moreover such testing must be carried out on-farm, with the full participation of farmers, in order to determine the ease of application and any problems associated with the package. The participants in the workshop therefore strongly recommended that efforts be made to carry out further adaptive research on IPM options for small-scale, resource-limited banana farmers in Africa.

An IPM project proposal was developed and funded by the UK Department for International Development (DFID). The project started in mid-2000 and was implemented by the national programs of Uganda (National Agricultural Research Organization, NARO), Kenya (Kenya Agricultural Research Institute, KARI) and Tanzania (Agricultural Research and Development Institute, ARDI), in collaboration with INIBAP and IITA, under the framework of the regional banana network, BARNESA. The project implemented a set of farmer-participatory trials to test efficacy of IPM methods under farmer conditions and focused on improving adoption rates. The BARNESA strategy included a series of stakeholder meetings for the development of both "top down" and "bottom up" participatory research trials.

The project tested IPM options in various combinations in a range of agro-ecological (varieties, diseases/pest pressure, soil fertility management levels, climatic factors) and socio-economic (farmer factors, market access, other crops, material and extension inputs) settings in benchmark sites in Kenya, Tanzania and Uganda. The farmer-participatory nature of the project also aimed to train farmers so that they could use IPM approaches in managing pests and diseases on other crops within their farming systems. The focus of the project was on improving productivity for resource-limited farmers and this was the major criterion used in selecting farmers to participate in the project.

Methodology and approaches

Selection of IPM options and establishment of on-farm trials

During the initial phase of the project, a number of stakeholder meetings were held, and as a result of these, project sites and participating farmers were identified in Uganda, Tanzania and Kenya. A total number of 108, 31 and 116 resource-poor farmers participated directly in the participatory evaluations in Uganda, Tanzania and Kenya, respectively. Baseline data was collected from each farm, consisting of information about the farm management practices, pest and disease incidence and socio-economic factors related to the household. IPM options to be tested (Table 1) were selected by the farmers in consultation with scientists and extension workers, based on the results of the baseline data collected and on initial knowledge of cost-effectiveness of the options. A detailed description of the IPM options assessed and the experimental designs of the on-farm trials can be found in the subsequent papers. The project had linkages with other on-going initiatives in the region, particularly those with an interest in the multiplication, distribution and evaluation of improved germplasm, as well as the use of tissue-culture as a means of obtaining clean planting materials.

An on-station neem (*Azadirachta indica*) seed powder experiment was established at ARDI, Tanzania and KARI, Kakamega, Kenya. These trials assessed the effects of neem seed powder on the incidence of weevils and nematodes and were established in order to obtain additional information for strengthening the on-farmobservations.

Empowerment of stakeholders

This was approached by a combination of training, dissemination of information and technology, and stakeholders meetings, farmers' field days and exchange visits.

Table 1. The options chosen at each of the field sites taking part in the farmer-participatory project on integrated pest management.

	Tanzania	Uganda	Kenya
Existing fields	Neem powder Crop sanitation	Crop sanitation *Tagetes minuta* Neem Urine/ash	Crop sanitation *Tagetes minuta* *Tithonia diversifolia* Neem Weevil trapping
New plantings	Clean planting material Weevil trapping Mulch *Tephrosia* Organic fertilizers	Clean planting material Improved varieties Fertilizers Mulch	Clean planting material Improved varieties

Training at various levels formed a keystone of the expected project impact. Within the framework of the project, a training course was conducted for field technicians and scientists, from 3 to 10 May 2001, focusing on *Musa* pests and diseases, IPM technologies, cultivar diversity, farmer participatory research methodologies, socio-economics and farming systems. The course covered broad overviews and practical training on the use of pest and disease assessment protocols. The training was provided by specialists in pest management (NARO/IITA), novel technologies for controlling pests and diseases (IITA/NARO), banana socio-economics (NARO), on-farm research (NARO) and germplasm characterization (INIBAP/NARO).

During the training course, a farm visit was organized to pay special attention to both socio-economic aspects of on-farm participatory research and to the assessment of pest and disease distribution and incidence. The course was attended by 15 trainees, comprising of extension officers, NARS research technicians, scientists, NGO representatives, curators of banana collections and representatives from other related projects (FAO Farmer Field School projects, Kagera Community Development Project (KCDP) in Tanzania). The knowledge acquired facilitated the execution of project activities and the dissemination of IPM technologies in the three project countries and beyond.

A statistical (SAS) training course was organized by IITA at the NARO Kawanda research centre on 13-28 March 2002. The analysis of on-farm experimental data was discussed in detail.

In order to effectively disseminate knowledge, extension materials were produced and translated into the main languages (Kibukusu, Kiswahili, Luganda and Runyankole) at the three benchmark sites. These extension materials were pre-tested in the benchmark sites before their large-scale distribution. The topics were discussed with all stakeholders and are as follows: description of different banana pests and diseases prevailing in East Africa; the use of neem seed powder against weevils and nematodes (processing and application); paring and hot water treatment of suckers; banana weevil trapping; the use of *Thitonia diversifolia* and *Tagetes minuta* (barriers/mulches); desuckering and crop sanitation; plant spacing; digging of the planting hole and re-filling of the planting hole; manures and compost and their application; propping and guying; and banana transportation.

Annual stakeholders meetings were held in the three countries. These meetings were well attended and served to demonstrate the increasing interest in the project, not only among participating farmers, but also the wider community. In addition, they provided an opportunity for the farmers to describe their projects and the various experiments being carried out to non-participating farmers and other members of the community.

In order to further extend the IPM philosophy, farmer field days and meetings of various types were organized. Farmers, extension officers and researchers met on a bi-monthly

basis in each country. These occasions provided a forum for scientists and technicians to interact with participating farmers, as well as allowing farmer-to-farmer exchanges of information. In Uganda and Tanzania, farmers not only interacted within the IPM project, but also with those involved in an INIBAP/BARNESA-managed banana *in situ* conservation project.

During these farmers' meetings, field days were organized in the trial plots in order to demonstrate the effect of the different IPM options available from within and beyond the benchmark sites. Encouraging non-project farmers to participate in the field days, combined with the distribution of extension materials, enhanced interactions and farmer-to-farmer transfer of IPM technologies.

In addition, Ugandan project farmers and extension officers made a visit to the NARO, Kawanda research station to see the banana collections, experimental fields and to meet collaborating scientists. Besides in-country visits and meetings, cross-border exchange visits also took place. For example, a group of Kenyan farmers, extension officers and scientists visited the Ugandan IPM benchmark site, where they received training on all aspects of banana cultivation ranging from planting to post harvest processing and marketing. In fact, Ugandan farmers, extension officers and scientists were the trainers and guides.

Finally, farmers' banana growers associations were also established at the three sites. The Lwengo Banana and Plantain Farmers' Association was established on 11 April 2001 at the Lwengo benchmark site, Masaka district in Uganda. It currently has 150 members and its goal is to improve food security and incomes through banana growing in order to eradicate poverty at both the household and community level. Similarly, the Bungoma Banana Growers Association (BUBAGRAS) established in September 2002 at the Bungoma benchmark site in Kenya, (currently with 85 registered members) has the goal of improving household food security and income by increasing banana productivity. Finally, the *Kikundi cha wakulima wa migomba cha kata Ibwer*a (KIWAMKI), established on 15 January 2003 at the Ibwera benchmark site in the Kagera region of Tanzania, with 79 members, has almost identical aims. These three associations could provide a useful channel through which to direct future activities.

Data collection

Data on plant growth, yield, agronomical practices, disease and pest damage, labour requirements and cost per IPM option were collected in the trial and control plots. Farmer evaluations of the different IPM components were also conducted. Farmers, extension officers and scientists collaborated in the data collection activities, while data analysis was carried out by both the IPM research assistants and the statisticians at NARO/IITA. Details on data collected per trial/site and data analysis can be found in the subsequent papers.

At the end of the project, a survey of all participating farmers was carried out. The survey focused on the following points: Did all the selected farmers participate to the end of the project? If not, why not? Which IPM options did the farmers believe were effective? Which options would the farmers continue to use? Which options are not acceptable and why?

Results and future needs

Results from the on-farm and on-station trials were presented at the end-of-project workshop, which was held from 8 to 9 December 2003, bringing together all collaborators (farmers, scientists, extension officers, NGO representatives) to discuss the results obtained during the three and a half years of the project.

Presentations were made on the importance of bananas in the project regions and the results/outputs of on-farm and on-station activities. The end-of-project survey carried out in the framework of the project was also presented, as well as some related and highly relevant IPM work conducted in the Eastern and Southern African (ESA) region.

Working group discussions focused on remaining gaps, activities and partners needed for future scaling-up of the project (Table 2). Detailed economic viability analysis of each option will need to be continued in order to present farmers with reliable information with regard to options and packages. The farmers will then be able to select combinations of options according to their needs and means.

Possible packages for new fields include:
Clean planting material + Host plant resistance + Cultural practices
Host plant resistance + Useful associated plants
Possible packages for existing fields include:
Cultural practices + Useful associated plants
Host plant resistance + Cultural practices + Useful associated plants

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Table 2. Overview of the actions and partners required for scaling up the project and remaining gaps to be tackled.

Options	Scaling up	Partners	Gaps
Cultural practices (Sanitation, mulching, and manure application)	•Promotion •Raising awareness •Mobilizing farmers •Farmer to farmer visits •Training extensionists •Field days •Exchange visits	•Socio-economists •CBOs and NGOs •Local leaders / policy makers •National research institutes •Extensionists •Farmer field schools •Farmers and their associations	•Detailed economic viability analysis
Cleaning planting material (Corm paring)	•Promotion and extension •Increased production •Mobilization •Production of tissue culture plants •Farmer training •Exchange visits •Farmer field schools •Field days	•Socio-economists •CBOs and NGOs •Tissue culture labs •Universiies •Local leaders / policy makers •National researchinstitutes •Extensionists •Farmers and their associations	•Detailed economic viability analysis •Farmer training in nursery/ tissue culture plantlets management
Resistant plants (Yangambi km 5, and FHIA hybrids)	•Production of tissue culture plants ·•Acquisition of germplasm •Mobilization and sensitization •Information dissemination •Establishing mother gardens	•Tissue culture labs •Socio-economists •CBOs and NGOs •International institutes- •Universities •Local leaders /policy makers •Extensionists •Farmers and their associations •Processors •Traders •Market agencies	•Detailed economic viability analysis •Palatability and acceptability •Addressing the complex nature of pest and diseases •Disease resistance of commercial cultivars •Product development •Monitoring and evaluation of performance •Additional market information
Useful associated plants (Neem, Tephrosia, and Tagetes minuta)	•Production •Promotion •Providing seedlings to farmers •Preparation of standard formulations •Training	·•Private companies •CBOs and NGOs •Socio-economists •Research centres •Universities •Local leaders •KFRI, ICRAF, ICIPE •Private sector •Farmers and their associations •Extensionists •Traditional herbalists •Regulatory bodies •Credit providers •Business consultants	•Detailed economic viability analysis •More tree nurseries needed •Availability of seed •Additional experiments with other useful associated plants

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The effect on nematodes of clean planting materials and fertilizer in Masaka district, Uganda

A. Barekye[1], W.K. Tushemereirwe[1], P. Ragama[2], E.B. Karamura[3] and G. Blomme[3]

Abstract

On-farm experiments were carried out in Lwengo sub-county, Masaka district, Uganda to investigate the effect of clean planting materials and fertilizer application on levels of nematodes and banana yields. The common cultivar 'Nakitembe' (AAA-EAHB) was used. The clean planting materials consisted of suckers, which were pared and subsequently treated with chlorpyrifos (Dursban^{Tm}) for one hour. There were three treatments per plot: 1) farmers' material (*i.e.* suckers that were not pared); 2) clean planting material; and 3) clean planting material, combined with fertilizer application. Nematode population densities and associated damage were assessed at frequent intervals and preliminary yield data were also collected. The results revealed that farmers' materials had the highest percentage of dead roots, although nematode densities were comparable with the other two treatments. Clean planting materials that had received fertilizers did not differ significantly from those without fertilizer application in terms of root damage and nematode counts. Preliminary yield data indicate that plants receiving fertilizer produced the highest bunch weight (14.0 kg), although this was not significantly different from farmers' materials (9.4 kg) or clean planting materials without fertilizer (10.7 kg).

Introduction

Baseline research conducted by the National Banana Research Programme and the International Institute of Tropical Agriculture (IITA) have identified and prioritized a number of key constraints to banana production in the banana growing areas of Uganda. These include: declining soil fertility, a complex of pests and diseases, post-harvest problems, socio-economic constraints and low genetic diversity (Gold *et al.*, 1994). In the absence of diseases, soil fertility is a major factor causing reduced banana yields (Stover, 2000). In 2000, at the beginning of the project, a survey carried out in the Masaka district revealed that farmers ranked declining soil fertility as the third most important constraint, after insect pests and weeds.

[1]NARO, Kampala, Uganda [2]IITA Kampala, Uganda [3]INIBAP-ESA, Kampala, Uganda

Several factors are responsible for the decline in soil fertility. These include over-cultivation, population/land pressure, lack of capital to purchase soil amendments and other inputs, as well as leaching of soil nutrients by excessive rains (Rubaihayo, 1991). Bwamiki *et al.* (1994) have argued that one of the factors causing declining banana yields is reduced potassium levels in the banana growing areas of Uganda. Key technologies that can address soil fertility problems include: soil erosion control measures, using organic and mineral fertilizers, and cultural treatments for improving plant growth. In this study, the soil fertility problem was addressed by focusing on the use of fertilizers for increasing banana yields, while assessing the importance of this factor.

In addition, plant parasitic nematodes can cause variable yield reductions. It has been estimated that the annual worldwide banana yield loss due to plant parasitic nematodes is 19.7% (Sasser and Freckman, 1987). More specifically, Speijer and Kajumba (1996) reported a yield reduction of up to 50% in Uganda. The consequences of nematode infestations may be manifested by stunted growth, delayed maturation, reduced bunch size, toppling (Speijer *et. al.*, 1994) or a reduction in root fresh weight (Barekye *et al.*, 2000).

Farmers continuously plant bananas either by expanding their plantations or by filling gaps, using planting materials from their own or neighbouring plots. However, these materials may be infested with pests and diseases (Speijer *et al.*, 1995). Indeed, the most important mode of spreading banana pests (nematodes and weevils) to new fields is through infested planting materials (Bridge *et al.*, 1995; Sarah, 1989; Seshu Reddy *et al.*, 1999).

A number of options exist to improve the quality of planting materials. Paring, *i.e.* the removal of roots and affected rhizome tissue, followed by hot water treatment, has been found to be effective in eliminating pests from planting materials (Seshu Reddy *et al.*, 1999). However, the techniques and costs required have limited the adoption of these procedures. Tinzaara *et al.* (2002) have developed a method of treating pared suckers (*i.e.* lateral shoots) with the chemical chlorpyrifos (Dursban^{Tm}), which was found effective in eliminating weevils and nematodes under screen-house conditions. Nevertheless, it was not clear whether this technique would be effective under farmers' conditions.

Hence, the overall objectives of this study were to investigate the effect of clean planting materials and fertilizers on pest levels and banana yields at the farm level, and to compare nematode population build-up and root necrosis between farmers' planting materials and pared and chemically treated suckers.

Materials and methods

Farmer selection

Farmers were chosen through a stratification method based on parish characteristics within the sub-county (e.g. larger parishes were assigned more farmers than smaller

parishes). Opinion leaders, extension staff, and to a lesser degree, administrators, provided information used in stratification and selection of farmers. One of the criteria used was the availability of suitable land to host the trial. The farmer was required to have at least a quarter of an acre which had not been used for banana cultivation for at least 2 years.

Farmers were requested to plant the cultivar 'Nakitembe' according to their normal practice. They did not pare the corms and only removed most of the roots before the actual planting. Farmers accessed planting materials from their own fields and if these were not enough, they obtained suckers from neighbours; planting began on 2 October 2001 using 1 m to 1.2 m tall suckers.

One month after the farmers had planted their own materials, banana suckers of the same cultivar 'Nakitembe' were collected from within the sub-county, pared and immersed in Dursban^{Tm} for 1 hour (at a rate of 15 ml of Dursban^{Tm} in 20 L of water) to remove weevils and nematodes. The clean planting materials were subsequently planted in plots without fertilizer application and in plots with fertilizer application.

Plot sizes varied from farmer to farmer depending on the land area available; nevertheless each plot had a minimum of 30 plants. Only two farmers had plots large enough to contain up to 40 plants per plot. In total, seventeen farmers participated in the trial, with each farmer having three contrasting plots.

Six months after planting, the following fertilizers were applied by researchers: Urea 46% N (38 g per mat four times a year, *i.e.* at the beginning of each rainy season and six weeks later); Tri-super phosphate 46% P_2O_5 (60 g per mat once a year) and Muriate of potash 60% KCl (43 g per mat twice a year). These fertilizer application rates are only half of the recommended doses, as it was anticipated that farmers would not apply the recommended rates because of the associated high costs.

Data collection and analysis

Nematode damage assessment was carried out at regular intervals, according to Speijer and Gold (1996). Roots were extracted from a 20 cm x 20 cm x 20 cm hole at the base of a recently flowered plant. Functional cord roots were separated from the dead cord roots and both were counted. Dead roots were considered as those that were completely shrivelled and these were expressed as the percentage of the total roots (dead and living roots).

Five roots were randomly selected from the living roots and their lengths reduced to approximately 10 cm. Each root section was split longitudinally and the proportion of the root showing necrosis, for a maximum of 20%, in each half was evaluated. The percentages for each of the five segments are then added up.

Subsequently, the five root segements were taken to the laboratory at the Kawanda Agricultural Research Institute, where they were chopped into small pieces and mixed thoroughly. A sub-sample of 5 g was taken and macerated in a kitchen blender for 15 seconds. Nematodes were extracted according to the modified Baermann funnel technique (Hooper, 1990) over a period of 24 hours. The suspension containing nematodes was transferred into vials and left to stand for about five hours, allowing the nematodes to settle out. Afterwards, the volume of the water was reduced to 25 ml, and 1 ml transferred to a microscope slide, where the nematodes were identified and the individual species quantified. Finally, the number of nematodes was extrapolated to represent counts for 100 g of roots.

For the yield data, farmers were provided with scales and requested to weigh every bunch they harvested from each of the plots. It should be noted that by the time the experiment ended, very few bunches had been harvested.

The GLM procedure (SAS Institute Inc, 1990) was used to analyse the data. Means of nematode damage indices and bunch weights were computed and separated using Tukey's studentised range test at a probability level of 5%.

Results

In the first 12 months after planting there were no dead roots in the treatment plots compared to the control plots. However, the percentage of dead roots increased to the point that after 24 months they ranged from 21.9% to 29.2% (Table 1).

The percentage of the root cortex with necrosis in clean planting materials treated with fertilizers did not differ from those that had never received the fertilizers (Table 2). Conversely, the population of *Helicotylenchus multicinctus* was consistently higher in the farmers' material than in the clean planting materials (Table 3). The exception was 18 months after planting when the populations in the clean planting materials were similar to those from the farmers' materials, in spite of the different treatments (Table 3). It appears that the addition of fertilizers may have lowered the abundances of *H. multicinctus* considerably over the entire period.

When fluctuations in nematode numbers were considered, the counts of *Pratylenchus goodeyi* were not significantly different among the treatments. *Radopholus similis* densities were only significant at the first sampling, with the farmers' material recording 761 nematodes per 100 g of roots (data not shown). Thereafter, the trends in population build up of these two nematode species were not consistent.

Table 4 shows the overall mean nematode counts of *P. goodeyi, R. similis* and *H. multicinctus* for each of the treatments. Farmers' materials had high counts of *P. goodeyi* and *R. similis*. For these two species, there were no significant differences

in nematode counts between the plots using clean planting material with and without fertilizers.

Farmers' materials and clean planting materials that had never received fertilizers had higher nematode counts of *H. multicinctus* than the clean planting materials that had received fertilizers. The clean planting materials that had never received fertilizers had four times the number of nematodes per 100 g of roots. This was not different from the counts obtained from the farmers' materials (Table 4).

Table 1. Mean percentage of dead roots (%) at four sampling times as a function of the type of planting material used.

	6 months	12 months	18 months	24 months
Farmers' material	2.3 ± 1.2 a (n=57)	2.3 ± 1.2 a (n=36)	5.0 ± 1.3 a (n=55)	29.2 ± 3.0 a (n=35)
Clean planting material	0.7 ± 0.6 a (n=59)	0.0 ± 0.0 b (n=38)	3.7 ± 1.0 a (n=60)	25.8 ± 3.1 a (n=38)
Clean planting material + fertilizer		0.0 ± 0.0 b (n=39)	3.9 ± 1.0 a (n=60)	21.9 ± 2.9 a (n=38)

Means in a column followed by the same letter are not significantly different at P<0.05 according to Tukey's studentised range test.

Table 2. Mean root necrosis (%) at four sampling times as a function of the type of planting material used.

	6 months	12 months	18 months	24 months
Farmers' material	0.3 ± 0.1 a (n=57)	0.5 ± 0.2 a (n=36)	2.9 ± 0.7 a (n=55)	0.5 ± 0.2 a (n=35)
Clean planting material	0.0 ± 0.0 a (n=59)	0.1 ± 0.0 b (n=38)	1.8 ± 0.6 a (n=60)	0.0 ± 0.0 b (n=38)
Clean planting material + fertilizer		0.0 ± 0.0 b (n=39)	1.9 ± 0.6 a (n=60)	0.1 ± 0.06 b (n=40)

Means in a column followed by the same letter are not significantly different at P<0.05 according to Tukey's studentised range test.

Table 3. Mean number of *Helicotylenchus multicinctus* per 100 g of roots at four sampling times as a function of the type of planting material used.

	6 months	12 months	18 months	24 months
Farmers' material	1821 ± 775 a (n=57)	2711 ± 848 a (n=36)	2518 ± 583 a (n=55)	1500 ± 572 a (n=35)
Clean planting material	290 ± 92 b (n=59)	1617 ± 1102 ab (n=38)	2525 ± 733 a (n=60)	239 ± 97 b (n=41)
Clean planting material + fertilizer		204 ± 107 b (n=40)	1108 ± 318 a (n=60)	163 ± 105 b (n=43)

Means in a column followed by the same letter are not significantly different at P<0.05 according to Tukey's studentised range test.

Table 4. Overall mean number per 100 g of roots of *Pratylenchus goodeyi, Radopholus similis* and *Helicotylenchus multicinctus* as a function of the type of planting material used.

	P. goodeyi	*R. similis*	*H. multicinctus*
Farmers' material	416 ± 248 a (n=183)	368 ± 124 a (n=183)	2147 ± 366 a (n=183)
Clean planting material	80 ± 21 b (n=143)	83 ± 52 b (n=143)	1175 ± 307 a (n=143)
Clean planting material + fertilizer	14 ± 13 b (n=198)	236 ± 11 ab (n=198)	277 ± 134 b (n=198)

Means in a column followed by the same letter are not significantly different at P<0.05 according to Tukey's studentised range test.

Table 5. Mean bunch weight as a function of the type of planting material used.

	Bunch weight (kg)	**n**
Farmers' material	9.8 ± 0.7 a	35
Clean planting material	10.7 ± 1.0 a	34
Clean planting material + fertilizer	14.0 ± 0.8 a	44

Means in a column followed by the same letter are not significantly different at P<0.05 according to Tukey's studentised range test.

The treatment clean planting material and fertilizer gave the highest mean bunch weight (Table 5), although the mean bunch weight from the plots that had not received fertilizer was not significantly different from the one in fertilized plots.

Discussion

Although root death is a natural process, nematodes tend to enhance the rate at which root death occurs. The low percentage of dead roots observed in the plants that had received fertilizers, could imply that fertilizers enhance new root growth or even extend root life. Increased plant vigour also increases plant tolerance to stresses such as nematode attack. The highest percentage of root cortex with necrosis was observed in the farmers' materials. These un-pared materials were initially nematode-infested. Nematode infestation results in root death, a reduction in the root system (size) and may eventually cause toppling (Speijer *et al*., 1994).

H. multicinctus has a wide host range. It exists naturally in the soil and on different plant species. This could be a possible reason why clean planting materials were re-infested with this nematode species. Farmers' materials had consistently higher nematode counts. This indicates that nematodes can be transferred from one plot to another through use of un-pared/un-treated planting materials.

Addition of fertilizers did not reduce nematode counts of other nematode species apart from *H. multicinctus*. It has been reported that improving plant nutrition increased nematode counts (Anon., 2002) and spiral nematodes were reported to have caused

heavy losses in other crops such as beans and maize despite the use of fertilizers (Kadji *et al.*, 2003). In this study, it appears that the addition of fertilizers reduced only the population of *H. multicinctus* significantly. The addition of fertilizers also reduced the proportion of dead roots. This suggests that fertilizer application favoured root growth and survival despite nematode attack. Therefore, it is possible that the use of fertilizers may make the banana plant more tolerant to nematode infestations.

Despite the low rates of fertilizer use, the addition of fertilizers led to an increase in banana yields. However, the frequency of fertilizer use on bananas is still low. What remains to be achieved is to demonstrate to farmers that there are economic returns by applying fertilizers.

This study indicates that nematode population build-up can be slowed down by using clean planting materials when establishing banana plots. As plants were only assessed over one crop cycle, for lack of resources, it is not clear at which stage nematode populations will reach damaging levels. In addition, preliminary results indicate that fertilizer application (at half of the recommended rates) increases yields in bananas. Banana yields are expected to improve with fertilizer application in the subsequent cycles. However, further research is needed to establish the long-term economic returns from fertilizer use, as well as its ability to control nematode populations over successive cropping cycles.

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Socioeconomic assessment of pest management practices in Lwengo sub-county, Uganda

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Abstract

Pests and diseases are the main constraints to banana production in Uganda. For the last three years NBRP, IITA and INIBAP have conducted on-farm research in Lwengo sub-county in southern Uganda to find appropriate technologies for controlling banana pests (specifically the banana weevil) in Uganda. Before the initiation of this research project, INIBAP carried out a baseline survey to document farmer pest management practices and the factors influencing the use of these practices. The objective of this paper is to provide a socioeconomic assessment of the banana pest management practices, based on the data obtained from the baseline and end-of-trials surveys. In the study site 70% of the farmers have access to less than 2 hectares of land. The main food and cash crop is the banana, which occupies 53% of the cultivated land. The banana weevil is the pest best known by farmers. The main sanitation practices are removal of old leaf sheaths and management of post-harvest residues (timely removal of corms and splitting of pseudostems). The high cost of inputs is the main reason for not using IPM practices. During periods of peak labour demand, most of the time is spent weeding and planting, leaving little human resources for implementing IPM practices.

Introduction

The banana is the major staple food crop in central and southern parts of Uganda. Current national production is estimated at nine million tonnes per annum, accounting for approximately 15% of the total global production. Between 1960 and the late 1980s, banana production shifted from traditional growing areas in the central region to the southwest of the country (Gold *et al.*, 1999; 2000). The decline in production in the central region was attributed to pest pressure, soil exhaustion and a number of socioeconomic factors (specifically labour), favouring some banana cultivars (mainly of the beer type), as well as the replacement by annual food crops. At the same time,

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a rapidly developing urban market demand led to an expansion of banana cultivation in the country's southwest. Food preferences and the high costs of competing cereals allowed the banana to establish itself as the primary staple in cities like Kampala and Jinja (Mugisha, 1994; Lynam, 1999). To sustain the production for meeting the growing demand, there is an urgent need to address the problems of pest and disease pressure by introducing new and viable integrated pest management (IPM) technologies.

Farmers have long recognized the banana weevil as one of the most important pests for reducing banana production in Uganda (Okech *et al*., 1999; Lamboll *et al*., 2000). Cultural controls have been recommended for managing the banana weevil since colonial times (1920s) (Okech *et al*., 1999). The cultural methods include the use of clean planting material, splitting pseudostems and corms, trapping adult weevils and compacting soil over the cut rhizomes to prevent access by ovipositing weevils.

Since the 1990s, the National Banana Research Programme (NBRP), in collaboration with the International Institute of Tropical Agriculture (IITA), has spearheaded IPM research on bananas for the control of the banana weevil. For the last three years, NBRP, IITA and the International network for the improvement of bananas and plantains (INIBAP) have conducted on-farm research, in Lwengo sub-county in southern Uganda, to find appropriate technologies for controlling banana weevil populations. The on-farm research trials included: the use of clean planting materials; dissemination of cultivars; the use of crop sanitation; investigating the effect of biorationals or reduced-risk pesticides (urine and ash) on weevils and nematodes; and the use of neem for controlling banana weevils and nematodes. Before the initiation of the trials, INIBAP carried out a baseline survey in two sites (Lwengo and Nyabubare) in order to document farmer pest management practices and the factors influencing the use of these practices.

The study was conducted to document existing IPM practices used by farmers; analyse the farmers' perceptions of IPM practices; and assess the cost effectiveness of the recommended IPM practices.

Materials and methods

The data were collected during a 2001 baseline survey in the Lwengo and Nyabubare sub-counties in southwestern Uganda and during an end-of-project survey following on-farm trials in the Lwengo sub-county. The dominant types of bananas grown in the study area are cooking East African highland bananas (EAHB-AAA), followed by beer EAHB and dessert types ('Sukali ndizi' and 'Bogoya'). A few households also produce small quantities of plantain. In terms of total food production, bananas are the most important crop grown in the area, followed by cassava, maize, beans, sweet potatoes, yams and potatoes. Bananas also lead other crops in terms of income generation. Cof-

fee was the second most important cash crop, followed by cassava, maize, groundnuts, field peas and sorghum.

The baseline survey involved 30 households from two villages in each of the two sub-counties. The households were selected using a stratified random sampling technique. Firstly, one parish was selected randomly from each sub-county. All the villages contained within it were divided into two groups based on the size of the household. One village was then selected randomly from each group.

With the help of local council officials, a list of the households in the village was obtained. The households were then divided up into three categories: upper, middle and lower socioeconomic class, using criteria defined by the farmers. The criteria used to stratify the households were defined using a combination of factors: production (mainly land, labour and capital); utilities (such as health and education, including being able to afford to send children to school); food security; assets (such as possession of a house and vehicle); and social status in the community. Farmers were randomly selected from each group. Individuals from the selected households were interviewed in relation to factors that were thought to influence the use of IPM practices and the data were collected using a structured questionnaire. Information obtained included: household characteristics, household access to resources (land, labour and capital), household objectives, production constraints, IPM practices used and the problems or constraints limiting the use of IPM practices.

Group interviews were conducted with farmers who participated in the IPM trials to assess the cost effectiveness of various practices. The interviews provided information on farmers' expectations, benefits, constraints and problems encountered during the course of the trials, as well as the factors limiting continued use of or costs incurred by adopting IPM technologies.

Data from the baseline survey were analysed using descriptive statistics while a partial budget analysis was carried out to evaluate current and alternative IPM options.

Results

Household characteristics

The households are characterized by large families with most having more than four people (Table 1). Most heads of households are men, the majority of whom reported an upper primary education. This low level of education may hinder the adoption of complicated technologies that require some skills and knowledge to interpret and implement. Land is a limiting factor to production, with most households (70%) having access to less than two hectares. Most of the land is allocated to cultivation, with bananas occupying the largest proportion.

Table 1. Household characteristics of banana farmers in Lwengo sub-county (30 households surveyed).

Household size	
1-3	6.7%
4-9	71.6%
10-12	15.0%
13-18	6.7%
Mean household size	7.2
Gender household head	
Male	82%
Female	18%
Education of household head	
None	6.6%
Lower primary	13.4%
Upper primary	65.0%
Post primary	15.0%
Land availability	
<1 ha	48.2%
1-2 ha	21.4%
>2-5 ha	23.2%
>5 ha	7.1%
Land allocation	
Total	2.0 ha
Crops	1.4 ha
Bananas pure stand	0.5 ha
Bananas mixed stand	0.3 ha
Bananas	0.8 ha

Source: Baseline survey, Lwengo sub-county, 2001.

Table 2. Banana production constraints as identified by 60 farmers in Lwengo sub-county.

Constraint	Weighted score*
Pests	145
Poor soils	95
Lack of inputs	61
Labour shortage	35
Low soil moisture levels	33
Plant diseases	30

*calculated as follws:

$$w=\sum_{i=1}^{5} f_i x_i$$

x_i=score attributed by farmers (from 1=least important to 5=most important)

f_i=number of farmers attributing a given score

Source: Baseline survey, Lwengo and Nyabubare sub-counties, 2001

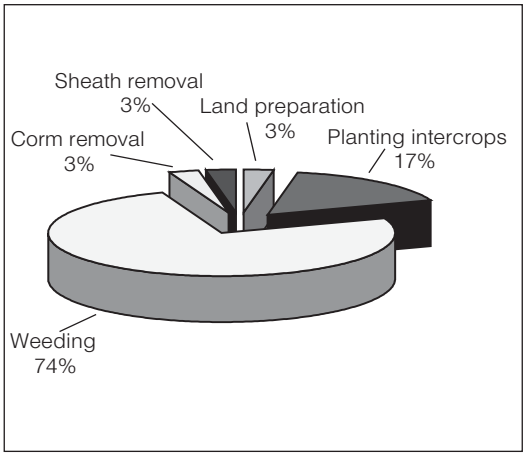

Figure 1. Allocation of work during periods of peak labour demand (30 households surveyed).

Table 3. IPM practices used in banana production by farmers in Lwengo sub-county (30 households surveyed).

	Proportion of farmers (%)
Sanitation	
Leaf sheath removal	70
Corm removal	67
Splitting pseudostems	62
Soil compaction around cut rhizomes	4
Plant nutrition	
Banana residues	63
Other crop residues	47
Grass mulch	23
Animal manure	30
Fertilizers	2
Direct methods	
Trapping	37
Biorationals	18
Clean planting material	17
Selection of vigorous suckers	13
Disease and pest tolerant cultivars	7
Chemical pesticides	5
Uprooting of infected plants	2

Source: Baseline survey, Lwengo sub-county, 2001

Households depended mainly on agriculture, followed by livestock and tree production. Trading in crops and small merchandise were the main non-farm activities. Paid work (both farm and non-farm) made a significant contribution to most households' cash income.

Production constraints

Production was constrained by a number of factors, among which pests were considered the most important (Table 2). The banana weevil was identified as the most important pest. A few farmers knew about nematodes but could not identify the damage they caused to bananas. A second important constraint was limited access to credit, which prevented farmers from using farm inputs such as grass mulch and animal manure. Only 32% of the farmers had obtained credit in the previous year prior to the interviews. Lack of access to financial institutions, high interest rates, risk aversion and high transaction costs were the main reasons cited for the limited acquisition of credit for farm production.

Farmers use a number of practices to manage banana weevils. The most common practice was crop sanitation, which included removal of old leaf sheaths and corms, splitting pseudostems and compacting soil on and around the cut corms to prevent banana weevil entry (Table 3). Some farmers also applied crop residues, grass mulch and animal manure to increase plant resistance to pests and diseases, although the main reasons for applying these inputs were to maintain fertility and moisture in the soil. A few farmers used direct methods for controlling banana weevils, with the main technique being trapping of adult weevils. Other direct methods used, in order of decreasing importance, included: biorationals (urine and ash), clean planting material, pest and disease tolerant cultivars, chemical pesticides and uprooting infested plants. Limited access to labour was the main constraint restricting sanitation practices, while low availability and the high cost of inputs reduced the use of grass mulch and animal manure (Table 4). Furthermore, use of crop residues and household waste was mainly constrained by limited access to labour and information, while chemical pesticide application was restricted not only by high costs, but by being unprofitable, as well as having harmful effects on the banana plants.

Most of the household labour was allocated to weeding, followed by sanitation, soil and water management practices. Women and children carried out most of the weeding, while men devoted more time to crop sanitation (Table 5). All three groups spent little time on soil fertility and moisture management, with children spending even less time on sanitation practices. During periods of peak labour demand, the household spent most of its time weeding, followed far behind by planting intercrops such as beans (Figure 1).

Economic analysis

The lowest cost/benefit ratio was obtained when only sanitation, with minor application of mulch and manure, was practiced (option 1) (Table 6). As shown in Table 7, sanitation requires the highest amount of labour, whereas the total cost is greatest with the application of neem.

Table 8 presents farmers' perceptions of benefits and costs of the different pest management practices. Desheathing, weeding, trapping, mulching and corm removal scored highest in terms of productivity gains. With regards to labour demand, corm removal was considered to take the largest proportion of labour, followed by weeding, and in terms of cash demand, mulching scored highest followed by corm removal.

Table 4. Limitations restricting use of pest management practices as described by farmers (30 households surveyed).

	Ranking
Sanitation practices	
Labour problems	***
Lack of information	*
Lack of equipment	*
Biorationals	
Lack of information	**
Lack of sufficient material	**
Smell of urine	**
Chemical pesticides	
Not affordable	***
Not profitable	***
Harmful to banana plants	***
Grass mulch	
Not available	***
High costs	***
Labour problems	***
Termite problems	*
Animal manure/coffee husks	
Not available	***
Not affordable	***
Crop and household residues	
Labour problems	***
Lack of information	**

*** most important, ** important, * least important
Source: Baseline survey, Lwengo sub-county 2001

Discussion

The results show that farmers depend more on land and labour than other inputs for farm production. Banana farmers practice mostly sanitation, which requires mainly labour (easily available at the farm level) and has low expenditures. However, activities that demand a lot of labour are less frequently carried out because of the need for supplementing family labour with hired labour. For example, corm removal, which requires more labour than can be provided by the family, was less frequently undertaken (once or twice a year), whereas desheathing was frequently practiced (twice in three months). Mulching and the application of animal manure were less frequently performed, and only by a few households, because of the higher expenses.

Access to cash is limited by the lack of credit markets and the nature of agricultural production; when inputs are demanded for production, the money obtained from sales has already been spent on other pressing household needs. Moreover, most households in Uganda practice rain-fed agriculture, which causes more uncertainty in terms of yield and prices obtained. Given the variations in yield and prices, farmers tend to be reluctant to invest in expensive technologies for fear of losing their money. Therefore,

Table 5. Proportion of working time (%) allocated by men, women and children to each pest management activity (30 households surveyed).

	Men	Women	Children
Weeding	27%	50%	82%
Sanitation	47%	28%	8%
Soil fertility and moisture management	26%	22%	10%

Source: Baseline survey, Lwengo and Nyabubare sub-counties, 2001

Table 6. Economic analysis of cultivating a one hectare banana field using different IPM practices given an hourly wage of 532 Ugandan shillings (1US$=1710 UgSh)

	Option 1	Option 2	Option 3
Yield (tonnes/ha)	12	16	28
Price (UgSh/tonne)	55 000	58 000	60 000
Revenues (UgSh/ha)	660 000	928 000	1 680 000
Family labour (man-hours)	548	572	677
Hired labour (man-hours)	137	143	188
Cost of hired labour (UgSh)	72 884	76 076	100 016
Cost of inputs (UgSh)	0	253 000	790 000
Total costs (UgSh)	72 884	329 076	890 016
Profits (UgSh)	587 116	598 924	789 984
Cost benefit ratio	0.12	0.55	1.13

Option 1 = Mainly sanitation
Option 2 = Sanitation + mulching
Option 3 = Sanitation + mulching + manure
Sources: Baseline survey data, Kisekka sub-county, 1998. Kisekka sub-county is neighbouring Lwengo sub-county, Masaka district. Input and output prices were based on data obtained from the end-of-project survey, Lwengo sub-county, 2003.

Table 7. Costs of various pest management practices.

	Sanitation	Neem	Urine and ash
Labour (man-hours/ha)	545	72	109
Cost of labour (UgSh/ha)	289 000	389 000	589 000
Input (kg/ha)	-	436	-
Price (UgSh/kg)	-	5 000	-
Cost of inputs (UgSh/ha)	-	1 635	-
Total costs (UgSh/ha)	**289 000**	**1 673 000**	**58 000**

Source: End-of-project survey, Lwengo sub-county, 2003.

Table 8. Relative benefits and costs of various pest management practices as perceived by farmers (32 farmers surveyed). (See Table 2 for calculation of weighted scores)

	Increased productivity (weighted scores)	Increased labour demand (weighted scores)	Increased cash demand
Sanitation			
Weeding	49	30	31
Desheathing	52	19	9
Corm removal	33	79	52
Deleafing	3	2	1
Chop pseudostems	2	13	1
Desuckering	12	8	-
Plant nutrition			
Mulching	41	68	89
Soil loosening	8	2	7
Soil bands/trenches	3	35	33
Compost manure	1	-	-
Animal manure	-	-	25
Direct methods			
Trapping	45	7	7
Biorationals	5	9	-

Source: End-of-project survey, Lwengo sub-county, 2003.

more labour is allocated to those activities that require less investment, such as weeding and crop sanitation.

Differences between the time men and women allocate to sanitation and weeding can be explained by the amount of energy required. For example, corm removal, desuckering and stump removal were carried out more often by men than women because of the strenuous nature of these practices. Gender differences caused by unequal access to information could also partly explain the distribution of work. Men tend to carry out the activities they feel they have more knowledge on, and hence avoid incurring monitoring costs for supervising others (spouses, children and hired labour) to do the same tasks. Thus, they leave women and children to do those activities they feel need minimal supervision, such as weeding and desheathing. During peak labour demand, most of the time is spent weeding and planting intercrops, thus compromising the time available for IPM activities. More labour is withdrawn from IPM activities as women are directed to annual crops, while the males concentrate on weeding.

The economic analysis suggests that the cost of implementing practices is the decisive factor influencing farmers' choices. The implication is that the practices requiring in-

vesting in material, such as neem, should be packaged in a way to reduce the cost the farmer before it is disseminated. A simple solution in this case would be for the farmers to grow their own neem trees. The only limiting factor would be obtaining the land on which to grow the trees. This leaves sanitation, weevil trapping, enhanced plant nutrition and clean planting material as the most viable IPM options for the control of banana pests and diseases in Uganda. However, since their only method of enhancing plant nutrition is the use of crop residues, which draws nutrients from other cropping systems, this practice is not sustainable. Mulching and manure application seem to be out of reach for most small-scale farmers.

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Farmer-participatory testing of integrated pest management options in western Kenya

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Abstract

A diagnostic survey carried out in 2001 at the Bungoma benchmark site in western Kenya revealed the agronomic practices performed by the farmers and the importance of pests and diseases. The nematode species, *Pratylenchus goodeyi*, was found in large numbers on all farms, while lower densities were observed for *Helicotylenchus* spp., *Meloidogyne* spp. and *Radopholus similis*. Fusarium wilt occurred mostly on the 'Apple banana' cultivar, while black leaf streak disease was observed on cooking bananas (e.g. 'Nasirembe', AAA-EAHB). Few farmers carried out cultural control practices (e.g. the use of clean planting material and desuckering). On-farm trials were then established to test various pest management practices. The application of sanitation practices and manure decreased weevil and nematode damage. The use of clean planting material (suckers that were pared and treated with hot water and of *Tagetes minuta* reduced corm damage and root necrosis, and increased yield. The three assessed Cavendish genotypes were resistant to Fusarium wilt and displayed low levels of damage caused by weevils and nematodes.

Background

Despite its importance, the banana has until recently received very little attention in research and extension activities. This has led to a severe yield decline over the past 20 years (Gold *et al.*, 1993). Pests and diseases are the major constraints to banana production (Gold *et al.*, 1993), with some of the important pests including the banana weevil, nematodes, while diseases such as Fusarium wilt and black leaf streak disease are highly damaging. Recent surveys undertaken in Kenya have shown that 80% of the 'Apple banana' and 'Gros Michel' plants are infested with Fusarium wilt (J.N. Kungu, personal communication). Yield losses due to banana weevils and nematodes have also been reported in other East African countries (Ngundo *et al.*, 1974; Bridge, 1988; Sikora *et al.*, 1988; Taylor, 1991; Gold and Bagabe, 1994) and throughout the world

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(Gowen and Queneherve, 1990). In fact, severe weevil and nematode infestations lead to stunted plant growth, delaying ratooning and plant toppling (Kashaija *et al.*, 1994). The traditional method of obtaining planting material from the existing plantation without paring or hot water-treatment also helps spread pests and diseases that reside in the planting material.

A number of workshops on integrated pest management (IPM) for the banana have been held in the region in the framework of the Banana Research Network for Eastern and Southern Africa (BARNESA). In these workshops, it was realized that there are a number of banana pest and disease management options, which have been developed and tested, but mostly tried out singly and only on one particular pest or disease. Hence, it was recommended that the options should be integrated to target the wide range of pests and diseases, and should be tried out with local farmers. The testing of these technologies should identify interactive effects, as well as being applied in a wide range of agro-ecological zones. In one of the workshops, the participants recommended that IPM options ought to be tested on the farms of resource-poor small-scale farmers.

The objective of this study was to evaluate a menu of options for the integrated management of pests and diseases at selected benchmark sites in western Kenya. In this paper, the evaluation of the IPM options is divided into five sections:

1. Assessment of pest and disease damage in relation to cultural practices.
2. Using sanitation and organic manure to curb pest damage in existing plantations.
3. The use of clean planting material and Tagetes minuta for reducing pest damage in new plantations.
4. Testing the resistance/tolerance of Cavendish varieties
5. Gender distribution of banana-related activities.

1. Assessment of pest and disease damage in relation to cultural practices

Introduction

Banana production in western Kenya is characterized by a low application of inputs. In general, most farmers do not apply inorganic fertilizers and/or perform recommended practices. Similarly, most farmers do not apply pesticides to control pests and diseases, nor do they maintain crop hygiene to reduce pest and disease incidence. Recent surveys undertaken in Kenya have shown that the incidence of diseases, such as Fusarium wilt, is as high as 80% in some areas, due to extensive cultivation of highly susceptible clones, including 'Apple banana' and 'Gros Michel' (J.N. Kungu, personal communication).

Nematodes are one of the most important banana root pests in the tropics, attacking almost all cultivars and causing root and corm necrosis, which is accelerated by other pathogens such as fungi and bacteria. The destruction of root and corm tissue reduces

water and mineral uptake, resulting in reduced plant growth and development. This leads to severe reductions in bunch weight and increases significantly the time period between two successive harvests. The most common nematodes infesting bananas include *Radopholus similis*, *Pratylenchus goodeyi*, *Helicotyenchus multicinctus* and *Meloidogyne* spp. Nematode species, occurrence, distribution and abundance are influenced by many factors including elevation (temperature), soil characteristics, cropping history, host plant cultivar and crop husbandry.

Fusarium wilt is also a major constraint to banana production in Bungoma district – especially on 'Apple banana' cultivars – and has been nicknamed *siye,* which means "it sweeps everything". Introducing tolerant varieties, such as cultivars from the Cavendish group, would help in reducing the impact of the disease. Black leaf streak disease, caused by the fungus *Mycosphaerella fijiensis*, reduces photosynthesis and leads to smaller bunches.

A diagnostic survey was carried out in 2001 in order to assess the agronomic practices performed by the farmers and the importance of pests and diseases. The Nalondo and Kanduyi divisions of the Bungoma district benchmark site in western Kenya were selected. These divisions have experienced a severe decline in banana production in recent years. In addition, sufficient land is still available for the expansion of banana plantations.

Materials and methods

Description of benchmark site

The Nalondo division is situated at 1300 to 1800 m and covers 164 km^2, with 520 people per square kilometer. It falls within the upper midland UM_3 and lower midland LM_2 agro-ecological zones. The soils are sandy clay loams and sandy clays. Rainfall is 1000 to 1600 mm per year and temperatures range between 16° to 30°C. The average landholding is five acres (two hectares) with seven to eight persons per household. The Kanduyi division is situated at 1200 to 1500 m and falls within the lower midland LM_1 and LM_3 agro-ecological zones. Annual rainfall ranges from 1200 mm to 1800 mm and the soils are sandy loams and clays. Landholdings range from two to five acres (0.8 to 2 hectares) and contain an average of eight people.

The farmers in these divisions grow mainly East African highland bananas and some introduced varieties such as 'Giant Cavendish', 'Dwarf Cavendish', 'Gros Michel', 'Kayinja', 'Apple banana', 'Mikhira kwangwe' and a sweet banana 'Uganda'. The problems facing farmers in these areas include: declining soil fertility, pests and diseases, inadequate knowledge of banana production, and lack of clean planting material, high yielding varieties and cash to purchase adequate inputs.

Baseline survey

The survey was conducted on 50 farms each having more than 20 banana mats. The damage caused by weevils and nematodes, the incidence of Fusarium wilt and black leaf streak disease, and the cultural practices applied by farmers were recorded. The data were analysed using the SPSS computer software for mean comparisons.

A simple questionnaire was used to assess the presence or absence of black leaf streak disease and Fusarium wilt diseases. A scoring system from 1 (hardly carried out) to 4 (rigorously practiced) was used to assess the cultural practices perfprmed in the plantations.

Assessment of corm damage: The assessment of damage caused by weevils was carried out on corms of recently harvested plants (<14 days after harvest). A cross-section was made at the base of the pseudostem (X) and 5 cm below the base (LX). For each cross-section, weevil damage was assessed for the central (X_i) and outer sections (X_o) of the corm using a standardized scoring system (Gold *et al.*, 1998). The total weevil damage per section (X_t) was calculated as the mean of X_i and X_o.

Assessment of root damage: To assess the damage caused by nematodes, root samples were collected from recently flowered plants. Roots were collected from a 20 cm x 20 cm x 20 cm excavation at the base of a mat. The extent of necrosis was given a score of 0 in the absence of necrosis or of 1 (20% necrosis) to 5 (100% necrosis) The percentage of necrosis was evaluated on 5 root segments that were 10 cm long each (see Barekye *et al.* in this proceedings). For nematode extraction and identification, five roots from each farm were gathered into a composite sample. Roots were washed, chopped into 1 cm pieces and thoroughly mixed. Five sub-samples of 5 g were taken and macerated in a kitchen blender for four seconds, and the resulting homogenate placed on pans.

Nematode extraction: Nematodes were then extracted over a 24-hour period using tap water. Nematode identification and counts were made from 1 ml aliquots. However, it was not always possible to sample 20 recently flowered and harvested banana plants at each of the 50 farms (Table 1).

Results and discussion

According to the survey, few of the farmers used cultural practices to manage pests and diseases. Even though most farmers carried out weeding, desuckering and detrashing (removing old leaves), these practices scored low, 2.1, 1.6 and 1.5 respectively. This suggests that farmers may not appreciate their importance and may profit from extension activities on the topic. Use of compost and of farmyard manure, and mulching also scored low at 1.7, 1.6 and 1.4, respectively. Using compost and farmyard manure is a useful practice since it adds nutrients to the soil, improves soil structure for water retention and enhances yields. Mulching, which helps to conserve moisture, also adds nutrients to the soil during decomposing.

Table 1. Number of banana mats assessed for pest damage at each of the 50 farms surveyed in Bungoma district, western Kenya.

Number of mats assessed	Number of farms	Percentage
Weevils		
5 to 10	9	18%
10 to 15	37	74%
15 to 20	4	8%
Nematodes		
5 to 8	35	70%
8 to 11	15	30%

Pseudostem removal and/or management and sanitation methods also scored low. Most of the farmers do not cut the pseudostems at ground level after harvesting even though these are known to be breeding grounds for banana weevils. This may explain the high damage levels observed. Although some farmers were cutting the pseudostems at ground level, these were not being removed or cut into small pieces allowing them to dry out quickly. Gold *et al.* (1997) reported that farms which practice sanitation have low weevil damage levels.

Most of the farmers practiced inter-cropping, which scored 1.8. Inter-cropping results in competition for nutrients between bananas and other crops. The banana is a poor competitor, and hence it is always disadvantaged (Okech *et al.*, 1998). Most of the crops inter-cropped with bananas included maize, beans, cassava and fruit trees. Interestingly, a lower incidence of weevils was reported in bananas intercropped with coffee compared to beans and maize (Gold *et al.*, 1993).

Most of the farmers do not use clean planting material, a practice which scored 1.1. Moreover, those who do are not following the proper instructions to prepare the suckers. Normally, farmers obtain planting materials from their own farm or their neighbours, a practice which tends to facilitate the spread of pests and diseases.

None of the farmers surveyed were utilizing useful associated plants, or had heard about using them to control banana pests and diseases. If introduced, these options would stand a higher chance of success since farmers were anxious to know how they could be applied.

Black leaf streak disease was mostly observed on cooking bananas. Because the fungus is spread by wind, the use of clean planting material might not help much in this case but farmers might benefit from learning about detrashing, the removal of infected leaves and the use of tolerant varieties.

Even though the damage caused by weevils affected on average less than 5% of the corm, this does not imply that it is not a problem. In some farms, the level of dam-

age reached 15%. Moreover, the infested corms that were rotten at harvest were not included in the assessment. In this study, only the corms of recently harvested mats (<14 days after harvest) were assessed.

No trapping of banana weevils was carried out and farmers were not even aware of the existence of trapping methods. Even though some farmers knew about the damage caused by banana weevils, they did not know how to identify weevils, even though damage caused by weevils was found on all surveyed farms. The data also suggest that the level of damage depends on the level of management carried out.

On most farms, the root necrosis index was 2, suggesting that nematodes could become a problem in the area. The most common nematode species in Bungoma district was *P. goodeyi*, followed by *Meloidogyne* spp. and *Helicotylenchus multcinctus* (Table 2). *R. similis* is usually common in areas below 1400 masl, while *P. goodeyi* is common above 1000 masl (Kashaija *et al.* 1994; Bridge *et al.* 1995; Fogain *et al.* 1998). This study was carried out in an area above 1400 masl, where *P. goodeyi* is the dominant species. Farmers apply mulch in some of the fields, a practice that appears to increase the numbers of *P. goodeyi* (Kashaija *et al.* 1998a), which may explain why the abundance of this species at the Bungoma benchmark sites was high, compared to other nematodes.

The results of the survey were presented and discussed at a stakeholders meeting at which the participants agreed on the options to test on-farm, as well as the criteria for selecting the farmers. It was agreed to select farms with corm damage of more than 5%, a root necrosis index of more than 2 and a high incidence of Fusarium wilt. The on-farm trials were established at the Bungoma benchmark sites on existing plantations and in newly created plantations using clean planting material.

2. Using sanitation and organic manure to reduce pest damage in existing plantations

Introduction

Weevils thrive in trashy, weedy and hence humid plantations. Weeding and the removal of all mulch within a radius of 40 cm from the mat have been advocated as

Table 2. Mean population densities of nematodes recovered from the roots of *Musa* spp. in Bungoma district, western Kenya (n=19 mats).

	Number of nematodes per 5 gram of roots
Helicotylenchus multcinctus	2.2 ± 0.5
Meloidogyne spp.	9.7 ± 2.4
Pratylenchus goodeyi	211.7 ± 40.1
Radopholus similis	0.0 ± 0.0

a good strategy for preventing weevils from approaching banana plants. Cutting the pseudostem of harvested plants and exposing it in small pieces to the sun, a sanitation method called 'cut and dry' that has been reported by Treverrow (1993), limits the number of breeding sites for weevils (Seshu Reddy *et al*., 1993) by providing egg-laying traps. Although the eggs hatch, the life cycle is interrupted when the pieces dry out and the larvae die from desiccation.

After its removal, the freshly cut corm can be used as a weevil trap. However, the use of pseudostem traps for controlling the numbers of adult weevils is controversial (INIBAP, 1988; Gowen, 1995). It has been argued that traps made of cooking banana pseudostems are more attractive to weevils than the ones made with the pseudostems of dessert banana cultivars. In addition, this trapping strategy has to be practiced by the whole community to prevent incursions of weevils from poorly managed plantations.

Desuckering, with special focus on the removal of water suckers and weeding, helps to reduce the humid environment at soil level and prevents not only weevil population build-up, but causes less intra-mat competition and as such increases bunch size.

Manure increases root and plant vigour, resulting in an increased tolerance to nematode damage. Organic manure also reduces nematode damage by raising the levels of biological control agents. This is in agreement with Obiefuna (1990) who reported that the use of poultry and farmyard manure caused a decline in nematode populations.

The objective of this study was to determine the effect of sanitation and manure on the damage caused by weevils and nematodes.

Materials and methods

The trials were implemented with 50 farmers in the Kanduyi and Nalondo divisions of Bungoma district. More than 50 mats of 'Nasirembe' (AAA-EAHB), a common cultivar that is highly susceptible to banana weevils and nematodes, were chosen at random on each farm. Each farmer had a control plot and an experimental plot replicated three times (ten mats per plot). The remaining plants were border plants. Eight mats per plot, and two plants per mat (the motherpant and one of the suckers) were sampled. Cultural practices carried out in the experimental plots included: desuckering (*i.e*. leaving only three suckers per mat), detrashing, cutting and splitting of the pseudostem immediately after harvest and weeding using a *jembe* fork. Manure was also applied twice a year at the rate of 10 tons/hectare. The control plots, one per farmer, were left for the farmers to manage.

The damage caused by weevils was assessed as in section 1 above. Banana weevil trapping was performed by using two pseudostem traps (*i.e*. split pseudostem halves of approximately 30 cm in length) per mat. The traps were made with the pseudostem of

Table 3. Effect of sanitation and manure on weevil numbers, corm damage and root necrosis (n=60 mats).

	Number of weevils per mat	LX_t (%)	X_t (%)	RNI	Dead roots (%)
Experimental plot	23.4 b	9.5 b	13.5 b	1.8 b	1.5 b
Control	28.5 a	12.6 a	18.4 a	2.2 a	2.2 a
LSD	2.0	1.8	2.2	0.8	0.22

LX_t: total damage on lower corm; X_t: total damage on upper corm; RNI: root necrosis index
Means followed by the same letter in a column are not significantly different (P<0.05) according to the Least significant difference (LSD) test

cooking banana cultivars, which are more attractive to weevils. The number of adult weevils was counted every three days, recorded and killed.

The level of damage on the corm and the root necrosis index (RNI) were assessed as in section 1 above. The numbers of functional and dead roots in the sample were counted and the percentage of dead roots calculated. The data were analyzed using the SAS statistical software package.

Results and discussion

The number of weevils, the level of damage on the lower corm (LX_t) and the upper corm (X_t), the RNI and the percentage of dead roots were significantly lower (P<0.05) in the experimental plots than in the control plots (Table 3). Weevil damage varied between farms in both the treated and control plots (Figure 1), which may due to the different levels of management practiced at the beginning of the experiment.

3. Using clean planting material and *Tagetes minuta* to reduce pest damage in new plantations

Introduction

Banana weevils and nematodes are commonly spread to new fields through infested planting material. Adult weevils only move short distances (less than 6 meters in a night). The use of clean planting material may reduce initial pest incidence and prevent rapid population build-up. Paring and hot-water treating suckers removes 99% of the weevil eggs and larvae (Gettman *et al.*, 1992; Gold *et al.*, 1998).

Tagetes minuta has been reported by Gold *et al.* (1997) to have nematicidal activities. However, combining *Tagetes minuta* and clean planting material has not been tested. The objective of this study was to determine the effects of clean planting material (pared and hot water-treated) and *Tagetes minuta* on the numbers of weevils and nematodes, and on banana yields.

Materials and methods

The trials began in November 2001 on 21 farms, with farmers selected at random using the criteria discussed during the stakeholders meeting. Sword suckers of the cultivar 'Nasirembe' were selected and all roots and outer parts of the corm were removed. These pared suckers were subsequently hot water-treated, which was carried out at 55°C. For the farmers to realize when the temperature reaches 55 °C, a metal piece was attached to a bit of wood using wax, which melts at this temperature. Hence, when this device is dropped into the water tank the wood starts floating as soon as the water temperature reaches the desired level, and at this point the heating was stopped. The pared suckers were placed in a water tank for approximately 15-20 minutes, and subsequently planted at a spacing of 3 m x 3 m. Each farmer planted 60 suckers in total. The treatments were:

paring + hot water treatment;

paring + hot water treatment + *T. minuta*;

T. minuta only.

The control plants were not pared and treated with hot water and no T. minuta was planted. Each treatment was performed on five farms, with each farm considered as a replicate.

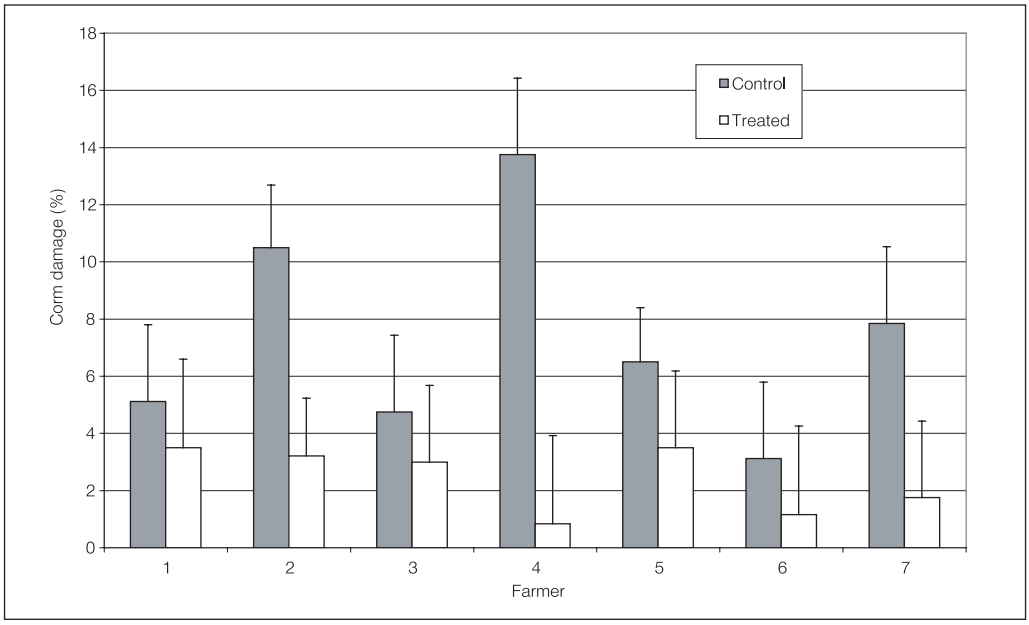

Figure 1. Effect of sanitation and manure on upper-corm damage in individual farms in Bungoma district, western Kenya. (For every farm, the values of corm damage in the experimental plots were significantly different from the ones in the control plots according to the Least significant difference test (n=50 mats).

Table 4. Effect of paring, treating with hot water, and *Tagetes minuta* on yields, weevil numbers, corm damage and root necrosis (n=50 mats).

	Bunch weight (kg)	Number of weevils per mat	LX_i (%)	X_i (%)	RNI	Dead roots (%)
T. minuta	10.0 c	14.5 a	1.2 a	1.3 a	2.5 b	10.3 b
Paring + hot water	11.5 b	6.5 b	1.0 b	1.1 b	2.8 b	9.6 b
Paring + hot water + *T. minuta*	12.5 a	5.5 b	1.1 b	1.0 b	1.2 c	8.5 b
Control	8.0 d	15.2 a	1.2 a	1.3 a	3.8 a	15.6 a
LSD	0.5	2.2	0.05	0.07	0.08	2.5

LX_i: total damage on lower corm; X_i: total damage on upper corm; RNI: root necrosis index
Means followed by the same letter in a column are not significantly different (P<0.05) according to the Least significant difference (LSD) test

Field management practices were applied as recommended and these included weeding and the application of farmyard manure (10 tons/hectare applied twice a year). Data on weevil numbers and damage, root necrosis and yields were collected 50 plants. Weevil damage was assessed using the cross section method described in section 1 above and weevil trapping was carried out using two split pseudostem traps per mat. Nematodes were assessed as described by Speijer and Gold (1996). The data were analyzed using the SAS statistical software package.

Results and discussion

The bunches were significantly larger (P<0.05) in the treated plants than in the control ones (Table 4). The number of weevil was significantly higher and the damage to the corm lower in the two treatments using clean planting material. This is because these plants had a faster rate of development and a delayed infestation by weevils.

The use of clean planting material and *T. minuta* increased yield by over 30% (Table 4). This agrees with Speijer *et al.* (1999) who reported that the use of clean planting material increased yields of highland bananas by as much as 30% to 50% during the first three cropping cycles. In Ghana, Kashaija *et al.* (1998b) noted that using nematode-free planting material increased yields by 60% during the first cycle and lengthened the lifespan of the plantation from two to more than five cropping cycles. The RNI was lower in the plots using clean planting material and *T. minuta* than in the plots with only clean planting material but the percentage of dead roots was not significantly different between the two (Table 4).

The treated plants were taller and had slightly thicker pseudostems than the control plants (Figure 2). This increased plant vigour was reflected in the yields, with those plants having the larger pseudostems producing higher yields.

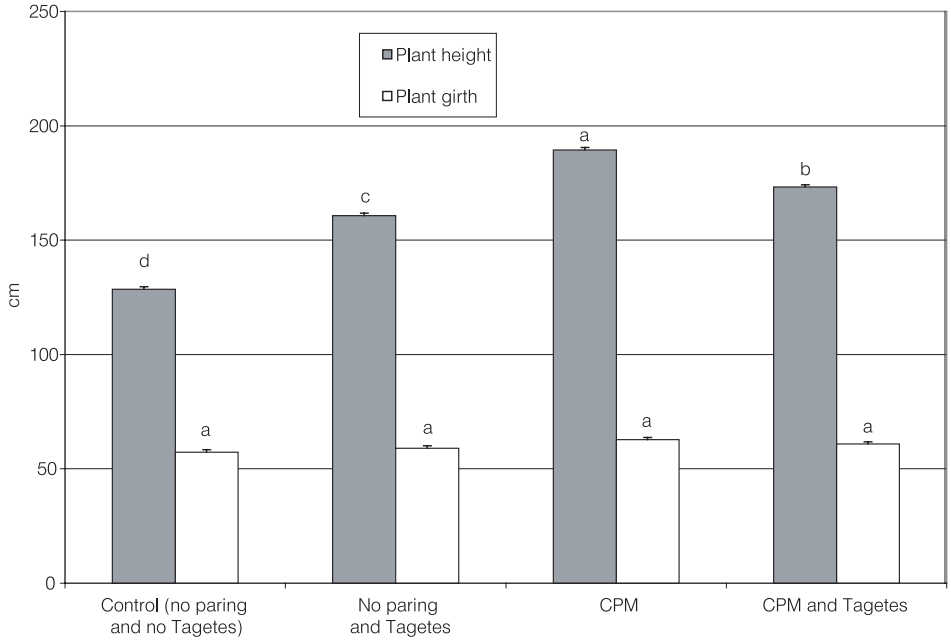

Figure 2. Effect of paring, treating with hot water, and Tagetes minuta on plant height and pseudostem girth of 'Nasirembe'. (A different letter indicates that the result is statistically significantly different according to the Least significant difference test (n=50 mats).

4. Testing the resistance/tolerance of Cavendish varieties

Introduction

A number of varieties resistant/tolerant to Fusarium wilt are available and could increase yields under local conditions, particularly in those areas hit by declining soil fertility and drought. In Kenya, the dessert bananas 'Gros Michel' and 'Apple banana' have been decimated by Fusarium wilt Race 1. As a result, Cavendish varieties, tolerant to Fusarium wilt, have been planted in banana growing areas around Nairobi, but few Cavendish varieties are currently cultivated in western Kenya.

Fusarium wilt is spread through planting materials, farm tools and erosion run-off. In addition, infestation by the root parasitic nematodes, *Radopholus similis* and *Meloidogyne incognita*, has been found to increase levels of Fusarium in a number of crops, including banana (Loos, 1959). The increased root damage facilitates the entry of fungi. Such an effect may not only lead to a breakdown in resistance to Fusarium wilt, but could also limit the effectiveness of cultural and biological controls.

The objective of this study was to evaluate the growth and yield performance of Cavendish cultivars.

Materials and methods

The trials began in November 2000 on 22 farms in the Kanduyi and Luuya divisions of Bungoma district in western Kenya. The approach used was a randomized complete block design, with each farm being a replicate. The cultivars assessed for Fusarium wilt tolerance were 'Grand naine', 'Giant Cavendish' and 'Chinese dwarf', and 'Apple banana' served as control. The planting material consisted of *in vitro*-derived plantlets. The plants were spaced at 3 m x 3 m and 10 tonnes/hectare of organic manure (filter mud or scum) were applied twice a year, starting at planting. Each farmer planted 15 plants of each variety for a total of 60 plants. Other cultural practices were implemented as recommended, *i e*. weeding, desuckering and detrashing. Data were collected on plant growth and yields, Fusarium wilt incidence, weevil damage and root necrosis.

Results and discussion

The 'Apple banana' plants were wiped out by Fusarium wilt before flowering on almost all farms. However, Fusarium wilt was not spotted on the other three cultivars. This suggests that Fusarium Race 4 is not present in the Bungoma area, since Race 4 affects the Cavendish group.

There was no significant difference ($P<0.05$) between the Cavendish cultivars with regard to the damage caused by weevils and nematodes (Table 5). Damage levels were low, which is not surprising since plantlets derived from tissue culture had been used. In addition, as plants were assessed during the motherplant crop only, the number of weevils and nematodes did not have time to build up to damaging levels. 'Chinese dwarf' produced significantly shorter plants but there was no significant difference in pseudostem girth between the cultivars (data not shown).

These Cavendish varieties, however, produce more suckers than the local cultivars, which means more time spent desuckering. Moreover, in order to sustain high yields these cultivars require fertilizers and need to be watered during the dry season.

Table 5. Effect of genotype on the level of damage caused by weevils and nematodes (n=50 mats).

	LX_i (%)	X_i (%)	RNI	Dead roots (%)
Grande naine	0.9 a	0.9 a	0.8 a	3.2 a
Giant Cavendish	1.0 a	1.0 a	0.7 a	3.0 a
Chinese dwarf	0.9 a	1.2 a	0.6 a	2.5 a
LSD	0.7	0.4	0.5	0.8

LX_i: total damage on lower corm; X_i: total damage on upper corm; RNI: root necrosis index
Means followed by the same letter in a column are not significantly different ($P<0.05$) according to the Least significant difference (LSD) test

Table 6. Gender distribution of banana-related activities (n=100).

Activity	Women	Men	Children
Field preparation	√	√	√
Digging holes		√	
Planting		√	
Weeding	√		√
Manure application	√	√√	√
Desuckering	√	√√	
Marketing	√		

5. Gender distribution of banana-related activities

Introduction

Gender plays an important role in agricultural production. Some activities are performed by either men or women alone or together. The objective of the study was to describe the gender distribution of banana-related activities in western Kenya.

Materials and methods

The study was carried out in Kanduyi and Nalondo divisions of Bungoma district in western Kenya. Farmers were interviewed using a semi-structured questionnaire. Information was collected by interviewing individual farmers and subsequently verified through group discussions.

Results and discussion

The interviews revealed that only men are responsible for planting bananas (Table 6), since they own the land. Banana is a perennial plant and as such is planted by the landowner. Preparing the planting hole is also reserved for men, whereas the whole family (women, men and children) participate in the preparation of the planting material. Weeding is carried out by women and children, manure application by all family members, and desuckering by both men and women. Interestingly, the women are in charge of marketing the bunches but the income is shared at the household level.

First impacts

Farmers' expectations from the on-farm trials were to acquire more knowledge on banana production; to increase food production and hence reduce poverty; to increase income at the household level; to be able to identify pests and diseases and learn how to control them; to be able to identify cultivars whether cooking or dessert varieties; and to recognise the type of suckers and how to plant them.

Farmers had some knowledge of banana cultivation prior to this project, but after three years participating in the project, they have acquired a range of skills, which should increase their yields in the future.

The training they received included weevil trapping, weeding, detrashing, desuckering, manure application, spacing, planting hole preparation, planting, the type of suckers to plant, paring, treating plants with hot water, data collection (plant growth characteristics and yield), identification of various pests and diseases and how to control them, preparing compost, how to use *Tithonia diversifolia* as an organic manure, how to use *T. minuta* and neem powder for controlling banana weevils and nematodes, and lastly how to make banana products such as cakes, fritters, etc. All these acquired skills can all contribute to increase household food security and income.

Because of this training, there was a significant increase in yields not only in the trial plots, but also in the benchmark site as a whole. This resulted in an increase of income at the household level. For example, Mr. Dismas Kalamu bought a sheep from his banana sales, while other farmers purchased chickens, clothes and even paid school fees. Some of the farmers are now banking 650 Kenyan shillings (1 US$=75 KSh) a month from plots containing 126 mats.

The following constraints were voiced by the farmers: lack of manure, labour or markets for their bananas, as well as limited awareness on the part of consumers of the availability of introduced varieties. Some farmers have no manure because they are poor, whereas others have no manure because they have no animals.

Thanks to the project, farmers are more willing to plant pared and hot water-treated suckers, as they observed for themselves that clean planting material enhances early maturation, reduces pest incidence and produces bigger bunches.

Cost-benefit analysis

A cost-benefit analysis, presented in Table 7, was performed based on the following assumptions: the bananas were harvested during the second year, farmyard manure was obtained from the farm, and planting materials were acquired locally free-of-charge. The yield was 15 tons/hectare at a plant density of 1000 plants/hectare. Bunches were sold at the farm gate, and calculations were based on a low but a realistic price of KSh 5/kg.

It is estimated that a net profit of KSh 24 000 could be obtained during the second year of production. However, these benefits could significantly increase during the third year, as the plantation establishment costs are absorbed. These results have to be considered in the context of a stable market situation for bananas.

Table 7. Cost-benefit analysis in Kenyan shillings of one hectare of 'Nasirembe' (AAA-EAHB) (1 US$=75 KSh)

	1st year	2nd year
Revenues (15 000 kg @ KSh 5/kg)	-	75 000
Land clearing	500	-
Land preparation	2 500	
Digging holes	10 000	-
Prepare planting material	2 000	-
Planting	5 000	5 000
Weeding	5 000	5 000
Manure application	2 000	2 000
Sanitation (desuckering, pruning, etc.)	5 000	5 000
Harvesting	-	2 000
Total costs	32 000	19 000
Balance brought forward		32 000
Profits		24 000

Some farmers (including non-project farmers) started applying technologies to other fields. The number of farmers attending the project's stakeholders meetings has risen by 20% annually, which should translate into a greater adoption of these technologies in neighbouring areas.

Conclusion and recommendations

The decline of banana production in western Kenya over the last twenty years threatens food security. Diagnostic surveys identified current plantation management practices, as well as the importance of pests and diseases, as limiting production. The results provide a baseline for future assessment of impact and effectiveness of intervention strategies.

Cultural control practices decrease the damage caused by weevils and nematodes, which should translate in higher yields. However, there is a need to continue with these trials since data were only collected over one production cycle.

The on-farm trials should continue to collect data on the ratoon crops. There is also a need to integrate the use of *T. diversifolia* into the on-farm trials to assess its effect on weevils and nematodes. The introduction of improved banana and plantain hybrids (e.g. FHIA hybrids) is also recommended. An additional useful investigation would be to analyse the roots and root exudates of *Tagetes minuta*. Finally, the use of neem seed powder for the control of weevils and nematodes should be introduced in the benchmark site.

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The effect of pest management practices on banana pests in the Kagera region of Tanzania

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Abstract

Thirty-one farmers from Ibwera village, in Tanzania tested integrated pest management (IPM) technologies in existing banana fields and in newly established fields over two crop cycles. The use of neem seed powder significant increased yield and reduced damage to the corm, as well as being highly acceptable to the farmers. However, neem tree planting *in situ* needs to be developed in order to lower the high transport costs currently associated with this option. Sanitation also had a significant positive effect on yield. In contrast, the application of mulch and the establishment of a barrier did not increase yields. Additional data from several ratoon cycles are needed to fully assess their potential effects. An economic viability analysis suggests that the positive effects of IPM options on yields may be offset by their associated costs. It is concluded that large numbers of farmers have to apply the IPM options simultaneously to prevent incursions of weevils from neighbouring farms.

Introduction

East African highland bananas (AAA-EAHB) are the most important staple crop in the Kagera region of Tanzania. However, yield declines in recent years have led to its replacement by annual food crops or more hardy brewing and dessert bananas (Mbwana and Rukazambuga, 1999). These declines have been attributed in large part to high numbers of banana weevils (*Cosmopolites sordidus* Germar) and nematodes (especially *Radopholus similis* Thorne and Cobb).

Integrated pest management (IPM) strategies for the control of banana weevils and nematodes include the use of habitat management (*i.e.* cultural control and useful associated plants), biological and microbial control, and host plant resistance (Gold *et al.*, 2001). During recent years, much progress has been made in research on banana pests in Tanzania, Uganda and Kenya, but limited impact has been made at the farm level. Habitat management options for the control of banana weevils and nematodes

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include the use of clean planting material, weevil trapping, sanitation (*i.e.* removal/destruction of crop residues), neem seed powder application and the establishment of nematode/insect repellent plants. These options are readily available for testing on-farm and, indeed, some banana growers in the region already apply cultural control methods (Ssenyonga *et al.*, 1999). In contrast, biological control options and resistant cooking bananas are long-term strategies that are not yet ready for delivery to farmers. However, some resistant landraces and hybrids belonging to other *Musa* spp. groups are being distributed to farmers in the Great Lakes region of East Africa.

The objective of this study was to evaluate existing IPM technologies (*i.e.* habitat management options) on-farm at a benchmark site in the Kagera region of Tanzania.

Materials and methods

The research was conducted in Ibwera village, Bukoba district, Tanzania. The Ibwera benchmark site lies between 1190 and 1325 m. Mean annual rainfall is 2000 mm, with a bimodal distribution. Farmers grow a mixture of East African highland banana cultivars along with introduced banana genotypes (e.g. 'Gros Michel', 'Pisang awak', 'Bluggoe', 'Ney poovan' and the recently introduced FHIA hybrids). Other important crops at the site are coffee, cassava, sweet potatoes, beans and maize. Banana productivity at the site has been declining in recent years due to pests and diseases, soil degradation, labour shortage and an inefficient plantation management (e.g. infrequent weeding).

At the onset of the research activities, a baseline survey was conducted on 50 farms in order to characterize management practices, as well as pest and disease incidence. Weevil damage was assessed on corm cross sections using the methods described in Gold *et al.* (1994), while nematode damage was evaluated using the root necrosis index method (Speijer and Gold, 1996). Minimum damage thresholds for farm selection were set at scores of at least 5% for the damage caused by weevils and root necrosis indices of at least 2 (*i.e.* 30% to 40% necrosis). Using these criteria, 31 farms were selected for the study.

The baseline survey was followed by a stakeholders meeting at which results from the baseline study were discussed and IPM options for on-farm testing were agreed upon. Participants identified banana weevil, plant toppling and low soil fertility as their primary banana production constraints. Participants also concluded that crop sanitation (*i.e.* removal/destruction of banana residues) was not practiced a lot. In addition, farmers appeared to be discouraged from using cultural control practices because they felt that any positive benefits might be offset by weevils entering their plantations from neighbouring farms where weevil control methods were not being implemented. Farmers in the Kagera region are especially reluctant to use chemical controls for banana pests, so they welcomed the testing of alternative options. All stakeholders agreed to

Table 1. Limonoid contents of neem seeds from Shinyanga, Tanzania.

Sample	Azadirachtin (mg/g)	Nimbin (mg/g)	Salanin (mg/g)
Neem oil	0.0083	0.773	0.321
Neem cake	0.681	1.807	0.676

Source: International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya

test neem seed powder and crop sanitation in existing banana plantations, while the use of clean planting material and the establishment of barrier crops to prevent the immigration of weevils from neighbouring fields were advocated for testing in new plantations. The IPM options were tested on established banana plantations, new banana plantations and on-station.

IPM options tested in established banana plantations

Neem seed powder

Neem seeds were obtained from trees in the Shinyanga region of Tanzania. The limoinoid contents of the neem seed powder and the neem oil produced from these seeds were determined at the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya (Table 1). From these data, it was determined that applications of 60 g of neem seed powder per mat would be an appropriate application level in on-farm studies (Musabyimana, 1999; A. Hassanali, pers. comm.). Five farms were selected for this study. Farmers were given 4 kg of neem seeds and were shown how to crush the seeds using hand mortars. The production of neem seed powder was carried out under the supervision of researchers and/or cooperating extension officers. In order to easily measure 60 g of neem powder, farmers were given a matchbox which could contain approximately 20 g of neem seed powder. Farmers were then asked to apply three matchboxes filled with the powder to each of the 60 banana mats that had been randomly selected by researchers. Applications were made to the same mats every three months for a period of three years. Banana mats growing in the same plots but not receiving neem powder applications were used as controls. These plants were subsequently selected and marked.

Data collection started three months after the first application. It was assumed that this period was sufficient for the treatment to start having an effect on the banana weevil populations and levels of damage. Four types of data were collected.

Assessment of weevil-associated damage. This was assessed in cross-sections made at the base of the pseudostem and through the corm 5 cm below the base. For each cross-section, weevil damage was assessed for inner (*i.e.* central cylinder) and outer (*i.e.* cortex) sections of the corm using a standardized scoring system from 0% to 100%.

Assessment of nematode-associated damage. This was evaluated using the root necrosis index method (Speijer and Gold 1996). Roots were collected from a 20 cm x 20 cm x 20 cm sample of soil dug out at the base of a recently flowered banana plant. All cord roots obtained from the sample were counted. Dead roots were separated from live roots. Five randomly selected live roots were split into halves and the root necrosis was assessed using a scale of 1 to 5.

Weevil trapping. Split banana pseudostem traps of approximately one foot in length were positioned next to banana mats. Old pseudostem traps were replaced with new ones at monthly intervals. Three days after the placement of the new traps, trapped weevils were collected, recorded and killed.

Yield data. Mat number and bunch weight were recorded by farmers and researchers. In existing banana plots, all genotypes belonged to the AAA-EAHB group. Bunch weight was recorded irrespective of the cultivar. Farmers used weighing balances with a precision of 1.0 kg.

Crop sanitation

Five farms were selected for this study. Results from the baseline study indicated that farmers carry out seasonal sanitation practices (*i.e.* twice a year during the onset of the rains while preparing for the planting of annual crops). However, under this experiment, farmers carried out regular detrashing and desuckering, while the pseudostems were removed after harvest. In addition, the pseudostems were chopped into small pieces and all banana crop residues were used as mulch. The same data were collected as above.

Neem seed powder and crop sanitation

Five farms were selected for this study. Sixty mats were selected per farm for both neem seed powder application and sanitation. The same data were collected as in experiment 1.

IPM options tested in new banana plantations

Barrier crop and mulch

In this experiment there were four treatments and four farms per treatment. 'Nshansha' (AAA-EAHB), a common cooking cultivar at the benchmark site, was used. The following treatments were applied: (1) barrier crop planted between new and old plantations; (2) mulch application in new plantations, (3) combinations of barrier crop and mulch; (4) control, which consisted of newly planted banana stands without a barrier crop or mulch. Although the practice of mulching is known to favour weevil population build-up, farmers insisted on using this practice as they believe it increases banana production. In all treatments, 30 banana mats were planted adjacent to an existing banana plantation, which

served as a source of banana weevils. Farmers planted a single line of *Tephrosia vogelii* as a barrier between the new banana plot and the weevil-infested plantation.

The suckers were pared and treated with hot water before planting. The *Tephrosia* barrier was planted during the preparation of the new banana plantation to surround the plot. The common thatch grass (*Hyparrhenia rufa*), available close to the farms, was used as mulch. Mulched fields were monitored to ensure that new mulch was applied when the old mulch had decayed/disappeared. Banana weevil data were collected as in experiment 1.

IPM options tested at the ARDI research station

Neem seed powder

The effects of neem seed powder on banana weevils and nematodes were studied in an on-station trial at ARDI Maruku. On-station experimentation offers more uniform conditions compared to on-farm trials and may give additional information. The treatments included: (1) dry neem kernel powder; (2) immersed neem kernel powder (1 kilogram of neem powder to 1 liter of water) and (3) control (no application). The banana plants were planted in a randomized complete block design with four replicates. There were border rows of banana plants in between the plots. Each plot/replicate contained four plants at a spacing of 3 m x 3 m. Maiden suckers of 'Nyoya' (AAA-EAHB) were collected from existing trials at ARDI Maruku and from nearby farms. These suckers were pared in order to reduce, but not eliminate, weevil/nematode infestation. Farmyard manure (55 tons per hectare) was applied to the planting holes. Plot management consisted of conventional practices including weeding, desuckering, detrashing and propping. Banana crop residues were used as mulch. Three months after planting, ten adult banana weevils of unknown age were released at the base of each mat in order to augment the existing weevil population. The same data were collected as for experiment 1.

End-of-project survey

After three years, a group discussion was organized with farmers involved in the IPM project and 50 farmers who had not participated in the project were surveyed. The end-of-project questionnaire focused on the cultural practices applied in banana fields. Because some of farmers interviewed during the baseline survey had participated in the project, 50 non-participating farmers were randomly selected. These farmers were asked to explain about their farm activities in the past three years (before the start of the IPM project) and their current activities. The results of the baseline survey results are included to show the situation at the beginning.

Cost-benefit analysis

Additional cost-benefit analyses were carried out to strengthen the recommendations made to farmers. The following data were used: yield data from the different IPM tri-

Table 2. The effect of neem seed powder, sanitation and their combination on bunch weight, weevil population numbers, weevil corm damage and nematode root damage (n=300).

	Bunch weight (kg)	Number of weevils per mat	Xi (%)	Xt (%)	RNI
Neem	24.3 a	22.7 a	7.1 c	8.9 c	2.0 b
Sanitation	18.6 c	21.4 a	11.5 a	16.8 a	2.5 a
Neem and sanitation	21.5 b	19.2 b	8.6 b	9.9 b	2.2 ab
Control	10.5 d	22.3 a	11.9 a	14.9 ab	2.4 a
LSD	1.5	1.5	0.8	0.9	0.3

Means in columns followed by the same letter are not significantly (P > 0.05) different by pair-wise comparison t-test of least square means.
Xl: corm central cylinder damage; Xt: total corm damage; RNI: root necrosis index

Table 3. The effect of mulch and barriers on bunch weight, weevil population numbers, weevil corm damage and root necrosis index (n=30)

	Bunch weight (kg)	Number of weevils per mat	Xi (%)	Xt (%)	RNI
Barrier and mulch	13.0 a	11.9 a	0.7 b	0.9 b	0.7 b
Mulch alone	13.9 a	13.2 a	1.1 a	1.0 a	1.1 a
Barrier alone	12.7 a	10.8 a	0.7 b	0.8 b	0.8 b
Control	14.1 a	11.3 a	1.1 a	1.2 a	0.8 b
LSD	0.19	0.47	0.05	0.05	0.06

Means in columns followed by the same letter are not significantly (P > 0.05) different by pair-wise comparison t-test of least square means
Xi: corm central cylinder damage; Xt: total corm damage; RNI: root necrosis index

als, current market price of banana, costs of the different practices (e.g. neem seeds, mulch, *Tephrosia* seeds, sanitation, etc.). The calculations were made for a hectare of bananas (*i.e.* 1100 plants per hectare at a spacing of 3 m x 3 m). The recorded yields were adjusted downwards by 5% to remove some of the factors that could have resulted in exceptionally high bunch weights recorded on the project farms. The initial cost for the establishment of a banana plantation was left out of the cost-benefit analysis as this investment is similar regardless of the IPM options used later on.

Results and discussion

IPM options tested in existing banana plots

All treatments resulted in significantly bigger bunches compared to the control plots (Table 2). There lowest values of damage to the corm and root necrosis index (RNI) were observed in the neem seed powder treated plots, even though the number of adult banana weevils in these plots was not significantly different from the one in the control plots and the plots where sanitation had been carried out (Table 2). Only the combination of neem powder and sanitation significantly decreased the number of adult banana weevils caught in the traps.

IPM options tested in newly established banana plots

The options of using mulch, a *Tephrosia* barrier and the combination of mulch and barrier did not have a significant effect on bunch weight (Table 3). Similarly, none of the IPM options significantly reduced the number of weevils. None of the treatments significantly reduced the root necrosis index. This could be due to the hot water treatment of the suckers which resulted in lower nematode densities. The use of only a barrier, and the combination of a barrier and mulch significantly reduced the total cross-section damage to the corm. Mulch alone was not effective in reducing the damage made by the weevils.

IPM options tested at the ARDI station

In the on-station trial, corm damage was lower in the treated plots than in the control plots (Figure 1).

End-of-project survey

In the end-of-project survey, it was noted that all the participating farmers were using farmyard manure in their banana plots. In addition, farmers had started buying more neem seedlings, while all the participating farmers were trying out several useful associated IPM practices to control banana weevils and nematodes. The results of the survey and group discussion are presented in Table 4.

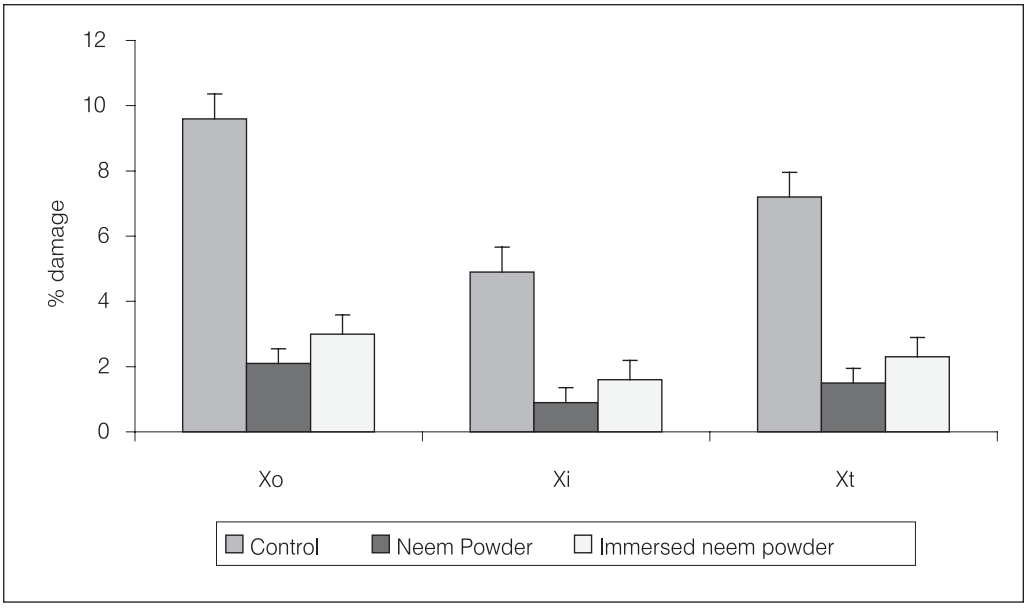

Figure 1. The effect of neem seed powder on corm damage assessed in an on-station trial (Xo: corm cortex damage; Xi: corm central cylinder damage; Xt: total corm damage).

When asked the 50 non-participating farmers were asked their source of information on banana IPM practices, it was revealed that 18 of the farmers had been informed by participants to the IPM project, 21 from neighbours not participating in the IPM project, and that 11 had acquired the information from leaflets and posters or during the stakeholder meetings.

Table 4. Results of the baseline survey conducted on 50 farms before the start of the project and of the end-of-project survey conducted on 50 non-participating farms.

Practice	Baseline survey	End-of-project survey	
		Retrospective	Current
Weeding	50	49	50
Mulching	40	45	50
Desuckering	49	49	50
Detrashing	48	49	50
Many intercrops with bananas	50	50	40
Immediate removal of pseudostem after harvesting	6	8	28
Use of clean planting materials	2	2	18
Use of useful associated plants	0	0	22
Use of compost	7	6	22
Trapping banana weevils	4	7	21

Table 5. Economic viability of the treatments in Tanzanian Shillings (1 US$=1120 TzSh) in a one-hectare plot of 1100 plants spaced at 3 m x 3 m.

	Neem	Sanitation	Neem + sanitation	Tephrosia	Mulch	Tephrosia + Mulch	Control
Mean bunch weight (kg)	24.3	18.6	21.5	12.7	13.9	13	10
Adjusted weight (5% less)	23.1	17.6	20.4	12.1	13.2	12.4	9.5
Adjusted yield per hectare	25 352	19 406	22 478	13 272	14 526	13 585	10 450
Price/kg (TzSh)	50	50	50	50	50	50	50
Revenue	**1 267 585**	**970 283**	**1 123 898**	**663 575**	**726 275**	**679 250**	**522 500**
Cost of neem	364 000		564 000				
Neem processing	10 000		10 000				
Neem application	5 000		5 000				
Weeding	50 000	100 000	100 000	50 000	25 000	25 000	50 000
Cost of mulch					100 000	100 000	
Mulching					10 000	10 000	
Detrashing	10 000	20 000	20 000	10 000	10 000	10 000	10 000
Desuckering	10 000	20 000	20 000	10 000	10 000	10 000	10 000
Cut of pseudostem	10 000	20 000	20 000	10 000	10 000	10 000	10 000
Remove corms	10 000	20 000	20 000	10 000	10 000	10 000	10 000
Cost of Tephrosia				5 000		5 000	
Planting of Tephrosia				5 000		5 000	
Total cost	**469 000**	**180 000**	**759 000**	**100 000**	**175 000**	**185 000**	**90 000**
Net benefit	**798 585**	**790 283**	**364 898**	**563 575**	**551 275**	**494 250**	**432 500**

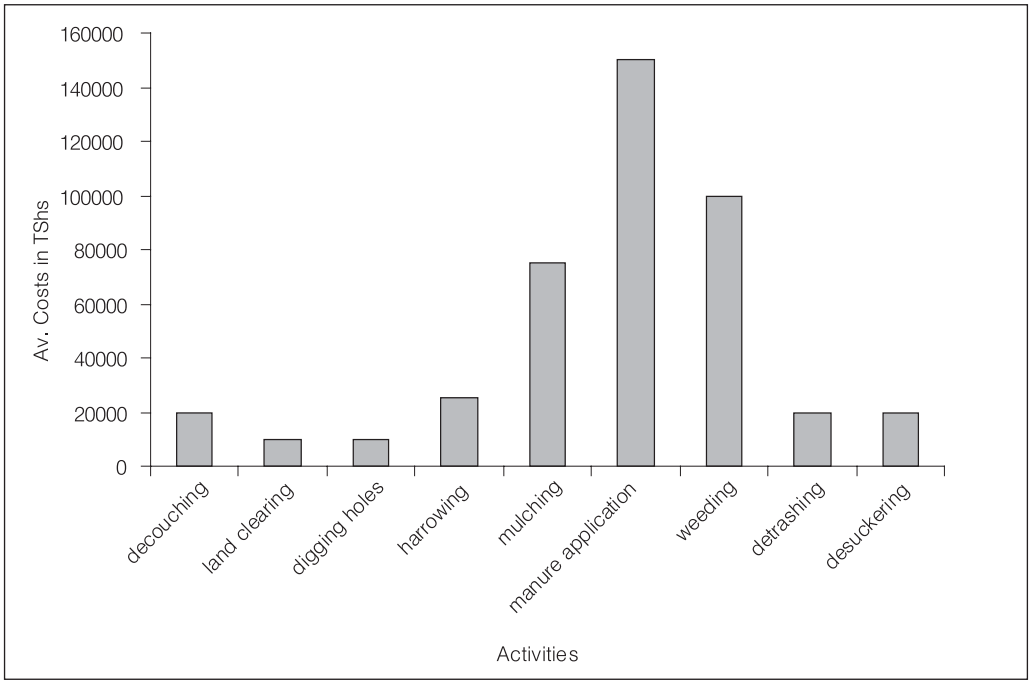

Figure 2. The average annual cost, in Tanzanian Shillings, of various cultural practices applied on a one hectare plot (1 US$=1120 TzSh)

Cost-benefit analysis

Cost of establishing one hectare of banana plants at 3 m x 3 m

Buying farmyard manure from an external source (if no animals are present on the farm) and transporting it to the farm was seen as the highest cost during the establishment and subsequent maintenance of a banana plantation (Figure 2). This was followed by weeding and mulching which are carried out at regular intervals during the year. The costs of decouching (*i.e.* removal of cough grass *Digitaria* spp.), land clearing, harrowing and preparing the planting holes are one-time costs incurred at the onset of the plantation. Finally, detrashing and desuckering have relatively low costs, and can be carried out simultaneously and at regular intervals during the year.

A detailed economic viability analysis of the potentially applicable IPM options is presented in Table 5. The calculations were carried out for one hectare of bananas (*i.e.* 1100 plants at a spacing of 3 m x 3 m). The application of neem seed powder and the planting of barriers demand a minimal input of labour. This is in contrast with sanitation (detrashing and desuckering), and especially mulching and weeding, which are very labour intensive.

The single and effective application of neem seed powder resulted in the highest net benefit, followed by sanitation, but the costs of neem were much higher than the ones for sani-

tation. Combining neem seed powder and sanitation increased the total costs, resulting in the lowest net benefit. As the neem seeds were obtained from a distant location, this option was also associated with high transport costs. Hence, it is assumed that this expense will significantly reduce once neem trees are established on the farms. Farmers have already started planting neem trees and this could be further stimulated with the help of local NGOs and CBOs operating in the Kagera region.

Sanitation also has a significant positive effect on yield. In contrast, the application of mulch and the establishment of a barrier did not enhance yields. Additional data from several ratoon cycles are however needed in order to fully assess their potential effects. The economic viability analysis indicates that the positive effects of IPM options on yield may be offset by their associated costs. It is also important that a large number of farmers apply the IPM options simultaneouslyto prevent the incursion of weevils from neighbouring farms.

Acknowledgements

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Effect of cultural practices, biorationals and neem on the banana weevil, *Cosmopolites sordidus* (Germar), and nematodes in Masaka District, Uganda

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Abstract

On-farm experiments were conducted in the Masaka District, Uganda to evaluate the effect of using cultural practices (sanitation, biorationals and neem extracts) for controlling banana weevil and nematode populations. Depending on the agronomic practices employed, such as banana residue management, participating farmers were classified into categories of low, moderate and high sanitation level. The effect of these sanitation practices on weevil damage was monitored. In another set of experiments, the effect of applying urine, ash or a mixture of biorationals on weevil and nematode populations and damage was recorded. Similarly, the effect of using neem cake for controlling weevils and nematodes was tested by the farmers. Our data demonstrate that there was a steady decline of weevil damage in banana fields in which the level of sanitation changed from low to moderate and/or high. However, biorationals showed only a limited effect on weevil damage and nematode numbers, and the application of 100g/mat of neem cake did not significantly reduce weevil and nematode damage. Further evaluation with farmers would be required before this practice can be recommended for use among the integrated pest management options.

Introduction

The banana weevil, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae), is one of the major constraints to banana production, especially for small-scale farming (Gold *et al*., 1999a; 2001). This species of weevil has been implicated (in conjonction with low soil fertility, nematodes and diseases) in the decline of banana productivity in many parts of Uganda (Gold *et al.,* 1999a). The female deposits eggs singly at the base of the banana plants at the low rate of 1-4 eggs/week (Abera *et al*., 2000). After hatching, the larvae tunnel into the corm and pseudostem of the plant causing stunting, delayed maturation, reduced bunch size, snapping and sometimes premature death of the affected plants (Rukazambuga, 1996). Therefore, this pest can cause high yield loss and shortened plantation life span if not controlled (Rukazambuga *et al.,* 1998).

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Adult *C. sordidus* are nocturnally active. They crawl over short distances, but may be sedentary for extended periods (Gold *et al.*, 2001). They favour crop residues and wet environments, including rotting pseudostems, damaged corms and moist discarded organic matter (Gold *et al.*, 2001; Treverrow *et al.,* 1992). Adults are also closely associated with the banana mat, being found mainly in the leaf sheath, around the roots, under loose fibres surrounding the base of the plant and sometimes in larval galleries (Treverrow *et al.*, 1992; Gold *et al.,* 2001). Management of banana residues is widely believed to suppress weevil populations and lead to reduced damage (Masanza, 2003).

Control options currently available to Ugandan farmers include pesticides and cultural methods (Gold, 1998). Chemical control is regarded by farmers as easy to manage, fast acting and effective (Gold *et al.,* 1993), but costly, and hence only available to wealthier farmers. Additionally, weevil resistance to these chemicals has recently been reported in Uganda (Gold *et al.*, 1999b) and elsewhere (Collins *et al.,* 1991). Consequently, some farmers use cultural practices, such as sanitation and trapping, to control weevil, but the effectiveness of these methods has received limited evaluation (Gold, 1998; Masanza, 2003). In spite of a large number of farmers being aware of these practices, implementing their wide-scale adoption has been difficult.

Utilization of biorational insecticides by farmers, including waste material extracts such as tobacco trash, wood ash, pepper and urine, has been recorded for banana weevil control (Ssennyonga *et al.,* 1999). Research has indicated that biorationals may suppress insect pest populations by affecting their orientation and reproductive behaviour (Liu and Stansly, 1995; Mostafa *et al.*, 1996). For example, some biorationals have been tested against storage beetles, *Callosobruchus chinensis* (Khaire *et al.*, 1992), and have shown a potential for reducing pests through repellence and oviposition deterrence. Pot experiments conducted in Uganda indicate that a mixture of ash, urine, pepper and tobacco are more repellent, and are better at suppressing weevil oviposition, than when used the biorationals were used singly (Tinzaara *et al.*, 2002). Nevertheless, though some Ugandan banana farmers do apply various materials for weevil control, there is no scientific data to support these practices.

The potential of using neem extracts for banana weevil and nematode management has been demonstrated in Kenya (Musabyimana, 1999; Musabyimana *et al.*, 2001). Application of powdered neem cake at 80-100 g/mat at four monthly intervals not only reduced banana weevil damage, but also significantly increased plant biomass and fruit yield, leading to the production of healthy and vigorous suckers. Hence, there is a need to validate the effect of neem extracts in farmers' fields in Uganda, as such studies will be useful in developing integrated pest management (IPM) packages.

Plant parasitic nematodes similarly cause great losses in productivity. In Uganda, Speijer and Kajumba (1996) reported a yield reduction of up to 50%, which was manifested by stunted growth, delayed maturation, reduced bunch size and toppling (Speijer *et al.*, 1994). A number of options are available for nematode control, including the use of break crops, chemicals, clean planting materials and flooding to suffocate nematodes. Most of these practices are not carried because farmers either cannot afford them or have limited knowledge on how to apply them. In a baseline survey carried out in Masaka (Ssennyonga *et al.*, 1999), farmers mentioned that they were using ash, pepper, tobacco, urine and other weeds for controlling banana weevils and nematodes. An earlier study (Gold *et al.*, 1993) also revealed that farmers were using biorationals to control weevils and nematodes. But as with the other control methods, researchers have no scientific evidence for the effectiveness of biorationals.

The objectives of this study were to determine the effect of using (i) sanitation practices on weevil damage and (ii) biorationals and neem extracts (neem cake) on weevil and nematode populations and damage.

Materials and methods

The study was conducted in Lwengo sub-county, Masaka district, 32 km southwest of the town of Masaka and between 1200-1300 m above sea level. Masaka district has two rainy seasons (March to May and September to December) with a mean annual rainfall of 1300 mm. *Cosmopolites sordidus* damage at the site is moderate (c.f. Gold *et al.*, 1994), while pest status on individual farms varies from very light to heavy.

Experiment 1: Effect of sanitation practices on weevil damage

The experiment was conducted in selected banana fields of different parishes to determine the effect of variable sanitation levels on weevil damage. The aim was to determine whether changing from low to moderate, and eventually to a high sanitation level, proportionally reduced pest damage.

The experiment started in May 2002 with the collection of baseline data on weevil damage on 100 farms with different sanitation levels. Farmers were then categorized according to level of sanitation they practiced (low, moderate and high). Their management levels agreed with the classification in Masanza (2003) (Table 1). Baseline data collection also aided the selection of participating farmers, which besides weevil damage levels, was based on the surface area under banana cultivation (>0.4 ha). A total of 19, 21 and 17 farmers were chosen from the low, moderate and high sanitation categories respectively. Following selection, a planning and training meeting was conducted in each parish and the effect of sanitation on weevil damage was subsequently monitored.

Table 1. Description of sanitation levels as perceived by farmers in Lwengo sub-county, Masaka district.

Sanitation level	Sanitation description
Low	Pseudostems and corms are left standing on the mat, or if cut at various heights above ground, are left intact and scattered throughout the banana field until they rot.
Moderate	Pseudostems and corms are chopped up or pseudostems stripped and spread, while stumps are cut at ground level within 4 to 6 weeks.
Intense (high)	Pseudostems and corms are chopped up weekly into small pieces and spread out to dry. Farmers in the intense category mulch with grass, maintain 3 plants/mat, remove corms twice a year, detrash more than twice a year, split pseudostems and have water trenches.

During the meetings, the activities practiced by the farmers in each sanitation category were highlighted. Farmers in the highest management level category mulch with grass, maintain 3 plants/mat, remove corms twice a year, detrash (remove old leaves) more than twice a year, split the pseudostems, and have water trenches. On the basis of these practices, the participating farmers were advised to do the following methods on their farms: to (i) cut off the stump, which is the lower part of the pseudostem (50-100 cm above ground) that was left behind when the pseudostem was removed after harvest, (ii) dig out the corms at least twice a year, (iii) cut the pseudostems into pieces, and (iv) detrash every three months.

The site was visited bi-monthly, and during each visit the farmers were shown how the practices should be applied. In addition, the field assistant, who resided at the research site, carried out monthly visits during which he would have discussions with individual farmers and inspect progress. A farmer-training meeting was also held during the course of the experiment.

Weevil damage assessment

Weevil damage was assessed in September 2002, as well as January, May and December 2003. Farmers were asked to keep some trapping materials in their fields in anticipation to these visits (at least two weeks before the sampling date). Weevil damage on the corms (at least 10 corms/field) of recently harvested plants (< 2 weeks) was assessed using the cross-section method of Gold *et al.* (1994) every 4-6 months. Cross-sections were made through both the collar (junction of corm and pseudostem) and the corm 5 cm below the collar. In each cross-section, the percentage of surface area consumed by *C. sordidus* larvae was estimated for the central cylinder and outer cortex. The mean of the four scores was calculated to generate an estimate of the total cross-section damage.

Experiment 2: Effect of using biorationals

The following biorationals were evaluated: ash; urine; and a mixture of ash + urine + tobacco. The treatments were agreed upon at a farmers' meeting which considered the

availability and levels to be used. Five, four and seven farmers were selected to test ash, urine and the mixture respectively, with each farmer considered as a replicate.

In each farmer's field, 40 mats were selected for the application of the biorationals, and the surrounding mats were used as controls. The first application was carried out in June 2002. Application rates of biorationals were agreed upon in a meeting with selected farmers and reflected common practices. One litre of cattle urine (sometimes human) was applied on each of the 40 mats in the plot and re-applied four weeks later. The cattle urine was gathered in a 20-litre plastic container from cattle kraals with urine collection canals. For the ash treatment, two plastic mugs (about 1 kg of wood ash from domestic fires) were applied on each mat every three months. The mixture was prepared by mixing 20 litres of urine with some 2 kg of ash and at least five crushed tobacco leaves. One litre of the mixture was applied on each mat and repeated four weeks later.

The baseline data were collected in May 2002, and the sampling conducted in October 2002, February 2003, May 2003 and December 2003.

Weevil population and damage assessment

The incidence of weevils in treated and control plots was estimated using pseudostem traps. Split pseudostem traps, 30 cm long, (Mitchell, 1978) were placed at the base of every mat. The traps were checked three days later for adult *C. sordidus* and the weevils were counted and recorded. Weevils from the different replicates (fields) were pooled before analysis. Assessment of weevil corm damage was carried out using the cross-section method described above on at least five harvested stumps from the treated and control plots.

Nematode population and damage assessment

Assessment of nematode damage was performed according to Speijer and Gold (1996). Roots were excavated from a 20 cm x 20 cm x 20 cm hole dug at the base of five recently flowered plants (< 2 weeks). The live roots were separated from the dead roots and both were counted. Dead roots were considered as those that were completely shriveled and expressed as the percentage of the total roots.

Five roots were randomly selected from the live roots, their lengths reduced to approximately 10 cm. These roots were split longitudinally and the necrosis caused by nematodes in each half of the root segment estimated. The necrosis in each root segment was estimated out of 20%, for a total of 100% for the five root segments.

The five roots scored for necrosis were taken to the laboratory at the Kawanda Agricultural Research Institute. They were chopped into small pieces, mixed thoroughly and 5 g weighed and macerated in a kitchen blender for 15 minutes. Nematodes were extract-

ed according to the modified Baermann funnel technique (Hooper, 1990) over a period of 24 hours. The suspension containing nematodes was transferred into vials and left to stand for about 5 hours, allowing nematodes to settle out. Thereafter, the volume of the water was reduced to 25 ml and 1 ml was sub-sampled and placed on a microscope slide and the nematodes were identified and individual species counted. Subsequently, nematode counts were extrapolated to represent counts per 100 g of roots.

Experiment 3: Effect of using neem cake

The objective of this study was to evaluate the effect of using neem cake on weevil and nematode populations and damage. The selection of participating farmers was based on the surface area under banana cultivation (>0.4 ha) and weevil damage levels. A total of 13 farmers participated in the study. After selection, a planning and training meeting was held for the farmers. Baseline data collection and subsequent sampling in selected fields was then conducted using the sampling methods described above.

The treatments consisted of neem treated and untreated plants. Each field had a treatment and a control (paired treatments). Neem cake (source: SARCO Company, Kenya) was applied to 20 mats, forming a plot in each field, while mats adjacent to the neem-applied plants were each considered as control plots. The neem cake was first applied in June 2002 at the rate of 100 g/mat. Further applications on the same mats were done in September 2002, January 2003 and May 2003.

Data analysis

The weevil damage data from the sanitation experiment were log-transformed and analysed using ANOVA of SAS (SAS Institute Inc., 1990), and means were separated using the Student-Newman-Keuls test (SNK). The data from the plots treated and untreated with biorationals and neem cake were compared using Student's t-test. Nematode counts were extrapolated to represent populations in 100 g of roots and means of nematodes and damage indices were calculated.

Results

Experiment 1: Effect of sanitation practices on weevil damage

All participating farmers were observed to implement the sanitation practices that were agreed upon, although only 60 % of the farmers were still using them towards the end of the study period (1.5 years). At the start of the experiment, weevil damage was significantly higher in low sanitation banana fields compared to those of moderate and high sanitation levels (Figure 1). There was a continuous decline of weevil damage over time in the originally low sanitation banana fields, as the management changed from low to moderate and/or high sanitation levels. By the end of the experiment, weevil damage was similar in the three types of fields. Although,

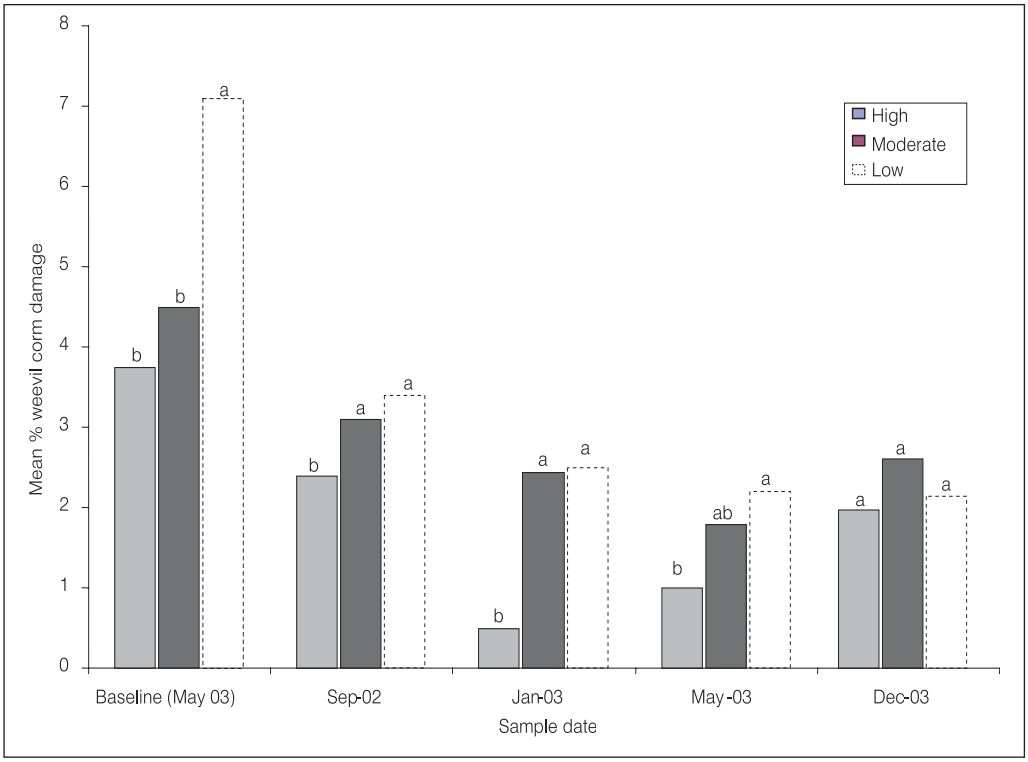

Figure 1. Average weevil damage to the corm in fields managed at different sanitation levels. Results from a given sampling time that have the same letter are not significantly different at P<0.05 according to Student-Newman-Keuls' test.

there sanitation levels increased with time, this has not translated into markedly reduced damage.

Experiment 2: Effect of using biorationals

The mean number of weevils captured in plots treated with ash, urine and the mixture were similar to the ones in the control plots (Table 2). Weevil damage in plots treated with ash was significantly lower than the one in control plots but there was no significant difference between the plots treated with urine or with a mixture of the two and tobacco and the control plots (Table 3). The mean number of dead roots, percentage necrosis and the number of nematodes in biorational treated and untreated plots were similar (Table 4).

Experiment 3. Effect of using neem cake

The mean number of weevils captured in the neem-treated plots was similar to the one in the control plots. There was no significant difference in the total cross-section damage between the treated and untreated plots but the damage to the inner corm damage

was higher in the control plots (Table 5). The proportion of dead roots and root necrosis in the treated and control plots were not significantly different (Table 6). The only significant difference was in the number of *Pratylenchus goodeyii*, which was lower in the neem-treated plots. The number of *Helicotylenchus multicinctus* was similar in the treated and untreated plots.

Discussion

Destruction of crop residues has been widely assumed to control weevil populations and reduce damage in banana plantations by eliminating adult refuges, food sources

Table 2. Effect of ash, urine and a mixture of both with tobacco on the mean number of weevils per trap (5, 4 and 7 farmers respectively tested the ash, urine and mixture, with each farmer considered a replicate. In the treated plots, 40 pseudostem traps were sampled four times).

	Number of weevils per trap		
	Ash	**Urine**	**Mixture**
Experimental plot	1.4±0.2 a	1.1±0.1 a	1.1± 0.1 a
Control	0.7±0.1 a	1.2±0.1 a	1.0± 0.1 a

Values followed by the same letter in a column are not significantly different at P< 0.05 according to Student's t-test

Table 3. Effect of ash, urine and a mixture of both with tobacco on weevil damage to the corm (5, 4 and 7 farmers respectively tested the ash, urine and mixture, with each farmer considered a replicate. Each field was sampled four times with 5-10 corms sampled from each plot each time).

	Xt (%)			Xi (%)		
	Ash	**Urine**	**Mixture**	**Ash**	**Urine**	**Mixture**
Experimental plot	1.2±0.3 b	4.0±0.6 a	2.9±0.5 a	2.8±0.8 b	4.8±1.2 a	3.6±0.8 a
Control	7.3±1.3 a	2.9±0.6 a	3.5±0.8 a	9.3±2.3 a	4.2±1.4 a	5.6±1.9 a

Values followed by a similar letter in a column are not significantly different at P< 0.05 according to Student's t-test
Xi: corm central cylinder damage; Xt: total corm damage

Table 4. Effect of ash, urine and a mixture of both with tobacco on nematode population levels and their associated damage (the value for all the parameters measured in the ash-treated experimental plots and in the control plots was zero). (5, 4 and 7 farmers respectively tested the ash, urine and mixture, with each farmer considered a replicate. In each plot, 5 roots were sampled four times over the experimental period).

	Proportion of dead roots (%)		RN (%)	Number of Pratylenchus goodeyii per 100 g of roots		Number of Helicotylenchus multicinctus per 100 g of roots	
	Urine	**Mixture**	**Urine**	**Urine**	**Mixture**	**Urine**	**Mixture**
Experimental plot	19.2±3.6 a	14.6±3.1 a	1.0± 0.7 a	0.0±0.0 a	435±268 a	720±368 a	516±45 a
Control	26.9±7.1 a	24.1±5.8 a	0.9± 0.6 a	0.0±0.0 a	438±438 a	186±91 b	141±60 b

RN=Root necrosis
Values followed by a similar letter in a column are not significantly different at P< 0.05 according to Student's t-test

Table 5. Effect of neem on weevil damage to the corm (each of the 13 fields were sampled four times, with 5-10 corms sampled from each plot each time).

	Xt (%)	Xi (%)
Experimental plot	3.3±0.2 a	2.6±0.3 b
Control	4.0±0.4 a	3.4±0.4 a

Xi: corm central cylinder damage
Xt: total corm damage

Table 6. Effect of neem on nematode population levels and their associated damage (each of the 13 fields were sampled four times, with 5 roots sampled from each plot each time).

	Proportion of dead roots (%)	RN (%)	Number of Pratylenchus goodeyii per 100 g of roots	Number of Helicotylenchus multicinctus per 100 g of roots
Experimental plot	18.4±3.1 a	1.7±0.6 a	22±16 b	597±196 a
Control	19.5±2.6 a	1.1±0.5 a	257±131 a	743±177 a

and breeding sites (Gold *et al*, 2001). The potential of sanitation practices for suppressing weevil populations and reducing crop damage has been demonstrated in Uganda (Masanza, 2003). In our results, we observed that farmers who were practicing high levels of sanitation were consistently having lower weevil damage. Although our study did not have controls, the impact of sanitation practices is suggested by the magnitude of the decline in weevil damage in banana fields that initially had low levels of sanitation. Weevil damage was generally low in plantations at the beginning of the study, and as a result, a change in agronomic practices did not have an observable effect on weevil damage, but it could be because it takes time before a significant change in damage or even in yield can be observed.

Our results on biorationals used independently or in a mixture showed limited or no effect on weevil and nematode populations, and on damage. There is a belief by some banana farmers in Uganda that biorationals control *C. sordidus* (Ssennyonga *et al.*, 1999*)*. Conversely, reports indicate that some of the biorationals known to control weevils may have a nutritive effect that induce the exposed banana plant to grow vigorously and thus tolerate weevil damage (Bosch *et al*., 1995). In studies conducted in the laboratory in Uganda, it was observed that the concoction had the potential to reduce weevil damage by repelling weevils from the banana plant and deterring oviposition (Tinzaara *et al*., 2002). However, this laboratory potential was not replicated under field conditions.

The effect of neem extracts on suppressing weevil and nematode populations, and reducing damage, has been recently demonstrated (Musyabimana *et al*., 2001). Our re-

sults indicate that neem extracts lower weevil damage in treated plants compared with untreated plants, although statistical analyses did not show a significant difference. We consider that the experimental period (1.5 years) was not sufficiently long for significant differences to be observed between the treated and untreated plots. Similarly, the effect of neem extracts on suppressing nematode populations and damage has been demonstrated (Musyabimana *et al*., 2001). In our studies, the percentage number of dead roots and root necrosis in neem-treated plots was not significantly different from the one in the control plots. There was a significant reduction in the numbers of *Pratylenchus goodeyii*, in neem-treated plots in comparison with control plots, though the numbers of *Helicotylenchus multicinctus* were similar in the treated and control plots. This could also be attributed to the experimental period being insufficiently long.

In general, this study shows to some extent that intensive sanitation practices could reduce the levels of weevil damage. However, detailed data are still needed to observe the effects of sanitation practices on yields. Biorationals had a limited effect on weevil and nematode populations, and should possibly be used as organic fertilizer to supplement nutrients. Application of neem cakes appears to have potential in controlling weevils and nematodes, although further evaluation will be required before they can be recommended for use as an IPM options.

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The influence of nematodes, weevils and management level on high mat, plant growth traits and yields in southwestern Uganda

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Abstract

We investigated the relationship between the level of management, the incidence of nematodes and weevils, and the 'high mat' phenomenon, and their effects on plant growth traits and yield. The East African highland bananas (AAA-EAHB) 'Mpologoma', 'Lwadungu', 'Nakitembe', 'Mbwazirume' and 'Kibuzi', the dessert banana 'Sukali ndizi' (AAB), the plantain 'Gonja' (AAB) and the beer banana 'Kayinja' (ABB) were assessed on farms in Masaka and Bushenyi districts. Genotype significantly influenced 'high mat' ($P<0.05$), nematode population density ($P<0.001$), banana weevil damage ($P<0.01$), bunch weight and plant growth traits. The level of management did not significantly influence 'high mat', the total nematode population density, or the weevil damage. Significant positive effects of location were only observed on weevil damage, root necrosis, bunch weight and plant growth traits. Strong significant and positive correlations were also observed between bunch weight and plant growth traits. However, bunch weight and plant growth traits were not significantly affected by 'high mat', weevils and nematodes. In addition, hardly any significant correlations were observed between 'high mat' and pest presence. 'High mat' was more pronounced in ageing fields, particularly in AAA and AAB cultivars. Hence, 'high mat was determined by the genotype and does not appear to be controllable through simple management practices or the reduction of nematode and weevil populations. An integrated management approach including the enhancement of the soil nutrient status, the application of cultural and IPM practices (*e.g.* using clean planting material, application of neem seed powder and botanicals), could be an effective approach to the promotion of vigorous growth and tolerance to pests in *Musa* spp. However, in order to curb 'high mat', regular replanting (every 3-5 years) of sections or whole plantations should be practiced.

Introduction

East African highland bananas (AAA-EAHB) are a staple food for the Great Lakes region of East Africa (Gold *et al.*, 1999) and in particular Uganda (Kajumba *et al.*, 2002), where they are a key component in both food security and agricultural sustainabil-

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ity (MAAIF, 1992; Tenywa *et al.*, 1999). The productivity of bananas depends upon, among other factors, healthy root growth. The *Musa* root system consists of adventitious or cord roots, which are mainly responsible for anchorage and transport of water and nutrients (Price, 1995). Positive correlations between bunch weight and root traits have been observed for dessert bananas (Lassoudiere, 1978; Robinson, 1996) and for the plantain 'Mbi egome' (Blomme, 2000).

In Uganda, yield decline in East African highland bananas has been attributed largely to poor agronomic practices, drought stress, soil fertility decline, use of unimproved cultivars, pests and diseases, and the `high mat´ phenomenon (Karamura, 1993; Ogenga-Latigo and Bakyalire, 1993; Bananuka and Rubaihayo, 1994; Gold *et al.*, 1999; Blomme, 2000).

Plant parasitic nematodes are recognized as a major constraint to production and are responsible for significant yield losses in East African *Musa* spp. (Fogain and Gowen, 1997; Speijer *et al.*, 1998). In Uganda, production losses associated with *Radopholus similis* and *Helicotylenchus multicinctus* have been reported to exceed 50% in highland bananas (Speijer and Kajumba, 1996). Nematodes feed, multiply and migrate in the banana roots and corm,*i.e.* the underground true stem, (Gowen and Quénéhervé, 1990), resulting in a necrotic and reduced root system (Speijer and De Waele, 1997). Blomme (2000) reported that nematode infection results in a strong reduction of the root system size, while the shoot growth tends to be less affected. This causes a higher shoot-root ratio which could lead to toppling in wind-prone areas. A nematode infection also delays ratooning (Blomme, 2000).

The banana weevil (*Cosmopolites sordidus*) is a primary constraint of East African highland bananas (Rubaihayo and Gold, 1993; Bosch *et al.*, 1995), hindering crop establishment and reducing yields. The larva is the most important stage of the banana weevil, attacking and destroying banana corms by creating tunnels as it feeds and develops. Tunnels then interfere with water and nutrient uptake, reducing plant strength and creating entry routes for secondary microorganisms. The damage predisposes the crop to snapping and sucker mortality (Koppenhoffer, 1993), toppling (Bosch *et al.*, 1995; Rukazambuga, 1996), prolonged maturation period and shortened plantation life. Corm damage may also interfere with root initiation, thereby leading to reduced bunch weight. Continuous attack over several cycles may result in up to 60% yield losses (Sengooba, 1986; Rukazambuga, 1996), which were estimated to increase five times from 1st to 3rd ratoon with East African highland bananas (Rukazambuga, 1996). Ittyeipe (1986) suggested that damage caused by banana weevils could increase due to the exposed corm ('high mat') in ageing fields. However, it is unclear whether under field conditions differential corm exposure plays a significant role in attracting weevils.

Declining yields of *Musa* spp. have also been attributed directly to poor management, with Okech *et al. (*1997) reporting significantly higher bunch yields in well-managed fields. The same authors postulated that banana pest problems can be reduced effectively through practicing good plantation management and, in particular, crop sanitation being the most successful method for solving weevil problems.

'High mat' is the tendency of the plant base to grow above soil level, thereby exposing part of the root bearing zone (Moreau and Le Bourdellés, 1963; Swennen and Ortiz, 1997). This phenomenon becomes more pronounced as the plantation ages and leads to a reduction in the root system development during consecutive ratoon cycles (Blomme, 2000). 'High mat' eventually results in reduced anchorage strength and enhances plant susceptibility to toppling.

In order to address some of the constraints faced by farmers in traditional banana growing areas, the study focused on (a) the influence of genotype, management level and location on 'high mat', nematode and weevil damage, bunch weight and plant growth traits, (b) the relationship between 'high mat', weevils and nematodes, and their effects on shoot and aerial growth traits, as well as yield.

Materials and methods

The study was carried out on farms in Masaka and Bushenyi districts, which are two prominent banana growing areas. The Masaka-Lwengo site falls under the banana-coffee system, while the Bushenyi site falls under the montane system (INIBAP, 2003). The altitude at the Masaka-Lwengo site is between 1 080-1 330 meters above sea level (masl), while the mean annual rainfall is 1200 mm. The soils at the Masaka-Lwengo site are classified as Luvisols (FAO, 1998), which are red loamy types overlying the basement complex which consists of schists, marbles, gneisses and granulites. The altitude at the Bushenyi site is between 1600 and 1800 masl, while the mean annual rainfall is 1588 mm. The soils at the Bushenyi site are classified as Acrisols (FAO, 1998). They are generally deep, well structured and fertile, mostly dark to brown volcanic soils rich in organic matter, but some are yellowish brown loams and sandy clay loams. More climatic data on these two sites has been reported by INIBAP (2003).

At each site, five EAHB genotypes ('Mpologoma', 'Lwadungu', 'Nakitembe', 'Mbwazirume' and 'Kibuzi'), the dessert banana 'Sukali ndizi´ (AAB), the plantain 'Gonja' (AAB) and the beer banana 'Kayinja' (ABB) were investigated. Banana mats in different ratoon stages were also assessed. Twenty plants per genotype were assessed at each site with 2-5 mats per farm. The mats selected consisted of a mother plant ready to harvest with 2-3 suckers. Selection of the EAHB genotypes was based on clone sets in order to include a representative genotype from each of the four clone sets (Karamura and Pickersgill, 1999). In addition, genotypes were chosen based upon their de-

Table 1. Characteristics of the assessed genotypes.

Genotype	Genomic group	Clone set	Susceptibility to high mat	Tolerance/ sensitivity to weevil damage	Resistance/ susceptibility to nematodes
Mpologoma	AAA-EAHB	Musakala	Moderate	Susceptible	Susceptible
Lwadungu	AAA-EAHB	Nfuuka	Moderate	Susceptible	Susceptible
Nakitembe	AAA-EAHB	Nakitembe	Moderate	Susceptible	Susceptible
Mbwazirume	AAA-EAHB	Nakitembe	Moderate	Moderate	Susceptible
Kibuzi	AAA-EAHB	Nakabululu	Moderate	Susceptible	Susceptible
Sukali ndizi	AAB		Moderate	Moderate	Susceptible
Gonja	AAB		High	Susceptible	Susceptible
Kayinja	ABB		Low	Moderate	Resistant

Sources: Seshu Reddy and Lubega, 1993; Gold et al., 1994; Musabyimana, 1995; Swennen and Ortiz, 1997; Rukazambuga, 1996; Abera et al., 1997; Karamura and Pickersgill, 1999

gree of susceptibility to 'high mat' (Swennen and Ortiz, 1997), resistance/susceptibility to nematodes (Musabyimana, 1995; Blomme *et al.,* 2001a) and tolerance/sensitivity to weevil damage (Table 1).

Farmers manage their plantations differently (Speijer *et al*., 1998) and this has an influence on productivity (Araya *et* al., 1998). Therefore, ten plants were assessed in well-managed fields, whereas the other ten plants were assessed in poorly-managed fields. The well-managed fields were mulched, old leaves were pruned, plants were properly spaced and weeding was carried out. Furthermore, other IPM practices (manure application, use of clean planting materials, host plant resistance and use of botanicals) were undertaken. In contrast, these practices were executed at minimum levels in the poorly-managed fields. These extremes of management levels were selected in order to obtain a better insight into the effect of farm management on the assessed traits.

At harvest, the root systems were completely excavated, which was started at least 3 m from the plant and executed carefully to avoid root breakage.. Roots were washed on a large sieve to facilitate the removal of all soil particles, and suckers were separated from the mother corm to facilitate the assessment. Yield and various plant growth traits of the mat assessed included bunch weight, leaf area, corm weight, cord root number, cord root weight and cord root length, which was measured using the line intersect method (Tennant, 1975). This latter method consists of scattering cord roots on a grid and counting the number of root grid-line interaction points. The number of interaction points was then multiplied by the conversion factor 2.3571 appropriate for the 3 cm by 3 cm grid used. Leaf area was calculated as: length x maximum width x 0.8

(Obeifuna and Ndubizu, 1979; Blomme and Tenkouano, 1998). In addition, the level of 'high mat' of the mother plant, the age of the plantation, nematode necrosis index and population density, as well as weevil damage percentage and soil nutrient status were assessed. The level of 'high mat' was scored as the percentage of exposed corm to the total corm length of the mother plant corm (Figure 1). The actual age of the plantation was estimated by the farmers.

Nematode damage assessment consisted of selecting randomly five functional roots, reducing their length to approximately 10 cm and splitting them longitudinally. One half of each of the five roots was scored for root cortex necrosis; each of the five root segments representing 20%. The functional root segments scored for necrosis were cut into 0.5 cm sections, completely randomized and a five-gram sample was taken for nematode extraction. After sample maceration in a kitchen blender for 15 seconds, nematodes were extracted overnight using a modified Baermann funnel method (Hooper, 1990). The counts were repeated three times using 2 ml aliquots out of a 25 ml volume containing all extracted nematodes. The numbers reported included all the life stages (males, females and juveniles). Nematode population densities were calculated per 100 gram of fresh root weight.

Weevil damage to the banana corm of the mother plant was assessed using the cross-sectional method (Gold *et al.*, 1994). In this method, two cross-sections were made at the collar (pseudostem/corm junction) and at 10 cm below the collar. For each cross-section of the corm, the percentage of surface area consumed by weevil larvae (galleries) was estimated independently for the central cylinder and the outer corm. The data

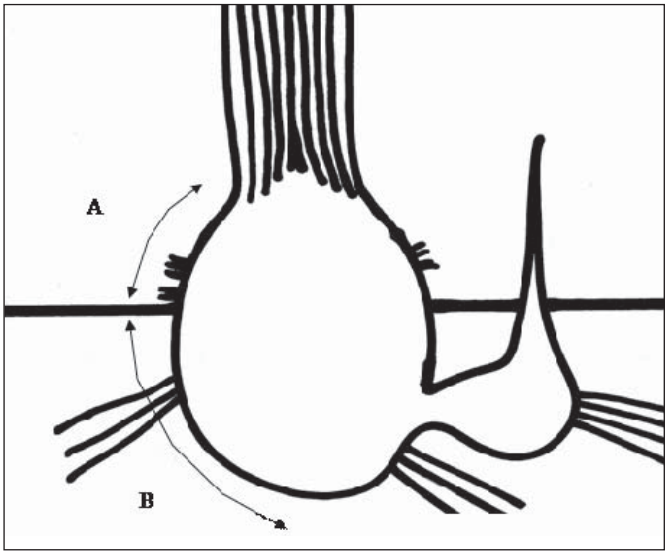


Figure 1. Measurement of high mat
% High mat = {A/(A+B)} x 100

from the two cross-sections were combined to form inner, outer and total damage. The mean of the two cross-sections was regarded as the weevil damage to the mother plant.

The data were subjected to statistical analysis using the Genstat statistical package (Genstat, 1999). Nematode population densities and weevil damage percentage were subjected to log x+1 transformation prior to the analysis. ANOVA was carried out to determine the influence of genotype, level of management and location on the different traits assessed. Correlation analysis was performed to determine the relationships among the assessed parameters.

Results and discussion

Soil composition

The analysis (Table 2) indicated that the levels of available phosphorus and exchangeable potassium at both locations were below the critical banana requirements (Okalebo *et al.*, 1993). Levels of calcium, sodium and organic matter were within the minimum requirements of the banana plants. Mean pH values of the soils at the Masaka site were above the critical value (5.2), whereas those at the Bushenyi site were below the minimum requirement. Soils with a pH value above the minimum requirement do not hinder vigorous plant growth (Tumuhairwe *et al.*, 1994) and give good nutrient availability without toxicity problems (Wortmann and Kaizi, 1997). Low levels of N, P and K (below the critical value) have been associated with slow growth and low yields of bananas (Bhargava *et al.*, 1992).

Influence of genotype

The results show a genotypic effect on 'high mat' level, nematode population density, percentage weevil damage and the growth characteristics assessed (Table 3). 'High

Table 2: Chemical and physical properties of top soil in farmers' fields at Masaka and Bushenyi.

Top soil depth	Ca (cmol/kg)	K (cmol/kg)	N (%)	Na (cmol/kg)	OM (%)	P (ppm)	Sand (%)	Silt (%)	Clay (%)	pH
Masaka										
0-15 cm	9.0	0.29	0.18	0.16	4.3	5.1	54.8	7.2	37.0	5.6
15-30 cm	7.1	0.19	0.14	0.27	3.3	2.5	53.8	6.2	40.0	5.4
Bushenyi										
0-15 cm	7.0	0.40	0.12	0.21	5.6	8.2	64.3	9.5	26.3	4.9
15-30 cm	4.7	0.23	0.24	0.19	4.6	5.5	60.3	9.9	29.8	4.9
Threshold value*	>4.0	>0.44	>0.20	<1.00	>3.0	>15.0				>5.2

*Critical levels for banana nutritional requirements (Okalebo *et al.*, 1993)

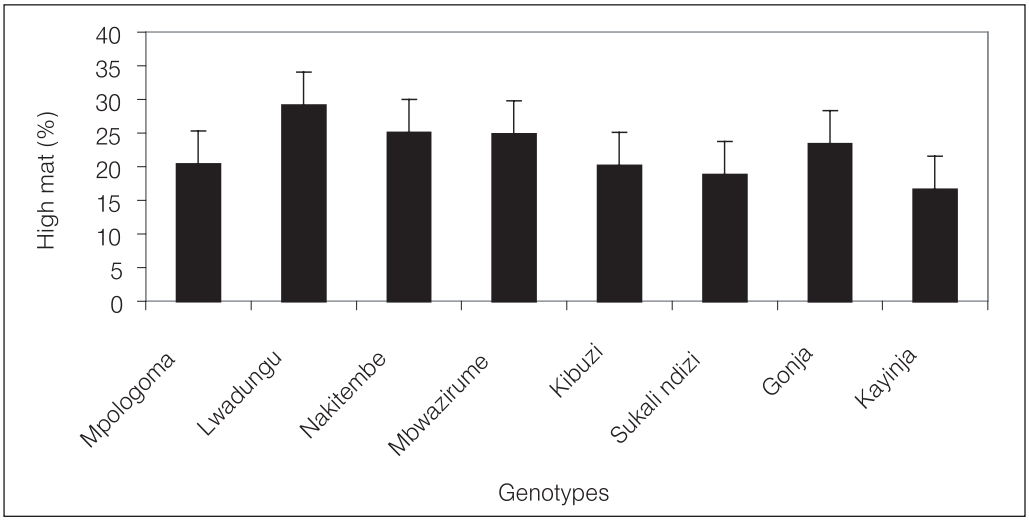


Figure 2. Level of high mat for the different genotypes.

mat' was more pronounced in the EAHB and plantain 'Gonja' than in the beer banana 'Kayinja' (Figure 2). Swennen and Ortiz (1997) reported the susceptibility of plantains to 'high mat, as well as that the apical meristem of an ABB cooking banana is deeper in the soil than that of a plantain for plants of the same age. This could indicate that plantains are more prone to 'high mat; than ABB cooking bananas (Swennen *et al.*, 1988).

The nematode population densities were significantly higher in Bushenyi than in Masaka (Table 4). The highest total number of nematodes was found in the East African highland bananas, in particular, in 'Mbwazirume', with 49 800 and 67 900 nematodes per 100 g of roots in well- and poorly-managed fields respectively at the Bushenyi site. The plantain `Gonja´ contained 50 150 and 15 750 nematodes per 100 g of roots in well- and poorly-managed fields respectively at the Bushenyi site. Low nematode population densities were found for 'Kayinja' and 'Sukali ndizi' at both locations, with root necrosis following the same trend (Figure 3). These results are in agreement with Musabyimana (1995) and Blomme *et al.* (2001a), who found that East African highland bananas and plantains were the most susceptible genotypes to nematodes. Although, high numbers of nematodes and associated damage were observed for 'Mbwazirume', this genotype maintained high yields under well-managed plantations (Table 5). In agreement with these results, Speijer *et al.* (1998) reported a compensatory root growth under high nematode attack in mulched plots.

The genotypic effect on weevil damage (Table 3) suggests varying degrees of tolerance/sensitivity among the genotypes. 'Lwadungu' showed the highest damage level, while 'Sukali ndizi' was the most resistant to banana weevils (Figure 4). Similar results for 'Sukali ndizi' were reported by Kiggundu (2000), while Gold *et al.* (1994) noted a high

Table 3. Mean squares and significance levels for the assessed parameters.

Source of variation	Df	High mat (%)	Bunch weight (kg)	Total leaf area per mat (cm^2)	Corm dry weight (kg)	Cord root number per mat	Cord root length per mat(cm)	Root dry weight per mat (kg)	Root necrosis index (%)	Nematode densities per 100 gr of roots	Weevil damage (%)
Genotype (G)	7	450.9*	1 079.1***	0.62***	89.82***	273 152***	0.47***	1.47***	251.64**	2.55***	59.61**
Management level (ML)	1	258.9	1 221.2***	1.48***	61.96***	585 248***	0.58***	1.82***	6.71	0.01	42.35
Location (L)	1	90.3	1 637.2***	5.77***	11.26*	2 109 738***	0.12*	0.38*	284.62***	0.04	593.27***
G x ML	7	166.2	1 33.8***	0.13	17.8***	56 802	0.06*	0.23**	171.20*	0.03	14.99
G x L	7	138.7	1 73.8***	0.36***	17.01***	131 266***	0.18***	0.19**	388.02***	0.10	63.64***
ML x L	1	121.5	74	0.03	7.67	79	0.03	0.02	31.66	0.08	12.28
G x ML x L	7	257.2	74.2	0.23***	11.87***	35 918	0.07*	0.07	182.89*	0.08	14.67
Residual	279	204.1	35.6	0.07	2.33	31 200	0.03	0.07	74.10	0.06	18.17

*, **, *** Significantly different at P<0.05, P<0.01 and P<0.001 respectively

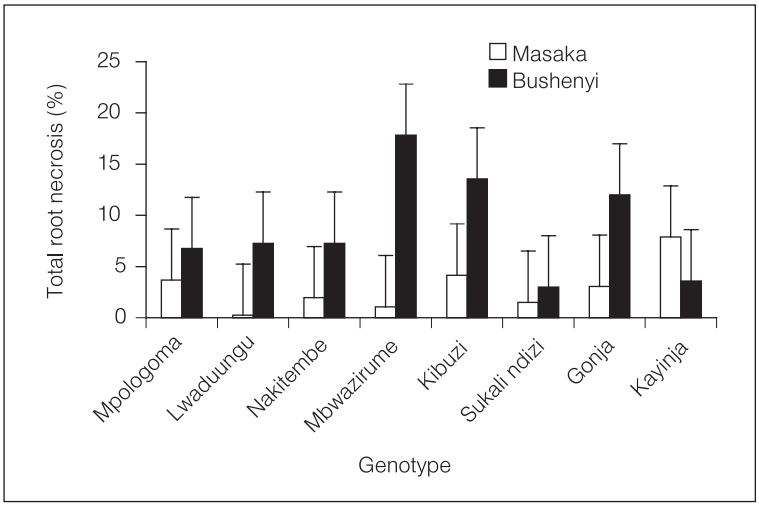


Figure 3. Total root necrosis index for the various genotypes at the Masaka and Bushenyi sites.

susceptibility of the East African highland bananas and the plantain 'Gonja' to weevils. Abera *et al.* (1997) suggested that the different levels of weevil damage across genotypes may be attributed to corm hardiness, chemical characteristics (antibiosis) and weevil preferences.

Influence of management level

Management level neither significantly influenced the level of 'high mat', root necrosis, total nematode population density nor weevil damage (Table 3). However, a significant effect ($P<0.001$) was observed for the plant growth traits and bunch weight (Table 3). In agreement with our results, Rukazambuga (1996) reported the same levels of weevil attack in stressed (intensively intercropped) and healthy (mulched) banana systems. Blomme (2000) also observed a significant effect of agronomic practices on the *Musa* root system development.

The level of crop management had positive direct effects on bunch weight, total leaf area, corm weight, cord root number, cord root length and root weight (Tables 3 and 5). The highest yields were obtained in well-managed fields, whereas the lowest were observed in poorly-managed fields. For example, 'Mpologoma' produced fresh bunch weights of 23.97 kg and 13.06 kg respecively in well-and poorly-managed fields. The low yield in the poorly-managed fields was possibly due to intramat competition (Robinson and Nel, 1990), as well as the lack of vigorous IPM and plantation management practices, such as mulch application (Bananuka and Rubaihayo, 1994).

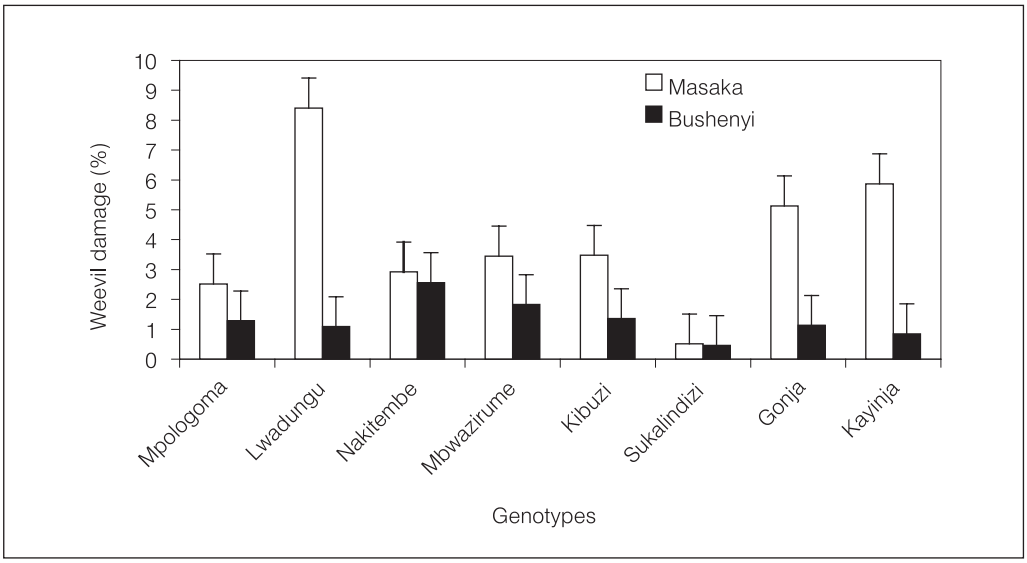
Influence of location

This had a significant effect on the weevil damage level, root necrosis index, bunch weight and the plant growth traits (Tables 3 and 6). However, the location neither

Table 4. Mean nematode densities (per 100 g of roots) of various nematode species in well-managed (A) and poorly-managed fields (B).

Genotype	Location	*Radopholus similis*		*Pratylenchus goodeyi*		*Helicotylenchus multicinctus*		*Meloidogyne spp.*		Total number of nematodes per 100 g of roots	
		A	B	A	B	A	B	A	B	A	B
Mpologoma	Masaka	25	200	0	0	3 325	1 400	0	0	3 350	1 600
	Bushenyi	0	0	35 850	24 550	0	0	0	0	35 850	24 550
Lwadungu	Masaka	0	0	0	0	700	2 875	0	0	700	2 875
	Bushenyi	0	0	15 300	23 400	0	0	0	0	15 300	23 400
Nakitembe	Masaka	0	0	1 800	0	4 925	1 450	0	25	6 725	1 475
	Bushenyi	0	0	30 650	22 350	0	0	0	0	30 650	22 350
Mbwazirume	Masaka	0	0	0	0	1 600	1 400	50	0	1 600	1 400
	Bushenyi	0	0	49 200	67 900	0	0	600	0	49 800	67 900
'Kibuzi	Masaka	0	0	25	0	2 025	3 175	0	0	2 050	3 175
	Bushenyi	0	0	38 600	20 050	0	0	50	0	38 650	20 050
Sukali ndizi	Masaka	0	0	0	0	1 525	2 075	0	0	1 525	2 075
	Bushenyi	0	0	2 900	6 600	0	50	250	0	3 150	6 650
Gonja	Masaka	0	0	0	0	6 125	5 850	575	0	6 700	5 850
	Bushenyi	0	0	50 150	15 750	0	0	0	0	50 150	15 750
Kayinja	Masaka	0	0	0	0	3 425	1 050	0	0	3 425	1 050
	Bushenyi	0	0	4 150	4 200	0	0	0	0	4 150	4 200

Figure 4. Percentage weevil damage for the different genotypes at the Masaka and Bushenyi sites.



affected the level of 'high mat', or the total nematode population density. The mean percentage weevil damage was found to be higher in Masaka (4.04%) than in Bushenyi (1.32%). This difference is attributed to a variation in temperature as a result of altitude. These results are consistent with earlier surveys conducted in Uganda on highland banana clones (Gold *et al.*, 1994; Okech *et al.*, 1997).

The nematode species encountered were *Pratylenchus goodeyi, Helicotylenchus multicinctus, Radopholus similis* and *Meloidegyne* spp. The two sites had different nematode species because of the differences in altitude. Bushenyi, located at a higher altitude, had greater abundances of *Pratylenchus goodeyi,* whereas Masaka, being at a lower altitude, showed higher populations of *Helicotylenchus multicinctus* (Table 4). These results agree with other studies conducted in Uganda (Barekye *et al.*, 2000; Kashaija *et al.*, 1994), where *P. goodeyi* and *H. multicinctus* were more abundant and widespread than *R. similis*. The root necrosis index was higher in Bushenyi than in Masaka (Figure 3), with the difference in nematode damage at the two sites probably due to the presence of *P. goodeyi* in Bushenyi and the absence of *R. similis* in Masaka. Barekye *et al.* (2000) postulated that *R. similis* and *P. goodeyi* are the most destructive nematodes. However, in their absence other nematodes, such as *Helicotylenchus multicinctus* and *Meloidegyne* spp., cause substantial root damage.

Correlation analysis

Bunch weight was positively correlated with corm weight, total leaf area, cord root length and mat root weight (Tables 7a and b). These results are in agreement with

Table 5. Mean yield and plant growth traits in well-managed (A) and poorly-managed fields (B).

Genotype	Bunch fresh weight (kg)		Total leaf area per mat (cm^2)		Corm dry weight per mat (kg)		Number of cord roots per mat		Cord root length (cm)		Root dry weight per mat (kg)	
	A	B	A	B	A	B	A	B	A	B	A	B
Mpologoma	23.9	13.1	96 287	50 294	3.1	2.2	495.1	409.8	13365	1190	0.45	0.32
Lwadungu	19.2	11.3	946 675	74 268	4.7	2.7	614.0	429.7	18681	15387	0.59	0.44
Nakitembe	17.8	14.8	109 295	79 273	2.4	2.9	523.1	488.1	13842	14294	0.41	0.39
Mbwazirume	20.5	19.2	121 440	122 830	2.9	2.7	677.2	508.8	20594	16315	0.64	0.47
Kibuzi	16.4	15.2	134 683	99 318	2.5	2.2	616.4	457.6	19242	17230	0.50	0.43
Sukali ndizi	11.2	6.9	156 220	102 806	8.4	4.5	657.1	486.1	24229	16075	1.22	0.72
Gonja	11.9	10.4	83 174	83 694	1.4	1.4	393.3	406.4	11045	11848	0.46	0.35
Kayinja	5.1	3.8	62 598	68 868	4.4	3.9	375.0	379.4	11340	9680	0.47	0.41
LSD*	3.7	3.7	35 112	35 112	1.3	1.3	ns	ns	3623	3623	0.23	0.23

* Least significant difference

other observations by Robinson (1996) for dessert bananas and Blomme (2000) for the plantain 'Mbi egome'. The corm's ground tissue is starchy parenchyma, containing numerous vascular bundles, responsible for transporting water and nutrients to the pseudostem, leaves and developing bunch (Skutch, 1932). It is also an important storage organ for sustaining bunch growth and the developing sucker (Robinson, 1996). The significant relationship between bunch weight and the root traits indicates that a large root system may induce high yields (Blomme, 2000).

Bunch and corm dry weight, cord root length and root dry weight had significant positive correlation with total leaf area (Tables 7a and b). This indicates that the size of functional leaves determines plant size and yield (Martinez, 1984). Similarly, positive correlations between leaf area and bunch weight, corm weight and root traits were observed for genotypes belonging to a wide range of genomic groups (Blomme, 2000). In fact, the same author stated that leaf area and corm weight could be considered as the most important indicators for root system development of a banana plant. Even in a much earlier study, Skutch (1932) observed an interconnection between the leaves, the corm and roots, through the vascular system, which allows the interchange of assimilates, water and nutrients. Furthermore, Swennen (1984), Blomme and Ortiz (1996) and Blomme *et al.* (2001b) noted positive correlations between root system development and aerial growth characteristics in banana.

'High mat' did not significantly correlate with yield, nematode numbers or plant growth traits (Tables 7a and b). However, a non significant, but positive correlation was observed between 'high mat' and weevil damage. This could be due to increased weevil numbers during subsequent cycles. Abera *et al.* (1997) suggested that plants with 'high mat' were more prone to egg laying by the banana weevil increasing their susceptibility to weevil damage. The insignificant effect of 'high mat' on yield and plant growth traits may probably be due to the plant's survival mechanism, whereby the remaining roots elongate to compensate for the inability of the newly formed roots to develop. Furthermore, the maiden suckers may have contributed to the growth of the mother plant (Teisson, 1970). Hence, suckers may not only be sinks, but could also contribute to shoot and bunch development later on (Teisson, 1970). Blomme (2000) postulates that the plants are not completely independent of each other as long as the organic connection remains.

Strong positive significant correlations were observed between root necrosis and nematode population densities. Blomme *et al.* (2003) obtained similar results for a large number of *Musa* spp. genotypes. Similarly, Mcintyre *et al.* (2000) found that root necrosis significantly rose with increasing abundances of nematodes. However, there were few significant correlations between nematode numbers and root necrosis, and bunch weight, corm or aerial growth traits;, a negative tendency was observed for all the genotypes (Tables 7a and b). These results are in agreement with Blomme *et al.* (2003), in-

Table 6. Mean plant and pest damage traits in Masaka (M) and Bushenyi (B).

Genotype	Bunch fresh weight (kg)		Total leaf area per mat (cm^2)		Corm dry weight per mat (kg)		Number of cord roots per mat		Cord root length per mat (cm)		Root dry weight per mat (kg)		Root necrosis index (%)		Weevil damage (%)	
	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B
Mpologoma	14.8	22.2	67 809	78 773	2.6	2.7	574.5	330.4	14 284	10 271	0.41	0.36	3.7	6.8	2.5	1.3
Lwadungu	16.9	13.6	102 474	118 469	4.1	2.6	774.6	369	22 038	12 031	0.60	0.43	0.3	7.3	8.4	1.1
Nakitembe	12.1	20.4	50 642	137 926	2.1	3.2	548.7	462.4	14 146	13 990	0.33	0.47	1.9	7.3	2.9	2.6
Mbwazirume	15.6	24.1	78 914	165 357	2.4	3.3	624.3	562.6	18 851	18 058	0.53	0.59	1.1	17.8	3.5	1.8
Kibuzi	15	16.9	83 573	150 428	2.1	2.5	588.3	485.7	21 237	15 236	0.48	0.45	4.2	13.6	3.5	1.4
Sukali ndizi	7.4	10.7	107 117	151 910	7.1	5.8	659.7	483.5	19 873	20 431	0.86	1.07	1.5	3.0	0.5	0.5
Gonja	7.3	15	48 351	118 518	1.3	2.0	443.6	356.1	9 364	13 529	0.29	0.52	3.1	12.0	5.1	1.1
Kayinja	3.2	5.6	34 833	96 634	2.9	5.5	444.7	309.7	10 346	10 674	0.35	0.52	7.9	3.6	5.9	0.9
LSD*	3.7	3.7	35 112	35 112	0.9	0.9	110	110	3 623	3 623	0.16	0.16	5.4	5.4	2.7	2.7

*Least significant difference

dicating a negative influence of nematodes on yield, corm and the aerial growth traits. Nevertheless, nematode build-up and damage depends on the type of nematode species present. In this study, *R. similis* was virtually absent in most of the farms at both sites (Table 4), whereas in another study on bananas, *R. similis* was reported to be much more damaging than *H. multicinctus* (Barekye *et al.,* 2000)

For most genotypes, there were no significant relationships between weevil damage, and bunch weight or plant growth traits (Table 7a and b). However, there was a significant negative correlation between the percentage of weevil damage, and root and corm dry weight, total leaf area and bunch dry weight for 'Gonja' plants growing in poorly-managed farms. This may be attributed to the high sensitivity of the plantain 'Gonja' to weevil damage (Abera *et al.*, 1997).

The age of the plantation did not significantly influence nematode infestation levels and species, weevil damage or plant growth traits. However, a significant positive correlation was observed between the age of the plantation and the level of 'high mat' (data not shown). This high R^2 value (0.79) indicates that a very large percentage of the variability in 'high mat' could be explained by the age of the plantation (Rukazambuga, 1996). As plantations get older, the incidence of 'high mat' increases, which is in agreement with the observations made by Blomme (2000) on plantain hybrids and Swennen (1990) on plantains.

Conclusions and recommendations

The strong genotypic effect observed on the various traits indicates potential uses of certain genotypes in genetic improvement programmes. The level of management had positive effects on yield, corm and aerial growth traits. However, no such effect was observed for 'high mat', nematode numbers, or weevil damage. Under well-managed fields, there was enhanced root growth, yield and over all plant development. An integrated management approach, including fertilization and the application of cultural and IPM practices, (e.g. the use of clean planting material, application of neem seed powder and botanicals), is an effective approach to the promotion of vigorous growth and pest tolerance in *Musa* spp.

The lack of strong correlation between nematode numbers and root necrosis on the one hand, and 'high mat', bunch weight, root and aerial growth traits on the other hand, may be due to the absence of *R. similis*. Weevil damage was not significantly correlated with bunch weight and plant growth traits or 'high mat'. Reducing the incidence of weevils and nematodes will not affect the development of the 'high mat' phenomenon.

The significant positive correlations observed between yield, corm, root and the aerial growth traits confirms earlier findings (Blomme and Ortiz, 1996; Blomme *et al.,* 2001b).

Table 7a. Correlation coefficients between high mat, bunch weight, plant growth traits, root necrosis, nematode numbers and weevil damage for plants growing in well-managed fields (below the diagonal) and poorly-managed fields (above the diagonal).

Genotype		HM	BW	LA	CW	NR	RL	RW	RN	NP	WD
Mpologoma	**HM**		-0.24	-0.05	-0.24	-0.27	-0.26	-0.18	0.24	-0.03	0.34
	BW	0.37		0.41	0.28	0.14	0.17	0.23	-0.21	0.01	-0.34
	LA	0.49*	0.62**		0.56*	0.51*	0.63**	0.68***	-0.29	-0.09	0.33
	CW	0.30	0.69***	0.63**		0.73***	0.83***	0.83***	-0.44	-0.21	0.23
	NR	-0.13	-0.05	0.37	0.36		0.92***	0.86***	-0.46*	--0.38	0.30
	RL	0.41	0.42	0.73***	0.57**	0.64**		0.94***	-0.42	-0.21	0.26
	RW	0.34	0.59**	0.76***	0.82***	0.54*	0.87***		-0.41	-0.21	0.24
	RN	-0.11	0.00	-0.33	-0.25	-0.45*	-0.38	-0.35		0.47*	-0.28
	NP	-0.27	0.19	-0.16	-0.10	-0.65**	-0.38	-0.18	0.46*		-0.12
	WD	0.12	-0.15	0.01	0.23	0.15	0.11	0.16	0.27	-0.11	
Lwadungu	**HM**		0.10	0.28	0.09	0.03	0.14	0.15	-0.25	-0.19	0.37
	BW	0.03		0.75***	0.72***	0.62**	0.67***	0.69***	-0.26	-0.22	0.53*
	LA	0.19	0.30		0.71***	0.38	0.59**	0.70***	-0.18	-0.01	0.42
	CW	0.32	0.75***	0.20		0.80***	0.94***	0.93***	-0.37	-0.26	0.35
	NR	0.29	0.28	-0.14	0.72***		0.79***	0.82***	-0.49*	-0.47*	0.41
	RL	0.25	0.09	0.03	0.49*	0.76***		0.88***	-0.47*	-0.30	0.33
	RW	0.27	0.43	0.36	0.70***	0.59**	0.64**		-0.33	-0.21	0.26
	RN	-0.08	0.00	-0.12	-0.22	-0.39	-0.41	-0.44		0.68***	-0.48*
	NP	-0.18	0.17	0.21	-0.06	-0.22	-0.19	-0.18	0.75***		-0.40
	WD	0.41	-0.18	-0.29	-0.19	0.54*	0.27	0.11	-0.42	-0.33	
Nakitembe	**HM**		0.02	0.31	0.09	0.14	0.09	0.19	-0.38	-0.15	0.48*
	BW	-0.03		0.48*	0.56*	0.40	0.56*	0.64**	0.06	0.12	0.20
	LA	0.12	0.20		0.42	0.37	0.42	0.65**	-0.13	0.08	0.24
	CW	0.17	-0.13	0.48*		0.84***	0.92***	0.86***	-0.12	-0.28	0.36
	NR	0.27	-0.21	0.10	0.47*		0.84***	0.79***	-0.13	-0.33	0.32
	RL	0.17	-0.13	0.48*	0.89***	0.47*		0.86***	-0.12	-0.28	0.36
	RW	0.21	0.11	0.82***	0.70***	0.37	0.70***		0.03	0.00	0.43
	RN	-0.14	0.35	0.23	0.05	0.19	0.05	0.40		0.75***	-0.18
	NP	0.06	0.10	0.27	0.15	0.11	0.15	0.24	0.63**		0.04
	WD	-0.01	-0.19	-0.10	-0.24	-0.47*	-0.24	-0.21	-0.29	-0.29	
Mbwazirume	**HM**		-0.18	-0.33	-0.19	0.06	-0.21	-0.17	-0.22	-0.30	0.07
	BW	0.42		0.84***	0.77***	0.38	0.61**	0.78***	0.42	0.50*	0.07
	LA	0.60**	0.66***		0.67***	0.03	0.38	0.62**	0.66***	0.74***	-0.31
	CW	0.67***	0.85***	0.79***		0.45*	0.66***	0.87***	0.40	0.31	-0.28
	NR	0.21	0.13	0.12	0.22		0.67***	0.49*	-0.05	-0.12	-0.46*
	RL	0.61**	0.39	0.54*	0.60**	0.57*		0.84***	0.15	0.14	-0.38
	RW	0.67***	0.60**	0.74***	0.78***	0.43	0.86***		0.40	0.33	-0.37
	RN	-0.17	0.16	0.06	-0.06	0.13	-0.17	-0.10		0.89***	-0.34
	NP	-0.01	0.21	0.18	-0.03	-0.25	-0.19	-0.12	0.80***		-0.29
	WD	0.03	0.44	-0.34	-0.18	0.29	0.04	-0.15	-0.07	-0.21	

*, ** and *** Significantly different at P<0.05, P<0.01 and P<0.001, respectively

HM: high mat (%), BW: bunch weight (kg), LA: total leaf area per mat (cm²), CW: corm dry weight per mat (kg), NR: cord root number per mat, RL: cord root length per mat (cm), RW: root dry weight per mat (kg), RN: root necrosis index (%), NP: nematode population densities per 100 g roots, WD: weevil damage (%)

Table 7b. Correlation coefficients between high mat, bunch weight, plant growth traits, root necrosis, nematode numbers and weevil damage for plants growing in well-managed fields (below the diagonal) and poorly-managed fields (above the diagonal).

Genotype		HM	BW	LA	CW	NR	RL	RW	RN	NP	WD
Kibuzi	**HM**		-0.16	-0.24	-0.27	0.01	0.08	0.09	-0.14	-0.14	0.25
	BW	0.03		0.67***	0.25	0.21	0.34	0.67***	-0.44*	0.30	-0.03
	LA	0.05	0.53*		0.37	-0.09	-0.07	0.31	-0.15	0.63**	-0.08
	CW	-0.14	0.50*	0.64***		-0.25	-0.14	0.15	0.01	0.31	-0.24
	NR	0.38	0.05	0.01	0.33		0.75***	0.72***	-0.04	-0.19	-0.03
	RL	-0.14	0.52*	0.14	0.42	0.58*		0.63**	-0.24	-0.26	-0.04
	RW	-0.18	0.54*	0.39	0.70**	0.49*	0.77***		-0.39	0.11	-0.16
	RN	-0.14	0.12	0.31	0.08	0.08	-0.16	-0.03		-0.13	0.10
	NP	-0.33	0.10	0.10	-0.07	-0.06	-0.15	0.02	0.84***		-0.26
	WD	0.48*	-0.21	-0.42	0.44	-0.16	-0.19	-0.41	-0.06	-0.02	
Sukali ndizi	**HM**		0.49*	-0.27	0.39	0.01	-0.09	0.19	0.85	0.19	0.12
	BW	-0.12		0.08	0.61**	-0.02	0.20	0.39	0.54*	0.53*	0.33
	LA	-0.11	0.72***		0.16	0.25	0.27	0.12	0.08	-0.03	-0.02
	CW	-0.17	0.66**	0.43		0.42	0.42	0.55*	0.20	0.22	0.14
	NR	-0.20	0.24	0.22	0.65**		0.75***	0.53*	-0.45*	-0.28	-0.19
	RL	-0.07	0.58**	0.57**	0.53*	0.51*		0.84***	-0.40	-0.13	-0.2
	RW	-0.26	0.75***	0.78***	0.49*	0.28	0.85***		-0.21	0.02	0.10
	RN	0.09	0.16	0.09	-0.19	-0.10	-0.01	-0.07		0.51*	0.35
	NP	0.01	0.24	0.14	-0.04	-0.01	-0.09	-0.06	0.84***		0.12
	WD	0.22	0.08	-0.08	-0.06	0.04	-0.05	-0.05	-0.06	-0.02	
Gonja	**HM**		-0.23	-0.05	-0.47*	-0.48*	-0.34	-0.06	0.06	-0.03	0.30
	BW	-0.01		0.44	0.59**	0.31	0.52*	0.54*	-0.26	0.19	-0.46*
	LA	0.25	0.53*		0.63**	0.13	0.52*	0.73***	0.11	0.16	-0.46*
	CW	0.32	0.64**	0.25		0.68***	0.74***	0.80***	0.10	0.22	-0.51*
	NR	-0.16	-0.05	-0.27	0.17		0.69***	0.49*	-0.10	-0.04	-0.33
	RL	0.05	0.51*	0.18	0.64**	0.49*		0.80***	-0.01	-0.02	-0.40
	RW	0.28	0.59**	0.30	0.88***	0.16	0.80***		0.10	0.37	-0.48*
	RN	-0.09	0.19	0.28	0.02	0.09	0.19	0.10		0.35	-0.08
	NP	0.02	0.39	0.14	0.02	-0.10	0.16	0.13	-0.01		-0.17
	WD	0.57**	-0.04	0.15	0.O4	-0.15	-0.27	-0.22	-0.11	-0.11	
Kayinja	**HM**		0.25	-0.14	0.10	0.07	-0.16	-0.06	-0.03	0.06	0.36
	BW	-0.05		0.82***	0.80***	0.07	0.53*	0.83***	0.34	0.22	-0.30
	LA	0.37	0.48*		0.80***	-0.08	0.53*	0.76***	0.31	0.40	-0.34
	CW	0.42	0.51*	0.66***		0.10	0.70***	0.74***	0.25	0.45	-0.26
	NR	-0.50*	0.28	0.19	0.06		0.53*	0.21	-0.13	-0.06	-0.26
	RL	-0.26	0.64**	0.46*	0.42***	0.79***		0.71***	0.12	0.25	-0.53*
	RW	-0.08	0.73***	0.67***	0.58**	0.48*	0.76***		0.34	0.03	-0.28
	RN	0.38	-0.01	0.15	-0.01	-0.45*	-0.26	-0.04		0.04	0.03
	NP	0.06	-0.10	0.03	-0.16	-0.15	-0.25	-0.25	0.02		-0.06
	WD	0.17	-0.11	-0.22	-0.06	0.11	0.01	-0.13	-0.28	-0.16	

*, ** and *** Significant at P<0.05, P<0.01 and P<0.001 respectively

HM: high mat (%), BW: bunch weight (kg), LA: total leaf area per mat (cm²), CW: corm dry weight per mat (kg), NR: cord root number per mat, RL: cord root length per mat (cm), RW: root dry weight per mat (kg), RN: root necrosis index (%), NP: nematode population densities per 100 g roots, WD: weevil damage (%)

'High mat' was much more pronounced in the AAB and AAA groups than in the ABB group. However, 'high mat' did not influence yield and plant growth traits. Plants may have a survival mechanism whereby the remaining roots elongate to compensate for the reduction in the number of cord roots. In addition, due to the lifelong organic connection between the suckers and the mother plant, suckers can contribute to the nutrition of the mother plant (Teisson, 1970). Nonetheless, 'high mat' may make the banana mat more susceptible to toppling. As the plant ages and gradually grows out of the soil, its potential for producing maximum yields becomes impaired. Therefore, we recommend regular replanting of sections or whole fields every 3-5 years.

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Monitoring and evaluation of farmer participation in on-farm trials of IPM technologies in central Uganda

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Abstract

This paper summarizes results from a monitoring and evaluation study based on field observations of the activities carried out by 180 farmers participating in on-farm trials of technologies to improve banana productivity in Bamunanika sub-county, Luweero District, Central Uganda. The main objective was to determine what farmers do and why, the time taken, the inputs used and the costs incurred. The study addresses two criticisms, namely (a) the lack of a methodology for monitoring and evaluating farmer participation and (b) the difficulty of using objective standards for assessing results or for applying rigorous quality controls. The combination of using observations and interviews allowed self-corrective mechanisms to be introduced into the methodology. Labour is overwhelmingly provided by family members, mostly men attracted by the increasing value of banana sales. Inputs mainly come from the farm, while labour accounts for 90% of total costs.

Introduction

In monitoring and evaluating agricultural research and development, two closely related gaps should always be considered, i.e. experimentation by farmers themselves and a methodology for monitoring farmers' participation, as originally recognised by Okali *et al.*, (1994). These considerations have been tackled by several agencies, including the CGIAR (1997) centres which set up a system-wide program for participatory research and gender analysis. Other agencies have also developed innovative approaches such as participatory monitoring and evaluation, which accords the key role of planning, selection methodology and the assessment of the results from research and development for the primary stakeholders directly affected (IDS, 1998; IIED, 1998) and participatory learning and action, which enables stakeholders to learn from the intervention and take appropriate action of their own. They emphasize the need to create an environment that fosters innovative technological change, the importance of end-user organizations for facilitating co-operation and collaboration (Ssennyonga, 1996), collective action, access to information, markets and credit (Bruin and Meerman, 2001).

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Against this background, two approaches for monitoring and evaluating farmer participation in on-farm trials have been applied. In the first one, all field activities carried out by farmers, their frequency, costs and benefits are observed and recorded by field enumerators and analysed by the authors. In the second one, using in-depth investigations, end-user experimentation is documented both on the formal trial plots and on (participating and non-participating) farmers' own experimental plots. These attendant social processes include the creation of new organizations, marketing arrangements, and the enhancement of the farmers' capacity for informed decision-making. Both approaches aim to determine the extent of participation, which can be affected by gender, ethnicity, social status, age, distance from markets, etc. This paper highlights results obtained by using the first approach. Results from the second approach (in-depth probing) will be presented in another paper.

The overall objective was to assess whether and how participation in on-farm trials will empower the farming community to achieve a sustainable capacity for experimentation and innovation and hence accelerate banana productivity. The specific objectives were:

1. To determine the nature and extent of farmer participation in on-farm trials.
2. To assess the costs and benefits for participating farmers.
3. To disaggregate farmer participation in terms of socio-economic sub-groups.

Materials and methods

NARO researchers held a planning meeting in July 2000 to review the available technologies for reducing constraints to banana production. This was followed by participatory planning meetings between researchers from NARO, ICIPE and IITA, and farmers and local leaders from the 42 villages in the six parishes making up the study area. After evaluating the potential of the available technologies, farmers, in consultation with researchers, selected four treatments: (a) improvement of soil fertility, (b) increased plant nutrition for managing pests and diseases, (c) using exotic high yielding cultivars tolerant to pests/diseases/drought, (d) and improved banana husbandry. Using random methods, 180 farmers in 24 villages were selected to participate in on-farm trials. Subsequently, the researchers designed plot layouts, and educated farmers in a broad range of skills, such as plot preparation and management, improved banana husbandry, and farmer to farmer extension. This was followed by researchers and farmers together inspecting and marking out trial plots, which were planted with banana in October 2000 and April 2001. Planting material, credit and supervision was provided by the researchers.

Data were collected between April and October 2002 among the 180 farmers participating in on-farm trials. Six field enumerators were trained to not only collect data

using formal instruments such as monitoring forms, but also to record events, observations and issues which have a bearing on the on-farm trials. The data collected were discussed with the NARO socio-economist during his weekly supervisory visit to the project area. The specific methods used by field enumerators were as follows. Each field enumerator (n=6) visited 30 farmers per week or six farmers a day. He/she visited the banana plot in the presence of the person responsible for the management of the experimental plot or in their absence, any other person with shared responsibility for managing the plot. The field enumerator would inspect the banana plot to determine whether any activities had been performed since the last visit. Standardized data (age, gender, etc.) would then be recorded on the person(s) who had performed the activities, time taken, reasons for performing them at that time, inputs applied, their costs and benefits, as well as relevant observations such as the quality of work carried out. Subsequently, once every 5-7 weeks, the combined team of NARO and ICIPE socio-economists, (together with one of the statisticians), also visited the project area. A day was spent with the field enumerators who, each in turn, gave reports of (a) their experiences, (b) constraints encountered, (c) evaluation of farmers' performance and (d) relevant field observations. In addition, the socio-economists, statistician and field enumerators visited a sample of farmers, interviewed them and recorded observations of their families, farms and living conditions. Data collected were analysed using largely descriptive statistics and qualitative methods.

Results and discussion

Study population

The domination of the sample population by children is reflected in their high relative share (54.4%). The economically active population, aged 15-64, represents only 44% of the total sample population. Each economically active adult supports almost 1.3 dependants. This ratio would be substantially higher if we discounted the population aged over 14 still at school. The mean age of household heads was 44.0 for men and 42.7 for women. Overall, sex composition was skewed (106 men for every 100 women) possibly due to (a) influx of men from other regions, (b) under-enumeration of women, (c) over-enumeration of men, or (d) a combination of these factors. This age structure reflects a rapidly growing population underlining the need for increasing food production using environmental-friendly technologies, as well as better management of the resource base (Table 1).

Data collected from the population aged more than six years old showed a very high literacy rate of 96%, possibly due to (a) literacy having been a major criterion for selecting participating farmers, (b) the introduction of universal primary education, or (c) a combination of (a) and (b). Sixty-eight percent of people had some form of pri-

Table 1. Number and percentage of men and women in each age group.

Age Group	Men	Women	Men and women
0-4	139 (11.5%)	139 (11.5%)	278 (23.0%)
5-14	181 (15.0%)	198 (16.4%)	379 (31.4%)
15-64	271 (22.4%)	257 (21.3%)	528 (43.7%)
65+	17 (1.4%)	6 (0.5%)	23 (1.9%)
Total	608 (50.3%)	600 (49.7%)	1208 (100.0%)

Table 2. Number and percentage of men and women aged 6 or more who have received formal education.

Educational level	Men	Women	Men and women
No formal education	11(2.4%)	29 (6.3%)	40 (4.3%)
Primary education	318 (67.8%)	311 (67.5%)	629 (67.6%)
Secondary education	101 (21.5%)	105 (22.8%)	206 (22%)
Tertiary education	39 (8.3%)	16 (3.4%)	55 (5.9%)
Total	469 (50.4%)	461 (49.6%)	930 (100%)

mary education and only 6% had a tertiary education (Table 2). High literacy is likely to enhance farmers' participation (e.g. capacity for keeping records) as well as being receptive to adopting new technologies.

Cultural practices

Twenty-two different activities were observed and recorded between April and October 2002, for a total of 5429 observations (Table 3). The distribution by both parish and activity is skewed due to five factors:

1. The number of farmers selected in the six parishes was uneven: Kibirizi (34), Kiteme (52), Kibanyi (28), Kyampisi (52), Mpologoma (28) and Sekamuli (24).
2. Soil fertility and related resources vary between and within parishes and farms, which affects such activities as weeding.
3. The design and nature of activities also affect the frequency with which they are performed. For example, mulching reduces the frequency of weeding. Similarly, manure and husks are applied only seasonally.
4. Differences in the performance of field enumerators may have influenced the number of observations recorded, though no data was gathered to account for this factor.
5. Differences in the farmers' performance would have had an important effect. For example, although 1073 observations were made in relation to harvesting, for recording data and weighing banana bunches only 4 and 53 observations were noted

Table 3. Number of times, and percentage of time, an activity was observed in each parish.

Activity	Kibanyi		Kibirizi		Kiteme		Kyampisi		Mpologoma		Sekamuli		Total	
Coffee husk application	0	0%	0	0%	1	0.1%	0	0%	4	0.3%	4	0.5%	**9**	**0.2%**
Corm removal	0	0%	0	0%	1	0.1%	1	0.1%	40	3.3%	0	0%	**42**	**0.8%**
Data recording	0	0%	0	0%	3	0.3%	1	0.1%	0	0%	0	0%	**4**	**0.1%**
Deleafing	178	28.2%	160	25.4%	215	24.1%	285	22.7%	234	19.6%	204	24.9%	**1276**	**23.5%**
Desheathing	8	1.3%	5	0.8%	10	1.1%	39	3.1%	1	0.1%	1	0.1%	**64**	**1.2%**
Desuckering	12	1.9%	0	0%	88	9.9%	166	13.2%	54	4.5%	53	6.5%	**373**	**6.8%**
Gap filling	3	0.5%	2	0.3%	5	0.6%	0	0%	2	0.2%	5	0.6%	**17**	**0.3%**
Digging pit holes	21	3.3%	8	1.3%	4	0.5%	1	0.1%	128	10.7%	0	0%	**162**	**3.0%**
Harvesting	112	17.7%	111	17.6%	61	6.8%	435	34.6%	212	17.7%	142	17.3%	**1073**	**19.8%**
Manure application	14	2.2%	5	0.8%	28	3.1%	1	0.1%	14	1.2%	39	4.8%	**101**	**1.9%**
Mulching	57	9.0%	39	6.2%	117	13.1%	2	0.2%	66	5.5%	49	5.9%	**330**	**6.1%**
Planting trees	0	0%	0	0%	1	0.1%	0	0%	0	0%	1	0.1%	**2**	**0.01%**
Ploughing	4	0.6%	5	0.8%	19	2.1%	12	0.9%	6	0.5%	2	0.2%	**48**	**0.9%**
Prunning	9	1.4%	35	5.6%	1	0.1%	1	0.1%	37	3.1%	0	0%	**83**	**1.5%**
Pseudostem splitting	6	0.9%	4	0.6%	93	10.4%	50	4.0%	99	8.3%	81	9.9%	**333**	**6.1%**
Rouging	1	0.2%	4	0.6%	1	0.1%	0	0%	0	0%	0	0%	**6**	**0.1%**
Slashing	11	1.7%	18	2.9%	13	1.5%	4	0.3%	15	1.3%	1	0.1%	**62**	**1.1%**
Soil conservation	3	0.5%	4	0.6%	19	2.1%	5	0.4%	18	1.5%	18	2.2%	**67**	**1.2%**
Stump removal	0	0%	0	0%	2	0.2%	0	0%	6	0.5%	4	0.5%	**12**	**0.2%**
Urine application	0	0%	0	0%	3	0.3%	0	0%	0	0%	9	1.1%	**12**	**0.2%**
Weeding	191	30.2%	211	33.4%	206	23.1%	227	18.1%	258	21.6%	207	25.2%	**1300**	**23.9%**
Weighing bunches	2	0.3%	20	3.2%	2	0.2%	26	2.1%	3	0.3%	0	0%	**53**	**1.0%**
Total	**632**	**11.6%**	**631**	**11.6%**	**893**	**16.5%**	**1256**	**23.1%**	**1197**	**22.1%**	**820**	**15.1%**	**5429**	**100%**

respectively. This implies that only a small proportion of the bunches harvested were also weighed. The distribution of mean activities performed by households further corroborates this trend. Mpologoma parish, with the second lowest numbers of farmers, has the highest mean number per household (42.7), followed by Kyampisi (39.2), Sekamuli (34.2), which has the lowest number of farmers, Kiteme (27.9) and Kibirizi (18.6). Further evidence was generated by the in-depth study which showed that a significant proportion of the farmers were not desuckering according to instructions. Instead, more suckers were being kept than recommended, as they were an additional source of income from sales.

The practices shown in Table 4 are classified into six types: (1) sanitation, (2) pest management, (3) weed control (4) disease management through plant nutrition, (5) soil management and (6) others. However, one caveat needs to be stated. Although activities such as mulching and manuring directly enhance soil fetility and should therefore fall under soil management, they were performed during the disease management trials. This is because diseases such as leaf spot diseases are managed through enhanced plant nutrition. In particular, three features stand out prominently. Firstly, noticeable disparities occur in the frequency distribution of observations by activity type; these are explicable by similar factors affecting the distribution of observations by activity.

Secondly, activities for managing important constraints such as pests (7.2%) and soil fertility (5.5%) represent a minor proportion of the total frequencies. This may be because pests did not pose important problems in the first three years, and many of the soil management activities, such as digging trenches and pits, were not performed weekly or fortnightly. In addition, some of the soil management activities such as manuring and mulching are classified under disease management.

Thirdly, sanitation (26%) and weed control (25%) are allocated the highest importance, a finding also reported in the labour allocation study at the Kisekka benchmark site in southern Uganda (Ssennyonga *et al.,* 2003).

Out of a total of 1046 frequencies (of reasons), only 16 (1.5%) referred to the time dimension, the remainder were reasons for performing the activities in question. In this context, we have examined the data from four perspectives. The first perspective was to focus on the 22 activities and the various reasons given by farmers for performing them. Some of these activities are carried out for as many as eight different reasons. For example, deleafing is undertaken to enhance plant health/growth (7), enable plants to capture adequate water run off (19), enhance yield (2), control weeds when leaves are mulched (21), give plant a clean look (35), control pests and diseases (34), comply with NARO instructions (3), remove broken leaves (6), reduce leaves (1) and because it is necessary (3).

Table 4. Distribution of cultural practices.

Sanitation		Pest management		Weed control		Disease management through plant nutrition		Soil management		Others	
Deleafing	23.5%	Corm removal	0.8%	Weeding	24.0%	Manure application	1.9% application	Coffee husk	0.2%	Desuckering	6.9%
Desheathing	1.1%	Pseudo-stem splitting	6.1%	Slashing	1.14%	Mulching	6.1%	Digging pit holes	3.0%	Gap filling	0.3%
Pruning	1.5%	Rouging	0.1%			Fungicide application[1]		Ploughing	0.9%	Harvesting	19.8%
		Stump removal	0.2%			Fertilizer application		Soil conservation	1.2%	Planting trees	0.1%
								Urine application[2]	0.2%	Data recording	0.1%
										Weighing bunches	1.0%
Total	**26.1%**		**7.2%**		**25.1%**		**8.0%**		**5.5%**		**28.0%**

[1]NARO financed and applied the fungicide
[2]Farmers apply urine to control pests

The second perspective was to look at how an end-result can be achieved by several activities. For example, good yields can be achieved by applying manure (2), weeding (7), deleafing (11), desuckering (7) and mulching (10). This perspective highlights the notion that several activities contribute to the achievement of a single end-result. Such a perspective is important as it dispels the notion of a causally linear relationship between an activity and its effect.

The third perspective focused on the distribution of the recorded reasons and their frequencies. In total, 1046 frequencies were recorded, but the distribution by either reasons or activities was very skewed. For example, farmers gave seven reasons for harvesting bananas, accounting for 54.3% of the total. Similarly, examining the activity frequencies carried out for the various end-results revealed a skewed distribution. For example, necessary activities undertaken have a major cumulative share (35%). However, activities performed to control pests and diseases (6.4%), and to increase productivity (6.5%) accounted for only a minor share.

The fourth perspective examined whether the farmers' reasons matched researchers' expectations. It is also necessary to explain the different reasons farmers and researchers gave for undertaking the various activities. For example, farmers state that bunches of bananas are weighed: (a) to comply with NARO instructions (5%), (b) because it is necessary (5%), (c) for sanitation purposes (1%), and (d) to control pests and diseases (1%). Since the researchers aim at getting reliable data on yield and income from different treatments, in this study there appears to be a problem with communication. Researchers should use these results to initiate a dialogue with farmers on the reasons for performing the various activities.

The gender, age and relationship of the people carrying out the observed activities were recorded. Information on the gender and relationship to the head of the household is summarised in Table 5. Family members perform 98.7% of the observed activities, though not in terms of time expended, and most of the family labour is supplied overwhelmingly (95.4%) by the nuclear family. Other relatives contributed only 3.3% of the total number of observations and laborers (mostly women) accounted for only 1.3% of the observations. Finally, a greater proportion of the labour was provided by men (59.3%) than women, mainly because of the growing importance of banana as a cash crop, which attracts men to agriculture. Many women have requested researchers to assist them setting up their own banana plots, an important issue which NARO should investigate.

Table 6 shows that weeding was by far the most time-consuming activity, followed by desuckering, pruning and grass mulching. Three activities with markedly lower time allocations range from digging trenches, manuring and the application of coffee husks.

Table 5. Frequency and relationship to household head (HoH) of the people performing the various cultural practices.

Activity	Men									Women								
	HoH	Son	Grandson	Brother in-law	Uncle	Brother	Laborer	Total	HoH	Wife	Daughter	Niece	Grand daughter	Sister	Mother	Aunt	Laborer	Total
Deleafing	597	29	3	10			1		63	385	61		9		1	2	4	
Weeding	600	152	29	17		3			40	392	148	1	34	1	3	1	33	
Harvesting	336	23							17	237	19		1					
Slashing	21	1		1						3	1							
Coffee husk application	8										1							
Manure	63	4		1					5	15								
Ploughing	21	8		1					3	18	4		1				1	
Desuckering	224	14	2	4	1				5	66	7						5	
Mulching	158	16	4	8					21	66	13		1		1		9	
Pseudostem management	159	13	4						7	45	11						3	
Corm removal	19								1	5	2				1			
Stump removal	7	1							2	1								
Urine										10								
Digging holes	4																	
Rouging	1	1								1								
Trench digging	34	3					2		1	12	2							
Tree planting	2																	
Gap filling	11	1								2	1							
Ash application																		
Fungicide																		
Rubbish refuse																		
Total	2265	266	42	42	1	3	3	2622	165	1258	270	1	46	1	6	3	55	1805
%	51.2	6.0	1.0	1.0	0.02	0.1	0.1	59.2	3.7	28.4	6.1	0.02	1.04	0.02	0.1	0.1	1.2	40.8

Table 6. Time spent performing each activity.

Activity	Time (Hours)
Manuring	488
Desuckering	16 593
Mulching	13 378
Pruning	16 577
Weeding	39 345
Digging trenches	5 455
Coffee husk application	30
Total	91 885

However, these data may have been overestimated by at least one third. This is due to several considerations. Firstly, the maximum number of visits should have been 9360 in a year. Since the recorded time amounts to 91 885 hours, each visit represents 9.8 hours per week or about 2 hours per day. This is unlikely to be the case because independent studies in the Masaka District, southern Uganda show that the total time expended for crop and livestock production is 2 hours per day (Ssennyonga *et al.*, 2003). Indeed, similar studies in Ghana also produced a daily allocation of 2 hours. Secondly, the experimental plots are on average only 0.25 acres. Thirdly, up to 50% of the plots are mulched, reducing the budget for weeding substantially. Hence, in the second round of monitoring and evaluation, field assistants will be trained to work with farmers to calculate more efficiently the time taken for undertaking the various activities rather than simply recording farmers' time estimates.

Inputs

Information on the sources of inputs (Table 7) was sought because it is an important indicator of agricultural sustainability. The fact that 78% of inputs were obtained from

Table 7. Sources of farm inputs.

Inputs	Purchase		Donation		Own farm	
	Frequency	%	Frequency	%	Frequency	%
Grass mulch	8	4.8	31	18.6	128	76.6
Ash	0	0	0	0	1	100
Pesticide	1	33.3	2	66.7	0	0
Rubbish/Refuse	0	0	0	0	6	100
Fertilizer	1	11.1	8	88.9	0	0
Urine	1	5.9	0	0	16	94.1
Coffee husks	10	76.9	0	0	3	23.1
Manure	5	3.9	8	6.2	116	89.9
Total	**26.0**	**7.5**	**49.0**	**14.2**	**270.0**	**78.3**

the farming system, as well as being renewable, is highly indicative of a self-sustaining system, though this reveals little about the adequacy of inputs. The second most important source of inputs were obtained from other farmers, such as grass mulch (63.3%) and manure (16.3%), as well as from NARO (fertilizers and fungicides, 20.4%). In addition, marginal (8%) sources of inputs, such as coffee husks comprise 77% of this category. Finally, it was noticeable that the overwhelming proportion (85%) of observations were recorded on grass mulch (48%) and manure (37%), which is probably a reflection of the importance they are given in soil management and plant nutrition for disease control. Pests were not considered an important constraint.

Eight inputs are listed in Table 8 with their respective quantities and costs. In order to gain a clearer understanding of the data presented, additional contextual information is required, such as the frequency of application, amount applied, number of farmers expected to apply the various inputs, and area to be served. This information has not yet been compiled but will be incorporated into the next round of data analysis. For purposes of estimating costs, the focus is placed on the quantities applied and associated monetary expenses. Regarding the quantities, only three inputs, namely coffee husks, mulch and manure are used in relatively large amounts. Not surprisingly, the same three inputs also have the highest costs, which include transport. Finally, the expenditure of artificial fertilizers and fungicides is financed by NARO. Urine and ash are farmers' own innovations. Urine, which is applied to manage pests such as weevils, is, according to NARO researchers, more effective as a plant nutrient source (potassium) than as a pest control agent.

Coffee husks are the most costly input because in 77% of the cases, they are bought, as well as requiring motorized transport due to distance. The second most costly input is grass mulch despite the fact that in 77% of the cases it is obtained from the farm.

Table 8. Quantity and cost of inputs.

Input	Quantity	Cost (Ug Shs)
Coffee Husks	39 381 kg	964 842
Manure	171 619 kg	377 562
Grass mulch	38 466 bundles	692 369
Fertilizer	173 kg	86 355
Urine	787 drums	5 113
Waste from kitchen	893 kg	*
Ash	171 kg	*
Fungicides	5 L	40 000
		2 166 268

*cost was not estimated

However, the major cost element is the intensity of labour required to carry it from the valley floor to the banana plot. The third most costly input is manure, which, although 90% of it originates from the farm, is labour intensive, often requiring transport by wheel barrow. Fungicides and fertilizers are supplied and applied by NARO. The cost of ash and kitchen waste (e.g. peelings, leftovers, etc.) has still to be estimated.

The cost schedule (Table 9) of certain cultural practices resembles the labour budget profile. Weeding is the most costly activity, followed by desuckering, pruning and mulching, digging trenches, manuring and coffee husk application.

Table 9. Cost of labour for various activities.

Activity	Cost (Ug Shs)
Manuring	107 360
Desuckering	3 650 460
Mulching	2 943 160
Pruning	3 646 940
Weeding	8 655 900
Digging trenches	1 200 100
Coffee husk application	10 780
Total	**20 214 700**

Cost-benefit analysis

The total number of banana bunches produced was 15 780. At a mean price of Ug Sh 1469.4 per bunch the income from the sale was Ug Sh 23 187 388. On the basis of the total number of sellers, the total and mean number of bunches sold, and the total and mean income earned, the six most important East African highland banana (EAHB) cultivars (out of the 16 evaluated) were: Mpologoma, Kisansa, Atwalira, Mbwazirume, Kabana 3, and Nnakitembe. By contrast, Siira, Saba, Pita, Musakala and Kabana 4 were the poorest performers. The income generated from brewing beer and selling banana leaves has not been collected in this study, though this will be dealt with in an investigation to follow.

The total number of suckers sold was 44 360 (26% of the number of suckers produced were sold, 55%were given away for free and 9% were used in their own new plots etc). At an average price per sucker of Ug Sh 380 (NARO pays Ug Sh 300 for a sucker, whereas farmers pay Ug Sh 420), the sale of suckers generated Ug Sh 16 857 098. On the basis of the number of sellers, total and mean number of suckers sold, and the total and mean income earned, the six best EAHB cultivars were: Kabana 3, Mpologoma, Kisansa, Nnakitembe, Mbwazirume and Atwalira. Conversely, Saba, Pita, Musakala, Siira and Kabana 1 were the poorest performing cultivars. Considering that the suckers were sold several months after planting, their contribution to cash income was significant. Combining the sale of bunches and suckers amounted to a gross income of Ug Sh 40 044 486 (US$ 22 883). the large volume of 52,326 suckers

Capital costs were not estimated because many of the implements were also utilized in the cultivation of other crops, including bananas produced on non-experimen-

tal plots managed using traditional husbandry. Separating these costs would have taken a disproportionately large amount of time for a non-economic study such as this. As a result, only inputs and labour have been estimated and they add up to Ug Sh 22 380 968.

The net income was Ug Sh 17 303 518, or a benefit/cost ratio of 1.8. If labour costs had been reevaluated downwards by a third, to be more realistic, the benefit/cost ratio would have been 2.5. Hence, both results are much higher than the estimated benefit/cost ratio of 0.97 for banana production in a baseline study from the same area (Bagamba *et al*., 2000). Banana production is not only a lucrative enterprise, but probably surpasses economically all other crops grown in the area, including coffee.

Conclusion

The use of bananas for home consumption (47%), selling (35%), giving (8%) and beer brewing (3%) has brought considerable benefits to the community in only two years. Nevertheless, several aspects of post harvest utilization present major challenges to researchers. The methods used to distil gin from banana juice pose both health and safety hazards. Furthermore, more efficient ways of extracting juice should be examined. Beer brewing has been neglected by post-harvest programmes. Equally neglected is the feasibility of processing textiles from banana fibre to add value to, and income from banana production.

Although this study did not focus on social benefits, the results highlight two important aspects. Firstly, the farmers must be able to feel that they are better off using the technology, and this can only take place when they perceive that the benefits outweigh the costs. Consequently, their own financial and management resources will be used to experiment with the technology. Secondly, they must be convinced that the technology is reliable. The information gathered clearly shows that the farmers met almost all the financial and labour costs from their own resources. Furthermore, during numerous meetings, the community delivered the following challenge. If researchers could demonstrate technologies for enabling farmers to grow bananas productively for more than three years, the farmers would invest more resources into banana production, but only after solving the food problem. Indeed, one of the most unforgettable impressions gained during the field visits was the optimism and enthusiasm shown by farmers, who confidently asserted that this time round, they would be able to grow bananas productively for more than four years. In addition, they talked about achieving poverty reduction and food security, constructing better homes or rearing improved livestock. They also derived satisfaction from the social recognition. These subjective assessments of benefits are crucially important as they influence the actions that may bring about material rewards.

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The contribution of soil quality to yield and its relationship with other factors in Uganda

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Abstract

In Uganda, highland banana yields (5-30 t $ha^{-1}yr^{-1}$) are low in comparison to potential yields (70 t $ha^{-1}yr^{-1}$) due to high pest and disease pressure, soil fertility decline, and poor management. Although it is generally accepted that soil exhaustion is a major cause of low and declining yields, there are almost no data to demonstrate this relationship. Most studies show that banana soils are relatively fertile and often contain sufficient nutrients for optimum growth. Nonetheless, K, N and Mg deficiencies are commonly detected in fertilizer trials and banana foliar samples. The growing commercialization of banana increases the export of plant nutrients from the farms to the urban centers. Contrary to commercial production in most parts of the world, Ugandan banana growers do not use chemical fertilizers to replenish soil nutrient stocks. Instead, they rely on organic supplements, causing further soil fertility decline of annual cropped fields and grassland. Although nutrient losses can be minimized with improved organic matter management, sustaining long-term soil fertility without the use of external inputs seems unlikely. There is evidence showing that pest and disease pressure are closely related to soil fertility and plant nutrient uptake. However, the functional relationships between pests, diseases and soil fertility problems are yet to be resolved. When developing improved crop management options, it is necessary to address pest, disease and soil problems in an integrated way.

Introduction

East African highland bananas (AAA-EAHB) are one of the most important food crops in Uganda, where consumption varies between 150 and 500 kg per person per year (Tushemereirwe *et al.*, 2001). However, there is growing concern over the sustainability of the current production systems, as low and declining yields have been reported in various areas.

Reports on yield decline in central Uganda date back from as early as 1940-1950 (McMaster, 1962; Masefield, 1949), but this phenomenon seems to have accelerated in the 1970s and 1980s (Gold *et al.*, 1999b). During the same period, the banana has

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become an important cash crop with increasing production in southwest Uganda, as farmers supplied expanding urban markets in central Uganda. Although estimates of yield decline in the literature vary widely, the best estimate is that average yields in central Uganda declined from around 9 t $ha^{-1}yr^{-1}$ before 1970 to 6-7 t $ha^{-1}yr^{-1}$ in 2005. A 20-30% decline may seem dramatic, but recorded yields in central Uganda have never been high, in comparison to southwest Uganda. Current yields are around 17 t $ha^{-1}yr^{-1}$ in the Masaka district (Tushemereirwe *et al.*, 2001) and increase to 30 t $ha^{-1}yr^{-1}$ or more moving southwest to the Bushenyi and Ntungamo districts. In spite of reported yield declines in southwest Uganda (Gold *et al.*, 1999a), the question remains why yields in central Uganda are low in comparison to the southwest.

Although uncertainties exist over the size and the areas of yield decline, it is clear that yields are far from the 60-70 t ha^{-1} yr^{-1} that have been achieved on stations (Tushemereirwe *et al.*, 2001) and on farms (Smithson *et al.*, 2001) in Uganda. It is generally agreed that banana productivity problems are induced by a combination of pests, diseases, poor soil fertility and drought stress. Many of these factors can be largely influenced by farm management. There are numerous reports (e.g. Gold *et al.*, 1999a) which state that during the last few decades, banana management has deteriorated in central Uganda and is, therefore, at the root of banana productivity problems. There have also been extensive research reviews on banana pests and integrated pest management in recent years (e.g. Jones, 2000; Talwana, 2002; Gold *et al.*, 2003).

Compared to integrated pest management (IPM), relatively little research has been conducted on soil quality constraints, especially in the East African highland banana systems. For example, since 1990, although more than 15 doctoral students have addressed IPM in highland banana systems, to our knowledge, only one has focused on soil fertility. The objectives of this paper are: (i) to give an overview of soil quality constraints in Ugandan banana systems, (ii) to identify soil fertility research gaps and (iii) to investigate how soil quality issues are interlinked with pests and diseases, giving an outlook on what this means in terms of future research and farm management.

Soil quality constraints

The hypothesis that soil fertility reduction contributed to declining banana yields in central Uganda was first advanced by Masefield (1949) and McMaster (1962). Over the last fifty years, this hypothesis has been repeated so often (e.g. Bekunda and Woomer, 1996; Sseguya *et al.*, 1999), that it has virtually been accepted as an established fact. However, there are little data supporting this soil fertility decline hypothesis in the banana growing regions of Uganda. In central Uganda, Smithson *et al.* (2001) compared historical soil data from 186 banana fields in 1968 with soil data from 152 banana fields analysed between 1995-1998, and found no significant decrease in soil fertility status,

or in the nutrient concentrations of banana leaves. In 2000, Ssali and Vlek (unpublished) resampled soils from 149 agricultural fields in Uganda that were originally analysed in 1960. They found that the soil organic matter content had not changed, though soil pH, Ca and K had decreased, most notably in the Victoria-Lakeshore region, where banana-coffee based systems are common.

Most highland bananas in Uganda are grown on ferralsols and acrisols (UNESCO, 1977). These soils have a low inherent fertility and nutrient availability largely depends on mineralization of the soil organic matter (Sanchez *et al*., 1989). In Uganda, a substantial proportion of bananas are grown in plots near the homestead (Rufino, 2003), which receive organic domestic residues, as well as being more frequently mulched than plots further away. Bekunda and Woomer (1996) and Wortmann and Kaizzi (1998) also showed that most farmers transferred annual crop residues to their banana fields. This may explain why banana fields in general and homestead plots in particular contain more nutrients (especially P and K) than annually cropped fields and other plots further away (Bosch *et al*., 1996; Wortmann and Kaizzi, 1998; Rufino, 2003).

Researchers worldwide (e.g. Twyford, 1967; Walmsley et al., 1971; Lahav and Turner, 1983; Bertsch, 1986; Landon, 1991; Rubaihayo *et al*., 1994; Delvaux, 1995; Lopez and Espinoza, 2000) have published guidelines for the interpretation of chemical soil data for banana farmers. These guidelines were mostly addressing commercial AAA-banana plantations. Although, there is sometimes large variability in the minimum soil requirements that different authors published (e.g. exchangeable K vary from 0.2 to 1.5 mEq/100g dry soil), the average banana soil in Uganda (e.g. Rubaihayo *et al*., 1994; Bananuka and Rubaihayo, 1994a; Wortmann and Kaizzi, 1998; Smithson *et al*., 2001; Rufino, 2003) has optimum soil fertility according to the average of the guidelines (Table 1). This might partially explain why Bananuka and Rubaihayo (1994a), Smithson *et al*. (2001) and Rufino (2003) found such poor correlation between soil fertility parameters and bunch yields. Smithson *et al*. (2001) in Rubale, and Okech *et al*. (2004b) in Mbarara also found that the banana response to K fertilizer was not related to the initial or final soil K status. Thus, although it seems as if most banana soils in Uganda have a reasonable soil fertility status when compared to the

Table 1. The average of the minimum soil requirement for AAA bananas based on a number (n) of studies worldwide (3 < n >10) and the average composition of top soils in Ugandan banana plots (7 < n > 13).

	pH	N	K	Ca	Mg	P*	Zn
		(%)	(meq/100g dry soil)			(mg/kg)	
Guidelines	5.1	-	0.6	3.0	0.9	8	3.0
Uganda	6.0	0.13	1.3	5.9	2.0	23	-

* Extraction methods for available P were not always properly indicated. Hence, values are only indicative.

literature guidelines, conclusions drawn from soil chemical analysis alone in relation to banana nutrient deficiencies should be viewed with caution.

Instead of trying to detect nutrient deficiencies through soil analysis, many researchers have focused on foliar analysis (e.g. Wortmann *et al.*, 1994; Bosch *et al.*, 1996; Smithson, 2001; Rufino, 2003; Smithson *et al.*, 2004). However, the use of foliar analysis is ambiguous, as plant nutrient concentrations vary as a function of: (i) plant part, (ii) age and stage of the plant, (iii) temperature, (iv) soil matrix potential (i.e. water stress) and cultivar. Furthermore, the plant regulates growth so as to maintain a minimum nutrient concentration or ratio in the plant, making it difficult to detect how severe the deficiency is. Nonetheless, there are ways to overcome some of the above-mentioned constraints, e.g. by sampling at a specific time and by looking at nutrient ratios (diagnosis and recommendation integrated system – DRIS – norms) rather than at absolute nutrient concentrations (Sumner, 1979). In Uganda, most of the studies that used foliar analysis (e.g. Smithson *et al.* 2001; Ssali *et al.*, 2003; Rufino, 2003; Smithson *et al.*, 2004) identified K as a major constraint, often followed by N and Mg. However, it should be noted that the threshold values for foliar K in AAA-EAHB established by Wortmann *et al.* (1994) have yet to be confirmed. Although phosphorus deficiency does not seem to be a frequent problem for East African highland bananas, little research has been conducted on micronutrients. Bosch *et al.* (1996) found very low Zn and Cu in comparison to DRIS norms established for other AAA cultivars.

A third way of identifying nutrient constraints is by conducting fertilizer trials. Zake *et al.* (2000) found marked increases in highland banana yields over time when different K applications (25-200 kg ha^{-1} yr^{-1}) were combined with a standard 100 kg ha^{-1} N and P application. After four years, the yields in the K fertilized plots (25-32 t ha^{-1} yr^{-1}) were up to 60% higher than compared to the control plots (12 t ha^{-1} yr^{-1}), with minor differences between varying K doses. These trials imply that only small K doses were enough to eliminate K deficiency and that other constraints were limiting when minor doses of K were applied. Rubaihayo *et al.* (1994) found that fertilizer alone (100g N, 100g P, 200g K per stool) increased yields from 10 to17 t ha^{-1} yr^{-1}. A yield increase from 12 to 16 t ha^{-1} yr^{-1} was observed when 100 kg N, 50 kg P and 100 kg K ha^{-1} yr^{-1} were applied on a K-deficient soil in an on-station trial in Mbarara (Okech *et al.*, 2004b). However, yield increase due to fertilizer application is not always the case. Ssali *et al.* (2003) noted very little effect of mineral fertilizer application (50 kg N, 15 kg P, 50 kg K, 12.5 kg Mg ha^{-1} yr^{-1}) in weevil-infested fields. Similarly, Smithson *et al.* (2001) reported that mineral fertilizers only increased yields significantly when nematode and weevil pressure were low. Furthermore, Smithson *et al.* (2004) found that applying 100 kg ha^{-1} yr^{-1} K fertilizer increased yields by 24-37% in comparison

to a control that also received 100 kg N and 25 kg P ha^{-1} yr^{-1}, but application of a Mg-sulfate fertilizer did not increase yield, despite the presence of a DRIS-identified Mg deficiency.

In years with severe drought, Okech *et al.* (2004b) concluded that fertilizers did not significantly increase yields. Hence, moisture stress was not the yield-limiting factor in non-mulched plots in this case. Mcintyre *et al.* (2000) and Ssalli *et al.* (2003) observed that soil water recharge and, thus, the quantity of plant available water was higher in mulched than non-mulched plots. Bananuka and Rubaihayo (1994b) attributed a 66% yield increase between distant and homestead plots as the latter received higher quantities of mulch greatly improving moisture retention. Although, soils near the homesteads were more fertile, they hypothesized that most soil nutrient concentrations were still high enough in the more distant plots and, therefore, could not have caused the poorer yields. Hence, Rukazambuga *et al.* (2002) attributed lower yields in intercropped non-mulched banana plots to increased moisture and nutrient stress, in comparison with the higher yields of the non-intercropped mulched plots.

Apart from the chemical soil quality, soil physical properties play an important role in banana systems, as these characteristics largely determine how much water is available for the banana plants. Bananas need 25 mm of water per week for satisfactory growth (Purseglove, 1985), which corresponds to 1300 mm per year when evenly distributed. In most of the banana-growing regions in Uganda, annual rainfall varies between 1000 and 1300 mm per year, with the exception of areas in the far southwest and Mount Elgon where rainfall can reach 1500 mm per year. Banana growing areas in Uganda experience a bimodal rainfall pattern, with dry spells in June-July and from December to February. Hence, the annual rainfall is often below the optimum and the presence of dry spells can cause serious moisture stress. Bananas have a very shallow rooting system with 60% of the water extracted from the top 30 cm of the soil (Landon, 1991). Furthermore, bananas are not efficient at extracting water from drying soils (Landon, 1991), making them much less tolerant to drought than most other crops in Uganda. Therefore, the soil's infiltration rate and water holding capacity are important factors that can largely influence how much drought stress a banana plant will experience. Nonetheless, moisture stress has received relatively little attention in Ugandan banana research. Serious moisture stress in the dry season was confirmed by Rubaihayo *et al.* (1994) who deduced that bananas in mulched plots performed better due to moisture conservation. Similarly, Bananuka and Rubaihayo (1994a) and Zake *et al.* (2000) showed that a (partial) surface application of coffee husks outperformed complete incorporation into the topsoil, which suggested that not only nutrient deficiency, but also moisture (retention) was a limiting fac-

tor. McIntyre *et al.* (2000) also observed higher yields in mulched plots, with soil humidity generally lower in the mulched plots due to better plant growth and higher transpiration rates.

Potential soil fertility constraints and research gaps

Conflicting reports on the severity of soil fertility constraints give the impression that these constraints might not be very important. Does this mean that there is, or will be, no soil fertility problem? Not necessarily. Even if nutrient deficiencies are not the main cause of the current yield gaps, there remains a high probability that nutrient deficiencies will become more important in the near future.

Nutrient cycling is highly dynamic in banana-based cropping systems, due to the continuous presence of large amounts of fresh biomass, and a relative small proportion of edible dry matter; i.e. only 22% of the dry matter from a mature banana plant is pulp (Yamaguchi and Araki, 2004). Hence, the recycling of dead leaves and pseudostems, as well as banana peels is essential for the maintenance of nutrient levels within the cropping system. However, with the need to feed rising urban populations this system is under increasing pressure. As banana exports from rural areas to urban centers mount, more nutrients are removed from the farm and remain dispersed in pools from which recycling back to agriculture is barely feasible (Bekunda and Manzi, 2004). For example, banana bunches, especially the peel, are particularly rich in K and exportation of this element is of major concern. If the nutrients exported from banana fields (Table 2) are not replenished by organic or inorganic fertilizers, this leads to the overexploitation of soil nutrient stocks and inevitably to yield decline in the long run. This trend of nutrient mining can be observed in many African farming systems (Smaling, 1993). In order to compensate for nutrient loss, Smithson and Giller (2002) have supported the judicious use of mineral fertilizers to maintain soil fertility, as they consider that the application of organic fertilizers and leguminous crops is important, but cannot compensate for the overall loss in most cases.

Most banana farmers realize that it is essential to retain banana trash in the field and to add large quantities of organic amendments to maintain soil fertility. Bekunda and Woomer (1996) observed that banana farmers in the Lake Victoria Basin of southern-central Uganda have increased the use of organic matter resources over time to improve and maintain soil fertility. In their study, farmers who did not apply large quantities of organic matter (especially cattle manure) produced much smaller bunches (13 kg) as opposed to farmers who did (20 kg). However, the differences in banana yield were partly offset by the higher plant densities in plots with less organic matter inputs, and other agronomic practices (e.g. crop sanitation) might work better for farmers investing in soil organic matter management. Certainly, the use of cattle manure is closely

Table 2. Estimated average nutrient uptake in kg/ha by the fruit and whole plant when yield is 50 t/ha, calculated on the basis of average literature values on AAA bananas worldwide.

	N	P	K	Mg
Uptake by fruit	104	10	285	13
Uptake by whole plant	309	37	1018	55

Table 3. Fertilizer recommendations in Uganda and worldwide. The average worldwide recommendation is based on 18 sources from America, Asia, Africa, and Australia. Please note that N, P and K are in kg ha^{-1} yr^{-1} element and not in kg P_2O_5 and K_2O.

Cultivar	Source	N	P	K	Mg
AAA-EAHB	NARO (for Uganda only)	150	25	100	15
AAA dessert types	Worldwide (18 studies)	306	42	460	60*

*On soils with sufficient Mg supply, application of Mg fertilizer is often omitted.

related to the farm size (Bekunda and Woomer, 1996; Sseguya *et al.*, 1999), suggesting that animal excrement can only be part of the solution as increasing population densities tend to decrease farm size. Furthermore, Wortmann and Kaizzi (1998), noted that livestock contributes little to the flow of nutrients between farms in eastern and central Uganda.

Wortmann and Kaizzi (1998) reported that the loss of N and P at four Ugandan banana sites was compensated by the large amounts of organic materials that are transferred from other land use types (annual crops, grassland) to the banana farm. Although N and P balances might sometimes be positive for banana production, the transfer of nutrients from annual crop and grassland plots to banana plots leads to an acceleration of soil exhaustion in the majority of the farmland. As a consequence, a general decline in soil nutrient stocks at the farm level cannot be prevented. In addition, soils under annual crops lose many nutrients through harvest and erosion (Wortmann and Kaizzi, 1998); this process is further accelerated when vegetation cover is reduced due to soil fertility decline. Although Lufafa *et al.* (2003) calculated that soil erosion under banana was only a third of the erosion losses from annual cropland in the Lake Victoria Basin in Uganda, nutrient losses from erosion of banana fields can still be substantial due to the relative high nutrient concentrations in the topsoil.

Commercial banana cropping has a much longer history in Latin America and other tropical regions, as well as being carried out on large-scale farms. However, the export of banana bunches (mostly AAA dessert types) to local urban centers, and Western countries has not led to a massive yield decline, as large quantities of mineral fertilizers are used by most commercial banana farmers (Table 3). However, in the Lake Victoria Basin in Uganda, less than 5% of banana farmers use mineral fertilizers (Bekunda and Woomer, 1996). Similarly, Sseguya *et al.* (1999) observed in his survey that less than

1% of the banana farmers in Mukono district use mineral fertilizers. Indeed, the use of fertilizers in Uganda is probably among the lowest in the world. Both Bekunda *et al.* (2001) and Sseguya *et al.* (1999) showed that the non-availability of credit is one of the major constraints for the adoption of mineral fertilizers. Furthermore, Bekunda and Woomer (1996) concluded that there is a lack of research on optimal fertilizer recommendations for banana, as well as farmers often not knowing which fertilizers to use and how to apply them. The long duration of the banana crop cycle may also hamper the adoption of fertilizers, since farmers require significant patience before they see any returns to fertilizer investments. Even those farmers that used mineral fertilizers were putting more emphasis on N fertilization than on P and K fertilization (Bekunda and Manzi, 2004). However, this latter study agrees with Wortmann and Kaizzi (1998) that in the long term, there is a greater need for the use of P and especially K fertilizers, than for N fertilizers.

Soil quality issues, and pests and diseases

All pests and diseases influence soil fertility in an indirect way through the reduction of plant growth. Smaller plants take up less nutrients, thus depleting the soil fertility stocks less rapidly. However, nutrients that are not taken up can be leached or eroded from the soil, allowing them to be lost from the system completely, whereas nutrients in the standing biomass (except for the bunch in most cases) can be recycled as crop residues after harvest. Nutrient losses due to erosion and leaching can also be accelerated when the banana canopy opens up due to poor growth. As an additional consequence, the reduction of self-mulching and the increase in radiation raise soil temperature and enhance mineralization of organic matter. There is ample evidence that bananas are soil surface feeders (e.g. Ssali, 1977; Kashaija *et al.*, 2004). If plants do not take up the nutrients released during mineralization, then these nutrients can be lost from the system through erosion and leaching. Hence, any pest or disease that reduces banana biomass production and canopy cover can trigger a process of reduced nutrient cycling and increased nutrient losses through erosion and leaching. Although parts of this hypothesis have been put forward earlier (e.g Swennen *et al.*, 1988), the effects of pests and diseases on nutrient cycling have not been quantified yet.

Weevils

The banana weevil, *Cosmopolites sordides* (Germar), is the most important insect pest of bananas. The larvae bore into the corm, reducing nutrient uptake and weakening the stability of the plant, which leads to reduced bunch weight and mat die-out (Gold *et al.*, 2003). Okech and Gold (1996) concluded from a literature review that phytophagous insects are sensitive to nutritional changes in host plants. Bosch *et al.* (1996) suggested that weevil damage might be related to plant and soil phosphorus, and cation con-

centrations, with special emphasis on the K/Mg ratio. Bosch *et al.* (1996) cited earlier studies by Borges Perez *et al.* (1983), who had suggested similar relationships between plant and soil P, Zn, Mg and K content, and the ability of a plant to close off infected or damaged cells with pectin and tylose (gel substances). However, the relationship between plant nutritional status and damage by weevil infection has never been confirmed. On the contrary, Smithson *et al.* (2004) applied different doses of K and Mg fertilizers, but saw no effect on foliar concentrations or weevil damage. Similarly, Ssali *et al.* (2003) noted no effect of organic and inorganic amendments on the percentage weevil damage. In addition, Rubaihayo *et al.* (1994) found about 50-60% more weevils in plots closer to the homestead than plots at a distance; this was attributed to more favorable micro-environments created by the input of household residues near the homestead. Nevertheless, despite the increased weevil pressure, yields in the homestead plots were about 25% higher.

Even if no direct link has been proven between plant nutrition and weevil damage, several studies have indicated that reducing weevil pressure greatly enhances the benefits of any inorganic and organic soil amendment. Although, Rukazambuga *et al.* (2002) demonstrated that relative banana yield loss was similar for intercropped bananas receiving no external input and those receiving mineral fertilizers and mulch, absolute yield loss (in t ha^{-1} yr^{-1}) due to weevils was twice as high in the plots in which external inputs had been used. Similarly, Rubaihayo *et al.* (1994) found in on-farm trials that fertilizer alone increased yields from 10 to 17 t ha^{-1} yr^{-1}, and when combined with pesticides or pesticides and mulch, yields increased to 23 t ha^{-1} yr^{-1} and 32 t ha^{-1} yr^{1} respectively. However, Smithson *et al.* (2001) concluded that where pest levels were already high, it was not economical to apply fertilizers. Hence, soil fertility management should be combined with weevil pest management to increase the profitability of soil fertility intervention.

Nematodes

The root burrowing (*Radopholus similis*) and root lesion (*Pratylenchus goodeyi*) nematodes affect root growth and the ability of roots to take up nutrients. Talwana (2002) investigated the relationship between nematode infection, root necrosis and nutrient concentrations and uptake. His results were conflicting in that reduced plant N and P concentrations were found in nematode treatments, but these declines were mostly not significant. Moreover, plants infected with nematodes showed better plant growth, indicating that nutrient uptake was hardly affected. In addition, Talwana (2002) observed higher Ca concentrations in nematode infected plants and hypothesized that Ca plays a role in the plant defence mechanism caused by physiological stress of the cell membranes. Similarly, Bwamiki (2004) suggested that mechanisms of nematode suppression are linked to K, Ca, Mn and Zn uptake. Bwamiki (2004) also found that

nitrate-based fertilizers produced higher biomass, and lower nematode damage and populations in comparison to ammonium-based fertilizers.

In a nutrient solution experiment, Talwana (2002) confirmed that the negative effect of nematodes could partly be mitigated through an increased application of plant nutrients. Not only did plants grown in a medium with high nutrient concentrations grow better, but the nematode numbers in the fresh roots also decreased with increased nutrient concentration. In a field trail, Bwamiki (2004) confirmed that a balanced fertilizer application (268 N, 26 P, 38 K, 55 Mg, 70 Ca, 55 S kg ha^{-1} yr^{-1}) not only produced higher yields when compared to farmer practices (no fertilizer) or a tentative recommendation (150 N, 25 P, 100 K, 15 Mg, kg ha^{-1} yr^{-1}) by the National Agricultural Research Organisation (NARO), but also reduced nematode damage to similar levels as occurred in nematicide treated plots. Hence, the work of Talwana (2002) and Bwamiki (2004) suggests that balanced plant nutrition improves plant resistance to nematodes. Micronutrients might play a vital role in this, but the underlying processes have not yet been identified.

McIntyre *et al.* (2000) recorded that nematodes did not affect root biomass, aboveground biomass or plant nutrient concentrations in an on-station trial. However, root necrosis significantly increased with nematodes. This led to a significant yield decrease in mulched but not in bare plots. Hence, there was significant interaction between mulch and nematode inoculation. These results are in line with those mentioned for weevils, in that soil fertility amendments (both organic and inorganic) have a higher beneficial effect when combined with measures that reduce pest pressure.

Fusarium wilt

Fusarium wilt is widespread in East Africa, but it is still found primarily on recently introduced susceptible cultivars (Ploetz, 1993). It is caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cubense* (Smith) and the disease pressure appears to be lower in clayey soils with a high fraction of the mineral, montmorillonite (Toussoun, 1975). Borges Perez *et al.* (1983) discovered that unbalanced P/Zn and K/Mg ratios led to Fusarium wilt in a cultivar that was supposed to be resistant. Similarly, Hecht Buchholz *et al.* (1998) found that Zn-deficient bananas were more affected by fusarium wilt than non-deficient plants. Hence, there are several indications that certain soil characteristics favour the presence of fusarium wilt, though the data are scanty and no soil management recommendations have yet been made.

In Rwanda, farmers consider that the exotic beer bananas (ABB), which are susceptible to fusarium wilt, grow better on poor soils than the AAA-EAHB beer bananas (Okech *et al.*, 2004a). The farmers' observations are in agreement with the lower plant nutrient concentration requirements of AB and ABB bananas in comparison with AAA bananas

(Bosch *et al.*, 1996; Lahav, 1995), which suggests higher nutrient efficiency of AB and ABB bananas. Hence, in Rwanda, fusarium wilt incidence will likely be higher on poor soils, due to the relative larger proportion of ABB bananas, though this does not necessarily imply that fusarium wilt is related to soil nutrient status.

Banana streak virus

Banana streak virus (BSV) is primarily spread by vegetative propagation (Jones, 2000) and no mention has been made so far of links with soil characteristics or management. However, preliminary results from Murekezi (pers. comm.) based on an on-station trial in Kawanda in Uganda indicates that the relative yield loss due to BSV decreases from around 30% to 10% when soil management is improved through the application of fertilizers and a thick mulch layer (10 cm). Why disease expression is reduced when soil management is improved is yet unknown.

Black Sigatoka

Black Sigatoka, or black leaf streak, was first reported in Uganda in 1990 (Tushemereirwe and Waller, 1993), with the leaf spot disease reducing plant photosynthesis and growth. The disease can be chemically controlled on plantations (Jones, 2000), as well as by cultural control practices including deleafing and decreasing the humidity of the air and soil (Jones, 2000). Humid soils and leaves tend to favour the growing conditions and spore formation of the fungi causing the disease. The effects of the disease can be partially mitigated by the use of fertilizers, as this increases the rate of leaf production, which helps maintain photosynthesis at adequate levels. However, no clear functional relationship with soil fertility has been established to date.

Banana bacterial wilt

This disease broke out in the Mukono district, central Uganda, in 2000 and has spread rapidly to the neighboring districts over the last three years. Bacterial wilt infects all banana types and is most likely spread by infected tools, infected planting material, as well as insects, cattle and humans if they come into contact with infected plants (Tushemereirwe *et al.*, 2003). So far, no relationship with soil characteristics has been established.

Conclusions and research outlook

Although it is generally assumed that soil fertility decline has been one of the major causes of banana yield decline in Uganda, there is little evidence to support this assumption. Most banana fields can be found on highly weathered soils with low inherent fertility. However, given the proximity of many banana fields to the homesteads, most farmers tend to apply much of their available organic amendments (i.e. crop and household residues, manure) to the banana crop. Consequently, the majority of the

banana soils are relatively fertile when compared to other farm plots, yet this practice cannot solve the negative nutrient balance at the farm level. It is necessary to look beyond the banana field, and to address soil fertility constraints at the farm level if we want to improve the sustainability of these systems. Hence, the role of banana-intercropping systems and a permanent banana canopy for soil and water conservation deserve special attention in this respect.

The availability of organic amendments and mulch is decreasing due to land intensification. Recommendations should be developed for how farmers can optimize the utilization of these scarce resources. Every farmer and banana researcher agrees that mulching is beneficial, but at present there are no clear recommendations for the minimum quality and quantity of mulch needed to address soil fertility, drought, and pest constraints on the land.

In spite of most banana soils being relatively fertile, both foliar analysis and fertilizer trials have shown that K, and to a lesser extent N and Mg deficiency, frequently occur. Relatively little research has been conducted on the role of micronutrients. Although mineral fertilizers are expensive in Uganda, it seems that their use in the long-term will be inevitable. In areas with low yields, mineral fertilizers will not be economical, but when drought, pests and diseases are not a major problem, then the use of mineral fertilizers might be an option, especially when farmers are close to urban centers and bunch prices remain relatively high and stable. In addition, some commercial farmers may not have organic matter resources available and would need to rely entirely on mineral fertilizers to achieve nutrient balance. Hence, more research is needed to develop tailor-made fertilizer recommendations. Rather than giving a blanket recommendation for the whole of Uganda, fertilizer recommendations should be based on the soil nutrient supply, the target yield (depending on pests, diseases, and drought), management level, cost-benefit ratio and the availability of credit to the farmer. In many cases, the application of P, and to a lesser extent N, might not be useful and might even lead to nutrient imbalances (e.g. P-Zn antagonism).

Nutrient cycling in banana systems is highly dynamic due to the large amount of nutrients in the banana biomass. Pests and diseases will reduce the banana biomass and plant nutrient uptake, which might trigger a negative spiral of yield and soil fertility decline. This process has not been quantified yet, though it calls for an integrated approach to pest and soil management. Already, there is substantial evidence showing that farmers will benefit most from pest and soil management intervention, when these are combined. The role of micronutrients and nutrient ratios with respect to plant defence mechanisms is still poorly understood. However, it is clear that some recent studies in this field show promising results for the future development of integrated pest and soil fertility management.

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Cultural control of banana weevils in Ntungamo, southwestern Uganda

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Abstract

The International Institute of Tropical Agriculture and the Uganda National Banana Research Programme tested and evaluated selected cultural management options for the banana weevil through on-farm farmer participatory research in Ntungamo district, Uganda between 1996 and 2003. A farmer adoption study of these cultural practices was also undertaken. Tested technologies included: (1) pseudostem trapping; (2) soil fertility and water management practices (grass mulch, soil and water conservation bunds and farm yard manure); and (3) crop sanitation (destruction of crop residues that serve as breeding grounds for banana weevils). This paper reports on the efficacy of these controls, as well as farmers' observations on the feasibility of their adoption. The difficulties in carrying out farmer participatory research in highly heterogeneous banana stands is also discussed.

Introduction

The banana weevil is a key production constraint of East African highland bananas (AAA-EAHB) (Gold *et al*, 1993, 1999). Currently, farmers rely on cultural practices for weevil control (Seshu Reddy *et al*., 1998; Gold *et al*., 2001), but few data are available on the efficacy of these practices, their costs and benefits, and factors influencing farmer adoption. These limitations have demanded testing and validation of the technologies' on-farm conditions.

Available cultural practices for banana weevil control include use of clean planting material, cropping systems management, pseudostem trapping, mulching and crop sanitation (Gold *et al*., 2001). The use of clean planting material technologies (paring, hot-water treatment, tissue culture plantlets) takes advantage of the banana weevil's limited dispersal capability by keeping the pest out of new fields. Field studies suggest that clean planting material is likely to provide benefits for only a few crop cycles and cannot be seen as a permanent solution (Gold *et al*., 2001). This is because some clean planting methods (paring, hot-water treatment) greatly reduce, but do not elimi-

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nate the pest (Gold *et al.*, 1998). Seshu Reddy *et al.* (1995) observed that trapping can significantly reduce weevils in farmers' fields. However, sustained use of trapping by farmers was not achieved.

The International Institute of Tropical Agriculture (IITA) and the Uganda National Banana Research Programme (UNBRP) tested and evaluated selected cultural management options for the banana weevil through on-farm farmer participatory research in Ntungamo district, southwestern Uganda between 1996 and 2003.

Materials and methods

The studies were carried out in Kikoni parish, which lies between longitudes 30°13.66'E and 30°13.85'E and latitudes 0°52.88'S and 0°53.79'S at an elevation of 1300-1560 masl. Farm holdings in the area were generally small, averaging 0.85 ha (range 0.4-5.9 ha) in our surveys. Bananas occupied more than 60% of the cultivated land and were mostly from contiguous plantations in a complex topography including hills, valleys and uneven terrain (Okech *et al.,* 1998). The area has a bimodal distribution of rainfall (800-1500 mm) falling between March to mid-May, and September to December. Banana weevil populations and damage in the study area ranged from light to very high (Gold *et al.*, 1997).

Tested technologies included: (1) pseudostem trapping, (2) soil fertility and water management practices (grass mulch, soil and water conservation bunds), and (3) crop sanitation (destruction of crop residues that serve as breeding grounds for banana weevils). A farmer adoption study of these and other practices for banana weevil control was also undertaken. The efficacy and implementation feasibility of these controls, as well as farmers' observations, are presented and discussed.

A Participatory Rural Appraisal (PRA) and diagnostic survey (DS) conducted from December 1995 to May 1996 preceded research activities in the area. The PRA, involving group discussions and key informant interviews, identified farmers' perceptions of banana production constraints and served as a means for developing researcher-extension-farmer collaboration. Subsequent group discussions were undertaken before each on-farm research activity. The DS verified farmers' perceptions, quantified pest status of banana weevils and nematodes, characterized banana-based cropping systems, and generated data used in identification and selection of the research farms.

In the initial survey, 50 farms were haphazardly selected from seven villages, namely Buhandagazi, Kamunyiga, Karegeya, Kyangara, Musaana, Ruguma and Ryagusha. Agronomic practices including cropping systems, application of soil amendments (mulches and/or manure), sanitation (i.e. removal, shredding, spreading of corm and spent pseudostems) were characterized as described by Gold *et al.* (1997). Weevil pop-

ulations were estimated using mark and recapture methods developed by Southwood (1978) and modified for the banana weevil by Gold and Bagabe (1997). Weevil damage was estimated on 20 newly harvested plants/farm using the scoring method developed by Gold *et al*. (1994). Three approaches to control weevils were tested.

Pseudostem trapping. Researcher-managed plots and farmer-managed ones were compared with regards to their effectiveness in reducing banana weevil populations and corm damage between June 1996 and July 1997 (Gold *et al*., 2002). Researcher-managed trapping (9 farms) was intensive, involving placing a trap on every mat once every month. Farmer-managed trapping (9 farms) was at the farmers' discretion and was undertaken piece-meal (placing 0.1-0.6 traps/mat without following a regular time interval). Controls (9 farms) consisted of farms where trapping was not practiced. Baseline data on weevil populations and corm damage were taken before the implementation of treatments. Banana weevil populations were subsequently estimated 6 and 12 months later, while corm damage was scored regularly on freshly harvested plants.

Soil fertility and water management. Various practices were investigated to observe how low yielding, moderately weevil-infested old banana plantations would respond to cultural soil and water productivity improvements, such as conservation contour bands, mulch and/or farmyard manure. The study tested the hypothesis that the construction of soil and water conservation bunds along the farm contours, as well as the application of mulch or farmyard manure, could increase stand productivity while also reducing banana weevil pressure. During a period of four years, the effects of mulch and contour bunds were evaluated by three treatments on 13 randomly selected farms. An area measuring 36 x 36 m was delineated in each of the farms and subdivided into three equal plots (i.e. 12 m x 36 m) containing 50 to 55 mats. The three treatments, (i) control, (ii) contour bunds only and (iii) contour bunds plus swamp grass mulch, were randomly assigned to the plots. The treatments were implemented in August-September 1996 (at the beginning of the second rainy season). Contour bunds were 45 cm wide and 30 cm deep. The bunds were stabilized by planting *Seteria splendida* grass, which also served as a source of mulch or fodder. Grass mulch (10 cm thick) was applied to the third treatment at the beginning of the trial and placed 50 cm away from the banana mats. A new layer of mulch was added once every year (in August) until the conclusion of the study. Other cultural management practices such as weeding, desuckering to leave three plants/mat, and crop sanitation (removal and shredding of the residues within two weeks of plant harvest) were uniformly applied to all treatments. Weevil populations were estimated from each plot in June of each year using the mark-release-recapture method as described above. Banana weevil damage was assessed in corm cross sections continuously from every harvested plant in each plot.

Crop sanitation. Crop residues that serve as breeding grounds for banana weevils (Masanza 2003) were destroyed to evaluate its effect on banana weevil populations and corm damage. The study ran from 1999 to 2003. A baseline survey was carried out on 60 farms to characterize crop sanitation levels being practiced by the farmers and to measure the initial weevil population abundances and corm damage. Levels of sanitation were categorized as low, moderate and high, based on the frequency and intensity of sanitation practices. Volunteer farmers in the low and moderate sanitation levels were asked to increase their levels of sanitation for the period of the study (i.e. low to moderate, low to high, and moderate to high), while other farmers maintained their baseline levels. Weevil populations and corm damage were estimated at three month intervals using the methods of Gold and Bagabe (1997) and Gold *et al.* (1994) respectively.

Farmers' knowledge was partly investigated by trying to understand their perceptions and knowledge of the banana weevil and its biology. Farmers in Ntungamo were categorized into three groups (bottom, middle, top) according to wealth indicators and interviewed individually using semi-structured questionnaires.

Farmers' management practices included sanitation, trapping, pesticides, and biorationals (ash, urine, etc.). Sanitation was defined to include leaf sheath removal, splitting of pseudostems, corm removal, corm covering and stump removal. Trapping included placement of split pseudostem traps at the base of the mats and covering the harvested corm with banana leaf.

Resource allocation to the activities was estimated based on the man-hours/acre that were dedicated to each of the different practices.

Results

Pseudostem trapping

Results showed that there was a general decline in weevil populations in Ntumgamo, including controls, during the course of the study. After one year, populations were 61%, 53% and 38% lower in researcher-managed, farmer-managed and controls, respectively. Adjusting for the overall decline in the weevil population during the course of the study showed that trapping contributed to a reduction of 38% of the weevil population in the researcher-managed plots and 27% in the farmer-managed plots (Table 1). The study further observed that there was no clearly defined trend at the individual farm level in numbers of weevils removed by trapping or reduced populations. Plantation management, surrounding land use and weevil immigration from neighbouring farms may have partly mitigated against trapping effects. Researcher-managed trapping resulted in reducing corm damage by 49%, while farmer-managed trapping had

Table 1. Mean percentage of banana weevil population changes following one year of pseudostem trapping in farmers' fields in Ntungamo district, Uganda (Gold *et al.* 2002).

	June 1996- January 1997	January 1997- July 1997	Overall change
Population changes			
Control	-42%	12%	-38%
Farmer-managed	-50%	-9%	-53%
Researcher-managed	-49%	-42%	-61%
Adjusted reductions			
Farmer-managed	-14%	-19%	-27%
Researcher-managed	-12%	-52%	-38%

no effect on damage during the course of the study. Therefore, it should be noted that population reduction through trapping may have been gradual, as a lag time would be expected between population change and corm damage reduction. At the termination of the study, farmers recognised the benefits of trapping, though expressed concerns about the feasibility of this method due to the labour and resource requirements, let alone weevil immigration from neighbouring farms possibly offsetting its usefulness.

Soil fertility and water management practices

Weevil adult populations in the contour bunds and mulch trial fields at the beginning of the trials (1996) ranged from 8000 to 9000 weevils/ha (Figure 1). In 1997, the densities significantly increased to 11 000-12 000 weevils/ha in the plots with contour bunds and those with mulch, but remained at the same level in the control plots. These relative increases were attributed to the greater soil-moisture holding capacity in these two treatments which is more favourable to banana weevils. A general decline in weevil populations was observed between 1997 and 1999 in all the treatments, although populations in contour bunds,

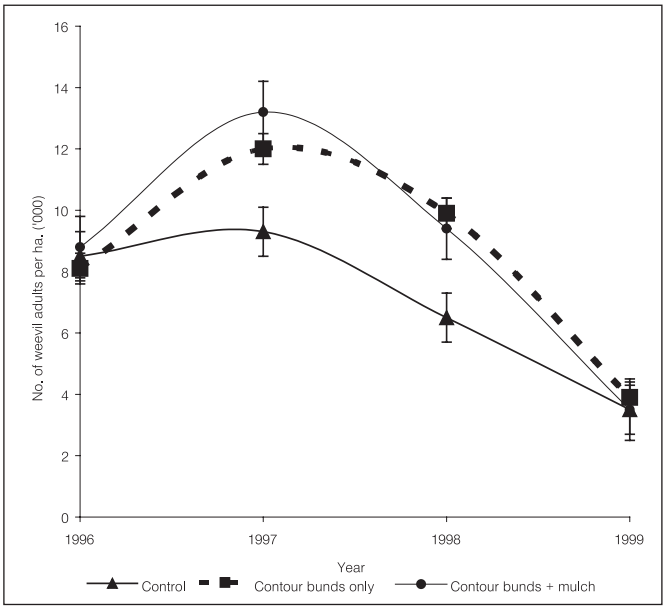

Figure 1. Banana weevil populations under different soil fertility management practices at Ntungamo, Uganda. (Okech *et al*., unpublished)

and contour bunds plus mulch treatments, remained higher than the controls. However, these treatment differences were not significant by the end of the study.

Banana corm weevil damage at the beginning of the study (1996) ranged from 4% to 4.5%, which was rated as moderate (Gold *et al.*, 1994). The damage levels declined uniformly in all the treatments from moderate to low (< 2.5%) between 1997 and 1999 (Figure 2), though the differences between the treatments were not significant. There was a general increase in yield in all treatments in the first two years of the study, but contour bunds and mulch treatments had significantly higher yields than the controls by the fourth year of the study (Figure 2).

Crop sanitation

Weevil populations increased greatly on most farms during the course of the study. In the initial 26 months, densities increased slightly and were similar among treatments. Subsequently, the highest population increases occurred on banana stands maintained at low sanitation levels, peaking at 52 000 weevils/ha (Figure 3). By contrast, densities on the farms upgrading from low to moderate sanitation levels were only 13 000 weevils/ha, while populations on farms upgraded from low to high sanitation levels remained at about 2000 weevils/ha throughout the study.

The difference in corm damage between low and high sanitation practicing farms increased over time (Table 2). By 2002, total damage for the high sanitation farms

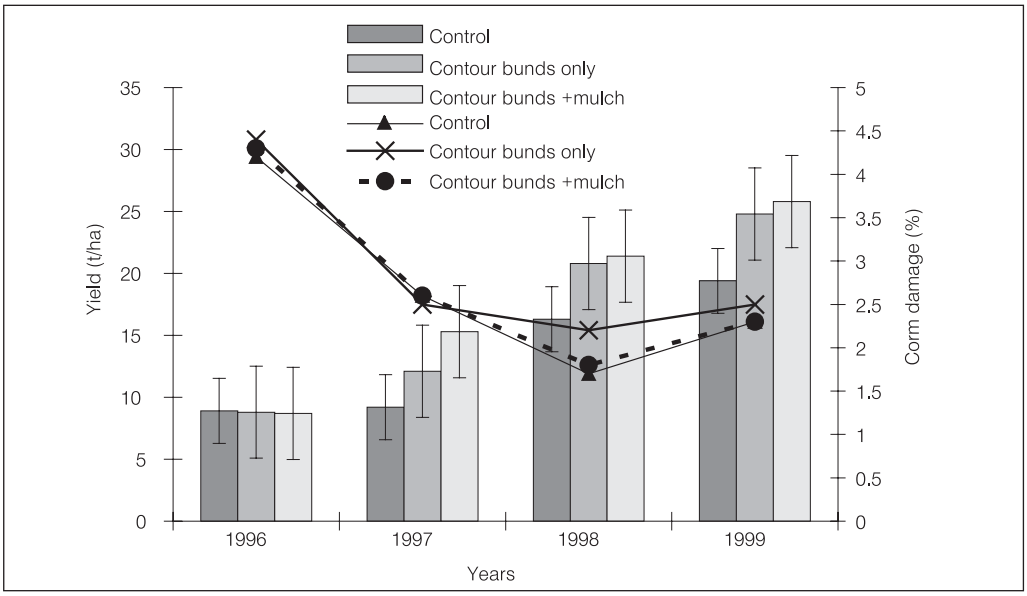

Figure 2. Changes in banana corm damage by weevils (line graph) and yield (bar graph) in soil conservation bunds plus mulch trial at Ntungamo, Uganda. (Okech *et al.*, unpublished)

throughout was 1.5%, while damage on low sanitation farms averaged 3.6%. Lower levels of corm damage were observed on farms which upgraded their sanitation levels, i.e. total damage decreased by 41% and 43% on farms upgraded from low to high, and moderate to high, respectively. In contrast, total damage remained at the same levels on farms that maintained low levels of sanitation throughout the study. On farms achieving moderate and high sanitation levels, total damage decreased by 23% and 35%, respectively.

Farms using high levels of crop sanitation also produced the largest bunch weights (> 20 kg), although these were not significantly different from those implementing moderate levels of sanitation (about 15 kg). Farms with the lowest levels of sanitation produced the smallest bunch weights (about 12 kg).

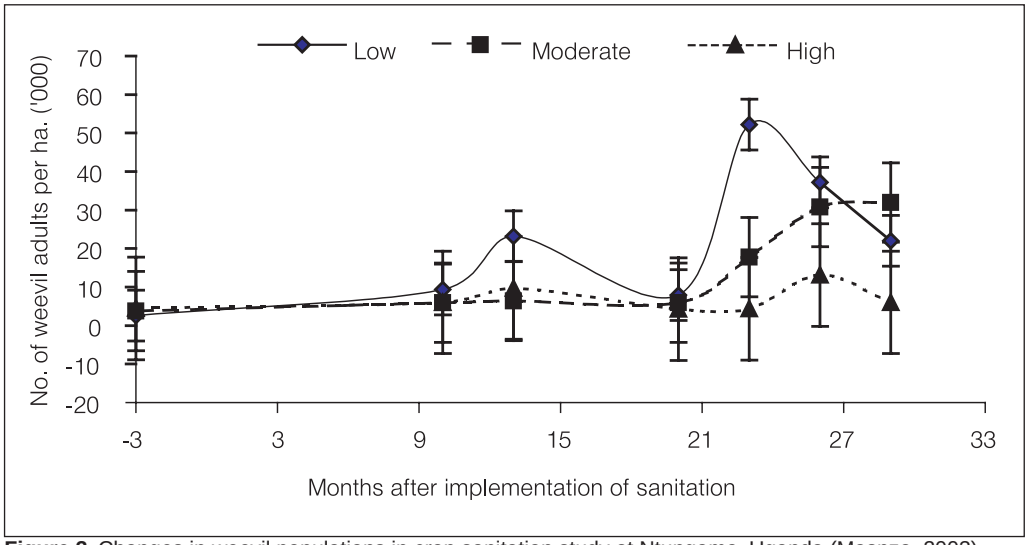

Figure 3. Changes in weevil populations in crop sanitation study at Ntungamo, Uganda (Masnza, 2003)

Table 2. Corm damage in farms employing various crop sanitation treatments, including groups of farmers increasing sanitation intensity from baseline levels, Ntungamo district, Uganda (Masanza, 2003).

Sanitation level[1]	Total corm damage (%)			
	1999 (baseline)	2000	2001	2002
L-L	3.6±0.42	4.0±0.30	3.5 ± 0.29	3.6 ± 0.56
L-M	3.8±0.27	3.0±0.20	3.6 ± 0.19	2.9 ± 0.41
L-H	2.7±0.52	1.6±0.37**	2.1 ± 0.36**	1.6 ± 0.73**
M-M	2.6±0.66	2.0±0.46*	2.5 ± 0.46	2.0 ± 0.93
M-H	2.1±0.74	1.6±0.52**	1.6 ± 0.52**	1.2 ± 1.04*
H-H	2.3±0.85	1.2±0.60**	1.6 ± 0.60**	1.5 ± 1.20

Means in a row followed by * or ** are significantly different from baseline data by Dunnett's test at $p \leq 0.05$ or $p \leq 0.01$, respectively.
[1]L=Low; M=Moderate; H=High. e.g. L-M: farmers who employed low sanitation during baseline survey and implemented moderate sanitation during study.

Table 3. Farmers' knowledge and understanding of the biology of banana weevil in Ntungamo District, Uganda (Bagamba *et al*., unpublished).

Weevil lifecycle	Proportion (%) of farmers in each socio-economic stratum capable of identifying the weevil development stages			
	Top	Middle	Bottom	Overall
Egg-adult	18.2	4.0	2.0	4.7
Larva-adult	9.1	6.0	40.0	29.1
Egg-pupa-adult	0.0	8.0	6.0	5.8
Egg-larva-pupa-adult	27.3	44.0	18.0	26.7
Do not know	45.5	28.0	20.0	33.7
No response	18.2	16.0	14.0	15.1

Farmers' knowledge of the weevil

At Ntungamo, the majority of farmers (74%) rated the weevil problem as either of moderate or high importance. However, most farmers did not fully understand the biology of the weevil (Table 3). Overall, less than 30% of the interviewed farmers were able to describe its four life stages (egg, larva, pupa and adult), while many farmers did not recognise that the larva and adult were different forms of the same insect. A higher proportion of farmers in the middle economic stratum could describe the complete life cycle. In addition, the majority of farmers in the lower and middle strata considered the adult as the most destructive stage, while the majority in the top stratum considered both adult and larva as the most damaging. This limited understanding of the weevil's biology may be one of the factors contributing to the low adoption of cultural methods for its control.

Farmers' management

Sanitation practices were the most widely known and used among the IPM technologies. Overall, about 90 % of the farmers interviewed used them to a varying extent (Table 4). However, of the 59 % of the farmers who had tried weevil trapping, 24% had subsequently abandoned this method. Covering harvested corms with banana leaves was the most common trapping method in use. The utilisation of biorationals was rarely practiced, while pesticides were not employed. Corm removal was rated as the most effective control, followed by stump removal, corm covering and leaf sheath removal (Table 5). Biorationals were rated as least effective.

Resource allocation

Labour was the major production input, mainly used in weeding, crop sanitation and soil fertility improvement. Those in lower and middle economic strata allocated most

Table 4. Proportion (%) of farmers knowing and using different banana weevil IPM technologies in Ntungamo district, Uganda (Bagamba *et al*., unpublished).

Technology	Top stratum			Middle stratum			Bottom stratum			Aggregate		
	K	U	T/A	K	U	T/A	K	U	T/A	K	U	T/A
Leaf sheath removal	100	100	0	83	97	0	100	97	0	98	98	0
Split pseudostem	100	100	0	100	94	6	97	97	2	98	96	0
Corm removal	100	75	17	90	84	13	97	85	14	95	84	14
Corm covering	100	83	8	89	94	3	93	74	12	94	81	9
Stump removal	100	100	0	100	100	0	97	97	2	98	98	33
Mulch placement	75	92	0	91	89	0	87	83	0	86	86	0
Trapping	50	42	8	60	34	25	62	34	26	57	35	24
Chemical (Furadan)	80	0	75	100	0	0	33	2	72	36	1	0
Ash	100	25	0	85	19	3	77	14	0	81	17	1
Urine	100	8	58	55	0	0	69	6	0	69	5	1

K= People who know; U= People using technology; T/A= People who tried and abandoned.

of their labour to sanitation, followed by weed control and a lesser extent, soil fertility improvement (Table 6). Those in the top socio-economic stratum allocated more labour to soil fertility improvement. Lower allocation of labour input into weeding by households in the top socio-economic stratum might be linked to the heavy mulching and the associated plant biomass from pseudostems.

Discussion

Cultural controls, including trapping and crop sanitation, have been widely recommended for the control of banana weevil (Gold *et al.*, 2001). However, few data are available on the efficacy, costs and feasibility at the farm-level for these methods. Our studies in Ntungamo district, Uganda confirm that systematic trapping can be an effective method for controlling the banana weevil, and even whose value is recognised by many farmers. However, few farmers adopt this method because of labour (perceived as "drudgery") and material requirements. Farmers also considered that the hours required for weevil trapping competed with other crop activities and leisure time. In addition, pseudostems for traps are often in short supply, especially during periods of low harvest.

Sanitation was rated by farmers as highly effective against banana weevils and consequently received greater labour resource allocation despite its drudgery. Vigorous, healthy looking plants and larger bunches influenced the farmers' perceptions. Similar observations were reported by Masanza (2003) from farms that maintained high levels of sanitation. Okech *et al.* (1998) observed greater banana residue biomass accu-

Table 5. Farmers' perceptions of effectiveness of banana weevil IPM technologies in Ntungamo district, Uganda (Bagamba *et al.*, unpublished).

Technology	Farmers' perceptions (%)			
	Very effective	Moderate	Low	Do not know
Leaf sheath removal	54	24	21	2
Split pseudostem	37	28	33	2
Corm removal	89	7	3	1
Corm covering	78	14	6	1
Stump removal	80	17	2	1
Mulch placement	31	12	55	2
Trapping	61	28	9	2
Chemical (Furadan)	50	0	36	14
Ash	2	12	83	3
Urine	5	3	90	2
Cultivar selection	12	26	60	2
Clean suckers	39	39	17	6

Table 6. Labour used by farmers in each socio-economic stratum in Ntungamo District, Uganda (Bagamba *et al*., unpublished).

Activity	Labour (man-hours/acre)			
	Top	Middle	Bottom	Overall
Weed control				
Hand hoeing	336	357	594	495
Mulching	52	17	13	18
Sanitation				
Sheath removal	48	144	177	154
Deleafing	46	144	187	159
Desuckering	51	169	152	14
Stump removal	96	118	200	164
Split pseudostems	85	55	51	56
Corm removal	63	151	130	129
Soil fertility improvement				
Manure application	278	5	6	7
Compost/residue application	167	17	10	12
Total	**1221**	**1176**	**1520**	**1341**

mulation in farms with careful management including sanitation. The larger bunches reported by Masanza (2003) may have been due to a combination of benefits such as the mulching effect of banana residues and the associated recycling of nutrients and increased organic matter.

Soil conservation bunds, mulch and farmyard manure are soil fertility management practices and are not expected to control banana weevils. In fact, mulching appears to increase the incidence of banana weevil (Rukazambuga *et al*., 2002). The results indicate that soil conservation bunds, mulch and manure had additive effects on banana yields over crop sanitation. Farmers in the high socio-economic stratum obtained greater yields and income mainly because they used manure and mulch. Thus, this reinforces the recommendation that it is worth investing in soil fertility amendment activities to benefit from the overall banana production, including weevil control. Farmers use sanitation methods because there is little expense involved besides labour, which can be provided by the family. However, practices such as mulching and manuring involve some capital investment, thus reducing their use and adoption.

Farmer adoption of cultural controls reflects a number of factors including commercial versus subsistence objectives, levels of available resources, understanding of banana weevil biology and perceptions of its importance. In addition, the perceived efficacy and benefits of IPM methods, as well as their costs remain important. Farmers

in Ntungamo district are subsistence growers who market part of their production. It is likely that farmers in more commercial growing areas, such as Mbarara district would be more willing to adopt controls, including weevil trapping and crop sanitation.

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The biology and pest status of the banana weevil in the East Africa Great Lakes Region: A review of research at IITA and NARO

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Abstract

The banana weevil, *Cosmopolites sordidus* (Germar), is an important production constraint of the East African highland bananas (AAA-EAHB) in the Great Lakes region, and techniques need to be found that can reduce damage to the plant and increase productivity. Four multi-cycle yield loss trials were conducted in Uganda. In the first trial, yield reduction increased from 5% in the plant crop to 47% in the third ratoon (values reflect both plant loss and reduced bunch weight). In the second trial, mulched banana plots outperformed unmulched bananas by 39%. Although the losses to the banana weevil were similar in both systems (18.6% and 14.2% in mulched and unmulched, respectively), the absolute values were 90% higher in mulched (3.4 tons/ha per crop cycle) than in unmulched banana plots (1.8 tons/ha per crop cycle). In the third trial, weevil attack destroyed more than 30 % of banana mats, suggesting that this pest does reduce plantation life. Yield losses ranged from 30 to 60% each year. The fourth trial looked at the effect of NPK fertilization on yield loss to banana weevil at a site with low pest levels. In plots without fertilizer, weevil damage caused yield losses reaching 30% in the third crop cycle. By contrast, fertilizer application not only increased plant vitality and yield, but also eliminated losses during low levels of weevil pressure.

Introduction

The banana weevil, *Cosmopolites sordidus* (Germar), is an important pest of East African highland bananas (AAA-EAHB) in the Great Lakes region (Gold *et al.*, 1999, 2001). The larvae bore into the corm, reducing nutrient uptake and weakening the stability of the plant, and in newly planted banana stands can cause high levels of sucker loss and poor crop establishment (McIntyre *et al.*, 2002; Messiaen, 2002), even leading to crop failure. In established fields, weevil damage can cause plant loss through snapping and toppling, reduced bunch weight, as well as mat die-out and shortened stand life (Rukazambuga *et al.*, 1998; Gold *et al.*, 2001). Damage and yield losses tend to increase with time. The banana weevil has been a principal factor in the decline and disappearance of the highland cooking banana in central Uganda

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(Gold *et al.*, 1999) and western Tanzania (Mbwana and Rukazambuga, 1999), while early stages of yield decline have been observed in parts of southwestern Uganda. Plantains (AAB) are also highly susceptible to banana weevil attack, while other banana groups grown in the region show intermediate to high levels of resistance (Kiggundu *et al.*, 2003). The adults are most often associated with banana mats and cut residues, often residing in the soil and base of the leaf sheaths where they are not apparent to the casual observer. The larval damage is indirect and within the corm. Thus, many farmers do not have a clear idea of the importance of banana weevil on their farms. Although flight is uncommon and the adults crawl only short distances, immigration from neighbouring farms may offset farmers' control practices.

The banana weevil's host range is restricted to *Musa* and *Ensete*. The insect originated in southeast Asia, from where it has spread to all the major banana growing regions of the world (Waterhouse, 1993). Although, the banana weevil was first reported in Madagascar in 1903 and Uganda in 1908 (Gold *et al.*, 2001), it most likely arrived on the continent much earlier; bananas (which originally similarly evolved in southeast Asia) were introduced into Africa more than 2000 years ago (Mbida *et al.*, 2001). The banana weevil is now distributed throughout sub-Saharan Africa, although it tends to be unimportant at elevations over 1600 masl.

Banana weevil biology

The banana weevil is a K-selected insect (c.f. Pianka, 1970) with a long life span and low fecundity. Marked adults have been recovered in field trials four years after release (Rukazambuga and Gold, unpubl. data). Oviposition is generally considered to be < 4 eggs per week in the laboratory and < 1.5 eggs per week in the field (Abera 1997; Gold *et al.*, 2001). Hence, population growth is slow. The adult biology is characterized by long life span, limited mobility, low fecundity and slow population growth. The adults are also free living and attracted to their hosts by plant volatiles (Budenberg *et al.*, 1993). Ovipositing females are especially attracted to freshly cut corms making young suckers, which have been recently detached from banana mats for use as planting material; these are particularly vulnerable. Males produce an aggregation pheromone that is attractive to both sexes.

The weevil attacks all banana phenological stages, including crop residues. Eggs are laid in the leaf sheaths in the lower pseudostem or in the outer surface of the corm, (Abera, 1997), often below the soil surface. The immature stages are within the host plant. The larvae preferentially feed in the corm, but will attack the true stem and pseudostem. Damage is generally higher in the cortex than the central cylinder (Gold *et al.*, 1994) and tends to be greater 5-10 cm below the collar than at the collar (Gold *et al.*, unpubl. data). Although, pupation is usually in the corm cortex, it can also occur in the pseudostem of cut residues. Under tropical conditions, the immature

Table 1. Population densities of banana weevil adults on farmers fields (50 farms/site) in three districts in Uganda. (Source: Gold *et al*., 1997; unpublished data)

District	Range (adults/ha)		Median population	
	Low	High	Adults/ha	Adults/mat
Ntungamo	1 600	149 000	9 300	15
Mbarara	850	15 000	3 500	6
Masaka	2 000	41 000	10 000	17

stages (i.e. from egg to adult) take 5 to 7 weeks.

The adults are negatively phototrophic and nocturnally active between 18:00 and 06:00 hours (Cuille, 1950; Uzakah, 1995), with greatest activity between 21:00 and 04:00 hours (Uzakah, 1995). Although they tend to be inactive during the daytime, Padmanaban *et al*., (2001) recovered weevils in freshly set traps during the daytime in mulched fields, suggesting at least some diurnal activity. Banana weevil adults are hydrotrophic, favouring moist environments and occur most commonly in the soil around the base of banana mats or associated with crop residues (Gold *et al*., 1999c). They may also be found under leaf sheaths at the plant base, as well as occasionally entering old galleries within the corm. Population densities may be estimated through mark and recapture studies (e.g. Price, 1993). In Uganda, adult populations show considerable variability among farms within watersheds (Table 1) suggesting the influence of stand management on pest status. Weevil density may be as much as 2.5 times higher in mulched than in unmulched plots because of more favourable soil moisture conditions (Price 1994; Rukazambuga *et al*., 2002).

Table 2. Proportion of marked weevils that moved a given distance from point of release in banana stands at the Kawanda Agricultural Research Institute, Uganda. (Source: Gold *et al*., 1999)

Days after release	Distance traveled		
	< 5 m	6–15 m	> 15 m
0-90	62%	28%	10%
91 –180	38%	42%	20%
180-365	42%	39%	20%

The banana weevil is a sedentary insect that rarely flies. Dissemination is primarily through movement of planting material, although adults can move between proximal banana stands. The adults may remain in the same place for weeks or crawl short distances. Maximum movement of banana weevil has been recorded at 35 m in three days (Gold and Bagabe, 1997) and 60 m in five months (Delattre, 1980). Sequential trapping of marked weevils in Uganda showed that only a small proportion moved more than 15 m in one year (Table 2). Mulching appeared to encourage weevil activity (Gold *et al*., 2001); in 10 weeks, 60% of the weevils in a mulched banana stand moved > 10 m, compared to only 27% in an unmulched field.

Pest status

Yield losses to banana weevil have been associated with sucker mortality, reduced bunch weights and shorter stand longevity. In newly planted fields with existing weevil populations and no alternative host stages, plant mortality may be high (Ambrose 1984; Price 1994; McIntyre *et al.*, 2002; Messiaen, 2002). A single larva can kill a sucker if it attacks the growing point (C. Gold, pers. observ.). McIntyre *et al.*, (2002) recorded 40% mortality in newly planted suckers due to banana weevils and an additional 40% mortality in the replants used for gap filling. Where banana is planted in clean fields, initial banana weevil populations are often low and most suckers are successfully established. With slow rates of weevil population increase, several years can pass before serious damage becomes evident and, therefore, single cycle yield loss trials may be misleading.

Materials and methods

The International Institute of Tropical Agriculture (IITA) and the Ugandan National Banana Research Programme have conducted a series of on-station trials to determine yield loss of highland banana to banana weevil and to provide insight into the pest status of this insect. The trials were planted in isolated, weevil-free fields where banana had not been previously grown.

Weevil and nematode-free planting material was used in all cases. 'Furadan' was applied to suckers (Trial 1 and 3) or suckers were pared and immersed in hot-water baths (54°C for 20 minutes) to eliminate pests. Adult banana weevils were subsequently released into the fields following crop establishment. Weevil populations, estimated by mark and recapture studies, showed substantial declines in the first months following release, but eventually returned to and then exceeded the original release levels. Weevil damage to the central cylinder was estimated in cross-sections employing the assessment methods of Gold *et al.*, (1994). In all trials, nematode damage, estimated using root necrosis indices (Gold *et al.*, 1994), was negligible (0-2%) suggesting that yield losses could be attributed entirely to banana weevils. The trials ran from 4 to 7 years.

Trial 1. Effects of banana weevil attack on yield of individual banana plants

Trial 1 was conducted at Kawanda Agriculture Research Institute (Rukazambuga 1996; Rukazambuga *et al.*, 1998). It consisted of banana plants (cv 'Atwalira') planted in adjacent plots (25 mats/plot) divided by corrugated metal barriers (30 cm wide, buried to a depth of 15 cm) that were intended to impede weevil movement between treatments. Weevils were released at densities of 10, 20 and 40 weevils/mat (1:1 sex ratio), 9 months after planting. The release was timed to coincide with the onset of the first rainy season following establishment of the crop and was carried out shortly before the

onset of flowering. At the time of release, weevil populations in the fields were negligible. Populations were routinely monitored by placement of pseudostem traps in the different plots.

The appearance of large numbers of marked weevils in traps placed in control plots in the months immediately following release indicated that the insects readily crossed the corrugated metal barriers. Treatment differences quickly disappeared and the barriers were removed. As a result, we evaluated the effects of banana weevil damage on growth and yield of individual plants. This was made possible as subsequent evaluation of corm damage suggested that the weevils showed no preference between attacking larger, more vigorous plants and smaller or stunted plants (based on plant size measured before the release of the weevils). Bunch weights were compared against levels of corm damage. Yield loss was estimated by comparing realized yields with expected yields (i.e. bunch weights obtained from plants with low levels of weevil damage). The trial was run for four crop cycles.

Trial 2. Effects of banana weevil attack on banana yield in infested compared to uninfested plots.

Trial 2 was conducted at IITA Sendusu Farm in Namulonge (Gold *et al.*, 2004). It employed four treatments: (1) no banana weevils (control); (2) low weevil density (5 adults released/mat); (3) intermediate weevil density (10 adults released/mat); (4) high weevil density (20 adults released/mat), laid out in a randomised complete block design with six replications. Plots consisted of 50 banana mats (cv 'Atwalira') separated by 15 m grass alleys to restrict weevil movement between treatments.

The weevils were released after 9 months. During the 18 months following release, weevil populations were estimated on four occasions by mark and recapture methods, and abundances were adjusted to conform to the original release densities. This proved to be impractical. Subsequently, weevils were excluded from the control plots by regular applications of 'Dursban' and no further releases were made in the weevil-infested plots. The trial was run for 7 years encompassing 9 crop cycles.

Trial 3. Effect of banana weevil damage on plant yield under different management systems

Trial 3 was conducted at the Kawanda Agricultural Research Institute (Rukazambuga 1996; Rukazambuga *et al.*, 2002) andwas run concurrently with Trial 1. It explored the effects of crop management on weevil populations and damage, as well as highland banana (cv 'Atwalira') yields. Treatments consisted of: (1) intensive banana-finger millet intercropping (i.e. continuously intercropped throughout trial); (2) bare ground banana monocultures (with addition of manure to planting holes); and (3) mulched banana monocultures. Manure was added to the planting holes of treatments 2 and 3.

The trial was planted in a split plot design (main plots with and without weevils) separated by corrugated metal barriers. Twenty weevils were released per mat in weevil-infested plots 9 months after planting. The original experimental design was modified following weevil invasion into the weevil-free main plots and analysis was carried out on attack levels on individual plants.

Trial 4. Effects of NPK on yield loss from weevils under low to moderate level of weevil pressure

Trial 4 was conducted at Mbarara stock farm (Okech *et al.*, unpubl. data). Its objective was to test the hypothesis that bananas growing under fertile soil conditions are more tolerant of banana weevil attack than those grown in less fertile soils. Amendments of NPK fertilizer to banana plots (cv 'Enyeru') provided different levels of soil fertility in a trial planted at the Mbarara stock farm. Treatments were: (1) fertilizer plus weevils; (2) no fertilizer plus weevils; (3) fertilizer without weevils; and (4) no fertilizer and no weevils. Plots (49 banana mats) were separated by 20 m grass alleys. Fertilizers were applied at the rate of 100 kg N ha^{-1} $year^{-1}$ split across four applications (urea 46%), 50 kg P ha^{-1} $year^{-1}$ in two applications (Triple Super Phosphate 46%) and 100 kg K ha^{1} $year^{1}$ (Muriate of Potash 52%) in two applications. Dursban was applied regularly to treatments 3 and 4 to maintain the plots free of weevils. Weevil damage was estimated in the corm cortex and central cylinder using the methods of Gold *et al.*, (1994). Here we report the results for the first 4 crop cycles of an on-going trial.

Results and discussion

Trial 1. Effects of banana weevil attack on yield of individual banana plants

Banana weevil damage levels rose from 4% in the motherplant crop to 29% in the third ratoon crop (Table 3). Plant loss (death, snapping and toppling) and reductions in bunch weight also increased over time, such that yield losses increased from 5% in the motherplant crop to 44% in the third ratoon crop. The data suggest that plant loss contributed more to yield loss than reductions in bunch weight. Damage in one crop cycle affected the overall vigor of the mat and contributed to yield reductions in subsequent cycles. The low level of damage in the motherplant crop may have reflected the timing of release. However, subsequent studies showed that banana weevils preferentially oviposit on flowered plants (Abera, 1997). This probably explains why banana weevil attack had a large impact on yield, though only a modest effect on plant maturation times and size at flowering.

Trial 2. Effects of banana weevil attack on banana yield in infested compared to uninfested plots.

Weevil damage was similar in control and infested plots during the first year, moderately higher in infested plots during the second and third years and substantially

Table 3. Banana weevil damage and associated yield loss in 'Atwalira' over four crop cycles, at the Kawanda Agriculture Research Institute, Uganda (adapted from Rukazambuga, 1996 and Rukazambuga, unpublished data).

	Motherplant crop	1st ratoon crop	2nd ratoon crop	3rd ratoon crop
Damage	4%	10%	15%	29%
Plant loss	3%	9%	19%	29%
Bunch weight reduction	3%	7%	7%	25%
Yield loss	5%	15%	25%	47%

higher subsequently. Banana weevil attack contributed to high rates of mat disappearance (Figure 1) caused by the death of all plants on the mat failing to produce suckers. Disregarding mats that failed to establish in the plant crop, 35% of the mats disappeared in infested plots compared to 3% in controls. Additional plant loss (from plant death, snapping and toppling) in mats that did not disappear averaged 2% per year in controls and 12% per year in infested plots. Plants in weevil-infested plots were shorter and had thinner pseudostems than plants in control plots. During the final four years of the trial, 33% fewer bunches were harvested and mean bunch weights were 17% lower in infested plots than in controls (Table 4). During this period, yields, measured in kg/plot/year, were 42% lower in plots with banana weevils than in the control plots. During the last two years of the trial, yield losses to banana weevil were 57%.

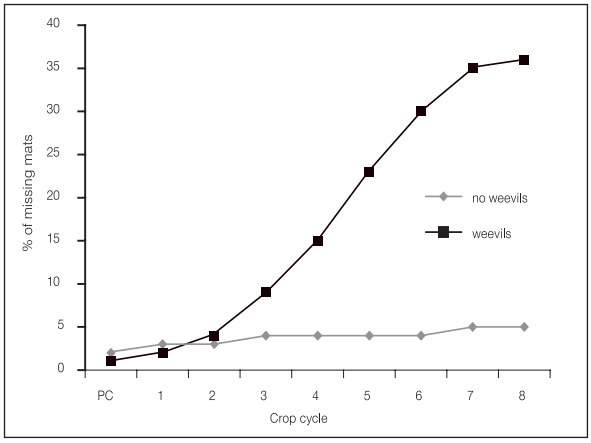

Figure 1. Cumulative mat disappearance (%) by crop cycle in uninfested and weevil-infested plots at IITA, Sendusu Farm, Namulonge, Uganda (source Gold *et al*., unpublished data)

Trial 3. Effect of banana weevil damage on plant yield under different management systems

In Trial 3, which was run over four crop cycles, expected yields and yield losses were calculated as in Trial 1. In monocultures, mulching provided a 39% yield advantage (Table 5). In contrast, yields for intercropped banana were 21% lower than bare soil monocultures and 43% lower than in mulched monocultures. Weevil damage was similar in all banana plots, as were the percentage yield losses among the different treatments (ranging from 14.2% to 19.6%). As in Trial 1, yield losses were determined by comparing realized yields with expected yields (i.e. mean bunch weight of plants with

low levels of damage). Yields were then estimated in kg/plot and extrapolated to tons/ha. These averaged 90% higher in mulched (3.4 t/ha) than in unmulched systems (1.8 t/ha).

Trial 4. Effects of NPK on yield loss from weevils under low to moderate level of weevil pressure.

Weevil damage in infested plots was relatively low (averaging 3.4%) and was similar for fertilized and unfertilized plots, while damage in protected plots was less than 0.5%.

Table 4. Yields of 'Atwalira' in uninfested (control) and banana weevil-infested plots in a 7-year trial at IITA Sendusu Farm, Namulonge, Uganda (Source: Gold *et al.*, unpublished data).

	1995-1997	1998-2001
Bunches (number harvested)		
Control	35.4a	42.4a
Weevil - infested	35.9a	28.3b
Bunch weight (kg)		
Control	17.4a	19.6a
Weevil - infested	17.4a	16.3b
Yield (kg per plot)		
Control	615a	803a
Weevil - infested	626a	463b

NB: Same letters within each group indicate that results are not significantly different (P>0.05) by $T_{>16}$-test

Table 5. Yields of 'Atwalira' and yield losses under different levels of management across four crop cycles at the Kawanda Agriculture Research Institute, Uganda (Source: Rukazambuga *et al.*, 2002).

Type of management	Yield (tons/ha)	Loss (%)	Loss (tons/ha)
Intensive intercropping	34.1	19.6	8.3
Monoculture-bare	43.2	14.2	7.2
Monoculture-mulched	60.1	18.6	13.7

Table 6. Yield loss or gain (%) in plots of 'Enyeru' treated with NPK and/or infested with banana weevil in comparison to controls (no NPK, no weevils) at Mbarara, Uganda (1996 - 2000) (Source: Okech *et al*., unpublished data).

Treatment	Motherplant crop	1st ratoon crop	2nd ratoon crop	3rd ratoon crop
NPK and weevils	4.3 ns	0.3 ns	1.1 ns	46.3**
NPK without weevils	1.4 ns	13.3*	1.0 ns	41.7**
Weevils without NPK	-5.2 ns	-15.8*	-37.8**	-40.3**

Pair-wise t-test of probabilities of LS means (REML method)
ns: no significant difference ($p > 0.05$);
*Significant difference at $p < 0.05$ and **$p < 0.01$

Compared to the control, adding fertilizer provided minor yield advantages during the first three cycles and a major yield advantage during the fourth cycle in both weevil free and weevil infested plots (Table 6). Limited yield advantages in the third crop cycle of these plots may have been attributed to an extended drought during the maturation phase of this cycle. In unfertilized plots, yield losses increased from 5% in the mother-plant crop to 40% in the third ratoon crop. In fertilized plots, yields in the third crop cycle were 20% lower in weevil-infested plots ($p < 0.05$), while there were no differences in yields during the other crop cycles. The results demonstrate that weevil damage, as low as 3%, can cause banana sucker stunting and yield losses when soil fertility is low. However, these damage levels were below the thresholds in fertilized soils.

Conclusion

Research trials in Uganda have shown yield losses attributable to banana weevil can exceed 50%. Owing to the insect's slow population growth, banana weevil problems increase over time and tend to be more pronounced in ratoon crops. Nevertheless, weevil attack in newly planted banana stands can impede crop establishment. Plant death in suckers may result from the feeding of a single larva if it hits the growing point.

In established fields, banana weevil damage causes yield losses through: (1) premature plant death, snapping and toppling; (2) reductions in bunch size; and (3) disappearance of banana mats. High levels of weevil attack can kill older plants, while snapping of weaker corms has been widely reported (Gold *et al.*, 2001). Although toppling is most often attributed to nematode damage, our results indicate that weevils can also contribute to toppling. In Trial 2, toppling was six times higher in weevil-infested plots than controls.

Another effect of banana weevil attack is the reduction of bunch size. In Trial 1, plants that had sustained heavy levels of attack over several crop cycles produced bunches that were half the size of plants that had largely escaped damage (Rukazambuga *et al.*, 1998). The pest's damage can also contribute to shortened plantation life, as reported by farmers in central Uganda (Gold *et al.*, 1999). In Trial 2, 35% of the banana mats that had established during the plant crop disappeared by the 8th ratoon crop.

Our trials showed that banana weevil attack resulted in smaller plants, as well as mat disappearance, leaving large gaps in the banana stand. As such, there may have been an indirect effect on soil fertility status by diminishing the plant's ability to absorb nutrients, thereby affecting the ability of the plantation to sustain its nutrient stocks. Banana is a shallow-rooted crop with high nitrogen and potassium requirements. Potassium is a highly leachable nutrient and, amongst the cations, it is the most dependent on standing biomass to maintain its levels in the cropping system. Poor biomass can lower potassium stocks, resulting in less transpiration of water, which in turn exacerbates

nutrient leaching to depths inaccessible to the banana. As the canopy is weakened, the unprotected soil becomes subject to conditions favouring organic matter decomposition. This releases nutrients stored in the soil organic matter, including phosphorus, sulphur and particularly nitrogen as nitrate, all of which are highly subject to leaching (J. Wendt, pers. comm.).

The data on yields suggest that mulching in highly beneficial for highland banana production. Nevertheless, yield losses to banana weevil are also higher in these systems. Thus, the benefits obtained by mulching would be even greater if banana weevils could be controlled. Moreover, the differences in system outputs indicate that the economics of banana weevil control vary between systems. As a consequence, control measure costs are likely to bring about even more substantial returns in the higher yielding systems.

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Nematode management at the International Institute of Tropical Agriculture in East Africa

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Abstract

As part of a strategy to improve banana production in East Africa, a number of individual options are being studied and assessed on-station for their potential to mitigate nematode damage and additional constraints, such as pests and diseases, and poor soil conditions. Interventions or combinations of options that address pests and diseases, as well as soil fertility issues, would be dually beneficial. The potential of one such intervention currently being investigated is the use of *Tithonia diversifolia* as mulch for its pesticidal and nutritional properties. However, in order to provide improved production recommendations on a sustainable basis, it is necessary to provide a range of options, which can be selected and combined according to the prevailing conditions. Therefore, additional aspects are being investigated, tested or recommended, including the use of clean planting material, which can be made available through the use of tissue culture plantlets. However, this is a relatively new technology, which is currently not available to many farmers. An alternative approach being investigated is disinfesting existing planting material (suckers) by developing an inexpensive technique. Further options include the use of botanicals as biopesticides, the identification and utilization of host plant resistance, as well as employing microbial suppressants.

Introduction

Banana production in Uganda is threatened by a number of constraints among which the banana pests (nematodes and banana weevils) are the major ones (Rubaihayo and Gold, 1993; Rubaihayo *et al*., 1994). Nematodes damage the roots leading to toppling, loss of fruits and subsequent high yield losses of the East African highland bananas (Speijer and Kajumba, 2000). In addition, nematode infestation can predispose bananas to other problems such as increased banana weevil infestation and Fusarium wilt (Speijer *et al*., 1993). The most damaging and widespread banana parasitic nematodes are migratory endoparasites (Speijer and De Waele, 1997), including the burrowing nematode (*Radopholus similis*), root lesion nematodes (*Pratylenchus goodeyi* and *Pratylenchus coffeae*) and the spiral nematode (*Helicotylenchus multicinctus*).

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Some sedentary endoparasitic root-knot nematodes (*Meloidogyne* spp.) are also often present in banana roots, but their pest status is unclear (Speijer and De Waele, 1997). Although *R. similis* is considered as the most important plant parasitic nematode of banana (Gowen and Quénéhérve, 1990; Gold *et al.*, 1993) the effects of other nematodes such as *P. goodeyi* and *H. multicinctus* need to be considered in pest management strategies. *R. similis* acts as the primary root invader, completes its lifecycle within 20-25 days and affects the root cortex, which becomes necrotic before killing the root (Adiko, 1988). Reduced or absence of roots will lead to declining nutrient absorption, while poor anchorage will eventually lead to toppling of the banana plant.

Nematode invasion on established banana plantations can be managed with the use of nematicides (Gowen and Quénéhervé, 1990). However, these can be costly, often unavailable and dangerous. Pesticidal compounds can also be degraded rapidly under tropical conditions, resulting in decreased efficacy (Sarah, 1989). Use of clean (healthy) planting material through paring and hot-water treatment or tissue culture plants, exposing rhizomes to sunlight for 14 days, application of botanicals, fallowing between crops, flooding the soil before planting, mulching the crop, and breeding for resistance are some of the more environmentally acceptable options for nematode management, which have been suggested and assessed (Sarah, 1989; Sikora *et al.*, 1989; Speijer *et al.,* 1996; Speijer and De Waele, 1997). At the International Institute of Tropical Agriculture (IITA), Sendusu, Uganda, a number of options for the management of nematodes are under evaluation for their efficiency, suitability and integration with other pest and disease management interventions.

On-going activities

Use of Tithonia diversifolia as mulch

Tithonia diversifolia (Mexican sunflower), locally known as 'Ekimwila', occurs commonly in uncultivated areas of the tropics (Sonke, 1997). It produces large quantities of biomass, tolerates pruning and can grow throughout the year providing a constant supply of biomass. *Tithonia,* when used as a mulch, reportedly improves crop production through increased soil fertility and reduced pest activity (Ganunga *et al.*, 1998; Gachengo *et al.*, 1999). Its effect on nematodes and appropriate application rates, which may lead to an effective reduction in nematode density and damage, while improving production, have yet to be established.

To establish the potential benefits of applying *Tithonia* to banana, a study is currently being conducted to determine the quantity required as mulch for effective *R. similis* management. Pared and hot-water treated suckers of the cultivar 'Mbwazirume' were planted in 3-litre polythene bags, inoculated with 1000 female nematodes, and one month later were transplanted into perforated half oil drums containing steam-steri-

lized soil. Following transplanting, drums were mulched using fresh *Tithonia* at rates equivalent to 0, 2, 4, 8 and 16 t/ha (dry weight) and compared to an uninoculated control without *Tithonia*. The trial design used randomized blocks with six replications per treatment. Plant growth parameters (e.g. number of functional leaves, plant height, pseudostem girth, corm diameter and number of live roots) were recorded, as well as nematode densities and damage every two months, until termination of the trial (9 months from planting).

Preliminary results suggest that increasing levels of *Tithonia* application increase plant growth parameters, which can be attributed to the increased nutrient supply from *Tithonia* (Ganunga *et al.*, 1998). Moreover, the root necrosis and galling indices due to *Meloidogyne* spp., as well as small and large lesions on the corm, were reduced with increased *Tithonia* levels. At harvest, it was noted that *R. similis* populations were lower ($P<0.05$) at *Tithonia* levels of 4 t/ha than without using *Tithonia*. Conversely, weevil damage was greater with increased *Tithonia* application, likely as a consequence of the favourable moist conditions created through mulching (Rukazambuga *et al.,* 1994). The mechanism by which *Tithonia* causes nematode suppression is currently not known.

Use of botanicals

The utilization of botanicals as a nematode control strategy has been demonstrated on several crops including banana, and can be advantageous where the plants in question are readily available and accessible. Hence, they can provide an inexpensive and environmentally suitable pest management option for farmers. Some plants that have been shown, or suspected, to possess nematicidal properties are currently being investigated for their potential as a nematode management option at IITA: neem (*Azadirachta indica*), African marigold (*Tagetes minuta*, locally called 'Kawunyira'), *Crassocephalum crepidioides* (locally called 'Sekoteka') and *Tithonia diversifolia*. *Tagetes minuta*, *C. crepidioides* and *T. diversifolia* commonly occur in fallow land in Uganda. Farmers, when weeding their bananas, often leave C. *crepidioides* in the fields in the belief that it is associated with heavier bunch yields, as a consequence of nematode suppression (Ssango, pers. com.). The neem tree, on the other hand, is well known for the pesticidal activity of azadirachtin, which occurs in all parts of the plant (Kraus, 1995). In Kenya, Musabyimana (1999), Musabyimana and Saxena (1999) and Musabyimana *et al.* (2000) found that neem treatments significantly reduced *P. goodeyi* and *Meloidogyne* spp. populations on bananas comparable to the synthetic nematicide 'Furadan 5G', and even after 8 months remained active against nematodes, while the nematicidal activity of Furadan had declined. In addition, the African marigold contains compounds that stimulate production of oxygen radicals, which block nematode metabolism. It has been reported to suppress a number of nematode species on various crops, including *Pratylenchus* spp. on flower bulbs in the Netherlands (Gommers *et al.*, 1982).

A study is currently being conducted at IITA to establish the potential of using botanicals of these plants as alternatives to synthetic nematicides. Suckers of the local cultivar 'Mbwazirume' were pared, hot-water treated at 55°C for 20 minutes before planting in plastic bags, and inoculated with 1000 female *R. similis* nematodes one month after planting. Two months later, 80 g and 160 g fresh weights of the different plants were crushed and incorporated into the soil around the banana bases, and compared to untreated controls. Application of botanicals is being repeated on a bi-monthly basis with data recorded on plant growth, nematode counts and damage. Results are yet to be obtained.

Clean planting material: corm paring and hot-water treatment

Use of clean, healthy and/or disinfested banana planting material as a management strategy against banana nematodes can be highly effective (Sikora *et al*., 1989; Gowen, 1993; Speijer *et al*., 1996). The problem of banana nematodes is continuously perpetuated through the use of infected planting material. Farmers, who are unaware of the microscopic worms infesting the roots and corm, remove planting suckers from infested fields to plant in new fields or sell to other farmers, unconsciously maintaining and exacerbating the nematode problem. Clean material can be provided as tissue-culture plantlets, which, while gaining in popularity, especially in Kenya, currently remain inaccessible to most Ugandan farmers. An alternative is to treat suckers before planting and ensure that nematodes are not passed on between farmers and to new fields.

Suckers with their roots removed (pared) and dipped in hot water at 52-55°C for 20 minutes is highly efficient at sanitizing the suckers and providing improved yields through nematode management (Speijer *et al.,* 1996; Speijer and De Waele, 1997; Speijer *et al.,* 2001). However, the system is time consuming and complicated for many farmers, resulting in low adoption rates (Kajumba *et al.,* 2003). To simplify the method and improve its adoption, IITA is currently investigating dipping pared suckers into boiling water for short periods. The objective is to establish the duration for immersing different sized suckers for effective nematode control and survival of the suckers, before testing in farmers' fields.

A split-plot trial with two levels of treatment: sucker size (main plot factor) and time duration (sub plot factor), has been established using small, medium and large suckers, and dipping the bananas for 10, 20 and 30 seconds. Data to be collected will include sucker mortality, plant growth, and nematode counts and damage.

Breeding for resistance

The identification and use of host plant resistance against nematode pests provides one of the most promising platforms towards sustainable nematode management and improved banana production. However, within the East African highland banana group

a high degree of susceptibility to *R. similis* exists (Dochez *et al.*, 2000). Furthermore, little is known of the susceptibility of banana cultivars within this group to the other prevalent nematodes, as most work has focused on the more pathogenic *R. similis*. Breeding bananas for specific traits is also a lengthy process given the inherent difficulties of sterility and crop cycle length (Vuylsteke, 2000). However, at IITA an active *Musa* breeding program is in progress with nematode resistance being one of a number of desirable traits being selected for (IITA, 2002). Crosses between 'Calcutta 4', a wild banana species with resistance to *R. similis*, and lines from various clone sets have resulted in a number of hybrids with promising resistance against *R. similis*. The prospects for the development of consumer desirable cultivars/hybrids with resistance to nematodes is therefore promising.

Use of microbial endophytes

A novel approach to pest management in bananas being investigated at IITA is the use of avirulent fungal endophytes (Niere *et al.*, 2002). Evidence shows that plants infected (hosting) with avirulent endophytic fungi are provided with protection against various pests and diseases (Clay, 1991; Sikora *et al.*, 2002). A current study is investigating naturally occurring avirulent endophytic fungi on bananas in Uganda, isolating them, and re-inoculating on tissue culture banana plantlets to identify suitable isolates with pest management potential. Preliminary results indicate that tissue culture banana plantlets inoculated with certain isolates of *Fusarium oxysporum* are less susceptible to *R. similis* attack, increasing the potential survival (initially) of the plantlets (Niere *et al.*, 2002). Studies are on-going to establish the persistence of the endophytes over cropping cycles and their benefits in terms of banana production

Future prospects

Helicotylenchus multicinctus

To date, limited assessment of the specific pathogenicity of *H. multicinctus* on banana has been undertaken, one reason being the difficulty the nematode has posed to efficiently culture it. At IITA, cultures of *H. multicinctus* have been established from different geographic locations in Uganda in order to conduct pathogenicity studies for comparison with highly and less virulent *R. similis* isolates. In due course it is expected that *H. multicinctus* will be included within the resistance screening activities.

IPM of banana nematodes

While a number of specific studies are being conducted at IITA in East Africa for the management of nematodes on banana, their control, as well as other pest and disease constraints, is dependant upon an integrated `basket of options' strategy. No single

management option for nematodes or other pests and diseases is likely to be sustainable in isolation. Banana systems are complex, and the sustainable management of pests and diseases needs to be sufficiently dynamic, requiring the integration of a number of options depending on the conditions, circumstances and prevailing pest complex. Resistance to pests and diseases, where possible, should provide the foundation for additional options to maximize banana protection and the returns to the farmer. IITA is working towards this goal, in collaboration with national programmes and other research centers.

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