Propositions

1. The behaviour of the banana weevil is as unpredictable as Dutch weather.

   This thesis

2. Crop protectionists need lectures not only in pest biology and behaviour, but also in farmers' behaviour.

   This thesis

3. With no "*matooke*" (banana) in central Uganda, there is no food security even with sacks of rice, maize meal and beans filling the food store.

4. A Ph.D. thesis write up should follow the life history of the banana weevil.

5. Limited mobility does not mean limited ability, and lazy brains may exhaust the legs.

   A modification of an old *Luganda* saying

6. War does not determine who is right - but who is left.

   Anonymous

7. Never attempt to drown your sorrows in alcohol - apparently they learn how to swim.

Propositions accompanying the Ph.D. thesis:

"Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) populations and associated damage".

Michael Masanza Wageningen, September 9, 2003

Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) populations and associated damage

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Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) populations and associated damage

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Contents

Abstract

The banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is a serious pest of bananas. However, its ecology is not well elucidated especially in East Africa where plantations are up to 50 years old and are under various management and cropping systems. No single satisfactory control strategy has been found. Detailed information on *C. sordidus* biology and ecology is needed to explain the population dynamics of this pest in order to develop a comprehensive package for the small-scale farmer to alleviate the pest problem. Cultural control forms the first line of defence in pest control. For instance, removal of crop residues after harvest by chopping is a widely recommended cultural strategy for *C. sordidus* control. However, the actual effect of these practices on the insect's population dynamics is not clear. This study was aimed at investigating the effect of crop sanitation on population dynamics of *C. sordidus* and its associated damage.

Laboratory and field studies on the biology and ecology of this pest on crop residues were conducted in Uganda. We found that corms are most attractive to the weevils than any other type of crop residues. Oviposition occurred on residues up to 120 days after harvest, but mainly on freshly harvested residues up to 30 days, implying that residues should be left up to a month before destroying them.

In the study on survivorship of *C. sordidus* in crop residues, our results revealed that the pest successfully completes its life cycle within crop residues and emerging adults from different aged residues are equally fit. As crop residues can be a source of *C. sordidus* infestation to the standing crop, they need to be destroyed. There is a general belief that covering banana stumps after harvest helps reduce weevils in banana farms. However, there was no data available to prove that this practice is useful. Moreover, the real effect of covering stumps remained unknown. Our studies reveal that covering banana stumps after harvest reduces oviposition on them in the wet season, but encourages oviposition in the dry season. Therefore, farmers may cover the stumps in the wet but not in the dry season. Also, our studies suggest that covering all stumps in the wet season may encourage *C. sordidus* to oviposit on the crop. Therefore, some residues should be left in the inter-mat alleys to attract weevils away from the crop. The residues can then be destroyed after three to four weeks.

Removal and chopping crop residues in farmers' fields helped to keep *C. sordidus* populations and damage lower than when the residues were left to accumulate. In comparison, removal of all residues in young closed banana plots reduced *C. sordidus* populations but increased damage on growing plants and reduced the levels of natural enemies. The implications of these results on the role of crop sanitation in the integrated management of *C. sordidus* are discussed.

Everything God created is beautiful: even the "ugly" banana weevil.

Preface

My second name means "dry banana leaves" ... was it given to me by my parents prophetically depicting what I would be preoccupied with during most of my graduate studies? From the very early years of my life, apart from going to school, my activities revolved around helping my parents manage a banana plantation that provided most of the food for our "football team" family of 11 children born to *Mayi* and *Papa*. Because of limited space on this page, I will skip most of what transpired between my childhood days and undergraduate education. My M.Sc. thesis marked the turning point that would eventually bring me to this battle against an insect whose name in *Luganda* is "*kayovu*" (little elephant = banana weevil). The thesis work introduced me to the field of integrated management of *Cosmopolites sordidus*.

Shortly after completing studies at Makerere University, Kampala on integrated management of this pest, I was given an opportunity to start Ph.D. studies on the effect of crop sanitation on banana weevil populations and damage. The Rockeffeler Foundation, through a fellowship administered by the International Institute of Tropical Agriculture (IITA) funded the studies. In this respect, I thank Dr. Cliff S. Gold and Dr. E.B. Karamura of INIBAP, who selected me for this assignment. Cliff, I acknowledge your personal input from the inception of the study. You used your international connections to link me with Wageningen University, where I had the pleasure of joining the Laboratory of Entomology to develop the proposal and attend some relevant courses in Entomology. My promotor Prof. Joop van Lenteren and co-promotor Dr. ir. Arnold van Huis guided me through this process while at the Laboratory. Arnold, Cliff and Joop, please accept my sincere gratitude for the trouble you took reading through my manuscripts in preparation for submission of the thesis. Your "visual acuity" to spot mistakes that never looked obvious to me helped smooth out the articles for this book. In the same breath, I will not forget Ms Marthy Boudewijn for her committed attention every time I needed assistance on administrative aspects. Thank you Marthy. Ms Ineke Kok, I remember how you initiated me into the Dutch community when I first stepped in Wageningen. It is impossible to forget the kindness you showed me. Gerard Pesch, you have a large heart and I appreciate you. Only a few people know what you did for me when I came back from Uganda to start writing this thesis.

It would be unfair if I forgot the input from the Ph.D. discussion group. My colleagues, particularly Maartje, Ties, Gebre, Tibor, Karin, Frodo, Linnet, Jetske, Gladys, Mohammed, Linde, Trefi, Nina, Emmanuel, Sander and others, made useful comments on some of the manuscripts. Of course the company you gave during this period cannot go unacknowledged. It was refreshing to break the monotony of the computer keyboard and screen with a cup of tea outside the canteen when the capricious Dutch weather was a little bit friendlier. More thanks to Martinus Huigens (Ties) who did the Dutch translation of the summary and Trefas Hijnalka assisted in making some illustrations that needed artistic skill. I cannot ignore the warmth I received from the International

Christian Fellowship (ICF) that made me feel at home away from home during the most challenging months of thesis writing.

I also wish to acknowledge the input of Dr. Wilberforce Tushemereiwe (Tush), leader of the National Banana Research and Production Programme (NBRP) of the National Agriculture Research Organization (NARO) in Uganda. I remember you readily approved my requisitions for land needed for planting my trials. Many thanks to my colleagues at the IITA computer laboratory back at Kawanda. Hussein, Godfrey, Gertrude, Agnes, David Talengera, David Kaganda, Joseph, Pamela, Richard and Andrew, you made work on the banana weevil more enjoyable and fun even during difficult times of data collection in the field. Often, the tension and stress from work would go unnoticed. I cannot forget the co-operation I received from farmers in Ntungamo from whose banana farms I collected data for three years. To Dr. Suleman Okech stationed in western Uganda, I express my heartfelt appreciation for the several brain storming sessions both in the field and office. Your contribution on several occasions helped me think twice before designing my field trials. Philip Ragama, please accept my thanks for being there when I needed my data analysed. Your advice is gratefully appreciated.

I lack the proper words to express my gratitude to my dear wife Dr. Monica Musenero Masanza who was patient with me. I was often absent for weeks away in the field and worse when I had to leave you with family responsibilities for a full year. Monica, forgive me for leaving you 'husbandless' for such a long time. Thank you for being both a mother and "father" to our two children in my absence, yet you had your own career to pursue as well. Little Joshua and Michelle please, do not take it personal for leaving you without a father for a solid 12 months. To you, I dedicate this thesis.

Lastly but not least, thank you *Mayi* and *Papa* for the untold sacrifices you made, striving to give me quality education and tolerating many years of a student son. To my brothers (Sam, James, Nathan and Fred) sisters (Eunice, Sarah, Norah, Faith and Nancy), thanks for the prayers, moral support and encouragement. Your love gave me the impetus to move on amidst hardships. Finally, I am eternally grateful to God Almighty in whom I put all my faith to help me complete my studies. To you O God, I ascribe all the greatness and glory.

Michael Masanza Wageningen, September 9, 2003

Chapter 1

General Introduction

Michael Masanza

Chapter 1

General introduction

Background

A wider IPM approach is being sought to control the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). No single strategy has been effective in the control the pest. In this thesis, we present the effect of crop sanitation as a cultural control option in reducing banana weevil population and damage on farmers' fields. Cultural control forms the first line of defense in pest control and as such is the single most available strategy to resource-poor banana farmers in East Africa. Before describing the pest problem and the control options against *C. sordidus*, I will briefly discuss the origin and importance of banana (*Musa* spp.).

Origin and economic importance of *Musa* spp.

The genus *Musa*, originated from the Malaysian region of southeast Asia, from where it dispersed to other parts of the world (Shepherd, 1957; Simmonds, 1962). The crop is believed to have reached Africa between the first and the nineteenth century A.D. (Price, 1995; Karamura, 1998). Its cultivation is restricted to the belt between the 40^{o} latitudes because the crop cannot tolerate frost (Purseglove, 1985). It is grown throughout the tropics and the subtropics of Asia, America, Africa and Australia. Banana is an important fruit crop, second in production worldwide to grapes (Purseglove, 1985). Banana is a major staple food in much of the tropical region (Gordish, 1966; Kang and Reynolds, 1986; Chataigner, 1989). It is ranked among the four most important food crops in the world (FAO, 1993; Valmayor, 1994). In the East African Highlands, the endemic banana (genome group AAA-EA) is traditionally a main staple food (Tibaijuka, 1983; INIBAP, 1986) as well as a cash crop (Masefield, 1944; Price, 1995), and is grown on smallholder farms. The surplus is locally traded as a regular source of income (Davies, 1995). It is a major food security crop in the region because harvesting is possible throughout the year. The Lake Victoria region of East Africa Highlands has the highest density of banana in the world (Stover and Simmonds, 1987). In Uganda, banana is a staple food of the Bantu ethnic groups. This country is the biggest producer of banana in Africa (Purseglove, 1985). The Highland cultivars found in East Africa account for 75% of production in Africa and constitute 20% of the world's banana production (Baker and Simmonds 1951, INIBAP 1989). *Musa* spp. (genome group AAA-EA) is mainly grown in the highlands of East Africa, while Cavendish (*Musa* sp. genome group AAA) and Bluggoe (*Musa sp.* genome group BBB) are mainly found at the coastal regions of Tanzania (Simmonds, 1966; Mbwana, 1985; Rukazambuga, 1993).

Banana taxonomy and botany

Banana is a tree-like unbranched perennial herb, 0.8-15 m tall (Turner, 1994). It belongs to the family *Musaceae* in the order *Scitaminaceae* (*Zingiberales*). Edible banana in the *Eumusa* series has its origin from two wild species, *Musa acuminata* Colla and *Musa balbisiana* Colla (Simmonds, 1962). The edible forms are assigned genomes according to the species of origin A (*acuminata*) and B (*balbisiana*) (Simmonds, 1966), in the genome nomenclature. While *M. acuminata* is cultivated in three outstanding edible forms: diploid (AA), triploid (AAA) and tetraploid (AAAA), those of *M. balbisiana* are exclusively found in the hybrid forms (AB, AAB, ABB or ABBB) (Simmonds and Shepherd, 1955). It is the more vigorous triploid (AAA) and tetraploid (AAAA) rather than the diploid (AA) that are commonly grown.

The banana has a short subterranean stem (corm/rhizome) with buds from which arises a cluster of one or more aerial shoots called suckers. This group of suckers arising from a common corm is called a mat (=stool) (**Figure 1**). New generations of suckers arising from the mother plant (planted sucker) are called ratoons or crop cycles. The corm also bears adventitious roots, which arise from the cambium-like apical meristem of the central cylinder (Skutch, 1932; Stover and Simmonds, 1987). The roots laterally spread approximately 4-5 m (Price, 1995) and descend 75 cm deep but most roots are found within the top 40 cm of the soil profile (Lassoudiere, 1978; Price, 1995). Each corm gives rise to one terminal inflorescence, by extending throughout the centre of the pseudostem, maturing into a fruit (Stover and Simmonds, 1987; Espino *et al*., 1991). The fruit is commonly referred to as a bunch. After harvest, the apparent stem (pseudostem) and underground corm remain as residues, which may be removed or left intact.

Banana production constraints in East Africa

Despite the importance of banana, production of especially the predominant *Musa AAA-EA* has declined due to a complex of socio-economic and technical constraints, summarized in **Table 1**. Among the socio-economic production constraints is land shortage, poor farming methods, the lack of production inputs and poor marketing facilities. Small farms with dynamic cropping systems characterize most banana growing regions in East Africa. Because of increased land pressure, some farmers rent land from neighbours or grow annual crops, leaving out the perennial banana (Gold *et al*., 1993). The practice of fallow and crop rotation as a means of soil fertility conservation in banana growing areas is being abandoned due to land shortage. As a result, there is over-cultivation leading to a decline in soil fertility. Banana production is also constrained by lack of production inputs such as fertilizers and adequate labour, and, poor marketing strategy (ICIPE, 1992). Most farmers cannot afford these inputs and have no ready access to markets for their surplus produce, especially during a glut. However, most constraints limiting banana production are technical.

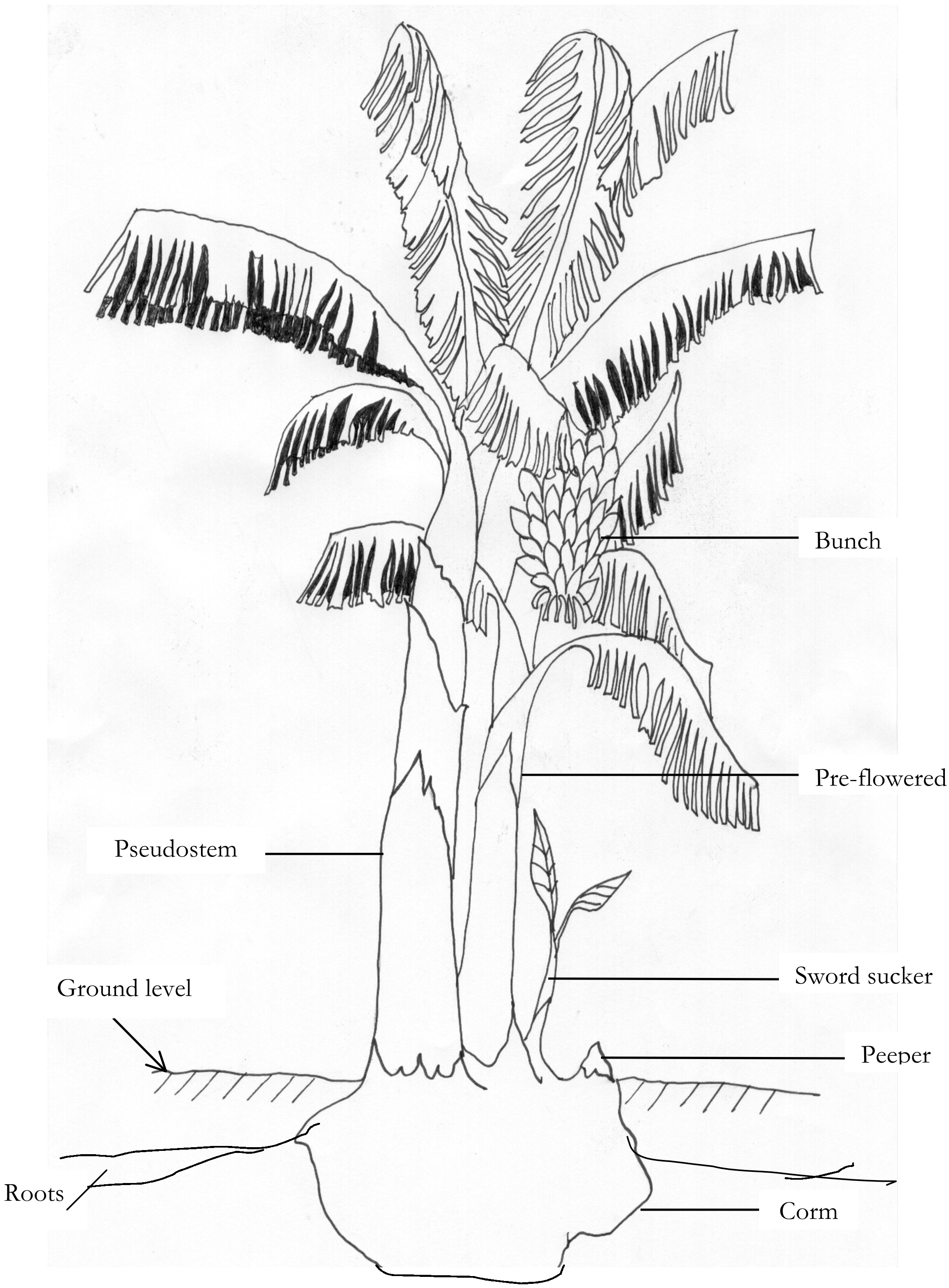

Figure 1. A schematic presentation of a banana (AAA-EA genome group) mat/stool.

Technical constraints

Among the recognized technical constraints of banana production are pests and diseases, soil nutrient deficiencies and lack of suitable varieties such as those tolerant and resistant pests and diseases (Wybou, 1974; Mau, 1984; Ashgar, 1984; Rubaihayo, 1991). Gold *et al.* (1993) summarized the pest constraints as a combination of weevils and nematodes. Farmers ranked soil exhaustion as constraint number one. However, we shall discuss mainly the pest and disease problem.

Table 1: Summary of banana production constraints in East Africa

Socio-economic	Technical
- Land shortage	- Pests e.g.
- Poor farming methods e.g.	• Banana weevils
• Over-cultivation	• Nematodes
- Lack of production inputs	- Diseases e.g.
• Adequate labour	• Panama disease
• Fertilizers	• Black sigatoka
- Poor marketing strategies	- Soil nutrient deficiencies
	- Lack of resistant/tolerant banana varieties

Pests and diseases

A complex of pests and diseases are the main factors considered responsible for the recent decline in banana production in Uganda. Among the most important diseases are: Fusarium wilt or Panama disease, caused by the fungus *Fusarium oxysporium, f. sp. cubense* Schlecht. emd. Synd. and Hans., and Black Sigatoka, caused by *Mycosphaerella fijiensis* var. *difformis* Mulder & Stover (Morelet) (Sebasigari and Stover, 1988; Tushemereirwe *et al.*, 1993).

The banana weevil *Cosmopolites sordidus* is the most notorious of the arthropod pests of the crop and needs to be controlled (Harris, 1947; Cann, 1966; Jones, 1986; Seshu Reddy, 1986; Stover, 1991). Other banana weevil species are secondary pests (Pinto, 1928): *Cosmopolites pruinosus* (Zimmermann, 1968), *Temnoschoita nigroplagiata* (Qued), *T. erudita* Duviv., *T. basipennis* Duviv (Harris, 1947), *Metamasius hemipterus* L. (Squire, 1972) and *Oidoporus longicollis* L. (Adisoemarto, 1983). Termites can also be important.

Root nematodes, mainly *Radopholus similis* (Cobb) Thorne, *Meloidogyne* spp. and *Pratylenchus* spp., cause great losses of plant root systems leading to toppling (Gold et al., 1994). Termites and vertebrate pests, such as baboons and monkeys, are also destructive in the field (Gold et al., 1993; Rubaihayo and Gold, 1993).

Cosmopolites sordidus in East Africa

Cosmopolites sordidus is important wherever banana (*Musa* sp.) is grown (Ostmark, 1974; Waterhouse and Norris, 1987). It especially attacks cooking banana (Sikora et al., 1989) and plantain (Jones, 1986). The weevil has been known for a long time in Uganda, so it was probably introduced with the crop (Harris, 1947). It was not a major pest by 1918 (Squire, 1972). Its incidence and severity increased mainly due to pesticide resistance and general poor stand management (Bridge, 1988; Swennen and Vuylsteke, 1988). Lately, surveys in banana growing areas showed severe weevil damage causing toppling of the plant (Sebasigari and Stover, 1988; Gold and Gemmill, 1991; Rubaihayo, 1991). In central Uganda, the cooking banana is being replaced by exotic types (*Musa ABB, Musa AB* and *Musa AAA*), which are more tolerant to pests (Gold et al., 1996). There has also been a general shift in production from the central region to the western highlands of Mbarara, Bushenyi and Ntungamo districts (Gold et al., 1999b). Banana stands, when well managed, could live up to 50 years and beyond in the past. Today, well-established gardens start deteriorating after only four years or so (Stover, 1991; Gold et al., 2003). Similarly, yields which were previously as high as 30 tons per ha slumped to 6-10 tons per ha (INIBAP, 1986). Banana production from the same area of 1.2 million ha dropped from nearly 9 million tons to about 5.5 million tons in a decade (1978-1988) (Rubaihayo, 1990). Even in the new areas where production has shifted to, banana weevil is becoming increasingly important.

Taxonomy of *C. sordidus*

Germar first described the banana weevil as *Calandra sordida* in 1824 (Beccari, 1967 cited by Schmitt, 1993). Later, other names assigned to it were *Sphenophorus sordidus* (Germar 1824), *Sphenophorus liratus* Gyllenhal 1838, and *Sphenophorus striatus* Fahraeus 1845. In 1885, it was eventually named *Cosmopolites sordidus* by Chevrolat. It belongs to the Order Coleoptera, Family Curculionidae, Sub-family Calandrinae, Tribe Calandrini, Genus *Cosmopolites* and Species *Cosmopolites sordidus* (Germar 1824). The pest has been called banana weevil, banana corm borer, banana beetle, banana root borer, the rhizome weevil and black banana borer and it has also many vernacular names.

Biology of *C. sordidus*

Morphologically, the eggs are elongate, oval and pure white and 1 - 2 mm in length (Jepson, 1914; Moznette, 1920; Froggatt, 1925; Beccari, 1967). A fully-grown larva ranges from 11 to 15 mm, is legless and has a brownish head (Froggatt, 1923; Cuille, 1950; Beccari, 1967). The pupa is up to 12 mm long and 6 mm wide. The adult is up to

14 mm long and 4 mm wide (Lescot, 1988). The insect is soft and brown at emergence, but the integument later hardens and becomes dark (Harris, 1947; Whalley, 1957, 1958).

Cosmopolites sordidus exhibits a typical K- selected life cycle (Pianka 1970): a long lifespan, low fecundity and high survival. The adult has a lifespan of up to four years (Gold et al., 1999c). Females oviposit at a rate of 1-3 eggs/week (Gold *et al.* 1999c). **Figure 2** summarizes the life cycle of *C. sordidus*. Eggs are deposited singly at the plant base in holes perforated by the ovipositing female using its rostrum (Schmitt, 1993). Koppenhofer (1993) found in pot trials 78% of the eggs on the rhizome, especially the crown, and 22% on the pseudostem base. However, under field conditions, most oviposition is near ground level at a maximum depth of 5 cm in the soil, mainly

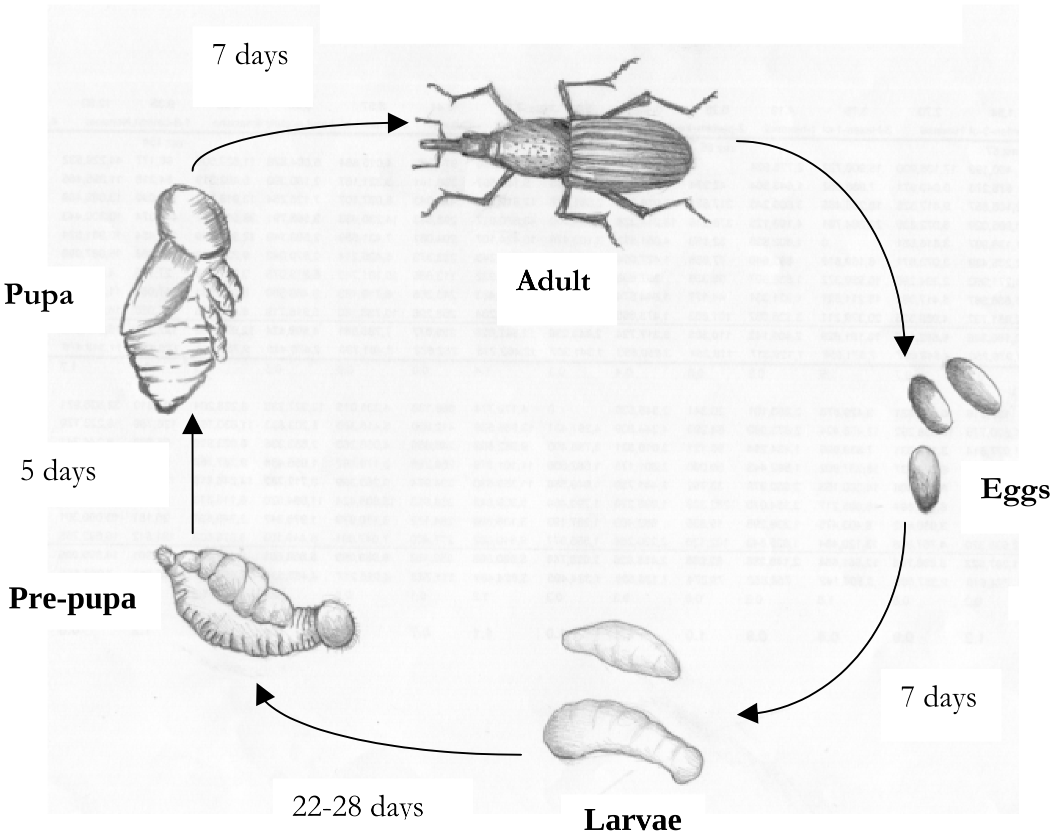

Figure 2. Generalized life cycle of the banana weevil Cosmopolites sordidus (germar) Coleoptera: Curculionidae).

in leaf sheaths of the pseudostem base, with greater egg density on older plants (Abera et al., 1997).

Incubation period varies from 4-15 days at 25ºC-28ºC (Schmitt, 1993) and 4-7 days under laboratory conditions of 23ºC-25ºC (Gold et al., 1999c). The larval stage varies from 25-32 days at 20ºC-25ºC (Mesquita and Alves, 1983), and 23 days at 25ºC-28ºC (Schmitt, 1993). The larvae have 5 to 8 instars (Schmitt 1993, Traore et al., 1993). The pupal stage lasts 4-30 days (Schmitt, 1993; Traore et al., 1993). Under tropical conditions, the total immature period ranges from 1 to 2 months (Seshu Reddy, 1986; Bakyalire and Ogenga-Latigo, 1992; Schmitt, 1993). In Uganda, the duration of egg to adult stage was 53 to 72 days (Bakyalire, and Ogenga-Latigo, 1992; Gold et al., 1999c).

Ecology

Habitat and host range

This weevil is a specialist herbivore on *Musa* spp. and *Ensete* (Moznette, 1920; Champion, 1968). However, some records indicate that it also attacks sugarcane (*Saccharum* sp.), yams (*Dioscorea* sp.), and cocoa (*Theobroma* sp.). Beccari (1967) cited *Ricinodendron hendelotii* (Euphorbiaceae), *Panicum maximum*, *Xanthosoma sagittifolium* (Araceae) and *Dioscorea batatas* (Dioscoreacea) as being attacked by *C. sordidus*, in addition to *Musa* and *Saccharum*. However, oviposition studies have shown that *C. sordidus* cannot complete its life cycle on these other plants (Martinez et al., 1990). Research on the ecology of the banana weevil has been carried out only on banana and Manila hemp (*Musa textilis*) (Arleu and Neto, 1984 cited by Schmitt, 1993).

Behaviour

It is difficult to study the behaviour of the adult weevil as it is nocturnal, negatively phototactic and prefers high humidity places (Ittyeipe, 1986). It rarely flies, but when stressed by exposure to insecticides or dry conditions it may spread its wings but not fly (Roth and Willis, 1963). Its host range limits dispersal of *C. sordidus*. Dispersal is mainly through transfer of planting material and by walking. In Uganda, maximum weevil movement has been recorded as 35 m in three days (Gold and Bagabe, 1997) and less than 3% of marked weevils found in pseudostem traps were recaptured in plots adjacent to those in which they were released (Gold et al. unpublished). This suggests that dispersal by walking is rare.

Host plant orientation in insects is a response to optical and chemical characteristics of plants. Since the banana weevil is nocturnal, it is expected to mainly depend on chemical cues from plant volatiles. It is positively hygroscopic and displays orthokinesis, klinokinesis and klinotaxis when exposed to different humidity gradients (Roth and Willis, 1963). Banana weevils aggregated under lures of higher humidity when they were exposed to different amounts of liquid water Cuille (1950). He concluded that weevils search for higher humidity, but also look for liquid water. Recent studies suggest that *C. sordidus* uses odour-conditioned anemotaxis in its orientation to fermented banana plant volatiles (Tinzaara et al., 2003).

Injury and Damage

Injury by banana weevil is caused by feeding and tunneling of larvae into corms and pseudostems (Harris, 1947; Whalley, 1957; Woodruff, 1969; Ostmark, 1974). Large tunnels made by growing larvae are up to 15 mm in diameter, extending 60 cm or more in the pseudostem (Wolfenbarger, 1964; Anon., 1977). Adults cause insignificant injury and damage as they mainly feed on crop residue.

The main damage by this pest arises from tunneling by the larvae destroying the vascular system and hindering the transport of nutrients and water which eventually weakens the plant (Harris, 1947; Anon., 1977). Heavily infested plants are prone to drought, produce small bunches, and may topple during strong winds before bunch ripening (McNutt, 1974; Bujulu et al., 1983; Sikora, et al., 1989; Bakyalire and Ogenga-Latigo, 1992). Toppling can lead to crop losses of 50 - 100% (Hord and Flippin, 1956; Sebasigari and Stover, 1988). Young plants propagated from infested planting materials are often also infested, and become stunted with reduced fruiting (Harris, 1947).

The main factors influencing damage by *C. sordidus* are the type of banana grown and crop management. In Uganda, the East African highland cooking banana (genome group AAA-EA) is the most susceptible while the beer types (AAA-EA and ABB) and "Bluggoe" (ABB) suffer very little weevil infestation and damage (Ogenga-Latigo and Bakyalire, 1993). Poor crop management, characterized by lack of pruning and accumulation of trash, normally leads to high weevil population and severe crop damage (Feakin, 1971; Hill, 1983). In the field, variable damage has been found among cultivars, with introduced beer types (AB, ABB) being relatively resistant (Gold et al., 1994; Kiggundu, 2000). It is possible that the various cultivars release semiochemicals in different quantities and composition to cause differences in attraction. Injured plants attract weevils probably because they produce more volatiles than uninjured plants (Treverrow et al., 1993). The variability in damage may also be due to acceptance and survivorship of weevils being different among the cultivars (Budenberg et al., 1991).

Control of *C. sordidus*

To control the weevil, a broad integrated pest management approach is being sought. Integrated Pest Management (IPM) has been defined as "a pest management system that, in the context of the associated environment and population dynamics of the pest species, utilizes all possible techniques and methods in as compatible a manner as possible and maintains the pest population levels below those causing economic injury" (FAO, 1973). An IPM strategy for *C. sordidus* should include habitat management (cultural control), biological control, host-plant resistance, biorationals and chemical control as the last resort.

Cultural control

Cultural control or habitat management, based on the manipulation of banana weevil habitat (Hargreaves, 1940; Harris, 1947; Feakin, 1971; Gold, 1998) is an appropriate option to the majority of smallholder farmers. This is because these methods are sustainable and often do not need costly external inputs. Among the recommended cultural practices are: crop sanitation (management of post-harvest residues), use of clean planting material, selection of cropping systems, improved crop husbandry practices to promote crop vigour and trapping (Gold et al., 2003).

Crop sanitation

Crop sanitation in banana stand management is the removal or destruction of plant residues i.e. corms and pseudostems after harvest. After harvesting, corm stumps and pseudostems are left in the banana fields at various levels of decomposition and can act as hiding places for adult weevils (Gold et al., 1999a) and oviposition sites for gravid females (Abera 1997). In Ecuador for instance, decomposing residues of the variety Gros Michel had up to 80% of field attack on while most attack on the variety Petite Naine was against standing plants (Vilardebo, 1960). In Australian Cavendish plantations, attack was confined to crop residues under conditions of low pest pressure (Treverrow et al., 1991), and plantations were able to tolerate very high weevil levels without suffering yield loss (Gold et al., 2003). However, heavy attack of the corms can weaken the support that these corms provide for the followers which may eventually topple (Stanton, 1994). Studies in Uganda showed heavy infestation of decomposed crop residues of a beer cultivar Kisubi (AB), with little infestation of fresh residues (Gold and Bagabe, 1997). Apparently, there are differences in oviposition preferences and larval survival of *C. sordidus* on crop residues. Heavy oviposition has been recorded on cut banana stumps of highland banana (genome group AAA-EA) cultivars (Gold et al., 2003).

The use of crop sanitation as a method of controlling *C. sordidus* will continually be doubted unless it is evaluated. Destruction of residue corms and pseudostems kills the eggs and larvae on them. Residues then act as traps drawing ovipositing females away from the growing plants (Waterhouse and Norris, 1987; Gold et al., 1998). Following this hypothesis, several recommendations were made; one of which was to place cut pseudostems in banana plantations to attract gravid females away from the growing plants (Treverrow, 1985; Allen, 1989). Other suggestions of managing crop residues were to cut and bury old pseudostems and corms with compact soil, to split and spread it as mulch, or to chop heavily infested corms (Hargreaves, 1940).

Despite these recommendations, some farmers and researchers have reservations about removal of crop residues. For instance, there is a theory that the banana stump provides nourishment to the growing suckers. Therefore, it was recommended that 1.5m of pseudostem should be left within the mat (Treverrow et al., 1992; Smith, 1995; Sponagel, 1995). Additionally, some farmers believe that removal or digging out corms would have a destabilizing effect on the followers, leaving the banana mat vulnerable to toppling by the wind (Karamura and Gold, 2000).

It is not yet clear whether reproduction in harvested crop residue reduces or increases damage to growing banana plants. Information is needed to investigate the attraction and oviposition preferences, eclosion rates and larval survival of *C. sordidus* of different cultivars.

Use of clean planting material

Introduction of the banana weevil into new stands is through infested planting material containing eggs and larvae (Waterhouse and Norris, 1987; Gowen, 1995). Use of clean suckers is therefore crucial (Anon., 1977; Gold et al., 2003). Clean planting material can be realized by getting suckers from weevil-free fields, paring of corms and hot water treatment to eliminate eggs and larvae. Crop husbandry practices such as desuckering, mulching, pruning, clean weeding and manure application increase crop vigour and hence tolerance against the banana weevil (MacNutt, 1974).

Selection of cropping systems

Multiple cropping often result in lower pest pressure by reducing immigration, increasing emigration and interfering with host plant location (Altieri and Letourneau, 1982). Uronu (1992) and Rukazambuga et al. (1994) found lower weevil populations by intercropping but not a higher yield. Hence, Gold et al. (2003) consider that some of the mechanisms by which intercropping influences herbivores may be irrelevant for *C. sordidus*, e.g. the increased effectiveness of natural enemies when pest dispersal is impeded. This is because effective natural enemies are not known in Africa and, the weevil does not fly, limiting its mobility. However, recent surveys in Ntungamo district in western Uganda suggest that coffee intercrop does reduce weevil attack on banana (Gold et al. unpublished). This may be due to the presence of alkaloids in coffee, which may be a weevil repellant (Kehe, 1988). Some cultivars are very susceptible to post-harvest attack while others are not (Treverrow et al., 1991; Gold and Bagabe, 1994). Knowledge of such differences with respect to weevil host preference can help in manipulating crop residues so as to control *C. sordidus* populations in multi-cultivar stands.

Trapping adult *C. sordidus*

Trapping of weevils by rhizomes and pseudostems is normally used in monitoring, but can also be used as a control method (Price, 1993). Two types of traps are used; viz. split pseudostem and disc-on-stump traps (Simmonds, 1962). The former are more frequently used than the latter (Mitchell 1980). The split pseudostem trap is made from post-harvest pseudostem pieces split longitudinally into two halves and placed with the cut surface on the ground near the target plant (Ogenga-Latigo and Bakyalire, 1993). In a control programme, traps are placed in banana stools against plants, and the weevils attracted to them are collected and destroyed (Hord and Flippin, 1956). Its full potential can be realized if used in combination with chemical and biological insecticides (Schmitt et al., 1992). A disc-on-stump trap is made by cutting a stump of harvested pseudostem 15-23 cm above the ground then placing a disc of pseudostem 7.5-15 cm long on it upper side. The trap is inspected 72 hours (3 days) after setting (Mitchell, 1980). Although this trap type is said to catch three times more weevils than the split type, it can only work when harvested stumps are available (Mitchell, 1980).

In East Africa, trapping reduced pest populations (Bakyalire and Ogenga-Latigo, 1992; Schmitt, 1993; Bosch et al., 1995; Masanza, 1995). Continuous trapping has resulted in up to 50% reduction in weevil numbers and 31% increase in yields (ICIPE, 1995). However, during surveys, trapping appeared to be tedious and labour intensive, with variable efficiency ranging from 2 - 25% of marked weevils recaptured (Gold et al., 1993, Gold et al., 1998).

Pheromones

To control weevils, traps can be baited with pheromones. The existence of male-produced aggregation pheromones has been demonstrated in the laboratory (Budenberg et al., 1993). The male-produced aggregation pheromone has been synthesized, identified as sordidin and configured in Japan (Mori et al., 1996). In Costa Rica, traps baited with the synthetic pheromone were more attractive than unbaited traps (Ndiege et al., 1996). It should be investigated whether this technology is within the reach of the smallholder farmer in East Africa (Tinzaara et al., 2002).

Host plant resistance

The search for host plant tolerance and resistance is a priority especially in the context of the small-scale/resource constrained farmer (INIBAP, 1988). In East Africa, some banana cultivars have been evaluated for resistance/tolerance to *C. sordidus* (Seshu Reddy et al., 1992); weevil multiplication rate and injury inflicted on the corm were taken into account. Also, a few wild bananas, and several cooking AAA-EA and diploid (AA) and triploid (AAA) dessert bananas have shown some level of resistance to the weevil (Ortiz et al., 1995), possibly through non-preference by corm hardness. Price (1994) also demonstrated that the AAA genome group showed resistance. In Uganda, resistance to attack by the pest has been demonstrated by the beer types (AAA) despite high weevil incidence in the plantations (Gold and Bagabe, 1994, 1997). The same authors reported that weevils attacking beer-banana preferred crop residues to standing plants, suggesting possible breakdown of repellants in tissue of beer banana on decomposition. Resistant cultivars may lack volatiles that attract weevils to susceptible cultivars. Indeed several volatiles thought to be responsible in contributing to cultivar susceptibility have been identified (Ndiege et al., 1996). In particular, 1,8 - Cineole was found to be present in all susceptible and tolerant cultivars but absent in a resistant cultivar "Mbu" (genome group ABB). After screening for tolerance, six cultivars have been recommended and supplied to farmers in east Africa (ICIPE 1992, 1995).

Biological control

Biological control is the use of a complex of natural enemies (predators, parasitoids and pathogens), to suppress pest population densities. A number of insect natural enemies in the orders Hemiptera, Dermaptera, Diptera, Coleoptera and Hymenoptera have been cited in the control of *C. sordidus* (Froggatt, 1928; Cuille, 1950; Roche, 1975; Mesquita et al., 1984; Roche and Abreu, 1983; Mesquita and Alves, 1984; Neuenschwander, 1988; Seshu Reddy, 1988; Schmitt, 1993). The authors also cited amphibians, platyhelminths and fungi as natural enemies of the weevil. In East Africa, three species of Dermaptera and three of Coleoptera were observed preying on immature weevil stages (eggs and larvae) in the rhizomes and pseudostems (Koppenhofer, 1993).

The banana weevil reached damaging levels after being introduced in East Africa where co-evolved natural enemies are probably absent. The first attempt to control the weevil by using biological means was classical biological control with *Plaesius javanus* (Coleoptera: Histeridae) a beetle that eats eggs and larvae (Jepson, 1914 cited by Moznette, 1920). The beetle was collected from Java and released in Fiji, where it successfully controlled the weevil population (Moznette, 1920; Cendana, 1922; Simmonds, 1966). After this success in Fiji, *P. javanus* was released in various places including East Africa but failed to establish (Simmonds, 1966). A beetle population that was released in Mexico in 1955 was found established in 1972, 18 years after its release indicating that establishment may take a long time (Barrera and Jimenez, 1994). The failure of *P. javanus* to establish in East Africa was possibly due to the insufficient number of released vigorous beetles (Harris, 1947).

The use of predatory beetles (Hydrophilidae) *Dactylosternum hydrophilides, D. abdominale* and *D. subdepressum* was unsuccessful. However, in a controlled experiment, *D. abdominale* reduced *C. sordidus* multiplication by up to 90% (Koppenhofer and Schmutterer, 1993). Apart from the Coleopteran predators, the ant *Tetramorium guineense* (Hymenoptera: Formicidae) was released successfully suppressing weevil populations in the field (Roche, 1975; Roche and Abreu, 1983).

Entomopathogenic nematodes have been successfully used in weevil control. The genera *Steinernema* and *Heterorhabditis* attack both the larval and adult stages of *C. sordidus.* They were introduced in various places and reduced weevil populations (Treverrow et al., 1991; Schmitt et al., 1993). However, the results were better when nematodes were combined with insecticides, compared to application of nematodes only (Kermarrec and Mauleon, 1989). Moreover, entomopathogenic nematodes have been reported to be less self-perpetuating in the environment compared to other natural enemies (Waterhouse and Norris, 1987). *Heterorhabditis* needs to be applied frequently to be effective, and this was considered uneconomical (Smith, 1995).

The fungi *Beauveria bassiana* (Bals.) Vuillemin and *Metarhizium anisopliae* (Metch.) Sorokin have demonstrated great potential against adult weevils (Figueroa, 1990). In the Caribbean, *M. anisopliae* successfully reduced *C. sordidus* population by 50% and corm damage by over 60%, with a yield increase of about 20% (Castineiras et al., 1991). However, the efficacy of these fungal pathogens depends on sufficient soil moisture at application and once the larvae are inside the corm they escape contact with the fungal spores (Pena et al., 1993). In Uganda, Allard et al. (1993) and Nankinga (1994) investigated the potential of biological control using indigenous entomopathogenic fungi. The fungi *B. bassiana* and *M. anisopliae* have been isolated from several banana-growing areas of the country, the first being the most promising biopesticide (Nankinga et al., 1994, Ogenga-Latigo and Masanza, 1995). However, the technology may prove to be sophisticated for farmers in Uganda.

Chemical Control

In the past, when the weevil problem was stable, farmers mainly used cultural methods to control the pest. Because of the recent upsurge of the weevil problem (Sebasigari and Stover, 1988; Ddungu, 1988; Rubaihayo and Gold, 1993), chemical control methods have also been used. This option has been considered more effective than other methods (Whalley, 1957; Vilardebo, 1973; McNut, 1974; Mitchell, 1980). Paris green was the first insecticide used in baits (Weddel, 1945) but this chemical was not immediately lethal to the weevil. The application of dieldrin 0.5% on bait and soil gave 100% control (Whalley, 1957), and later, the use of 2.5% dieldrin was also effective and economical (McNut, 1974). However, *C. sordidus* developed resistance to dieldrin, and cross-resistance to other cyclodienes (Edge, 1974; Mitchell, 1980; Swaine et al., 1980; Bujulu et al., 1983; Gold et al., 1999). Also, due to its persistence in the soil, dieldrin was considered an environmental hazard and its use is no longer allowed.

Organophosphates and carbamates, which replaced the cyclodienes, are widely recommended, and used on large-scale farms (Vilardebo, 1973; Mitchell, 1980; Bujulu, et al., 1983; Treverrow, et al., 1993). Timely application of chemical insecticides is economical and an effective way of keeping population levels below the economic damage (Treverrow et al., 1993). However, these chemicals are poisonous and often unavailable to resource-poor small-scale farmers.

Integrated Pest Management (IPM)

An overview of integrated management practices to reduce *C. sordidus* populations, their mode of action and potential for control of the pest in East Africa is shown in **Table 2**. Cultural control or habitat management is available for the resource-poor farmer. However, due to ignorance and labour constraints associated with this method, its full effectiveness has not been realized. Planting resistant cultivars has a great potential in

Table 2. An overview of integrated management practices to reduce *C. sordidus*, their mode of action and potential for control of the banana weevil in East Africa.

Practice		Mode of action	Potential in East Africa
Habitat management	Use of clean planting material by paring suckers from infested fields, use of tissue culture plants, hot water treatment	• Reduces weevil spread through transfer of infested suckers to new sites • Delays pest population build-up in new field	Good potential, practiced often but some farmers are ignorant, leaving infested roots intact fearing that plants may not establish
	Removal of crop residues	• Avoidance of alternative oviposition sites	Good potential but farmers consider it tedious.
	Trapping	• Reduces populations in infested fields	Good potential but considered laborious. Effect doubted.
	Removal of extra suckers, mulching, pruning, weeding, manuring	• Increases crop vigour and enhances crop tolerance to pest injury	High potential, often practiced but considered labour-intensive.
	Propping	• Increases tolerance to toppling by raising economic thresholds	Good, often practiced but negligence leads to crop losses.
	Crop rotation	• Avoidance of weevil emergence from infested crop residues and soil	Good potential but widely limited by land pressure and the long crop growth cycle.
Planting resistant cultivars		• Reduced host acceptance or non-preference and antibiosis	Good potential, but only with a few cultivars identified.
Biological control		• Reduction of weevil population due to mortality caused by pathogens, predators, parasitoids	Good potential but technologies are not yet at farmer level
Use of chemicals		• Spot application at planting prolongs infestation-free growth for 1-2 years.	Good potential but costly to the poor farmers, often improperly used leading to environmental problems

Modified from Schmitt, N. (1998). Integrated management of the Sweetpotato in Eastern Africa, Ph.D. thesis, Wageningen Agricultural University, the Netherlands.

weevil control, but applicability is limited because only a few resistant cultivars are available to the farmers. Additionally, much as biological control has good potential, the technologies for delivery of biocontrol agents is not yet at farm level. Lastly, the use of chemicals to keep weevil populations low has the disadvantages of possible abuse or misuse leading to environmental problems. To date, some banana farmers still focus on use of chemicals as the most effective solution to the weevil problem, believing other methods have not worked (Gold et al., 1993). However, just as it has been emphasized in the concept of integrating control methods into farming systems, growing a healthy crop is crucial in IPM (Brader, 1991). A participatory approach may be needed in which IPM is developed together with farmers (van Huis and Meerman, 1997) for the components to fit in the agro-ecological and socio-economic conditions of African farmers. The perception of Integrated Pest Management (IPM) has changed from technological into a methodological concept (van Huis and Meerman, 1997). The authors have given an evolutionary outline of the IPM concept into three levels. These are: (i) combining control methods and reduction of pesticide use; (ii) integrating control methods into the farming systems and (iii) developing IPM with participation of farmers. Even in the use of resistant cultivars, farmers may through experience have an idea about the potential of material to be used in host plant resistance research. In this study, a participatory research approach was adopted in implementing some crop sanitation practices in the management of *C. sordidus*.

Conclusion

In Uganda, resource-constrained farmers grow banana mainly on smallholdings. Clearly, cultural pest control methods are the most appropriate and available strategy to be incorporated into an IPM system for *C. sordidus* management, since they require minimal inputs.

Aim and objectives of this thesis project

Justification

In the quest to obtain a suitable IPM strategy for the control of *C. sordidus*, its ecology needs to be well elucidated in East Africa where plantations are up to five decades old and where the crop is grown under a wide range of cropping systems. Population dynamics need to be studied to develop a comprehensive package for the small-scale farmer to alleviate the pest problem. Cultural controls form the most readily available line of defense in banana pest control. Extension staff has emphasized some cultural control activities, and particularly crop sanitation by removal of crop residues. Nevertheless, the mechanisms of influence of crop residue removal on banana weevil population dynamics are not known. It is possible that chopped up corm and pseudostem residue attracts the gravid females. It is not clear yet whether or not there is migration from crop residue to standing plants. Basic information is needed on hatching success, larval performance, and weevil distribution and timing of attack under different crop residue management practices. This study is therefore aimed at investigating the population dynamics of *C. sordidus* and related damage to growing plants under different conditions of the banana crop habitat and using several of post-harvest crop residue management techniques and other traditional farm management practices. Ultimately, this will give insights into optimum integration of crop residue management with other appropriate banana weevil control strategies for the resource-constrained farmer.

Research objectives

The objectives of this study were:

1) To investigate attraction and host acceptance of *C. sordidus* on different aged crop residues in the laboratory
2) To investigate the distribution and timing of attack of the *C. sordidus* on different aged crop residues in banana fields
3) To assess the effect of different aged banana crop residues on *C. sordidus* survival
4) To evaluate the effect of crop sanitation on *C. sordidus* population dynamics and damage in banana fields

Thesis outline

First, the economic importance of banana and *C. sordidus* pest status are highlighted. The various pest control measures are reviewed and the need to search for the most appropriate strategy of *C. sordidus* control for resource-poor farmers is emphasized. The justification and objectives of the study are outlined (chapter 1). In chapter 2, we investigated the attraction and host acceptance of the *C. sordidus* of different aged crop residues. In chapter 3, we describe the distribution, timing of attack and oviposition of *C. sordidus* on banana crop residues. In chapter 4, we report the influence of age of crop residues on eclosion success and survival of *C. sordidus* larvae. In chapter 5, I analyze the effect of covering post-harvest corm stumps with soil on banana weevil oviposition. In chapter 6 and 7, we elucidate the effects of different levels of crop sanitation on the population and damage of *C. sordidus*. Finally, in chapter 8, implications of the mechanisms of crop sanitation for *C. sordidus* control are discussed in a wider IPM scope.

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Chapter 2

Influence of different aged banana crop residues on attraction and host acceptance of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae)

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Chapter 2

Influence of different aged banana crop residues on attraction and host acceptance of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae)

M. Masanza, C. S. Gold, A. van Huis

Abstract

Two choice experiments were conducted in the laboratory in Uganda at Kawanda Agricultural Research Institute to determine attraction and acceptance of different aged crop residues to the banana weevil *Cosmopolites sordidus*. In the first experiment, studies focused on different types and ages of residues of one susceptible highland banana clone "Nabusa" (genome group AAA-EA). Corms attracted 65 % of the test weevils, pseudostems 30 % and 5 % were non-respondents. Oviposition levels and the number of eggs per female were higher on young than old corms. In the second experiment, the same parameters were measured on banana residues of selected clones based on their levels of resistance and tolerance to banana weevil damage. Corms were more attractive to adults than pseudostems and flower stalks except for fresh residues of resistant clones. Pseudostems were more attractive than flower stalks with a few exceptions. The number of eggs per female did not differ across clones, but varied with residue age. The number of eggs per female was highest on flower stalks, followed by corms and pseudostems. Old flower stalks were more acceptable for oviposition than any other residue part.

Introduction

Banana is grown mainly in equatorial and subtropical regions with a well-distributed rainfall of at least 2000 mm annually (Simmonds, 1959). In the East African Great Lakes region, endemic cultivars of highland cooking banana (*Musa* spp., genome group AAA-EA) are important staple and cash crops ((Masefield, 1944; INIBAP, 1986; Price, 1995). These are grown on resource-poor smallholder farms with limited inputs.

The banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is a key highland banana production constraint and attack by this insect has contributed to the crop's decline in traditional growing areas of Uganda and western Tanzania (Gold et al., 1999, 2003). The larvae tunnel in the corm impeding water and nutrient uptake and weakening the stability of the mat. This may lead to sucker death snapping, toppling, reduced bunch size, mat die-out and shortened plantation life (Mitchell, 1980;

Rukazabuga et al., 1998; McIntyre et al., 2001; Gold et al., 2003). Banana weevil populations build up from planting and become more important in subsequent ratoon crops. For instance, damage levels increased from 7% in the first ratoon to > 20% in the third ratoon (Rukazambuga et al., 1998), while yield losses increased from 9% to 44% during the same time period.

The banana plant consists of an underground corm, a pseudostem (comprised of leaf petioles), the leaves and a true stem that grows through the centre of the pseudostem after termination of leaf production and which bears the flower and subsequent bunch. Banana is a perennial crop with suckers (new plantlets) emerging from the corm. Plants sharing a common corm are referred to as a mat. The phenological stages of the banana plant are peeper, sword sucker, maiden sucker, pre-flowered plant and flowered plant. Each plant produces a single bunch. Following harvest of the banana bunch, plant dies back leaving the pseudostem, true stem and attached part of the corm remaining as crop residues. These residues provide food and breeding sites for adult banana weevils (Froggatt, 1925). Bananas are harvested throughout the year so all plant stages (including residues) are continuously available to the banana weevil following harvest of the first cycle.

The banana weevil is an oligophagous insect attacking only the related genera *Musa* and *Ensete*. Within Africa, cultivars vary widely in their susceptibility to *C. sordidus* with highland cooking banana (AAA-EA) is considered among the most susceptible genome groups (Kiggundu et al., 1999; Kiggundu, 2000; Gold et al., 2003). Plantains (AAB) are also considered susceptible, while Gros Michel (AAA) is partially resistant and Kayinja (AAB), Kisubi (AB) and Yangambi-Km5 are highly resistant (Kiggundu et al., 1999).

The banana weevil may utilize plant volatiles in locating its host plant (Budenberg et al., 1993a; Tinzaara et al., 2002). Damaged plants (e.g. cut corm or pseudostem material) are especially attractive to banana weevils (Gold et al., 2002), suggesting that such injuries increase the level of volatiles being released by the plant (Dicke, et al., 1990, Bernays and Chapman 1994). The attractiveness of crop residues has been exploited through using these materials as traps to monitor or control the banana weevil (Koppenhoffer et al., 1994; Masanza, 1995; Gold et al., 2002).

Banana weevil adults are free-living, nocturnally active and positively hydrotrophic (Delattre, 1980; Ittyeipe, 1986). The weevils attack all phenological stages of the banana plant, including crop residues. Abera et al. (1999) reported highest levels of oviposition on flowered plants and residues, although Mesquita et al. (1984) observed that tissue from younger plants was more suitable for larval development.

Crop sanitation by destruction of residues has been proposed as a means of control against the banana weevil. Since crop residues are potential breeding sites for the banana weevil, they can contribute to increase in weevil populations in banana fields. Destruction of crop residues may therefore reduce overall banana weevil pressure including damage to the growing plants. It is unclear at what stages, however, residues are most attractive to ovipositing weevils and most suitable for larval survivorship. In other words, crop sanitation might be timed to encourage weevil oviposition on residues (rather than on plants) but then destroy these before the larvae can fully develop. This, in effect, would result in wasted weevil eggs without contributing to population growth.

The objective of this study was to determine what type and age of crop residues are most attractive and acceptable to banana weevils for oviposition. We also investigated whether there is a difference in oviposition on residues of different banana cultivars.

Materials and Methods

The experiments were conducted in the banana entomology laboratory at the Kawanda Agricultural Research Institute (KARI), 13 km north of Kampala and 1195 m above sea level. Ambient temperatures in the laboratory averaged about 25 °C during the study period.

Experiment 1: Weevil attraction to and oviposition on different aged crop residues of one cultivar

The objective of this experiment was to determine weevil attraction to and acceptance of different aged banana residues on one highland banana cultivar 'Nabusa' (AAA-EA). Seven treatments consisted of corms and pseudostems that were collected from maiden suckers or from residues at different calendar intervals after plant harvest (days after harvest or DAH): (1) fresh maiden sucker corm; (2) fresh corm (< 2 DAH); (3) old corm (14-30 DAH) (4) very old corm (>30 DAH); (5) fresh pseudostem (< 2 DAH) (6) old pseudostem (14-30 DAH) and (7) very old pseudostem (>30 DAH).

The conditions of the different-aged residues (namely colour, firmness, moistness and fungal growth) are described in Table 1. Firmness was determined by squeezing a sample of banana tissue between the thumb and first finger and classified as soft, moderately firm and firm. Similarly, for moistness, a sample of banana tissue was classified as moderately moist if it wetted the fingers on pressing, or very moist if water oozed out of it. The other conditions were assessed by visual observation.

Corm or pseudostem pieces (7 x 3 x 1 cm) were cut from the different-aged residues and presented to groups of 70 adult weevils in plastic containers (50 cm diameter, 20 cm high). In each bioassay, banana pieces (one per treatment) were placed equidistant from each other and the centre of the basin, using a completely randomised design. The experiment was repeated 10 times.

Table 1. Typical conditions of banana (*Musa* spp. Genome group AAA-EA) tissues of suckers, flowered plants and residues of different ages

Banana tissue type		Colour	Firmness	Moistness	Fungal growth
Fresh maiden sucker	Corm	White	Moderate	Moderate	✗
	Pseudostem	Green	Soft	Moderate	✗
	Flower stalk	White	Moderate	Moderate	✗
Fresh flowered plant	Corm	White	Moderate	Moderate	✗
	Pseudostem	Green	Soft	Moderate	✗
	Flower stalk	White	Moderate	Moderate	✗
Fresh harvested (<2 DAH)	Corm	White	Moderate	Moderate	✗
	Pseudostem	Green	Soft	Moderate	✗
	Flower stalk	White	Moderate	Moderate	✗
Old (14-30 DAH)	Corm	Brownish	Firm	Moderate	✗
	Pseudostem	Brownish	Soft	Very moist	✗
	Flower stalk	Creamy white	Moderate	Moderate	✗
Very old (>30 DAH)	Corm	Brown	Firm	Moderate	✓
	Pseudostem	Brown	Soft	Very moist	✓
	Flower stalk	Light brown	Soft	Very moist	✗

Fungal growth[1]: ✓ = present, ✗ = absent

Adult weevils were obtained from pseudostem traps in farmers' fields near KARI. Prior to assays, the weevils were maintained on banana (cv 'Namwezi' AAA-EA) corms in the laboratory for one week. Each weevil was used for a single bioassay and then discarded. The 70 weevils were placed at the centre of the basin, which was then covered with a polythene sheet with tiny holes for ventilation. After 24 hours, the number of weevils aggregating around each banana piece was counted. These weevils were sexed on the basis of punctuations on the rostrum (Longoria, 1968) and curvature of the last abdominal sternite (Roth and Willis, 1963). We determined oviposition levels on the different residues by gently paring the surface tissue and counting the number of eggs.

Experiment 2: Attraction to and oviposition on different aged host residues of several banana cultivars.

The objective of this experiment was to investigate weevil attraction to and acceptance of different aged residues of different banana cultivars. The bananas were selected from three weevil resistance groupings in farmers' fields, depending on the availability around

Kawanda and Sendusu. These included Atwalira (AAA-EA, susceptible), Ndibwabalangira (AAA-EA, susceptible), Mbwazirume (AAA-EA, susceptible), Nakitembe (AAA-EA, susceptible), Nakyetengu (AAA-EA, susceptible), Gonja (AAA, intermediate), Kisansa (AAA-EA, intermediate), Ndiizi (AB, resistant) and Kayinja (ABB, resistant), (Kiggundu, 2000). Plant materials from freshly flowered and freshly harvested banana were collected from the field or at calendar intervals after plant harvest. Treatments consisted of corms, pseudostems and flower stalks from three resistant clusters (susceptible, intermediate and resistant) of four different ages to give 12 treatments: (1) Freshly flowered - corm; (2) Freshly flowered - pseudostem; (3) fresh flowered – flower stalk; (4) freshly harvested - corm (<2 DAH) (5) freshly harvested - pseudostem (<2 DAH); (6) freshly harvested - flower stalk (<2 DAH); (7) old corm (14-30 DAH); (8) old pseudostem (14-30 DAH); (9) old flower stalk (14-30 DAH); (10) very old corm (>30 DAH); (11) very old pseudostem (>30 DAH) and (12) very old flower stalk (>30 DAH).

Corm, pseudostem or flower stalk pieces (7 x 3 x 1 cm) were cut from a given cultivar of a given age at a time and presented to groups of 60 adult weevils in plastic containers (50 cm diameter, 20 cm high). This was repeated in a series of bioassays for residues of each of the three cultivars selected from the three resistant clusters. In each bioassay, banana pieces (one per treatment) were placed equidistant from each other and the centre of the basin, using a completely randomised design. The experiment was repeated 10 times.

Adult weevils were obtained from farmers' fields and maintained in the laboratory in similar manner to those in *Experiment 1*. Each weevil was used for a single bioassay and then discarded. The 60 weevils were placed at the centre of the basin, which was then covered with a polythene sheet with tiny holes for ventilation. After 24 hours, the number of weevils aggregating around each banana piece was counted. These weevils were sexed and oviposition was determined using the same methodology in *Experiment 1*.

Data analysis

For both *Experiments 1* and *2*, means of adults, females and number of eggs per female on each residue type were subjected to SAS General linear models procedure (SAS Inc., 1997). Acceptance (number of eggs per female) was computed from data on females attracted and eggs deposited on each of the residues. Means were separated by Least Square Means pair wise comparison t-test.

Results

Experiment 1: Weevil attraction to and oviposition on different aged crop residues of one cultivar

Twenty-four hours after release, 95% of the weevils were found in association with banana materials. Corms from maiden suckers, fairly old and very old corm residues were most attractive to banana weevils. The number of weevils at these materials was significantly greater than those at the young corm and the very old pseudostem residues (P < 0.05) (Figure 1). There was no significant difference in attraction of adult weevils to different aged pseudostem residue pieces. Female attraction to banana material showed the same trend as males, except more females were attracted to fresh (i.e. 1-2 DAH) than older pseudostem pieces (Table 2), while more males were attracted to old (14-30 DAH) than fresh or very old pseudostem residues (P < 0.05).

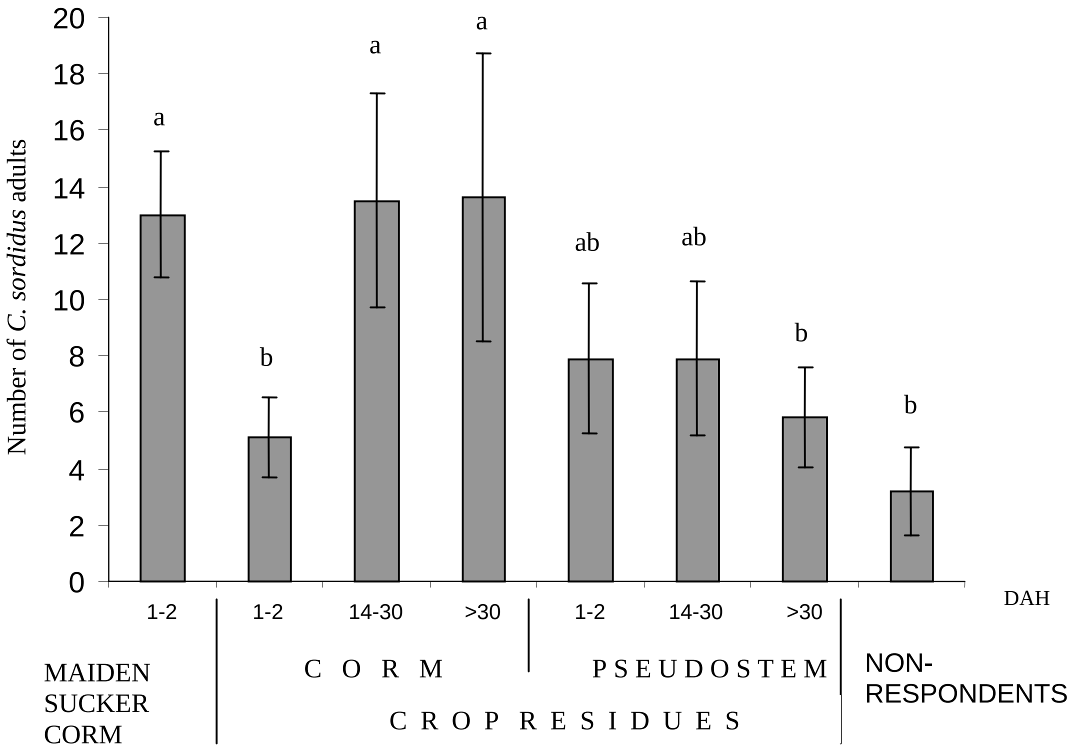

Figure 1. Number of adult weevils attracted to different aged host plant tissue of the same clone "Nabusa" (AAA-EA) in laboratory choice experiments. For each residue age (days after harvest – DAH) and type, means followed by the same letter are not significantly different by pair-wise comparison t-test of least square means (*Experiment 1*)

There was significantly higher oviposition on corms than on pseudostems (P < 0.01) (Table 3A). The greatest amount of oviposition occurred on corms from maiden and old (14-30 DAH) residues. Oviposition on pseudostem residues was low and similar on all aged residues. Individual females placed more eggs on corms of maiden suckers and fresh (1-2 DAH) residues (P < 0.05) (Table 3B). There were not significant differences in oviposition rates on older residue corms and all ages of pseudostems of residues.

Table 2. Total number of female banana weevils attracted to various banana tissues (cv Nabusa, AAA-EA) in laboratory choice experiments

	Maiden	Fresh (1-2)[1]	Old (14-30)	Very old (>30)
Corm	64a	21 b	66a	63a
Pseudostem		50a	29 b	28 b
Non-respondents	12 c			

[1](Days after harvest)
Means with the same letter are not significantly (P<0.05) different by probability of LS means pair-wise comparison t-test

Table 3. Mean oviposition on the various banana tissues (cv Nabusa, AAA-EA) in laboratory choice experiments (N = 10)

A. Total number of eggs

	Plant or residue age			
	Maiden	Fresh (1-2)[1]	Old (14-30)	Very old (>30)
Corm	17.4a	4.9 cd	10.0 b	6.3 bc
Pseudostem		1.2 d	1.9 d	2.5 cd
Non-respondents	0.0 d			

B. Oviposition per female

	Maiden	Fresh (1-2)[1]	Old (14-30)	Very old (>30)
Corm	2.7a	2.3a	0.7 b	1.0 b
Pseudostem		0.2 b	0.6 b	0.9 b
Non-respondents	0.0 b			

[1](Days after harvest)
Means with the same letter are not significantly (P<0.05) different by probability of LS means pair-wise comparison t-test.

Experiment 2: Attraction to and oviposition on different aged host residues of several banana cultivars

There was a tendency for banana weevils to be more attracted to the corms than to pseudostems and more attracted to pseudostems than flower stalks (Table 4 and 5)

Table 4. Least Square means for the number of adults attracted and the number of eggs per female on different banana clone residues (*Experiment 2*).

Susceptible group					Intermediate resistance group					Resistant group				
Clone	Residue age	Residue part	Adults	Eggs/♀	Clone	Residue age	Residue part	Adults	Eggs/♀	Clone	Residue age	Residue part	Adults	Eggs/♀
Atwalira	Flowered	Corm	13.7ab	1.6 d	Gonja	Flowered	Corm	16.9a	2.7 c	Kayinja	Flowered	Corm	13.4ab	3.8 b
		Pseudostem	9.3 b	0.7 d			Pseudo	3.5 c	0.4 d			Pseudo	12.7 b	0.5 d
		Flower stalk	4.7 c	2.5 c			Flo stalk	7.8 b	2.3 c			Flo stalk	9.3 b	3.8 b
	Freshly harvested	Corm	16.6a	1.3 d		Freshly harvested	Corm	18.2a	2.4 c		Freshly harvested	Corm	9.3 b	2.2 c
		Pseudo	8.6 b	0.4 d			Pseudo	8.3 b	0.7 d			Pseudo	11.9 b	0.9 d
		Flo stalk	1.9 c	5.7a			Flo stalk	3.1 c	4.4 b			Flo stalk	8.1 b	1.7 d
	Old	Corm	19.0a	1.4 d		Old	Corm	9.9 b	2.3 c		Old	Corm	10.6 b	2.7 c
		Pseudo	8.8 b	0.6 d			Pseudo	9.2 b	0.5 d			Pseudo	8.8 b	1.5 d
		Flo stalk	1.6 c	6.5a			Flo stalk	11.4 b	1.3 d			Flo stalk	13.4ab	0.9 d
	Very old	Corm	20.8 a	0.9 d		Very old	Corm	-	-		Very old	Corm	-	-
		Pseudo	7.5 b	0.2 d			Pseudo	-	-			Pseudo	-	-
		Flo stalk	1.3 c	4.9 b			Flo stalk	-	-			Flo stalk	-	-
Ndibwabala ngira	Fresh flowered	Corm	19.8a	1.5 d	Kisansa	Flowered	Corm	14.4ab	1.6 d	Ndiizi	Fresh flowered	Corm	15.0ab	2.2 c
		Pseudo	8.7 b	0.3 d			Pseudo	9.5 b	0.5 d			Pseudo	7.7 b	0.3 d
		Flo stalk	2.4 c	4.3 b			Flo stalk	4.8 c	0.8 d			Flo stalk	7.2 b	5.0a
	Freshly harvested	Corm	18.8a	0.9 d		Freshly harvested	Corm	15.1a	1.7 d		Freshly harvested	Corm	17.5a	2.3 c
		Pseudo	8.3 b	0.7 d			Pseudo	11.4 b	0.4 d			Pseudo	4.7 c	1.2 d
		Flo stalk	2.6 c	3.0 c			Flo stalk	2.3 c	1.3 d			Flo stalk	7.6 b	4.4 b
	Old	Corm	14.2ab	1.4 d		Old	Corm	16.3a	1.3 d		Old	Corm	15.7a	4.5 b
		Pseudo	11.5 b	0.3 d			Pseudo	11.4 b	0.2 d			Pseudo	9.2 b	1.3 d
		Flo stalk	2.8 c	2.9 c			Flo stalk	1.4 c	3.3 b			Flo stalk	5.3 c	5.6a
	Very old	Corm	16.6a	2.8 c		Very old	Corm	15.7a	1.1 d		Very old	Corm	18.0a	2.3 c
		Pseudo	7.4 b	0.4 d			Pseudo	8.6 b	0.3 d			Pseudo	5.3 c	4.0 b
		Flo stalk	5.2 c	4.8 b			Flo stalk	5.4 c	2.2 c			Flo stalk	6.1 c	6.7a
Nakitembe	Fresh flowered	Corm	18.2a	0.8 d										
		Pseudo	10.6 b	0.1 d										
		Flo stalk	1.2 c	2.0 c										
	Freshly harvested	Corm	10.7 b	1.9 c										
		Pseudo	12.4 b	0.4 d										
		Flo stalk	6.5 c	1.9 c										
	Old	Corm	13.7ab	1.7 d										
		Pseudo	4.7 c	1.1 d										
		Flo stalk	9.3 b	2.0 c										

	Very old	Corm	11.5 b	2.5 c
		Pseudo	12.8 b	0.6 d
		Flo stalk	4.9 c	3.8 b
Mbwazirume	Fresh flowered	Corm	13.9ab	0.8 d
		Pseudo	10.7 b	0.4 d
		Flo stalk	7.2 b	1.2 d
	Freshly harvested	Corm	11.5 b	1.0 d
		Pseudo	7.6 b	0.3 d
		Flo stalk	9.0 b	1.2 d
	Old	Corm	16.0a	0.7 d
		Pseudo	8.0 b	0.4 d
		Flo stalk	7.5 b	2.7 c
	Very old	Corm	18.8a	1.8 d
		Pseudo	8.3 b	0.2 d
		Flo stalk	2.0 c	7.1a
Nakyetengu	Fresh flowered	Corm	12.8 b	1.7 d
		Pseudo	11.7 b	0.3 d
		Flo stalk	5.6 c	1.9 d
	Freshly harvested	Corm	12.7 b	2.3 c
		Pseudo	10.3 b	0.8 d
		Flo stalk	8.1 b	2.7 c
	Old	Corm	13.7ab	1.3 d
		Pseudo	9.3 b	0.7 d
		Flo stalk	4.7 c	2.4 c
	Very old	Corm	17.8a	1.6 d
		Pseudo	3.0 c	1.0 d
		Flo stalk	8.3 b	2.0 c

In all columns, means followed by the same letter are not significantly ($P > 0.05$) different by pair-wise comparison t-test

Table 5. Least Square means (± s.e.) for the number of adults attracted and the number of eggs per female by banana tissue and banana resistance grouping (*Experiment 2*).

		Adults	Eggs/♀
A. Banana tissue			
	Corm	15.2 ± 0.31a	1.8 ± 0.12 c
	Pseudostem	8.8 ± 0.31 b	0.7 ± 0.12 b
	Flower stalk	5.5 ± 0.31 c	3.2 ± 0.12a
B. Banana resistance group			
Susceptible	Corm	15.5 ± 0.40a	1.5 ± 0.15 c
	Pseudostem	8.9 ± 0.40 b	0.5 ± 0.16 d
	Flower stalk	4.7 ± 0.40 c	3.3 ± 0.16ab
Intermediate	Corm	15.2 ± 0.67a	1.8 ± 0.26 c
	Pseudostem	8.9 ± 0.67 b	0.4 ± 0.27 d
	Flower stalk	5.1 ± 0.66 c	2.3 ± 0.26 b
Resistant	Corm	14.4 ± 0.69a	2.9 ± 0.27 b
	Pseudostem	8.4 ± 0.69 b	1.3 ± 0.27 c
	Flower stalk	8.1 ± 0.68 b	4.1 ± 0.27a

In columns, for attraction to banana tissue (A) and banana resistance groups (B), means followed with the same letter are not significantly ($P > 0.05$) different by pair-wise comparison t-test.

although results varied by cultivar. This was the trend in Atwalira, Kisansa, Ndibwabalangira, Mbwazirume and Ndiizi (Table 4). At the other extreme, corms of Kayinja were never more attractive than either pseudostems or flower stalks. In Gonja, corms were most attractive for flowered plants and freshly harvested residues, while all plant parts were equally attractive in old residue. Females tended to lay more eggs on flower stalks than on corms or pseudostems, although results varied considerably across cultivars and for different plant/residue stages.

Generally, the number of eggs laid per female across clones was similar, except on different aged residue tissues within given banana resistance groups. This was true for all residues of the susceptible clones Atwalira, Ndibwabalangira, Mbwazirume, Nakyetengu and Nakitembe, for the old and very old residues of the intermediate Kisansa and the resistant Ndiizi. Only in one case (very old Ndiizi) was pseudostem residue more attractive than corm residue. When comparing pseudostems, corms and flower stalks (Table 5A), and across resistance groups (Table 5B), corms attracted more adults than pseudostems and flower stalks. It seems that the pseudostems received the least number of eggs per female, while flower stalks had the highest (Table 5).

Discussion

Banana corm tissue attracted more weevils than pseudostem tissue. Cuille (1950) reported similar results. This implies that using crop sanitation to control weevils, special attention should be directed towards managing the corms. Old residues were very attractive compared to fresh corms and pseudostems. Cuille (1950) reported that residues attracted more weevils than standing plants and that attraction increases with residue age. However, oviposition did not follow a similar trend. Oviposition was highest on corms of fresh maiden sucker and freshly harvested plants. On pseudostems fewer eggs were laid than on corms. Cuille (1950) also demonstrated higher oviposition on younger plants, followed by residues, pre-flowered and flowered plants. Abera et al. (1999), foundthat most oviposition occurred on flowered and standing post-harvest plants with 60% oviposition on leaf sheaths of the pseudostem. This is likely because most plants had the corms underground; hence, adults laid eggs mostly on pseudostems. Older residues are mainly a refuge as they are moist (Masanza et al., Chapter 3). Adults have been reported to feed on dead plant material (Simmonds, 1966). Fresh residues with high food quality emit volatiles that attract gravid females (Ndiege et al., 1991). The results agree with field observations in Ntungamo, where the number of adults associated with residues was higher than that on standing plants (Masanza et al., Chapter 3). It implies that in order to reduce weevil populations, destruction of residues needs to start as early as possible to prevent the immature weevils from developing into adults.

In this study, attraction of the banana weevil varied among the different aged banana clone residues. This was also true for the field studies in the west of the country where some banana clones hosted more weevils than others (Masanza et al., Chapter 3). Attraction of phytophagous insects to a host depends on the amount of volatiles being emitted for orientation, as well as other chemical and physical factors that affect feeding and breeding (Bernays and Chapman, 1994). Orientation in insects is a response to optical and chemical characteristics of plants. Since the banana weevil is nocturnal, it mainly depends on chemical cues from plant volatiles. *Cosmopolites sordidus* is positively hygroscopic and displays orthokinesis, klinokinesis and klinotaxis when exposed to different humidity gradients (Roth and Willis, 1963). Banana weevils aggregated under lures of higher humidity when they were exposed to different amounts of liquid water Cuille (1950). He concluded that weevils search for higher humidity, but also look for liquid water. Recent studies suggest that *C. sordidus* uses odour-conditioned anemotaxis in its orientation to fermented banana plant volatiles (Tinzaara et al., 2003). The decision to accept or reject a plant is based on sensory information of the plant cues, as well as the physiological status of the insect (Schoonhoven et al., 1998).

In this study, some of the banana residues attracted fewer adults than others also depending on the stage of decomposition. Studies on feeding stimulants in adult banana weevil among various host plant cultivars showed that extracts from susceptible cultivars induced higher feeding than those from resistant ones (Rwekika, 1997). In our study, adult weevils were attracted more to corms than pseudostems with the exception of resistant fresh "Kayinja". It is possible that adult weevils were attracted by volatiles from fresh residues in this case to breed but not necessarily to feed. Such residues can therefore act as good traps for the adults.

Flower stalks of some clones were more acceptable as an oviposition substrate than other residues. Cut residues hosted a high percentage of adults especially in the true stem/flower stalk (Masanza, 1999). The flower stalk transports water and sugars to the developing fruit and may provide rich nutrition (Simmonds, 1966). Rwekika (1997) found salicin, a component of banana flower stalk tissue to be a feeding stimulant to the *C. sordidus*. It is possible that this compound is also an oviposition stimulant, making flower stalks likely major contributors to population build-up in banana fields. In a field survey on weevil distribution in banana farms with low sanitation, the number of immature weevils on cut residues was 50% higher than those maintained at high sanitation with crop residues destroyed (Masanza et al., Chapter 3). Earlier studies on distribution of weevils in banana fields showed that 28% of adult weevils were found attached to cut residues (Gold et al., 1999). Treverrow and Bedding (1993) reported that 60% of adult *C. sordidus* in a single stand were hosted on crop residues.

In this study, flower stalks of fresh and decomposed resistant cultivar Ndizii were very attractive to *C. sordidus* for oviposition. A study in Uganda showed that freshly harvested residues of resistant beer cultivar Kisubi (AB) were less infested than the decomposed ones (Gold and Bagabe, 1997). This result suggests that in a control programme, such residues can be placed in the plantation until they decompose to attract ovipositing *C. sordidus* and act as traps. After 30 days, the residues should be destroyed to allow quick drying so that the immatures can die before completing their life cycle. If left intact, these residues may act as a source of infestation to standing plants.

Residues are both breeding and hiding place for adults, and as such a source of infestation to the growing crop. Crop residues are attractive up to three months and probably beyond, and host lots of *C. sordidus.* Destruction of crop residues will reduce banana weevil populations. At least in two to 12 weeks after harvest, crop residues should be cut into pieces. The quick drying of residues will desiccate the eggs or eventually kill immature weevils.

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Chapter 3

Distribution, timing of attack and oviposition of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) on banana crop residues in Uganda

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Chapter 3

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Abstract

On-station and on-farm trials were conducted in Uganda to investigate the effect of crop residue management on attack, oviposition and distribution of the *Cosmopolites sordidus* on crop residues and growing plants. Oviposition and distribution were assessed on different aged standing and prostrate residues by destructive sampling. Similar data were collected from fields maintained at three sanitation levels. In the first experiment, oviposition occurred on residues as old as 120 days, but mainly between 0-30 days post-harvest. Weevil infestation varied among banana clones. In the second experiment, oviposition levels on standing residues were not significantly affected by age. Oviposition levels on prostrate four-week-old residues were two times higher than those on two-week-old residues, while the number of larvae on eight-week-old residues was three times higher than on two-week-old residues. The number of pupae did not differ at all ages of prostrate and standing residues. The number of adults in standing and prostrate residues on 16-week-old residues was two times higher than that on two-week-old residues. In the third experiment, farmers' fields maintained at high sanitation level had 50% lower eggs per residue than those kept at low sanitation level. The number of immatures per residue was 50% higher on banana corms than on pseudostems. Larvae were three times more abundant at low than at high sanitation. The number of pupae per residue at low sanitation was six times higher than at high sanitation level. Residues in fields at high sanitation hosted 50% less adults per residue than in fields at low sanitation. The results suggest that removal and splitting of corms after harvest is effective and practical in destroying immature growth stages of the pest.

Introduction

Banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is the principal insect pest of East African highland banana (*Musa* sp. genome group AAA-EA) (Sengooba, 1986; Sebasigari and Stover, 1988; Gold et al., 1999a). Damage is caused by larvae, which tunnel into the plant at the point of oviposition, and move to the corm where they feed. The plant base weakens leading to snapping and toppling. Tunneling also interferes with water and nutrient uptake resulting in delayed maturation and reduced bunch weight (Rukazambuga et al., 1998). Sustained attack on banana by *C. sordidus* over several crop cycles under high *C. sordidus* pressure may cause up to 48% yield loss in the third ratoon (Rukazambuga et al., 1998). A survey on banana pest problem in southwestern Uganda indicated that *C. sordidus* may cause up to 100% yield loss (Sengooba, 1986).

Cosmopolites sordidus is long-lived (up to 4 years) (Gold et al., 1998a; Gold et al., 2002) with a low fecundity (Delattre, 1980; Koppenhoffer, 1993; Gold, 1998a). Oviposition is generally estimated at less than 4 eggs per week (Abera, 1997). Females deposit eggs mainly at the plant base in leaf sheaths and corms. Oviposition occurs not only on all plant growth stages, 10-12% on suckers, 22-23% on pre-flowering, 22-37% on flowering, but also 19-32% on crop residues (Abera et al., 2000) which are an alternative breeding site and food source for *C. sordidus*. Almost all oviposition was within 5 cm of the collar (junction between the pseudostem and the corm) (Abera, 1997). In the tropics, development duration at ambient temperatures (22-27^{o}C) for eggs ranged from 6 to 8 days (Gold et al., 1999b).

First instar larvae emerging from leaf sheaths or corm surface move into the corm where they feed. In highland bananas, larval feeding is mainly 10 cm below the collar (Gold et al. unpubl. data). In Uganda, the larval stage lasted 3 to 4 weeks, the pupal period 3 to 8 days (Gold et al., 1999b), and the overall development period from egg to adult stage 40-48 days (Gold et al. 1999b). Bakyalire and Ogenga-Latigo (1992) recorded the total life cycle from egg to adult as between 53 and 72 days.

Adult *C. sordidus* is free-living, negatively phototactic, positively hygrophilic and feigns death when touched (Delattre, 1980; Ittyeipe, 1986). It rarely flies, but when stressed by exposure to insecticides or dry conditions it may spread its wings without flight (Roth and Willis, 1963). Dispersal of *C. sordidus* is limited by its host range, and therefore mainly through transfer of infested planting material. It occurs also by walking but this movement but only to a limited extent. Movement of more than 30 m in five days (Gold et al., 1998) and maximum movement of 60 m in five months Delattre (1980) have been recorded.

As early as 1920s, *C. sordidus* adults have been known to feed on banana debris (Froggatt, 1925). In Uganda, distribution studies showed that over 60% of the adults in a banana field were associated with cut crop residues (Gold et al. 1999c). High levels of oviposition (up to 200 eggs) have been found on a post-harvest banana stump (Rukazambuga, 1996). Gold and Bagabe (1997) reported high levels of attack on residues of a resistant clone 'Kisubi' (group AB). Similarly, a recent study in Indonesia showed that the infestation on residues of resistant cultivars (AAB) increased 3 to 44 times in two to three months after harvest (Abera et al., unpubl. data).

Crop sanitation, a form of habitat management, by removing and chopping up crop residues (corms and pseudostems) has been recommended since the 1920s (Froggatt, 1924; Ghesquierre, 1925) and continues to be widely recommended (Seshu Reddy et al., 1998). It is believed that destruction of crop residues eliminates adult refuges, food sources and breeding sites (Treverrow et al., 1991), lowers overall *C. sordidus* populations and reduces damage on standing plants in susceptible clones (Gold et al., 2003). In Uganda, some farmers practice crop sanitation at various levels and forms. A few farmers, notably in wind-prone areas cut corms to soil level and then cover the cut surface with a layer of soil, which is compacted to create a physical barrier to ovipositing females (Karamura and Gold, 2000). This is to protect suckers, which are attached to the mother plant. Destruction of post-harvest stumps deprives the suckers of a nutrient source as young suckers derive their nutrients from mother stumps after harvest (Wortmann et al., 1994).

The banana is a perennial herb with a short subterranean stem (corm/rhizome) with buds from which arises a cluster of aerial shoots (suckers) that pass through several stages of growth i.e. peepers, sword suckers, maiden suckers, pre-flowered and flowered plants. The corm also bears adventitious roots, which arise from the cambium-like meristematic layer of the central cylinder (Skutch, 1932). The roots laterally spread 4-5 m (Price, 1995) and descend 75 cm deep but most roots are found within the top 40 cm of the soil (Lassoudiere, 1978; Price, 1995). Each corm gives rise to one terminal inflorescence, by extending throughout the centre of the pseudostem, giving rise to an infructescence (Simmonds, 1966; Espino et al., 1991). This bears the fruits, which when harvested leaves a residue comprising a pseudostem attached to the corm. It is not clear when *C. sordidus* infests residues, what attracts the *C. sordidus* to the residues, and which condition of residue is most favourable for attack. Understanding what types of residues are attractive to *C. sordidus* will provide insight into setting up a residue management programme.

In this study, we tried to determine the crop residue stage that is most susceptible to *C. sordidus* attack in a field situation by assessing oviposition levels and the distribution of immatures and adults on different aged residues compared to standing plants.

Materials and Methods

This study was done in three steps: 1) A field survey to determine abundance and distribution of weevils on crop residues on farmers' fields in Ntungamo, 2) an on-station and 3) an on-farm field experiment at Kawanda and Ntungamo to determine *C. sordidus* ovipositional preferences and larval infestation on suckers and crop residues of different type and age.

Site description

Ntungamo is in the southwest of the country (30° 13.66" and 30° 13.85" E longitudes and 0° 52.88" and 0° 53.79" S latitudes), at an elevation ranging from 1300 to 1560 m above sea level. Precipitation at the site is 800-1500 mm rainfall per year with a bimodal distribution (March to May and September-December).

Kawanda is 23 km north of Kampala and 1195 m above sea level with mean precipitation of about 1190 mm per year, average daily temperatures of 16°C minimum and 29°C maximum.

Sendusu is 25 km northeast of Kampala, 1150 m above sea level with average precipitation of 1200 mm per year, average daily temperatures of 17.4°C minimum and 27.3°C maximum (McIntyre et al., 2000).

Experiment 1: Weevil adult and immature distribution on crop residues in Ntungamo

Farms: Two established multi-cultivar banana stands (> 50 years old) with high *C. sordidus* population density of at least 100,000 weevils/ha (90 weevils/mat) were selected for the study. Each field was about one ha in size and maintained at low sanitation level. The fields had different aged standing and prostrate residues scattered haphazardly throughout the farm.

Treatments: Farmer practices left two types of residues within the field: (1) Standing stumps consisting of the corm and 0.5 – 2.0 m of pseudostem; (2) Prostrate stems cut between ground level to 10 cm below the surface. These were then grouped into five age classes: 0-7 days after harvest (1) (DAH); 8-14 (2); 15-30 (3); 31-60 (4); 61-120 (5) DAH. In general, fresh residues were green and firm, while older residues turned dark brown with inner tissues in varying states of decomposition.

Data collection: Sampling was conducted during the rainy season of March-April 1999. Data were collected on randomly selected crop residues, identified to cultivar, age and location (standing or prostrate). The stumps extracted from the soil using a digging spear were first examined for adults and carefully pared using sharp knives to expose the eggs. The corm was then dissected carefully to expose immatures and other adults. The same was done for pseudostems. On the first farm, 53 standing and 25 prostrate residues were sampled, while 264 standing and 126 prostate residues were sampled on the second farm.

Experiment 2: Ovipositional preferences and distribution on crop residues in on-station trial

The plantation in Kawanda aged four years and comprised four plots of 30 x 70 m each separated by 20 m wide alleys. Planting density was 3.0 x 2.5 m with 10 x 28 stools (280 stools/plot). The plantation at Sendusu was aged 6 years and comprised two plots of 115 x 12.5 m each separated by 20 m wide alleys. Planting density was 2.5 x 2.5 m with 40-50 stools/plot. In both plantations, each stool comprised three plants (cv. 'Atwalira' AAA-EA genome group) (one flowered, one pre-flowered and one sucker). Plants were harvested continually. *Cosmopolites sordidus* density was 9,000 weevils/ha (15 weevils/mat), determined one week before treatment implementation by mark-recapture methods as employed by Gold and Bagabe (1997).

Treaments: *Cosmopolites sordidus* oviposition and larval infestation were evaluated on standing and prostrate residues at 0, 2, 4, 8 and 16 weeks after harvest, and prostrate residues at 2, 4, 8 and 16 weeks after harvest. Standing residues comprised banana stumps about 1.5 m high from the ground left *in situ* (i.e. still attached to the mat). For prostrate residues, the corm was cut 10 cm below the collar with 1.5 m of pseudostem attached. These were placed horizontal in inter-mat alleys at least one metre away from the mats.

Data collection: At each site, a total of five plants were sampled for each treatment in each of the wet and the dry seasons. Sampling was conducted over a period of time during the rainy season of March-April 2000. The stumps were extracted from the soil using a digging spear to remove the whole corm. Each stump was first examined for adults. Then the corm was carefully pared using sharp knives to expose the eggs. The corm was then dissected carefully to expose immatures and other adults. The same was done for pseudostems. In some cases, especially in older residues, it was impossible to remove the entire corm. The condition of the corms was determined by its moistness, hardness using the penetrometer and the degree of rotting.

Experiment 3: Ovipositional preferences and infestation of C. sordidus in farmers' fields on suckers and crop residues

To determine the timing and location of attack of *C. sordidus* in farmers' fields, a trial was conducted in the rainy season between September and December 2001 in Ntungamo. Farmers were asked to leave the crop residues after harvest. Work focused on the cultivar "Enyeru".

The site was at the same location as experiment one above. Fifteen farms with multi-cultivar stands. Five were consistently maintained at low, five at moderate and five at high sanitation (Table 1) for at least two years, with *C. sordidus* population density of 4,300-8,000 adults/ha (4 – 7 weevils/mat).

Table 1. Description of sanitation levels on farmers' fields in Ntungamo, July 1999

Sanitation level	Treatment description
Low – Control	Pseudostems and corms are left intact standing on mother mat, or, if chopped at various heights above the ground at the base from mat with a bit of corm, are left in inter-mat alleys scattered throughout the banana field for long periods until they rot
Moderate	Pseudostems and corms are chopped up or pseudostems stripped and spread and corms chopped to ground level 4 to 6 weekly and covered with soil till they rot
High/Intense	Pseudostems and corms are chopped up weekly into small bits and spread out to dry.

Treatments comprised low, moderate and high sanitation levels 1); six banana (cv "Enyeru") crop residue categories i.e. 1) suckers 2) standing freshly harvested 3) standing old 4) standing very old 5) prostrate old residues and 6) prostrate very old residues. The experiment was laid out in a Completely Randomized Design with five replicates. Individual farms were replicates. Fresh residues ranged 1-7, old residues 8-30 and very old residues 60-112 (DAH). Fresh residues were green and firm, while older residues turned dark brown with inner tissues in varying states of decomposition. Banana residues of similar size were prepared and suckers selected in farmers' fields during September-December 2001.

Data collection: After identifying a farm to sanitation level, mats of cultivar "Enyeru" were selected for study. Fifty banana stumps of fresh residues per farm were chopped at one metre above ground level. Standing residues were left intact on mother mats, while the cut prostrate residues were placed in inter-mat alleys at least one metre away from the mother mats. Standing and prostrate residues were set on the same day and left fore varying periods of time (i.e. treatments).

In each farm, ten samples were assessed within seven days after harvest, while ten were left standing *in situ* with the stump chopped one metre above ground level, and assessed within 30 days after harvest. Ten residues were not assessed until they were at least 60 but not later than 112 days after harvest. The other 20 stumps were then chopped at ground level with part of corm near the collar area and placed in inter-mat alleys away from the mother mat. Ten of them were assessed within 30 days after harvest while the rest was assessed at 60-112 days after harvest. Ten suckers selected per farm were sampled immediately. Each residue or maiden sucker was chopped at the collar level and removed from the mother mat with a corm about 10 cm below the collar attached.

First, adults associated with residues were assessed, followed by destructive sampling of corms to find immatures and any more adult *C. sordidus*. Corms were carefully dissected using sharp knives to locate the different *C. sordidus* immatures and any more adults. The same was done for pseudostems. The number of eggs, 1^{st}–3^{rd} instar larvae ($\leq$ 7 mm), 4^{th}–6^{th} instar larvae ($\geq$ 7 mm), pupae and adults found in corms and pseudostems were recorded.

Data analysis

For data from *experiment 1*, SAS General Linear Model (GLM) procedure was used to analyze number of eggs, larvae, pupae, teneral adults and adults by residue age, residue placement (standing or prostrate), location on residue (corm or pseudostem) and by clone/cultivar. Means for *C. sordidus* development stage by residue age, and location were first square root transformed before analysis and then re-transformed. Means were separated using Ryan-Einot-Gabriel-Welsch Multiple Range Test (REGWQ).

For data from *experiment 2*, two sets of analyses were performed on number of eggs, larvae, pupae and adults on standing versus prostrate and crop residue age. Mean of eggs, larvae, pupae and adults per residue for both sites were subjected to preliminary analysis to detect site and seasonal differences. When no such differences were observed, the means were pooled and subjected to ANOVA and mean comparison was performed using the Student-Newman-Keuls test of SAS (SAS Ins., 1997) General Linear Models.

For *experiment 3*, General Linear Models (GLM) of SAS was employed to analyze data on number of eggs, larvae, pupae and adults. Least square (LS) means by sanitation level, crop residue type/age and crop residue part were obtained. Treatment effects were detected using the pair-wise comparison t-test of LS means.

Results

Distribution of eggs, larvae, pupae and adults in farmer's fields (experiment 1)

Differences between the number of eggs between standing and prostrate residues and between rhizomes and pseudostems were not significantly ($P<0.05$) different (Table 2). The number of eggs on residues decreased with age, so did the number of larvae though not significantly (Table 3). Pupae seemed to be more abundant in older residues of 8-14 days old compared to fresh residues 1-7 days after harvest (Table 3). There was no significant ($P<0.05$) difference in numbers of adults per residue between residue ages (Table 3).

Table 2. Number of eggs on standing (n=124) and prostrate (n=116) residue (experiment 1).

Residue type		Age of banana residue (Days after harvest)				
		1-7	8-14	15-30	31-60	61-120
Standing	Rhizome	1.2a	1.0a	1.3a	0.7a	0.7a
	Pseudostem	1.2a	0.6a	1.4a	0.1a	0.7a
Prostrate	Rhizome	0.5a	0.4a	0.7a	0.1a	0.0a
	Pseudostem	0.0a	0.1a	0.0a	0.0a	0.0a

In columns, means with the same letter are not significantly ($P>0.05$) different by Ryan-Einot-Gabriel-Welsch Multiple Range Test (REGWQ).

Table 3. Mean distribution of eggs, larvae, pupae, teneral adults and adults by crop residue age (days after harvest - DAH) in farmers' fields (experiment 1)

		Mean number of each banana weevil growth stage				
Age of residue (DAH)	n	Eggs	Larvae	Pupae	Teneral adults	Adults
0-7	140	1.7a	2.2a	1.1 b	1.0a	1.9a
8-14	65	1.4abc	1.9a	1.5a	1.1a	2.2a
15-30	60	1.5ab	2.2a	1.3ab	1.0a	1.9a
31-60	65	1.1 c	1.9a	1.3ab	1.0a	1.7a
61-120	60	1.2 c	1.7a	1.1 b	1.1a	2.2a

In columns, means (after square root ($\sqrt{(\mathbf{x} + \mathbf{0.5})}$ transformation) followed by the same letter are not significantly ($P<0.05$) different by Ryan-Ginot-Gabriel-Welsch Multiple Range Test (REGWQ)

The number of eggs on "Entaragaza" AAA-EA was significantly higher than those on the other cultivars (Table 4). Cultivar "Enzirabushera" had significantly ($P<0.05$) higher larval counts per residue than the rest of the cultivars (Table 4), but were only significantly different from "Embiire", "Enyeru" and "Mbwazirume". Numbers of pupae on residues of all cultivars were not significantly ($P<0.05$) different (Table 4). Among cultivars, "Entaragaza" had a significantly higher ($P<0.05$) number of weevils per residue (5.5, n= 10) than the rest of the cultivars (Table 4).

Table 4. Composite means showing the number of different life stages of the banana weevil by banana (AAA-EA) clones in multi-cultivar banana stands in Ntungamo (experiment 1)

Banana clone		Banana weevil life stage				
	N	Eggs	Larvae	Pupae	Teneral adults	Adults
Entaragaza	10	3.9 a	4.9ab	0.0a	0.0a	5.5a
Enzirabahima	41	1.0b	2.2ab	0.1a	0.1a	3.0 b
Butobe	70	0.8b	2.5ab	0.0a	0.0a	1.1 b
Kibuzi	45	0.5b	2.2ab	0.1a	0.1a	1.7 b
Enyeru	204	0.4b	1.0 b	0.1a	0.1a	1.5 b
Enjagaata	5	0.0b	2.8ab	0.0a	0.0a	0.6 b
Enzirabushera	5	0.0b	6.8a	0.0a	0.0a	0.4 b
Embiire	5	0.0b	0.2 b	0.0a	0.0a	0.0 b
Mbwazirume	5	0.0b	1.6 b	0.0a	0.0a	0.0 b

In columns, means with the same letter are not significantly ($P<0.05$) different by Ryan-Einot-Gabriel-Welsch Multiple Range Test (REGWQ).

Timing and distribution of attack of *C. sordidus* on crop residues in the on-station trial (experiment 2).

Residue age had a significant effect on the number of eggs on prostrate but not standing banana residue (Table 5): the instance, the number of eggs per residue on four-week-old prostrate residues was more than two times higher than that on two-week-old residues, and the number of eggs then reduced four times on 16-week-old residues compared to than on four-week old residues.

The larval count on different ages of standing residues did not differ (Table 5). On eight-week-old prostrate residues, the number of larvae was about three times higher than that on two-week-old and 16-weeks old residues (Table 5). The number of pupae did not differ significantly between the different aged residues.

The number of adult *C. sordidus* in prostrate and standing residues gradually increased with increase in residue age in both standing and prostrate residues (Table 5). The number of adults in 16-week-old residues was about 1.5 to 2.5 times higher than in two-week-old residues.

Table 5. Number of *C. sordidus* eggs, larvae, pupae and adults by age of banana cv. 'Atwalira' (AAA-EA genome group) standing and prostrate residues (on-station trial, 5 replications) (experiment 2).

Residues	Week after harvest	Hardness (Newtons)	Moistness	Eggs	Larvae	Pupae	Adults
Prostrate	2	169 ± 12a	Moderate	2.3 ± 1.12 b	3.4 ± 2.04 b	0.2 ± 0.43a	3.3 ± 1.61 b
	4	191 ± 18a	Moderate	4.8 ± 1.33a	7.6 ± 2.42a	0.6 ± 0.51a	3.5 ± 1.92 b
	8	218 ± 29a	Very moist	3.3 ± 1.25 b	10.1 ± 2.28a	0.8 ± 0.48a	5.6 ± 1.80ab
	16	181 ± 24a	Very moist	1.2 ± 1.05 b	3.9 ± 1.92 b	0.7 ± 0.40a	8.0 ± 1.52a
Standing	0	116 ± 20 b	Moderate	3.2 ± 1.08 b	4.7 ± 1.96 b	0.9 ± 0.41a	4.9 ± 1.55 b
	2	188 ± 17a	Moderate	4.4 ± 1.34 b	4.0 ± 2.44 b	0.4 ± 0.51a	3.9 ± 1.93 b
	4	150 ± 14a	Moderate	3.3 ± 1.33 b	5.1 ± 2.43 b	0.4 ± 0.51a	4.0 ± 1.91 b
	8	141 ± 17a	Moderate	4.2 ± 1.29 b	4.0 ± 2.36 b	0.4 ± 0.49a	6.2 ± 1.87ab
	16	125 ± 13 b	Very moist	2.6 ± 1.75 b	2.0 ± 3.16 b	0.1 ± 0.67a	7.7 ± 2.52a

In columns, means followed by the same letter are not significantly ($P>0.05$) different by pair wise comparison t-test

Timing and distribution of attack in fields maintained at different sanitation levels (experiment 3)

Weevil distribution by sanitation level

The number of eggs, larvae, pupae and adults per residue were significantly different between sanitation levels except for the number of eggs and small larvae of low and moderate sanitation levels (Figure 1). In fields maintained at high sanitation, the weevil counts per residue were about two times less than at low sanitation.

Weevil development stages and residue age

The number of eggs was significantly lower on growing plants than harvested ones (Figure 2). For instance, suckers had two to three times less than standing and prostrate residues of four weeks old, and about two times less for 16 weeks old residues. The larval count increased significantly with residue age for both standing and prostrate residues, but more so for the latter, while, while suckers and fresh standing residue scored lowest. The number of pupae was significantly higher in prostrate than in standing residues (Figure 2). Older

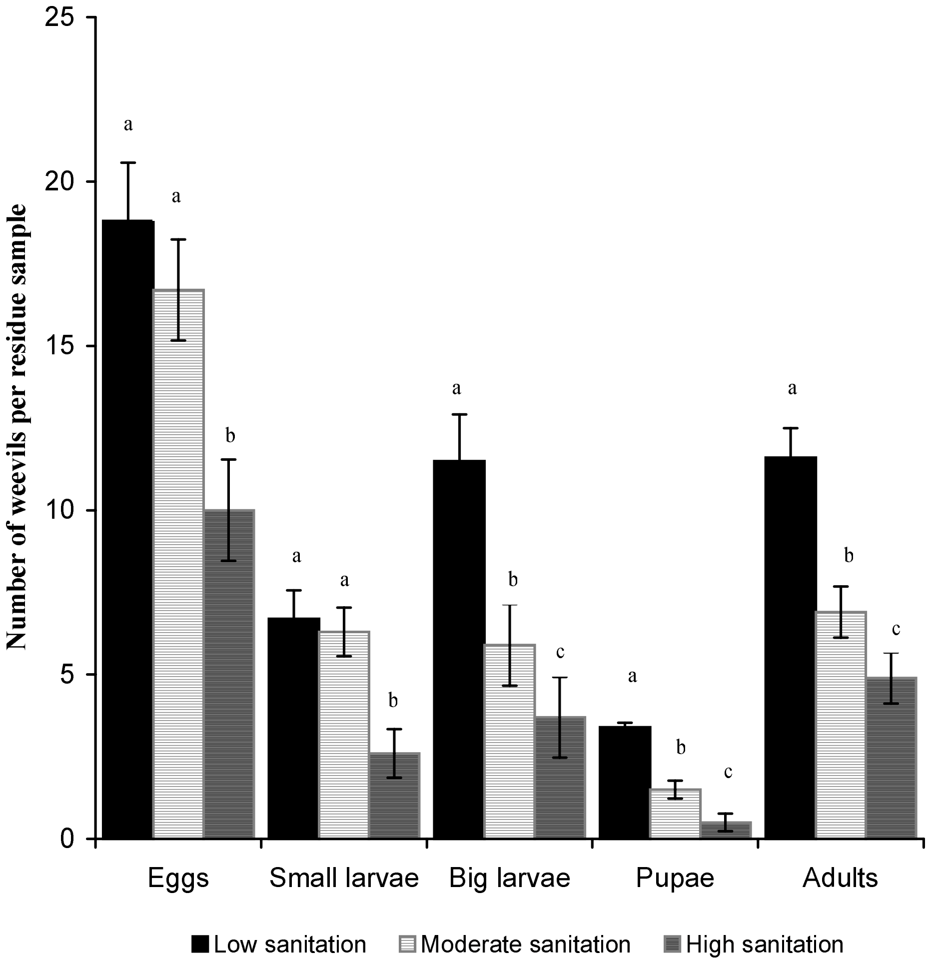


Figure 1. The number of *C. sordidus* at different development stages (LS means ± SE) in farmers' fields maintained at low, moderate and high sanitation in Ntungamo for one year. Means of each development stage followed by the same letter are not significantly different (pair-wise comparison t-test of LS means). NB: Small larvae (instar 1-3) and big larvae (instar 4-6).

residues housed more pupae than fresh residues. Prostrate residues had a significantly higher number of adult weevils than standing residues and growing suckers (Figure 2).

Weevil development stages in corms and pseudostems

The number of eggs on corms in fields maintained at low sanitation was about twice the number at high sanitation; this was the same for pseudostems (Figure 3). The number of larvae on corms and pseudostems at low sanitation level was about 2-3 times higher than that at high sanitation. The numbers of pupae found in corms and pseudostems at low sanitation were over 5 times those at high sanitation. The numbers of adults on corms at low sanitation were about three times those at high sanitation (Figure 3).

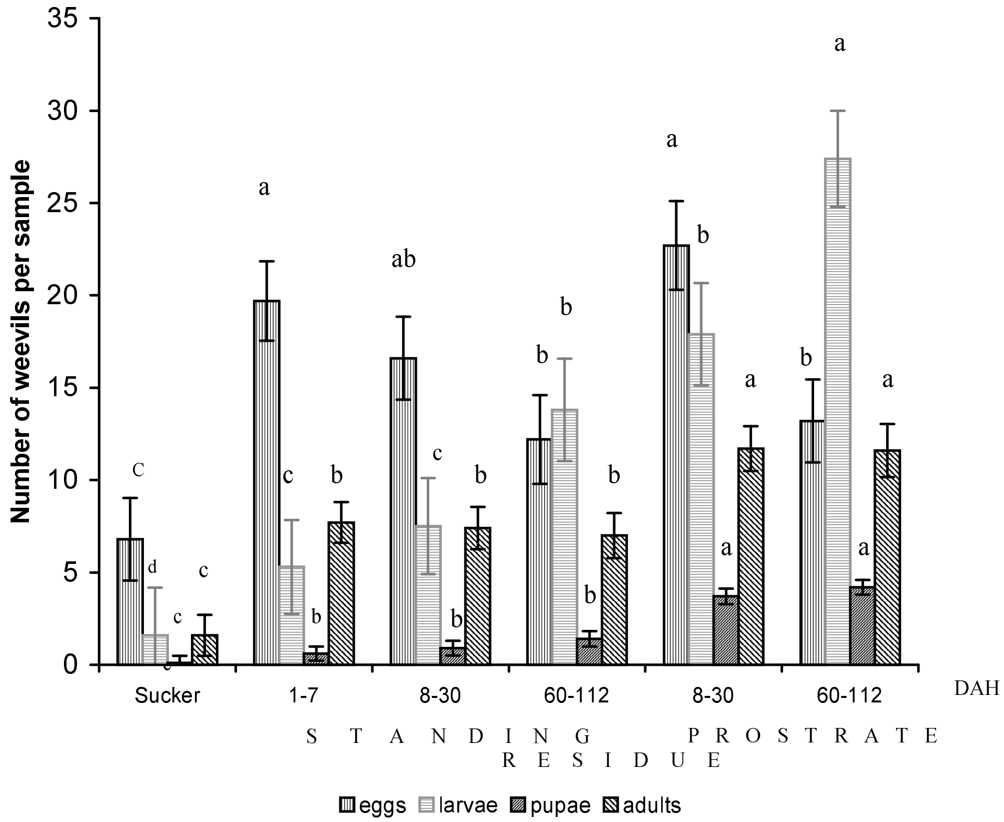
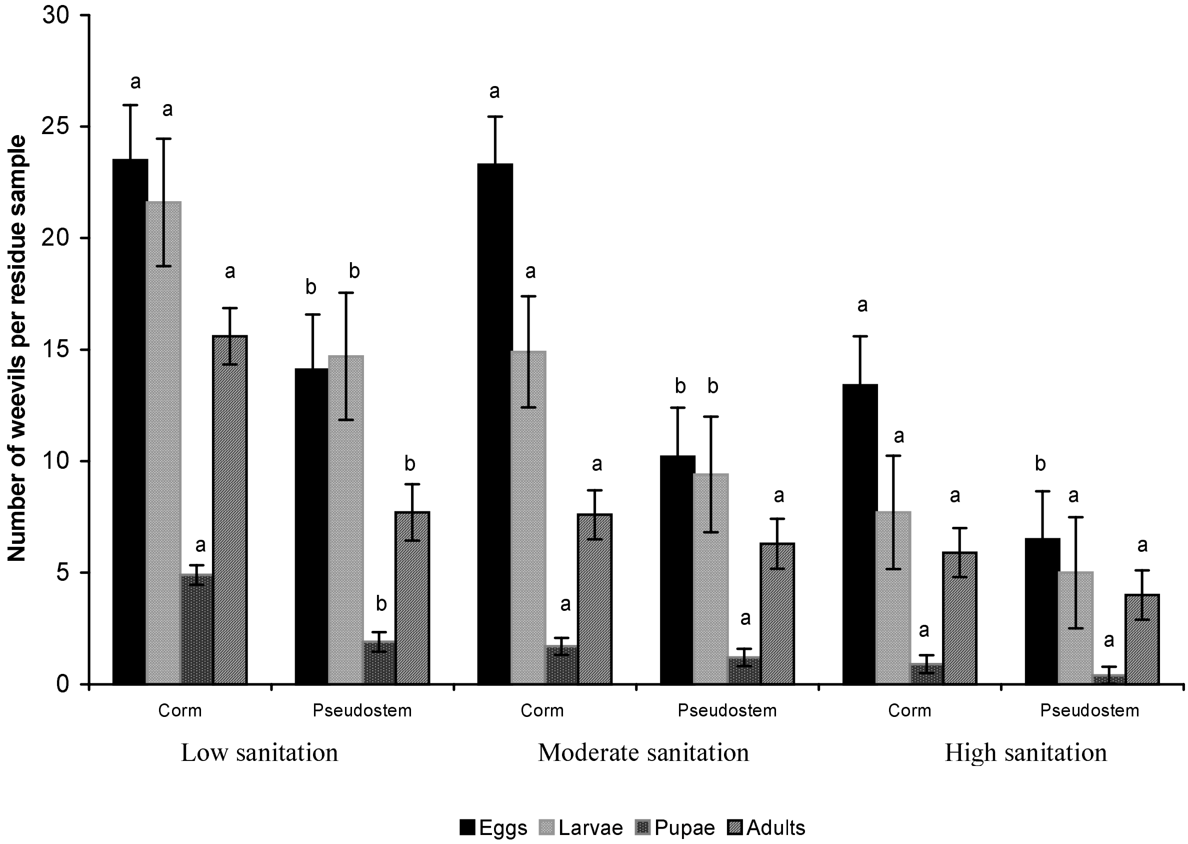


Figure 2. The number of *C. sordidus* eggs, larvae, pupae and adults by age of standing and prostrate crop residues of different age (DAH days after harvest) in farmers' fields maintained at low, moderate and high sanitation levels in Ntungamo for one year. For each weevil development stage, means followed with the same letter are not significantly different (pair-wise comparison t-test of LS means).

The number of eggs, larvae, pupae and adults at low sanitation was higher on corms than on pseudostems, for moderate sanitation levels this was only significant for the eggs and larvae, and at high sanitation only for eggs (Figure 3).



LS = Low sanitation; MS= Moderate sanitation; HS= High sanitation

Figure 3. The number of *C. sordidus* in different development stages in corms and pseudostems by sanitation level in farmers' fields in Ntungamo. Means of weevil numbers of a certain development stage and within each sanitation level followed by the same letter are not significantly different (pair-wise comparison t-test of LS means).

Discussion

Destruction of crop residues (corms and pseudostems) as a measure to control *C. sordidus* in banana fields is a quite widespread practice in the great lakes region (Karamura and Gold, 2000). However, a survey on crop sanitation as a control strategy against this pest revealed that 75% of the farmers practiced sanitation at a low level and only five percent practiced it at a high level (Masanza et al., Chapter 6). Crop sanitation involves uprooting and chopping underground rotten corms into small pieces for easy desiccation. This denies *C. sordidus* breeding and feeding sites (Treverrow et al., 1991). Until now, crop sanitation, as a control strategy by removal and chopping of corms and pseudostems after harvest remained a hypothesis. Quantitative studies to evaluate its effectiveness have not been conducted to decide for or against it (Karamura and Gold, 2000). Gold and Bagabe (1997) noted that while there were low damage levels on brewing cultivar "Kisubi" (AB), its residues were heavily attacked. They attributed this to a breakdown in host plant substances that repel the pest in growing plants. Currently, studies are in progress to document the effectiveness of crop sanitation in the control of *C. sordidus* populations and damage in farmers' fields. As part of the study, we have been investigating the ovipositional preferences of the *C. sordidus* in order to understand its biology.

In our study, most oviposition occurred on corms of older residues compared to growing suckers. Freshly harvested residues had higher oviposition levels than older residues. This demonstrates differential host plant preference or acceptance. However, there was higher larval survivorship in older residues than fresh residues and standing plants. Thus, older residues are more acceptable than younger residues or standing plants, suggesting that low survivorship on growing plants is due to antibiosis. It is possible that decaying host tissues release an abundance of volatiles that attract high numbers of adult *C. sordidus*. Budenberg et al. (1993), suggested that kairomones emitted from host plant tissue are important in host plant location. In this study, a plant (suckers) is less oviposited on than plants after flowering. These results are in agreement with those in a related study on ovipositional preferences on banana crop phenological stages, which reported that oviposition increases with plant age (Abera et al., 2000). These authors also report that most oviposition occurred in pseudostems than corms mainly due to easier accessibility of the former to the *C. sordidus*. Their work was conducted on a one-year-old plantation. In such fields, the corms are difficult to access and gravid females deposit their eggs at the collar on the pseudostem. On the other hand, we have found that oviposition, larval success and number of adults on crop residues were 34-50% more in corms than in pseudostems. This is likely due to easy access of gravid females to corms. In 50 year-old-plantations where we worked, corms are more exposed. Corms emit more volatiles and are more attractive to the pest than pseudostems (Budenberg et al., 1993). Further, pseudostems lose water faster than corms and hence the latter remain more attractive as a refuge for the adult and even immature stages. Interestingly, very old prostrate crop residues (16 weeks old) hosted a high number of adults compared to standing residues of similar age. This is most likely because prostrate residues, as opposed to standing residues, are on the ground and retain more moisture. Standing residues by 16 weeks after harvest are mostly desiccated and attract no *C. sordidus*. *C. sordidus* is positively hydrotactic, highly sensitive to moisture and can stay long without feeding (Froggatt, 1923; Simmonds, 1966; Cuille, 1950; Gold, 1998). This implies that as long as crop residues are moist, the adult *C. sordidus* will stay alive and will most likely get an opportunity to attack the standing crop.

Results of a survey on distribution of weevil development stages on banana residues in this study revealed some different levels in attack of clones. This was especially true for eggs, larvae and adults and interestingly, not so for pupae and teneral adults. It is possible that there is considerable mortality of immatures within the residues. However, those that survive contribute to population build up within banana stands. The differences in weevil attack among banana clones points a finger to differences in the break down of host resistance mechanisms in the clones. It is possible that some banana clones are attacked only after decomposition. Gold and Bagabe (1997) found that a beer cultivar (Kisubi genome group AB) was resistant to attack before harvest but became heavily infested when rotten. Such residues are a source of infestation to growing crops and need to be destroyed before rotting.

In general, *C. sordidus* numbers were higher in fields at lower than at higher crop residue management levels. Crop residues host a lot of immature and mature *C. sordidus* stages. This strongly suggests that removal and splitting of corms after harvest is of practical importance in destroying especially immature growth stages of the pest. Since all crop residues house immature *C. sordidus* stages, chopping them to small pieces as early as possible, preferably within two weeks after harvest, should destroy a big proportion of the pest population in its most destructive stage.

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Chapter 4

Influence of plant and residue age on egg eclosion and larval survival of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae)

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Chapter 4

Influence of plant and residue age on egg eclosion and larval survival of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae)

M. Masanza, C.S. Gold, A. van Huis and P.E. Ragama

Abstract

We conducted laboratory trials to investigate *Cosmopolites sordidus* eclosion success and larval survivorship on different aged banana residues at Kawanda in Uganda. When we inserted 24-hour old eggs into corm pieces of four different aged susceptible banana cultivar "Kisansa" (genome group AAA-EA), eclosion rates were 66% in fresh, 67% in moderately old, 64% in old and 58% in very old residues. To assess immature survival, 24-hour old larvae were put on banana corms of suckers and crop residues of the same cultivar "Kisansa" in single rearing chambers. The number of surviving individuals was recorded at three-day intervals until adults emerged. The number of surviving individuals 48 days after eclosion was 12% on sword suckers, 10% on maiden suckers and 7% on flowered plants, after 51 days 12% on fresh, 8% on old and 5% on very old corms. Larval duration and mean date of adult emergence increased with plant and crop residue age. Crop residue age did not affect adult weight, but the females were heavier than males. These results imply that fresh residues offer better nutrition for *C. sordidus* than old residues. However, since all residues offered a successful breeding place for the weevil, they should all be destroyed to prevent population build-up of the banana weevil.

Introduction

The banana weevil *Cosmopolites sordidus* (Germar) is an important pest on East African highland banana (Rukazambuga et al., 1998; Gold et al., 1999a). The adults are free living and most commonly found closely associated with banana mats and crop residues (Gold et al., 1998). Females lay single eggs in the base of the plant. All stages of plants including crop residues are attacked (Abera, 1997). The larvae tunnel in the corm, weakening the stability of the plant and interfering with nutrient uptake. Yield losses of up to 100% have been recorded (Sengooba, 1986; Gold et al., 2003). The banana weevil has been an important factor in declining banana yields in central Uganda, leading to a subsequent shift of banana production to the southwestern region of the country.

Cosmopolites sordidus has limited dispersal capability. The insect rarely flies and crawls only short distances (Gold et al., 2003). As a result, *C. sordidus* is most commonly spread through the movement of infested planting material. Such suckers usually support very few eggs and larvae; therefore initial populations in new banana fields are low (Gold et al., 1998; Abera et al., 1999). Although *C. sordidus* has a long life span, its low fecundity results in slow rates of population build-up (Gold et al., 2003). Rukazambuga (1996) monitored populations by mark-recapture methods following a release into a banana stand and found that *C. sordidus* numbers declined during the first eight months following release, but then increased five-fold during the subsequent two years. This illustrates how weevil problems are likely to increase with age of the banana stand.

Cosmopolites sordidus development rates and stage durations have been reviewed by Traore et al. (1993 and 1996) and Gold et al. (2003). Under tropical conditions, the egg stage lasts 6-8 days. Eclosion rates of 80% have been reported in the laboratory (Bakyalire, 1992; Griesbach, 1999), but these could be lower than those in the field due to handling, desiccation and fungal attack (Treverrow and Bedding, 1993). The larvae most commonly pass through five to seven instars. In Uganda, the larval stage lasts about 25 days (Gold et al., 1998), although larval periods of up to 51 days have been reported (Bakyalire, 1992). The pupal stage averages 7 days (Gold et al., 1998).

Larval survivorship in the laboratory may be reduced due to handling and food deterioration (Mestre, 1997). In Latin America, Mesquita and Caldas (1986) successfully reared 87% of larvae to pupae on young plantain plants, but only 50% of larvae pupated on flowered plants and on residues. Larval weights were greatest on young plants, while the larval developmental period was longer on residues suggesting that these were of lower food quality than young and flowered plants as the developmental period.

No information is available on larval performance on plants and residues of other *Musa* cultivar groups. For example, in Ntungamo district, Uganda, Masanza et al. (Chapter 3) observed vigorous larvae to be common in old, decomposed highland banana crop residues. Similarly, Gold and Bagabe (1997) and Gold and Hasyim (cited in Gold et al., 2003) found high levels of weevil attack on crop residues of otherwise resistant cultivars. This suggests that crop residues can serve as a breeding ground for banana weevils leading to higher populations and increased attack. For example, Gold and Bagabe (1997) proposed that crop residues in a stand of a resistant variety can support the build-up of weevil populations and then serve as a source of *C. sordidus* attack in an adjacent stand of a susceptible variety.

Cultivar resistance to *C. sordidus* is believed to be antibiotic in nature (Kiggundu, 2000; Gold et al., 2003). Attack on the residues of susceptible varieties suggests that antibiotic mechanisms break down following harvest of the bunch and dieback of the stem. The relative success of *C. sordidus* immatures on plants versus residues of susceptible varieties has not been determined. The implementation of crop sanitation practices (i.e.

destruction of crop residues) becomes increasingly important to the extent that weevil reproduction on crop residues contributes to the build-up of field populations and increasing damage in developing plants. At present, this is unknown. It is also important to know the timing of sanitation practices to maximize their effects in reducing *C. sordidus* populations.

In this context, it is critical to determine to fully understand the role of residues in *C. sordidus* population dynamics including the relative attraction of ovipositing adults to and immature success in residues and standing plants. It is also important to determine the stage of residue where peak oviposition occurs and to what extent *C. sordidus* larvae can complete their development on residues of different ages.

The primary objective of this study was to determine the success rates of *C. sordidus* immatures on residues of different ages and in different states of decomposition. In particular, we were interested in eclosion rates, larval development times and survivorship, pupal weights and the weights of teneral adults reared from different aged crop residues. The attraction of different aged plants and residues to ovipositing *C. sordidus* is reported by Masanza et al. (Chapter 2).

Materials and methods

Research on survivorship of *C. sordidus* immatures in different aged banana crop residues was conducted in laboratory studies in the banana entomology laboratory at the Kawanda Agricultural Research Institute. Kawanda is 13 km north of Kampala (0^o 25' N, 32^o 32' E), 1195 metres above sea level with 12-hour day-length throughout the year. Average daily temperatures are 15^{o}C minimum and 29^{o}C maximum with mean relative humidity of 76%.

Experiment 1: Eclosion success on different aged corm residues

The objective of this experiment was to determine if age of residue and its state of decomposition influenced eclosion rates of *C. sordidus* eggs. Treatments consisted of four different corm residue age classes: (1) fresh (1-2 days after harvest); (2) moderately-old (14-30 days); (3) old (31-60 days); and (4) very old (= advanced decomposition) (> 90 days).

The different aged plant residues were obtained from banana stands neighbouring Kawanda. Banana stumps were dug out whole using a digging spear. At the laboratory, the residues were pared and cut into pieces of required dimensions. We selected only corms with little or no prior *C. sordidus* infestation. Any signs of *C. sordidus* damage were pared away. Corm pieces weighing about 200g (7 x 3 x 1 cm) were cut from the different-aged corm residues (three to five pieces per residue).

In each corm piece, ten 2-4 mm deep holes were cut on the surface using the point of a sharp knife. Fresh (< 24 hour old) *C. sordidus* eggs were placed singly in each hole. The eggs were carefully picked from the filter paper using a fine brush to avoid damaging them. The corm pieces were then placed on moist filter paper at the base of alcohol-cleaned petri dishes. The petri dishes were placed on racks whose legs were immersed in water traps to protect the eggs from predatory ants. After 10 days, the corms were carefully dissected to determine the fates (eclosed or dead) of each inserted egg. Each treatment was replicated 20 times. The mean temperature during the experiment was 25 ^{0}C.

The eggs used in this experiment were obtained from a laboratory colony of *C. sordidus*. Banana maiden suckers (cv. "Atwalira" genome group AAA-EA), obtained from farmers' fields near Kawanda were carefully pared using a sharp knife to remove any *C. sordidus* eggs. Two pared suckers were placed in each of four 60 x 20 cm plastic buckets. Each bucket was infested with 250 unsexed adult *C. sordidus* that had been field-collected a week earlier and maintained on banana corms. The buckets were covered with lids perforated with small holes and kept in the laboratory at room temperature. After 24 hours, the suckers were pared to obtain eggs. These were immediately inserted into the test corm pieces.

Experiment 2a: Influence of plant phenological stage on larval survivorship

Larval survivorship was determined on three different phenological stages of highland banana (cv Kisansa). The treatments were (1) sword sucker; (2) maiden sucker; (3) flowered plant. Pieces of corm (7 x 3 x 1 cm = 200 g) were split in half and a small notch (large enough to accommodate a small larva) was cut into the interior of one half. A single recently emerged (< 24 hour) first instar larva was placed into this notch. The pieces were then placed back together with the larva on the inside.

The corm pieces were maintained in plastic buckets (60 x 20 cm). After three days, the corms were opened and the larvae were gently extracted. Head capsule measurements (c.f. Gold et al., 1999b) were taken for live larvae, which were then placed in fresh corms from the same treatment group. The head capsule of each larva was measured at the widest point (dorsal view) at 40 times magnification with a binocular dissecting microscope fitted with a calibrated micrometer. Larvae entering the fifth instar were determined by comparing their head capsule width measurements on a scale developed by Gold et al. (1999b). Measurements and replacement of corm material were conducted every three days until the larvae entered the pre-pupal stage. Post pre-pupal stage stages were left undisturbed (except for one time weighing) in the rearing chambers until the teneral adult stage. Weights of pupae and teneral adults, sex of the emerging adults and deaths were recorded. These weevils were sexed on the basis of punctuations on the rostrum (Longoria, 1968) and curvature of the last abdominal sternite (Roth and Willis, 1963). The experiment was repeated 4 times with each replicate consisting of 50 larvae per treatment.

The corms used in these experiments were obtained from plants taken from farmers' fields in Semuto, 50 km north of Kampala. Selected farms had low weevil incidence and predominantly consisted of the highland banana cultivar "Kisansa". Entire banana mats were uprooted with a digging spear and then transported to Kawanda. The corm material was handled as in *Experiment 1*, with infested parts rejected or pared away.

For these experiments, first instar larvae were obtained from a *C. sordidus* colony maintained in the laboratory. Three thousand adult weevils were placed in buckets containing highland banana maiden suckers. Each day eggs (< 24 hours old) were removed by paring the suckers. These were maintained on moist filter paper in petri dishes in the laboratory and monitored daily. Newly emerged larvae were used in the experiments.

Experiment 2b: Influence of residue age on larval survivorship

Larval survivorship on three different age groups of corm residues was determined using methods similar to those in *Experiment 2a*. The treatments were: (1) fresh corm (1-3 days after harvest); (2) intermediate-aged corm (7-14 days); and (3) very old corm (60-90 days). Experimental procedures and data collection were similar to those in *Experiment 2*.

Data analysis

For data from *Experiment 1*, means and percentages of *C. sordidus* eggs eclosed after 10 days were subjected to mixed model procedure (SAS Institute, 1997) with treatments as fixed effects while replicates were considered as random. Mean separation was carried out using orthogonal contrasts. For *Experiments 2a* and *b*, scatter plots of numbers of surviving individuals and emerging adults were made. Allometric curves for the total number of surviving individuals and emerging adults on corms of suckers and different residues were fitted using excel chart options (Microsoft Excel 2000) to fix trend lines, intercept and the R-square, such that:

$$Y = AX^{*(-B)}$$

where Y = number of surviving individuals, A = intercept, B = gradient estimated for survival and X is the independent variable (time i.e. days after eclosion).

Means of larval and pupal development stage duration were subjected to analysis of variance using GLM procedure (General Linear Models) of SAS (SAS Institute Inc., 1997). Differences in the effects of sucker and residue age on development were determined by pair-wise comparison t-test of Least Square Means. The effect of food on larval survival was analysed using GENMOD (generalized linear model) procedure of SAS (SAS Institute Inc., 1997), with an appropriate link (logarithm) and distribution (poisson, gamma or binomial) and offset (natural logarithm on time) functions. We assumed poisson distribution for larval survival, which is an example of count data whose distribution is not normal (Gomez and Gomez, 1984). We used logarithm as a link function for larval survival on dependent variables (larvae count over days after emergence). Logarithm link function was used to ensure that means have a positive value while the offset variable serves to normalize data to fitted cell means (SAS Institute Inc., 1997). For survival rate, gamma distribution was assumed with link function as logarithm on dependent variables survival rate over the number of observed larvae. Gamma distribution was considered appropriate, as this is life data that involves time lapse. For example, mortality occurred in some larvae before data were collected (Gomez and Gomez, 1984). For pupal count, Poisson distribution was assumed with link function as logarithm on dependent variables pupal count over logarithm of days after emergence for cumulative weevil survival. Differences among treatments were detected by pair-wise t-test comparison of LS means of pre-pupal head capsule width, pupal weights and adult weights.

Results

Experiment 1: Eclosion success on different aged corm residues
Eclosion rates on the fresh (66 $\pm$ 3%), moderately old (67 $\pm$ 4%) and old corms (64 $\pm$ 4%) were not significantly different from each other ($P > 0.05$). However, all three treatments were significantly different from those on very old corms (58 $\pm$ 4%).

Experiment 2a and 2b: Influence of plant and residue age on larval survivorship
Weevil mortality was lowest on sword suckers ($B = -0.75$, $R^2 = 0.98$) (Figure 1a) and fresh corm ($B = -0.75$, $R^2 = 0.92$) (Figure 1b), while the highest rate of mortality ($B = -1.08$, $R^2 = 0.99$) was recorded on very old corms (Figure 1b). On corms from standing plants after 48 days, 12% of the larvae survived on sword suckers, 10% on maiden suckers, and 7% on flowered plants. For residues, these figures after 51 days were 12% on fresh corm, 8% on old corm, and 5% on very old corm. Mean larval period and mean date of adult emergence (days after eclosion-DAE) increased with plant and residue age (Table 1a and 1b). There was 2% higher pupation and a shorter immature period on fresh versus old corms. By contrast, pupation on very old corms is more than 50% lower than on both fresh and old corms (Table 1b).

Forty-eight days after insertion of recently hatched (<24-hour old) larvae, there were no significant differences in number of larvae developed into the fifth instar on sword suckers, maiden suckers and flowered plants (Table 2). However, there were very highly significant differences in the number of pupae ($P=0.01$) and adults ($P=0.001$) that developed on sword suckers as well as on flowered plants but not on maiden suckers ($P>0.05$). More pupae and adults developed on flowered plants than on sword suckers. Cumulative larval survival rate was significantly higher on fresh corm with a parameter estimate of 1.18 (since the estimates add up to one) than on old and very old banana corm (Table 3). On very old corm, the estimate was highly significant and negative (-0.33) implying mortality was higher on these than on fresh and old corms. Parameter

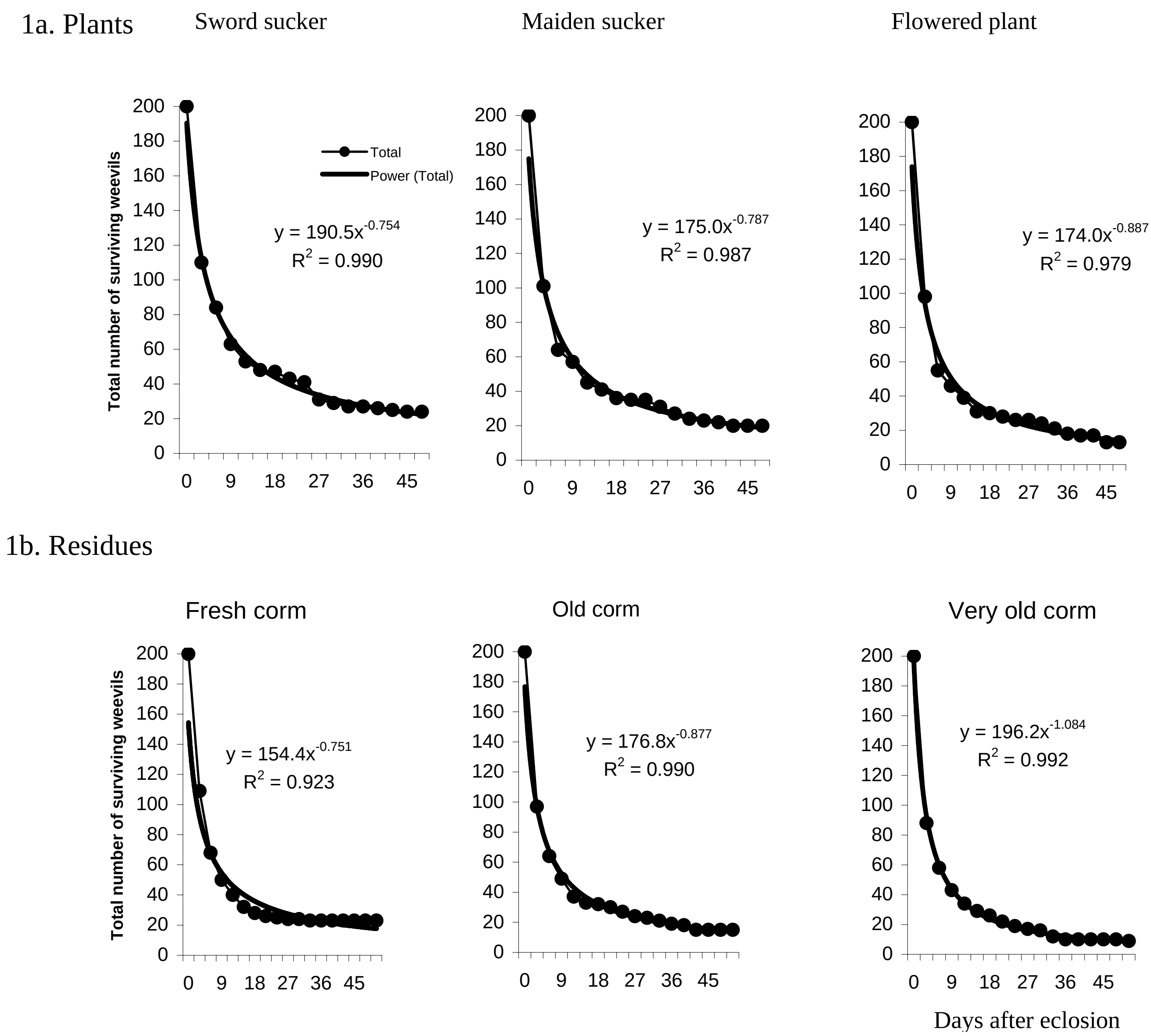

Figure 1. Larval to adult survivorship of *C. sordidus* and fitted inverse allometric curves for larvae reared on banana corms of (a) plants and (b) different aged residues.

estimates for larval survival rate were significant on all feeding material. On fresh corms, survival was best as its estimate was much higher (3.49) than that for old (1.24) and very old corm (1.32).

There was higher probability of pupation on fresh than on old corms. The parameter estimates for pupation rate was much higher (1.8) for fresh than for old and very old corm. Head capsule size for pre-pupal larvae reared on the different aged plants and residues did not significantly ($P > 0.05$) differ (Table 4a and 4b). Pupal weights were significantly ($P < 0.05$) higher on maiden suckers, flowered plants and fresh residue corms than on sword suckers, old residue corms and very old residue corms. In general, pupal weights increased with plant age and decreased with residue age. Weights of adult *C. sordidus* were not significantly ($P \leq 0.05$) affected by food material. However, pair wise comparison of male and female weights of weevils raised on residue corms showed significant (P $\leq$ 0.05) differences, females being heavier on fresh, old and very old corm (table 5).

Table 1. Mean larval duration (days after eclosion) and mean date of adult emergence on sword sucker, maiden sucker, flowered plant, fresh, old and very old residue corms (In parentheses = range of stage duration)

	Larval duration	N	% Pupating	Mean date of adult emergence
a. Plants				
Sword sucker	29.2 ± 0.52 c (24-36)	24	12.0	37.9 ± 0.61 b (33-42)
Maiden sucker	31.1 ± 0.55 b (30-36)	20	10.0	39.6 ± 0.68 b (36-48)
Flowered plant	36.4 ± 0.70a (33-42)	10	5.0	45.6 ± 0.96a (42-48)
b. Residues				
Fresh corm	32.3 ± 0.61 c (30-51)	19	9.5	39.1 ± 0.64 b (30-42)
Old corm	35.6 ± 0.65 b (30-39)	15	7.5	44.8 ± 0.78a (42-51)
Very old corm	39.4 ± 0.95a (33-45)	7	3.5	47.3 ± 1.01a (42-51)

In columns, means followed by the same letter are not significantly (P>0.05) different by pair-wise comparison t-test of least square means.

Table 2. Analysis of parameter estimates for total number of larvae, pupae and adults on sword suckers, maiden suckers and flowered plants corms (Poisson distribution and log as link function)

Parameter	DF	Estimate	Standard error	Chi-Square	Pr>Chi
Larvae (5th Instar)					
Intercept	1	-1.39	0.08	190.59	**
Sword sucker	1	-0.15	0.12	1.46	Ns
Maiden sucker	1	0.14	0.11	1.53	Ns
Flowered plant	1	0.39+	0.00		Ns
Scale	0	1.00	0.00		
Pupae					
Intercept	1	-1.43	0.15	88.15	**
Sword sucker	1	-1.02	0.27	14.59	**
Maiden sucker	1	-0.39	0.21	2.71	Ns
Flowered plant	1	1.84+	0.00		***
Scale	0	1.00	0.00		
Adults					
Intercept	1	-1.09	0.09	129.46	**
Sword sucker	1	-1.14	0.02	22.00	***
Maiden sucker	1	-0.31	0.17	3.06	Ns
Flowered plant	1	1.54+	0.00		**
Scale	0	1.00	0.00		

***P $\leq$ 0.001, **P $\leq$ 0.01, Ns = not significant P>0.05

Goodness of fit test for a) cumulative survival, deviance = 702, $\chi^2_{(30)}$ = 23.4

b) larval survival rate data: deviance = 201, $\chi^2_{(21)}$ = 9.6 (Model not rejected)

Table 3. Analysis of parameter estimates for cumulative larval survival, larval survival rate and number of pupae on different aged banana corms

Parameter	DF	Estimate	Standard error	Chi-Square	Pr>Chi-Square
Cumulative larval survival					
Intercept	1	0.25	0.04	35.5	**
Very old corm	1	- 0.33	0.06	26.4	***
Old corm	1	- 0.10	0.06	2.5	Ns
Fresh corm	1	1.18+	0.00		***
Scale	0	1.00	0.00		
Larval survival rate					
Intercept	1	-7.05	0.31	511.3	**
Very old corm	1	1.32	0.54	5.9	*
Old corm	1	1.24	0.50	6.3	*
Fresh corm	0	3.49+	0.00	0.0	**
Scale	1	1.00	0.03	0.0	
Number of pupae					
Intercept	1	-1.43	0.15	88.2	**
Very old corm	1	-1.02	0.27	14.9	**
Old corm	1	-0.35	2.71	2.7	Ns
Fresh corm	1	1.80+	0.00		**
Scale	0	1.00	0.00		

***P ≤ 0.001, **P ≤ 0.01, * P ≤ 0.05, Ns = not significant P>0.05

Goodness of fit test for a) cumulative survival, deviance = 2878, $\chi^2_{(30)} = 27.8$
b) larval survival rate data: deviance = 1124, $\chi^2_{(30)} = 43.8$
c) pupae deviance = 61.4, $\chi^2_{(15)} = 25$ (Model not rejected.)

Table 4. Pre-pupa larva head capsule width (*mu*), pupal and adult weight (LS means ± S.E.) of weevils reared on plants and corm residues

		Head capsule width (*mu*)	Pupal wt (*10^{-2}) g	Adult weight (*10^{-2}) g
4a. Plants				
	Sword sucker	105.5 ± 2.4a	10.8 ± 0.26 b	7.2 ± 0.4a
	Maiden sucker	104.2 ± 2.2a	11.7 ± 0.30a	6.6 ± 0.6a
	Flowered plant	103.4 ± 2.3a	11.5 ± 0.37a	7.1 ± 0.9a
4b. Corm residues				
	Fresh	103.7 ± 2.8a	11.5 ± 0.29a	6.9 ± 0.2a
	Old	106.0 ± 2.3a	10.7 ± 0.27 b	6.8 ± 0.2a
	Very old	106.4 ± 2.6a	10.2 ± 0.41 b	6.3 ± 0.4a

In columns within one treatment, means followed by the same letter are not significantly (P<0.05) different by pair wise t-test comparison of LS means.

Table 5. Adult weight (LS means ± S.E.) by corm age and sex of teneral adults

Age of corm	Sex of teneral adults	Adult weight (*10^{-2}) g
	Female	
Fresh		7.5 ± 0.28a
Old		7.3 ± 0.37a
Very old		7.2 ± 0.65a
	Male	
Fresh		6.4 ± 0.35 b
Old		6.3 ± 0.35 b
Very old		5.5 ± 0.29 b

In columns, means followed by the same letter are not significantly (P<0.05) different by pair wise comparison t-test of LS means.

Discusson

Crop sanitation has been widely recommended as a means of controlling *C. sordidus* by reducing adult refuges and breeding sites (Gold et al., 2003). The underlying assumptions appear to be that crop residues (1) encourage *C. sordidus* oviposition within banana stands; (2) are favourable hosts for larval development with greater levels of survivorship and subsequent adult fitness than in growing plants; and (3) contribute to an increased *C. sordidus* population and higher levels of attack on developing bananas. Thus, removal of these residues would lower weevil population levels and damage. None of these assumptions have been tested. Moreover, in order to the determine the best timing of sanitation measures, it is important to know if different aged residues display the same levels of susceptibility to banana weevil.

In Uganda, a study on oviposition rates, *C. sordidus* deposited 10-12% eggs on suckers, 22-33% on pre-flowered, 22-37% on flowering and 19-32% on crop residues (Abera et al., 1999). Rukazambuga and Gold (unpubl. data cited in Gold et al., 2003) found 200 eggs on one stump in another study in the country. These studies showed that crop residues encourage *C. sordidus* oviposition within banana stands.

In this study, egg eclosion rates were higher on residue corms that were three months old or less than on older residues. The 10-16% reduction in hatching in older residues may have been caused by the increasing abundance of saprophytic fungi in these corms that might kill the eggs. Nonetheless, the modest differences found in eclosion rates on different aged residues suggest that eclosion success is relatively similar for all staged residues. In contrast, the larval development period was lengthened and adult weight on very old corms was reduced. It should be taken into account that handling of the eggs in the laboratory could have increased their mortality, as reported in earlier studies (Ogenga-Latigo, 1992; Traore et al., 1993; Treverrow and Bedding, 1993).

Larval mortality rates were highest during the first nine days after eclosion. This mortality could possibly be due handling of the delicate early instar larvae of *C. sordidus*. It is also possible that early instar larvae are vulnerable to other mortality factors such as fungal attack. Larval survival was negatively correlated with residue age, survival being higher on fresh corm (up to 30 DAH) than on old corm residues aged (60-90 DAH). Mesquita and Caldas (1986) reported similar results with higher mortality in residues compared to those in young and flowered plants. A recent study in Uganda on attack by *C. sordidus* in mixed cultivar stands (Gold and Bagabe, 1997) demonstrated that standing plants of a beer cultivar 'Kisubi' (AB) was resistant to *C. sordidus* attack possibly due to plant resistance substances. However, rotten residue of the same cultivar was infested due to a likelihood of breakdown of toxic chemicals. Results of the present study conducted in the laboratory on 'Kisansa', a susceptible cooking banana AAA-EA cultivar, show that survival is higher on fresh residues. Although survival of immature stages is high on relatively fresh residue, most likely due to higher food quality in fresh compared to decomposing residues, the residues can also be a breeding place for adults.

Fitness can be defined as the ability of an individual to pass on genes to next generation (Godfray, 1994). The major components of female insect fitness especially fecundity is strongly correlated with body size (Jervis and Kidd, 1996). Larval size, pupal weight and adult weights can therefore be good measures of C. sordidus fitness. In our study, C. sordidus pupal weights were higher on fresh than on older plants and residues, although this was not reflected in the adult weights. Judging from pupal weights, this study suggests that fresh corm had a higher food quality; hence, weevils reared on them are likely to be more fit than those raised on older residues. Cuille (1950) reported similar results, though there was no information on effect of corm age on survival or fitness. Mesquita and Caldas (1986) also reported that pupal weights were lower in residues than on younger plants. In Uganda, field surveys on established banana plantations revealed disparities in C. sordidus attack even within cultivars (Gold et al., 1999a). Also, observations in multi-cultivar stands showed that some cultivars were only attacked after decomposition of residues (Gold and Bagabe, 1997). These observations imply that crop residues can be infested with weevils and act as a source of infestation for standing plants.

In our study, *C. sordidus* stage duration seemed to increase with plant and crop residue age. These results are similar to those of Mesquita and Caldas (1986), who attributed the prolongation of larval and pupal period of *C. sordidus* to reduced food quality of older plants and crop residues. In our study, the developmental period from egg to adult was 6-7 weeks under laboratory conditions (about 25°C). These results are similar to those of Gold et al. (1999b) who found a similar range of 6-8 weeks. Prolonged development period is due to an increase in the number of moults under unfavourable conditions such as poor food quality (Wigglesworth, 1972). This may produce less fit individuals for the next generation. However, in our study, though larvae reared on younger plants and fresh residue corms developed into heavier pupae, the result was not reflected in the adult stage. This suggests that although weevils reared on older residues took more time to develop than those reared on younger residues, they had the same fitness.

The present study suggests that weevils survive even on very old residue, and that residues did not only provide refuge for adults, but are also an oviposition substrate for gravid females in banana fields. Moreover, considering that larval size based on head capsule width was the same on all residues, it could imply that different aged residues have nearly the same capacity to support *C. sordidu*s larval development. Even if only a few larvae survive to reproductive stage, their contribution to population increase can be significant. This is because weevils can live up to four years (Gold et al., 1999c), and females may lay eggs throughout their lifetime. Therefore, all banana crop residues should be destroyed because they are a hiding and breeding place for *C. sordidus*, and, can be a source of infestation to the growing crop.

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Chapter 5

Effects of covering post-harvest highland banana (AAA-EA) stumps with soil on banana weevil *Cosmopolites sordidus* oviposition

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Chapter 5

Effects of covering post-harvest highland banana (AAA-EA) stumps with soil on banana weevil *Cosmopolites sordidus* oviposition

M. Masanza, C.S. Gold and A. van Huis

Abstract

The effect of covering post-harvest banana stumps with soil on banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) oviposition levels was investigated at Sendusu, Kawanda Agricultural research Institute (KARI) and in Ntungamo district of southwestern Uganda. In the first experiment we assessed oviposition levels in a banana system comprising growing plants and residues. Oviposition increased from sword suckers, reaching a peak 1 to 7 days after harvest and decreased thereafter. In the second experiment conducted on farmers' fields, corms received 70% of the eggs and pseudostems 30%. The area 5-10 cm below the collar received 27% of the eggs, the area 0-5 cm above the collar 30% and the area 5-10 cm above the collar 0.3%. The remaining eggs (43%) were laid 0-5 cm below the collar. The effect of stump height and covering the stumps was evaluated in both the wet and dry seasons at Kawanda and Ntungamo. Cutting stumps to ground level alone had no effect on oviposition. Covering post-harvest banana stumps reduced *C. sordidus* oviposition in the wet but not in the dry season.

Introduction

Highland cooking banana (AAA-EA) is a primary staple (INIBAP, 1986) and cash crop (Masefield, 1944) in the Great Lakes region of eastern Africa. It is mainly grown on smallholdings. In the past two decades, production in traditional growing areas has dwindled due to a range of inter-linked constraints including pests, diseases, poor soil fertility, less availability of labour and reduced management attention (Bosch et al., 1995; Gold et al., 1999a). The banana weevil *Cosmopolites sordidus* (Germar) is the most devastating insect pest in the area (Sengooba, 1986; Gold et al., 1999a). The larvae tunnel in the corm impeding water and nutrient uptake and weakening the stability of the mat. *Cosmopolites sordidus* attack can lead to crop loss at moderate damage levels and total crop failure under outbreak conditions (Sengooba, 1986; Rukazambuga et al., 1998; Gold et al., 2003).

The biology of *C. sordidus* has been reviewed by Gold et al. (1999a, 2003). It is a K-selected insect with long life span (up to 4 years) and low fecundity (< 2 eggs per week). The adults are free living and hygrotrophic. They rarely fly, crawl only short distances and are more active in the rainy season and in mulched rather than bare fields. Most are found near the base of the banana mat or associated with cut residues. *Cosmopolites sordidus* is attracted to its host by plant volatiles. In general, volatiles emerging from the corm are more attractive than those produced by the pseudostem. The males produce an aggregation pheromone that is attractive to both sexes (Budenberg et al., 1993).

Eggs are placed singly in shallow perforations made by the female in the corm and lower pseudostem. The proportion of eggs placed above versus below the soil surface varied between studies and may be affected by factors such as high mat (Koppenhofer, 1993; Abera, 1997; Gold et al., 2003). Trials on *C. sordidus* oviposition preferences showed that 22 to 23% of the eggs were placed on pre-flowering plants, 22 to 37% on flowering plants and 19 to 32% on crop residues (Abera et al., 2000).

After harvest, crop residues serve as shelters for adults (Gold et al., 1999b) as well as oviposition sites (Abera, 1997). Under field conditions, Gold et al. (1999b) found 65% and 28% of adults to be on or near banana mats and cut residues, respectively. The remaining 7% were found in the banana trash or in the soil away from the mat. Thus, most adult banana weevils are closely associated with banana material. Similarly, Abera (1997) found 25-32% on cut residues and 10-12% on standing stumps. In some resistant clones, infestation may reach high levels in crop residues (Gold and Bagabe, 1997), suggesting that a resistant mechanism breaks down upon harvest. This attack may contribute to weevil population buildup and greater damage on susceptible clones in the same or adjacent stands. Thus, the management of *C. sordidus* attack on crop residues may play an important role in an integrated pest management strategy for this pest.

Although chemicals, especially organophosphates and carbamates, have been successfully used against the banana weevil (Mitchell, 1980), these insecticides are beyond the means of most small-scale banana producers in East Africa. Moreover, resistance to dieldrin has been reported for banana weevil in the region and to a broad range of chemicals elsewhere (Bujulu et al., 1983; Gold et al., 1999c). Therefore, cultural controls (reviewed by Gold et al., 2003) still remains the safest and most appropriate control option for the resource-constrained smallholder banana farmer.

Crop sanitation (i.e. destruction of crop residues) has been recommended as an important control strategy for banana weevil (Ghesquiere, 1925; Seshu Reddy et al., 1998; Gold et al., 2003). Farmers practice a wide range of sanitation activities including cutting of the stem at ground level; covering of the corm with soil; removal of the corm; subsequent cutting up of the pseudostem and corm into small pieces; stripping of the leaf sheaths (comprising the pseudostem) and spreading them on the soil to dry. Among these, cutting of the pseudostem and covering of the remaining corm with soil is the simplest and least labour-demanding form of sanitation. Farmers believe that the soil layer provides a barrier to ovipositing females. However, no data have been available to demonstrate if this method is, in fact, effective.

In this study, we first investigated the distribution of *C. sordidus* eggs on growing banana plants and crop residues. We then evaluated the effect of covering residue corms with soil on weevil oviposition.

Materials and methods

Site description

The research was conducted at the International Institute of Tropical Agriculture's Sendusu Farm, the Kawanda Agricultural Research Institute (KARI) and on farmer's fields in Ntungamo district, Uganda. Sendusu is 28 km northeast of Kampala (0º 32'N, 32ºE, 1260 m above sea level) with mean annual precipitation of 1200 mm, with mean daily temperatures of 17ºC minimum and 27ºC maximum (McIntyre et al., 2000). Kawanda is 23 km north of Kampala (0º25' N, 32º32'E, 1195 m above sea level). Mean precipitation is 1190 mm per year and mean daily temperatures of 15ºC minimum and 27ºC maximum (Rukazambuga et al., 1998). Both sites have two rainy seasons (March to May and September to December). Ntungamo district (30º 13' E; 0º 53' S) is in southwestern Uganda, at an elevation ranging from 1300 to 1560 m above sea level. Precipitation at the site is 800-1500 mm rainfall per year with a bimodal distribution (March to May and September-December) (Gold et al., 2002). Mean daily temperatures are 15ºC minimum and 28ºC maximum (Meteorological Department of Uganda - Unpublished).

Experiment 1: Cosmopolites sordidus oviposition levels on different aged plants

Weevil oviposition preferences on different aged plants were determined in two six-year old banana (cv Atwalira, AAA-EA) plots (115 x 12.5 m) at Sendusu Farm. The original plant spacing was 2.5 x 2.5 m, but weevil attack resulted in high levels of mat die-out. At the time of sampling, 40-50 mats remained per plot.

A total of eleven mats were sampled. Each mat consisted of one sword sucker, one maiden sucker, one pre-flowered plant and one flowered plant. Where possible, residues of three different aged classes (< 7 days after harvest (DAH), 14-30 DAH, > 30 DAH) were sampled for each mat. Otherwise, a correspondingly aged residue was taken from a neighboring mat.

Data collection was by destructive sampling, involving uprooting whole mats using hoes and digging spears. Each sucker or residue was pared carefully to expose the eggs that had been deposited by resident weevils (natural infestation). The weevil pressure, estimated by mark and recapture methods (Masanza et al., chapter 3) was about 9,000 weevils/ha (15 weevils/mat).

Experiment 2: Distribution of C. sordidus eggs across different sections of banana stumps

To establish banana weevil oviposition preferences on different parts of banana stumps, field trials were conducted on two multi-cultivar highland banana stands in Ntungamo district. Each stand was > 50 years old and supported banana weevil populations of > 100,000 weevils/ha (90 weevils/mat). The fields were one ha in size and maintained at low sanitation levels with different aged residues scattered throughout the farm. Most commonly, the pseudostem was cut between 0 – 1 m above the ground. In all cases, the corm of the stump was left in the soil *in situ* attached to the remainder of the mat.

Sampling was conducted during the rainy season of March-April 1999. Banana stumps of different ages (i.e. 1-8 weeks after harvest) were randomly selected and extracted from the soil with the corms intact using a digging spear. The stumps were divided into four zones: 1) corm 0-5 cm below the collar; 2) corm 5-10 cm below the collar; 3) pseudostem 0-5 cm above the collar; and 4) pseudostem 5-10 cm above the collar. Each zone was carefully pared using sharp knives to expose the eggs and first instar larvae. On each farm, 30 residues were sampled, giving a total of 60 replicates.

Experiment 3: Effect of covering banana stumps on C. sordidus oviposition

Experiment 3a consisted of trials on the effects of covering banana stumps with soil on banana weevil oviposition were conducted in an existing field trial at KARI and on a farmer's field in Ntungamo district. Each trial consisted of three treatments: 1) banana stumps cut 5 cm above ground level; 2) banana stumps cut at ground level and left exposed on the surface; and 3) banana stumps cut 5 cm below ground level and covered with soil. Each trial was laid out in a completely randomized design with 10 replicates. After two weeks, the stumps were removed from the soil with a digging spear and pared using sharp knives to expose the eggs and first instar larvae. At each site, the trial was repeated in the wet and dry seasons.

Experiment 3b, conducted at KARI, consisted of two treatments in which recently harvested residues (i.e. < 7 days old) were: 1) cut at ground level and left exposed; or 2) cut at ground level and covered with 5 cm thick layer of soil. The treatments were arranged as matched pairs with 10 replicates. After two weeks, the stumps were removed from the soil and dissected for eggs and first instar larvae as in *Experiment 3a*.

Data analysis

For *Experiment 1*, the means for number of eggs found on the suckers and residues were subjected to General Analysis of Variance using Genstat version 3.2 on a GLM. The orthogonal polynomial method was employed to compare trends in oviposition among the seven treatments (assuming time was embedded in treatments). Mean separation was done using the least significant difference. For *Experiment 2*, means of eggs were pooled and analyzed as from one farm. Means for eggs at a particular location on all the residues were pooled and analyzed as eggs on corm or pseudostem at the different zones on these residues using General Linear Model (GENMOD) procedure of SAS (SAS Inst. Inc., 1997). Means were separated using Least Square Means (LS means) probabilities. For *Experiment 3a*, means of eggs were analyzed using the ANOVA procedures of SAS (SAS Inst. Inc., 1997) and differences in treatment effects were detected by use of mean contrasts. In *Experiment 3b*, means of eggs were subjected to a matched pair t-test to detect differences in treatment effects.

Results

Experiment 1: *Cosmopolites sordidus oviposition levels on different aged plants*

Cosmopolites sordidus oviposition increased with plant age, peaked on < 7 day old residues and then declined thereafter (Figure 1). Mean oviposition on < 7 day old residues was 5 times higher than on sword suckers. The data best fitted a quadratic polynomial distribution (F pr = 0.012, d.f. = 60).

Experiment 2: Distribution of C. sordidus eggs across different sections of banana stumps

Cosmopolites sordidus eggs were found throughout the corm and in the lowest 5 cm of the pseudostem, with very little oviposition in the pseudostem > 5 cm above the collar (Figure 2). Seventy percent of the eggs were placed on the corm.

Experiment 3: Effect of covering banana stumps on C. sordidus oviposition

In *Experiment 3a*, oviposition was four times higher during the wet season on exposed stumps than on stumps covered by a layer of soil in both the KARI and Ntungamo trials (Figure 3). By contrast, in the dry season, stumps covered with soil to a depth of 5 cm received 59% higher oviposition at KARI and 73% higher oviposition in Ntungamo than stumps left exposed at ground level.

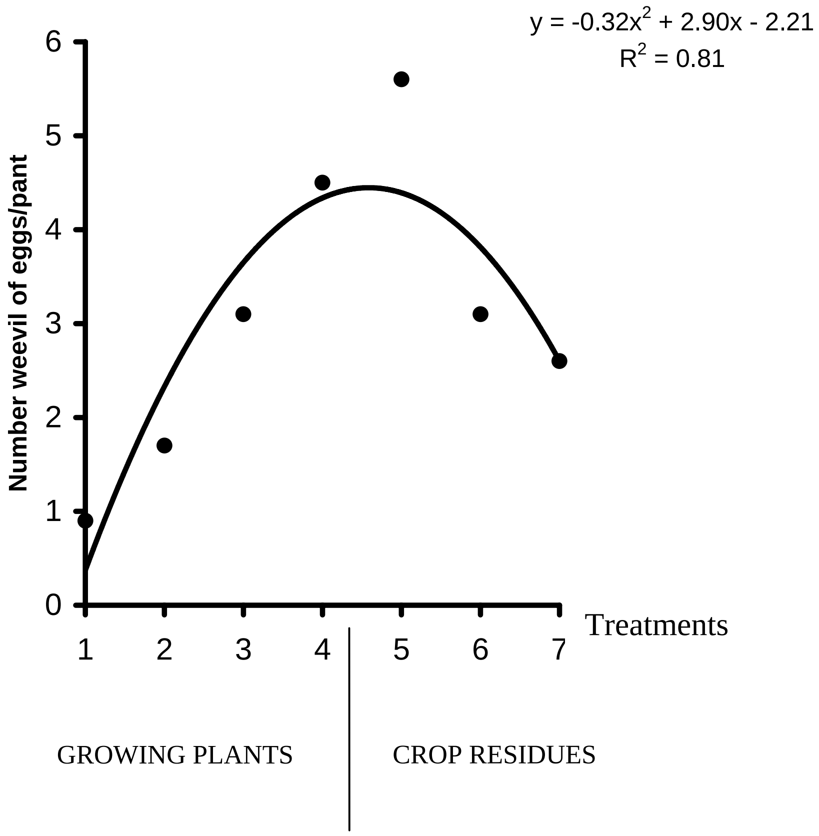

Figure 1. Mean number of *C. sordidus* eggs on growing plants and crop residues in a banana system at IITA's Sendusu Farm, Namulonge, Uganda. 1 = Sword sucker; 2 = maiden sucker; 3 = Pre-flowered 4 = Flowered; 5 = Post-harvest 1-7 Days after harvest (DAH); 6=14-30 DAH; 7 = >30 DAH. (Quadratic polynomial fitted the data; lsd = 3.03, e.s.e = 1.07). (Experiment 1)

Similar seasonal trends were found in *Experiment 3b* for stumps cut at ground level and covered with soil compared to stumps left exposed at ground level (Figure 4). Fifty percent more eggs were placed on bare stumps than covered stumps in the wet season although the difference was not significant. In contrast, nearly 3 times more eggs were found on covered stumps than on bare stumps during the dry season ($P < 0.05$).

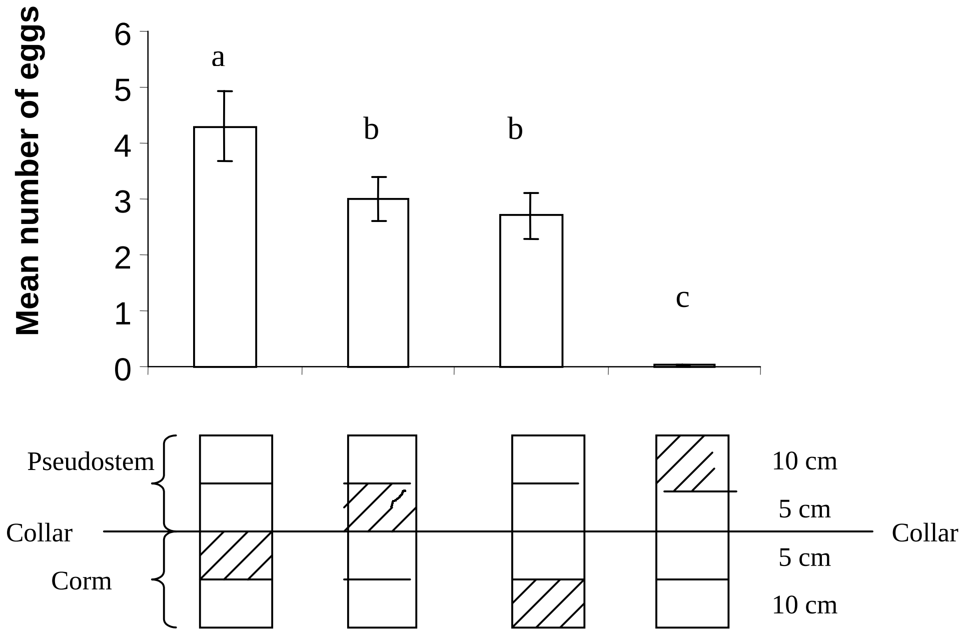

Figure 2. Mean number of *C. sordidus* eggs on banana corm and pseudostem residues on farmers' fields in Ntungamo district, Uganda. Means followed by the same letter are not significantly ($P<0.05$) different by lsd. (Experiment 2).

Discussion

Some farmers in Ntungamo district and elsewhere in Uganda have suggested that covering of residual stumps following harvest may reduce breeding by *C. sordidus* and subsequent attack on their banana plants. However, no data have been available to demonstrate whether or not such a practice might have any effect on *C. sordidus* populations.

The results of this study indicate that residues are a favoured oviposition site for *C. sordidus* in comparison with growing plants. Fresh residues appear to be most attractive to gravid females: oviposition by *C. sordidus* occurred mainly on crop residues aged one to seven days after harvest. It is likely that the cutting of the plant at harvest time results in the release of volatiles that serve as kairomones that are used in host location by the insect. In this study, the number of eggs on older residues declined, suggesting that sanitation, as a weevil control measure is most critical in the weeks following harvest. It might be beneficial to use these residues as a "trap crop" by allowing the weevils to oviposit for a week and then destroy the residues and any immatures in them.

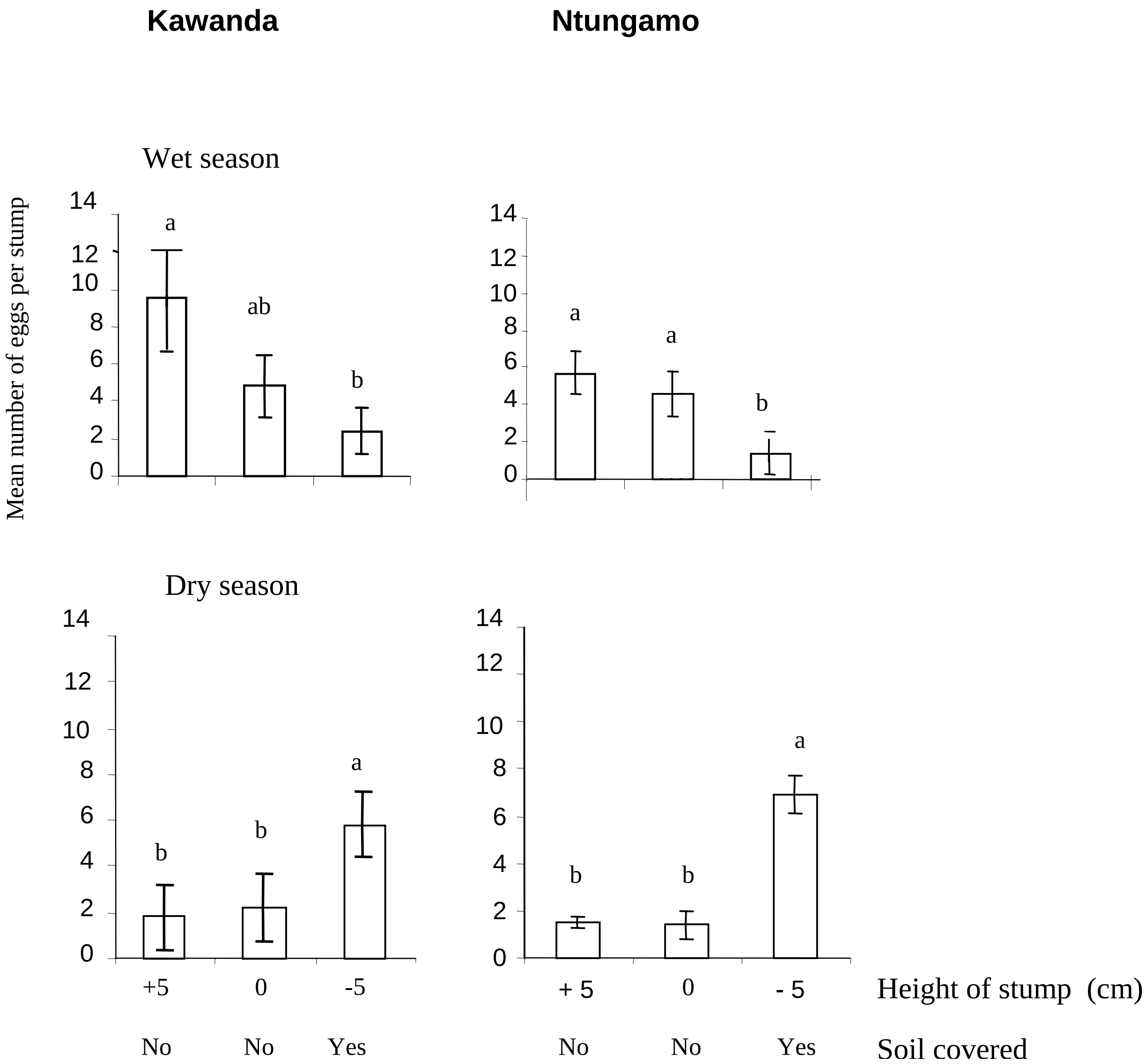

Figure 3. Effect of banana stump height and exposure on *C. sordidus* oviposition levels in wet and dry season trials at the Kawanda Agricultural Research Institute and on a farmer's field in Ntungamo district, Uganda. For each site within a season, means of eggs followed by the same letter are not significantly ($P>0.05$) different by pair-wise comparison t-test of Least Square Means. (Experiment 3a)

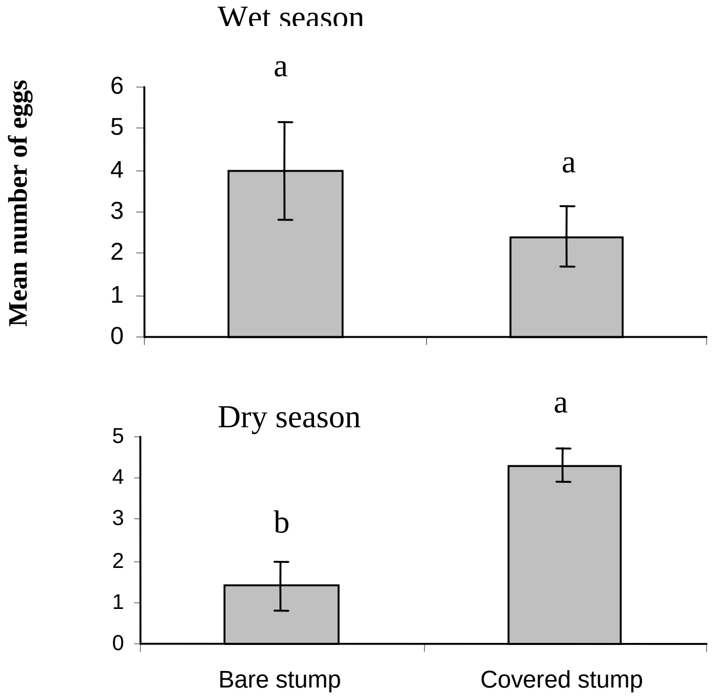

Figure 4. Effect of covering post-harvest banana stumps cut at ground level with a 5 cm-layer of soil on *C. sordidus* oviposition in the wet and dry season at Kawanda. Means followed by the same letter are not significantly different (P>0.05) by pair-wise comparison t-test of Least Square Means. (Experiment 3b).

The data in this study suggest that oviposition on the corm is more important than on the pseudostem. The area on the corm from zero to five centimetres below the soil had the highest number of eggs and a total of 70% of the eggs occurred in the corm. Similar results were reported by Cuille and Vilardebo (1963) and by Koppenhofer (1993), while Abera (1997) found more eggs on the corm than pseudostem only in systems with high mat (exposure of the corm above the ground surface). On bananas without high mat, Abera (1997) reported the majority of oviposition on the pseudostem although 75% of all eggs were below the soil surface. These results suggest that protection of the corm and below ground portions of the pseudostem may be most important in crop residue management.

Our results show that deep cutting of the corm and its removal may be beneficial in the wet season since *C. sordidus* adults are more likely to be active on the soil surface. Under these conditions, covering banana stumps after harvest appears to have deterred host finding and oviposition. Nevertheless, it is also possible that oviposition on banana plants might increase if all stumps were buried during the wet season.

In the dry season, oviposition was three times higher on covered stumps than on those cut at the soil surface, even though the soil cover was expected to form a physical barrier to gravid females (Karamura and Gold, 2000). *Cosmopolites sordidus* adults are positively hydrotropic, search for the highest air humidity and liquid water and are unsettled in environments with low humidity (Cuille, 1950; Roth and Willis, 1963; Ittyeipe, 1986). This suggests that the females may only oviposit under conditions of favourable soil moisture, which did not exist at the soil surface during this period. It is also likely that covering of banana stumps in the dry season preserves plant moisture, which probably also encourages *C. sordidus* oviposition. If left bare, the corms dry up quickly, making them not suitable for weevils.

Therefore, farmers should not cut and cover pseudostems in the dry season. The other alternative would be to dig out the stumps completely, but this destabilizes the banana mat, leaving the plants prone to toppling especially in windy areas. The corm of a mother plant gives rise to the new generation plants, for which it gives anchorage. If the corm of the harvested mother plant is completely dug out, soil around the rest of the mat is likely to become loose. Additionally, the smaller corm left may not provide sufficient anchorage when strong wind blows. In the wet season, farmers should cut the stumps 5 cm below the soil surface and cover with soil. This is because covering all stumps may leave standing plants vulnerable to attack. The remaining residues should be left in banana alleys for a week for weevils to oviposit on before they are subsequently destroyed. This will help reduce attack on standing plants.

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Chapter 6

Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) populations and crop damage in Uganda

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Chapter 6

Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) populations and crop damage in Uganda

M. Masanza, C.S. Gold, A. van Huis, P.E. Ragama and S.H.O. Okech

Abstract

An on-farm study of the effect of crop sanitation on the banana weevil, *Cosmopolites sordidus* (Germar) populations and corm damage was conducted in the Ntungamo district of southwestern Uganda. Farmers practiced sanitation levels that can be broadly defined as low, moderate and high. Soil conservation methods such as making bunds, mulching and application of manure were treated as covariates. Increase in sanitation level from low to high significantly reduced adult *C. sordidus* population density from 52,000 to 13,000 ha^{-1}, lowered corm damage by 41% after 3 years, enhanced plant girth by 10% and plant height by 13% at flowering and increased yield by about 70%. There was a slight relationship between *C. sordidus* population density and rhizome damage. Shifting from a low to a high sanitation level significantly reduced rhizome damage immediately. This study has demonstrated the great potential crop sanitation has in controlling *C. sordidus* populations and reducing damage to the crop.

Introduction

The banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is an important pest of East African highland banana (*Musa* spp., genotype AAA-EA) in Uganda. It is believed to have played a leading cause in the decline of cooking banana production in the country's central zone during the last 30 years (Gold et al. 1999). In on-station trials, Rukazambuga et al. (1998) found yield losses attributable to banana weevil to reach 48% in the third ratoon, while Sengooba (1986) observed total crop failure in some banana plantations during outbreaks in the country's southwest.

The banana is a perennial crop that produces new plants by suckering. Plants emerging from the same corm comprise a banana mat. Each plant produces a single bunch. Bunches can weigh 30 kg or more. As a result, the banana plant becomes too heavy and is subject to toppling during winds. Vulnerability to toppling is exacerbated by banana weevil and nematode attack at the base of the plant. After the bunch is harvested, the supporting stem dies back. The stem is usually removed, although handling of this crop residue varies considerably across sites and among farms. The stem may be cut at ground level or up to 1 m above the ground. The cut stem may be left intact or further cut into smaller sections that are left within the banana stand. Alternatively, some farmers chop the stem into small pieces that are then used as mulch. Additionally, some farmers remove the section of corm that has supported the harvested plant, although this requires extra labour and is sometimes seen as destabilizing the remainder of the mat.

Adult *C. sordidus* lives for up to four years (Gold et al., 1998a; Gold et al., 2003). It produces only a few eggs per week (Abera, 1997; Gold et al., 1999). The adults are free living and most often found at the base of the banana plant or proximal to crop residues. Stand management practices, especially crop sanitation practices, can influence the distribution of adults. Treverrow and Bedding (1993) found crop residues to host 60% of adult weevils in one stand, while Gold et al. (1999) found 25-32% of adults in prostrate residues and another 10-12% in standing stumps. The female deposits single eggs at the base of the plant. Under field conditions, Abera et al. (1999) reported 33% of banana weevil oviposition to be in standing crop residues (i.e. still attached to the mat). Rukazambuga (unpubl. data) observed more than 200 eggs in a single stump.

The emerging larvae tunnel through the corm and pupation is within the plant. Vilardebo (1960) reported that in Ecuador, on a variety Gros Michel (genome group AAA), most infestation occurred in residues. Gold and Bagabe (1997) found little infestation on recently harvested plants of the resistant cultivar Kisubi (AB), but infestation increased over time following harvest. Infestation build-up was highest on cut and prostrate residues. Similarly, in Indonesia, Gold (pers. comm.) found no larvae in recently harvested Pisang Awak plants (ABB), but more than 100 on one cut and prostrate residue. These data suggest that *C. sordidus* are attracted to, oviposit on and develop within crop residues. As a result, crop sanitation (i.e. destruction of residues) has been recommended as a means of weevil control in Uganda.

It is widely believed that destruction of crop residues (splitting of harvested pseudostems and/or removal of corms or rhizomes) eliminates adult refuges, food sources and breeding sites, lowers overall weevil populations and reduces damage on standing plants in susceptible clones (Gold et al., 2002). Residues may also serve as traps that draw gravid females away from growing bananas (Peasley and Treverrow, 1986; Waterhouse and Norris, 1987; Gold, 1998a). Crop sanitation as a means of banana weevil control has been recommended since the 1920s (Froggatt 1924; Ghesquierre, 1925) and continues to be widely recommended (Seshu Reddy et al., 1998). Chopped up crop residues may also act as mulch and source of nutrients for the followers (Karamura and Gold, 2000), having a direct effect on crop yield. Although crop sanitation (i.e. destruction of crop residues) has been recommended as a means of *C. sordidus* control in Uganda, few data have demonstrated the effects of crop sanitation on *C. sordidus* population and damage.

Therefore, this study: (1) evaluated the effect of crop residues on *C. sordidus* populations and corm damage in farmers' fields; (2) assessed the effect of crop sanitation on rate of crop growth and yield; and (3) investigated the effect of agronomic practices on efficacy of crop sanitation on banana crop performance, namely plant girth, plant height and bunch weight.

Materials and Methods

Farm selection and characterisation

A sanitation trial was established in Ntungamo, southwestern Uganda (30° 13.66" and 30° 13.85" E longitudes and 0° 52.88" and 0° 53.79" S latitudes), at an elevation ranging from 1300 to 1560 metres above sea level. Precipitation at the site is 800-1500 mm rainfall per year with a bimodal distribution (March to May and September-December). Average minimum and maximum temperature range is 15 °C and 28 °C. The soils in this watershed area are basically sandy-loams. Most banana farms ranged between 0.1 – 2.0 ha. Banana is a major food crop followed by millet, sweetpotato and sorghum. After coffee, banana is second in providing household income. A participatory rural appraisal conducted in the country brought forward several major production constraints of the banana crop: banana weevils, nematodes, soil fertility deterioration, labour costs and land shortage (Gold et al., 1993).

In a baseline survey from December 1998 to March 1999, crop sanitation levels were assessed on a scale of one to three (Table 1) and formed the basis of farm stratification. Out of the 60 farms selected, 75% practiced low, 20% moderate and 5% intense or high sanitation. In the assignment of treatments, farmers who were applying low sanitation were encouraged to either continue at the same level or shift to moderate sanitation or high sanitation level, those at moderate levels were to maintain this level or move to the high level, while those at the high level were asked to maintain this level. Four months later (July 1999), 11 of the farmers were at the low, 33 at the moderate, and 16 at the high sanitation levels (Table 2).

Experimental design

Treatments were assigned in an Incomplete Block Design, in which there are non-uniform replicates within a treatment and each farm was considered as a replicate that catered for shifts between management levels. These shifts in management necessitated close monitoring.

Treatment implementation commenced between July and November 1999. In September 1999, we checked monthly what farmers were actually doing with crop residues. This was necessary as it proved to be difficult for a farmer to maintain the same sanitation level because crop sanitation is labour intensive and depends mostly on family labour. So,

Table 1. Definition of sanitation (treatment) levels on farmers' fields in Ntungamo, July 1999

Sanitation level	Treatment description
1. Low – Control	Little or sporadic management: Base of stems left intact or cut periodically less than twice a month; Cut stems left intact on soil surface. Less than 5% of residues removed.
2. Moderate	Periodic cutting of stems at base of plant; every 4-6 weeks; Cut stems periodically chopped; corms left in soil. Moderate number of residues removed (about 45-60%)
3. High/Intense	Systematic cutting and chopping of crop residues (80-100%) e.g. every 1-2 weeks. Cut residues spread as mulch. Corms covered or removed.

Table 2. Sanitation levels as practiced by farmers in March 1999 baseline data, July 1999 and September 2001.

	N	Treatments					
		Low		Moderate		High	
Baseline data (3/99)		07/99	09/01	07/99	09/01	07/99	09/01
Low	45	11	12	27	28	7	8
Moderate	12			6	5	6	4
High	3					3	3
Total allocated	60	11	12	33	33	16	15

either farmers abandoned improved sanitation level and returned to older ones or adopted the improved sanitation level.

We observed that farmers who were found practicing low sanitation either remained at this level or shifted to moderate; very few moved to high. Those at moderate levels of sanitation either remained at the same level or shifted to low or high. Those at the high management levels remained at this level or shifted to moderate. This then changed the design to a cyclic Incomplete Block Design.

Data collection: Banana weevil adult populations were estimated on each farm by mark-recapture methods using split pseudostem traps (Southwood, 1978; Price, 1993; Gold and Bagabe, 1997). Baseline data were taken in March 1999. Sampling started in May 2000, ten months after treatment application, and continued in August 2000, March 2001, June 2001, September 2001 and December 2001. The number of marked and nonmarked weevils was recorded. The Lincoln index (Southwood, 1978) was employed to estimate the population:

$$N = (m^*n)/r \qquad 1$$

where N is the population estimate, m the number of individuals marked and released, n the total number of individuals captured, and r the number of marked individuals recaptured. Weevil population densities/hectare for each farm were estimated using data on stand size.

To determine corm damage by the banana weevil we assessed per farm: the percentage surface area of the corm cross-section at the pseudostem base upper cross-section and 5 cm below the pseudostem (lower cross-section) of 20 recently harvested banana stems (<14 days after harvest) (Gold et al., 1994b). In low sanitation treatment, where pseudostems and corms were left intact, only the upper cross-section damage was assessed. In the moderate sanitation and high sanitation level treatment, both the upper and lower cross-section damage was assessed. Percent corm inner (XI), outer (XO) and average (XT) cross-section damage was determined to establish the baseline data of March 1999. It was also determined at eight more sampling dates beginning three months after treatment implementation viz. October 1999, February, May, August, November 2000, February-March, May, August, November 2001 and February 2002.

In each of the sixty farms selected, five AAA-EA Highland banana suckers cv. 'Enyeru' of approximately the same age and height were selected in November 1999: sucker age ranged from one to two weeks after emergence (WAE) and height from 10 to 20 cm. In November 1999, growth parameters for each plant i.e. height, girth, and number of functional leaves were measured. A calibrated stick of about four metres long and tailor's tape were used to measure plant height and girth. Measurements were repeated at five more sampling dates at three months' intervals (February, May, August, and November 2000, and March 2001). At harvest, bunches were weighed using a spring balance. The levels of soil/water conservation such as the use of bunds and mulching and of manure application were scored using the scale: 1 (low), 2 (moderate) and 3 (high). Desuckering and manure application in farms were scored on a similar scale.

Data analysis

Changes in management levels on each farm were followed on a monthly basis in order to detect if there were any cyclic trends of a particular sanitation level. After getting these trends for each farm, a particular farm would then be assigned a treatment based on this trend, which was adopted to analyse data. Assume the starting treatments being low (L), moderate (M), and high (H) possible cyclic changes were L-L, L-M, L-H; M-L, M-M, M-H, and H-H, H-M, H-L. However, in practice farmers at L treatment remained at the same level L or changed to L-M or L-H; those at M remained at M, or changed to M-H while those at H either remained at the same level or changed to H-M.

Weevil population estimates and density and corm damage were analysed using a mixed model procedure (SAS Institute Inc., 1997a). Changes in the corm damage level (ΔD), were estimated by using the formula:

$$\Delta D = [(D_2 - D_1)/D_1]*100\% \qquad 2$$

where D_1 is the baseline corm damage, and D_2 the corm damage at a given sampling date and sanitation level. Damage data for 1999 (considered baseline in this case), 2000, 2001 and 2002 were analysed with sanitation treatment nested in time (years after treatment implementation) considered as fixed and residuals as random effects while least square means were compared to baseline and low sanitation adjusted to Dunnett test. Dunnet's test as derived for GLM and mixed models in SAS procedure (SAS Institute Inc., 1997b) is shown below:

A test declares a mean significantly different from the other by comparing all treatments to a control if (assuming general linear models)

$$|\Delta_i - \Delta_o| \geq d(\forall;k,v,\Delta)\ s\ \sqrt{1/n_i + 1/n_o} \qquad 3$$

where Δ_o is the control mean and d (∀;k,v,Δ) is the critical value of the "many-one *t*-statistic" for k means to be compared to the control with v degrees of freedom and a correlation Δ. The correlation term arises because each of the treatment means is compared to the same control. In our case, treatments do not have the same number of observations. Therefore, the correlation is calculated using the harmonic mean of the sample sizes of each of the treatments as their "common" sample size.

Assuming mixed models, as is the case with our analysis, probabilities for unequal number of observations with finite degrees of freedom,

$$\text{Probability} = \int_0^\infty \int_{-\infty}^\infty \phi(y) \prod_{i=1}^{k} \Phi\left(\frac{\lambda_i + qx}{\sqrt{1-\lambda_i^{\,2}}}\right) dy\ d\mu_v(x) \qquad 4$$

Where Φ, ø = functions; *x, y* = numeric variables; *k* = number of treatments; $i_1, \ldots, i_k$ = parameters from 1 to *k*; *v* = value at which degrees of freedom have been fixed.
Means were significantly different if $P \leq 0.05$. To determine the effect of sanitation level on growth parameters and bunch weight, management practices such as bunds, mulching, desuckering and manure application were treated as coviariates. Means of plant height (cm), girth (cm), number of leaves and bunch weight (kg) were subjected to One-

way (in randomised blocks) ANOVA using Genstat release 5.32. Growth parameter means were analysed with repeated measures ANOVA, time (months) being a repeated factor. Mean separations were accomplished with least significant difference tests LSD P=0.05.

Results

C. sordidus population density

Baseline *C. sordidus* population density (March 1999) was not significantly (P>0.05) different at the various sanitation levels (Figure 1 a and b). Population density did not significantly change in farms maintained at low, moderate and high sanitation until June 2001, two years (23 months) after implementation (Figure 1a). At that point, population densities significantly increased above the baseline on farms maintained at low sanitation:

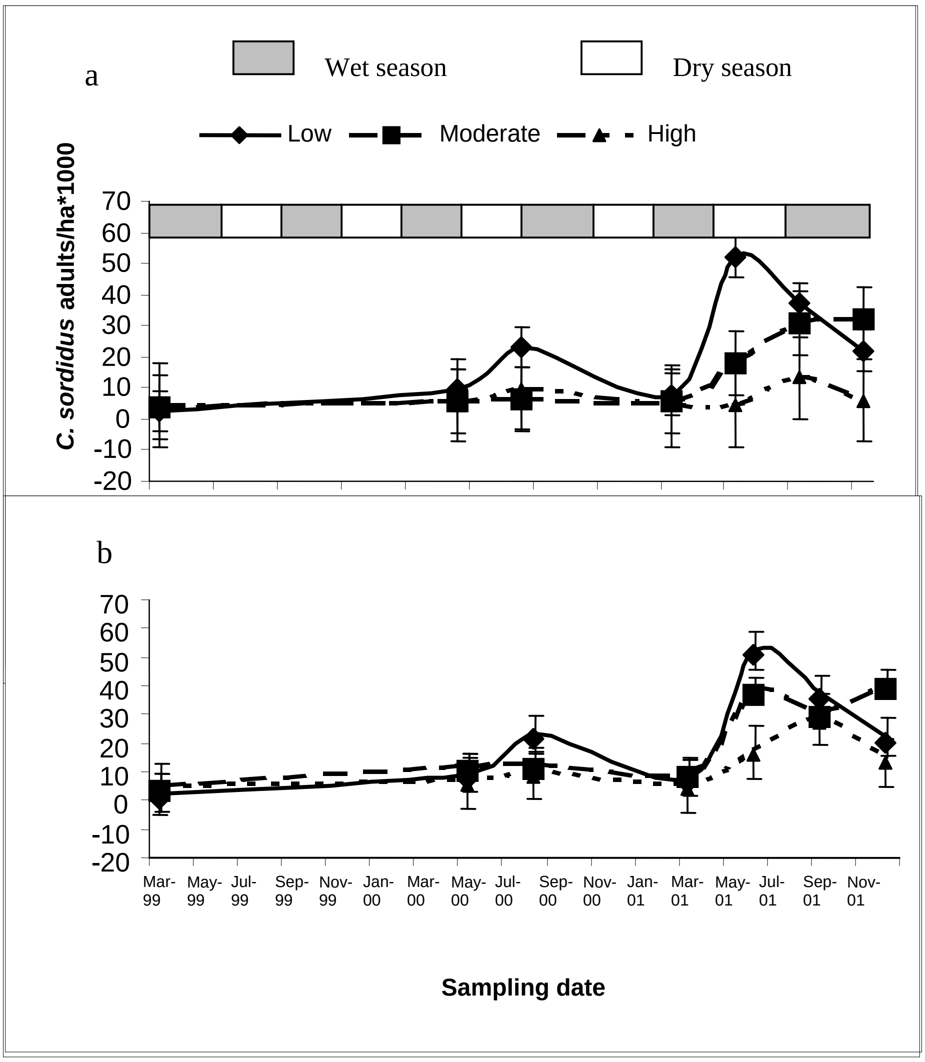

Figure 1. *C. sordisus* density in farms in Ntungamo when farms:
a: maintained the same sanitation levels;
b: Started at low levels and remaining at low or changed to moderate or high sanitation levels.

from 3,000 in March 1999 to 52,000 in June 2001 for farms maintained at high sanitation level compared to from 4,000 in March 1999 to 13,122 in June 2001. Population density on farms consistently maintained at high sanitation levels did not significantly ($P>0.05$) change from baseline throughout sampling time, and was significantly lower than the densities found at other sanitation levels (Figure 1a). Population density on farms upgraded from low to moderate and low to high was significantly lower than that on farms maintained at low sanitation after two years of treatment application (Figure 1b).

Average, inner and outer corm damage

Average corm cross-section damage by *C. sordidus* at baseline was negatively correlated ($r = -0.24$, $n=60$) with sanitation level. At post treatment application it decreased significantly ($P\leq0.05$) with increase in sanitation level (Table 3). Damage reduced by 41% on farms upgraded from low to high and 23% for those upgraded from moderate to high sanitation. For farms maintained at low sanitation level, average corm damage did not significantly change from baseline. There was little or no change in average corm damage on farms maintained at moderate and high sanitation.

Inner corm cross-section damage followed a similar trend to that described above (Table 3). On farms upgraded from low to high sanitation, damage significantly dropped by 39% in one year and by 65% in three years. Similarly, improving sanitation from low to moderate reduced damage by 21% in one year and by 53% in three years. Upgrading sanitation from moderate to high levels reduced damage by 76% in three years. Maintaining sanitation at high level kept inner damage more or less constant.

Outer corm damage reduced significantly on farms upgraded from low to high and moderate to high sanitation (Table 3). Two years after treatment implementation, damage reduced by 37% on farms improved from low to high and by 21% on those upgraded from moderate to high. There was a similar reduction in damage on farms maintained at high sanitation, but by the end of the sampling period, there was no significant change in outer damage from the baseline in all treatments.

Yield (bunch weight), Plant height, Girth, Number of leaves

Sanitation level affected bunch weight significantly (Table 4). The covariates, namely, bund construction, desuckering, mulching, and manure application were not significant. Bunch weight, girth, plant height and number of leaves were significantly higher in banana fields maintained at higher sanitation than at lower levels. Plant height at about three months pre-flowering (February 2000) to flowering stage (May to August 2000) was significantly higher in farms upgraded from lower to higher sanitation levels than that on farms practicing low sanitation. At flowering (May to August 2000), plants in fields maintained at moderate and high sanitation plus those upgraded from low to moderate, low to high and moderate to high sanitation levels were significantly taller than plants in

Table 3. Least square means (± S.E.) of average, inner and outer corm damage by sanitation level for baseline and subsequent sampling dates in Ntungamo (1999-2002)

Sanitation Level[1]	Average corm damage				Inner corm damage				Outer corm damage			
	Baseline 1999	2000	2001	2002	Baseline 1999	2000	2001	2002	Baseline 1999	2000	2001	2002
L	3.6±0.42	4.0±0.30	3.5 ± 0.29	3.6 ± 0.56	3.4 ±0.52	3.8 ±0.37	3.5 ±0.36	2.5 ±0.68	3.8 ±0.45	4.2 ±0.32	3.4 ±0.31	4.7 ±0.59
L-M	3.8±0.27	3.0±0.20	3.6 ± 0.19	2.9 ± 0.41	3.4 ±0.34	2.7 ±0.24	4.0 ±0.24	1.6 ±0.50*	4.1 ±0.29	3.4 ±0.21	3.2 ±0.21	4.2 ±0.43
L-H	2.7±0.52	1.6±0.37**	2.1 ± 0.36**	1.6 ± 0.73**	2.3 ±0.64	1.4 ±0.45**	2.3 ±0.45	0.8 ±0.91*	3.0 ±0.55	1.9 ±0.39**	1.9 ±0.39**	2.4 ±0.78
M	2.6±0.66	2.0±0.46*	2.5 ± 0.46	2.0 ± 0.93	2.3 ±0.81	1.5 ±0.57*	3.0 ±0.57	1.1 ±1.14	2.8 ±0.70	2.4 ±0.47*	2.1 ±0.49*	2.8 ±0.99
M-H	2.1±0.74	1.6±0.52**	1.6 ± 0.52**	1.2 ± 1.04*	1.7 ±0.91	1.3 ±0.64*	1.8 ±0.64*	0.4 ±1.28*	2.4 ±0.78	1.9 ±0.55**	1.5 ±0.55**	2.0 ±1.10
H	2.3±0.85	1.2±0.60**	1.6 ± 0.60**	1.5 ± 1.20	1.8 ±1.04	0.9 ±0.74**	1.8 ±0.74	0.5 ±1.48	2.6 ±0.91	1.6 ±0.63**	1.5 ±0.64**	2.5 ±21.27

Means within a given row are significantly different from baseline data by Dunnett's test (**P≤0.01; *P≤0.05)

Sanitation level[1]: L=Low; M=Moderate; H=High

Table 4. Plant height (cm), girth (cm) and number of functional leaves by sanitation level and sampling date in farmers' fields in Ntungamo, south-western Uganda (November 1999-March 2001)

Sanitation level[1]	Plant height (cm) Nov 99	Feb 00	May 00	Aug 00	Nov 00	Mar 01	Plant girth (cm) Nov 99	Feb 00	May 00	Aug 00	Nov 00	Mar 01	Number of functional leaves Nov 99	Feb 00	May 00	Aug 00	Nov 00	Mar 01	Bunch wt (Kg) Aug 00 to Mar-01
L	35a	142ab	209 b	231 b	300 b	346a	20a	47a	60 b	60 b	66a	77a	2.7 b	6.7 b	8.5 b	6.4 b	8.8 b	8.1a	11.7 b
L-M	32a	146ab	216ab	250 b	319 b	355a	19a	47a	63ab	63ab	69a	78a	3.0 b	6.7 b	8.9 b	7.0a	9.0a	7.3a	15.4a
L-H	24a	216a	222ab	255 b	320 b	364a	18a	48a	65ab	67ab	73a	79a	3.0 b	7.1ab	8.4 b	7.0a	9.1a	6.9a	20.9a
M	41a	152ab	266a	304a	342a	342a	22a	58a	65ab	71a	73a	75a	4.5a	7.1ab	6.9 c	7.1a	9.1a	2.1 c	17.3a
M-H	45a	206a	278a	305a	362a	386a	20a	54a	72a	74a	78a	78a	2.9 b	7.2ab	8.7 b	7.6a	9.7a	7.2a	20.4a
H	28a	179a	252a	299a	340a	345a	17a	53a	72a	70a	72a	82a	2.1 b	8.2a	10.4a	8.3a	10.2a	6.7a	20.1a

In columns, means followed by the same letter are not significantly (P>0.05) different by LSD.

Sanitation level[1]: L=Low; M=Moderate; H=High farms maintained at low sanitation. At harvest (March 2001), plant height was not significantly different among the treatments. Plant girth from pre-flowering to flowering stage (May to August 2000) for plants growing in fields upgraded from low to high sanitation levels and those maintained at moderate and high sanitation was significantly higher than plant girth in fields at low sanitation. Similarly, plants at low and moderate sanitation had a significantly lower number of functional leaves than those at high sanitation level from February 2000 to August 2000, three to nine months after emergence.

Discussion

For a long time, farmers have been advised to practice crop sanitation (Hargreaves, 1940; Harris, 1947; Treverrow et al., 1992; Sponagel et al., 1995). However, there are no experiments demonstrating the effect of sanitation on weevil population dynamics (Gold et al., 1999). These studies are difficult due to a number of confounding factors such as weather and soils affecting populations of *C. sordidus*. Experiments are further complicated by the adult weevil being nocturnal, negatively phototactic and preferring high humidity places (Ittyeipe, 1986). This makes it difficult to see and study the insect that gets desiccated in moisture free environments. In the wet season, therefore, banana weevils are highly active and mobile. In our study, results on weevil populations fluctuated over time, with variations over 1000%, the highest during or after the rainy season. Nevertheless, we were able to demonstrate to a great extent that crop sanitation reduces weevil population and damage.

Monthly rainfall during the years of study fluctuated with two peaks for a given year. Population density at baseline on 60 farms correlated negatively with sanitation level. Population density was highly positively correlated (r=0.54, n=60) with damage (Masanza, 1999). Peaks in corm damage were due to higher weevil activity such as oviposition and larval feeding occurring during the rainy season. Also, survivorship is higher during the wet season in and outside the residues leading to an explosion in populations. *C. sordidus* cannot survive without moisture and is very susceptible to desiccation (Cuille, 1950; Gold, 1998a). Weevils kept in dry soil died within 10 days while those kept in moist soil without food survived for 112 days (Viswanath, 1976).

In this study, weevil population density at high sanitation did not increase at the same rate as in fields maintained at low sanitation. In a related study, weevil distribution in farmers' fields indicated that crop residues hosted not only adults but also larvae and pupae (Masanza et al., Chapter 3). This is in agreement with earlier reports that weevils thrive in trashy plantations (Wallace, 1938). Treverrow and Bedding (1993) claimed that 60% of the weevils in the field emerged from crop residues. In a related study, crop residues hosted over 50% more eggs, larvae and adults than standing plants (Masanza et al., Chapter 3). All weevil growth stages were found in residues, implying that *C. sordidus* completes its life cycle therein. Duration of life stages on crop residues in the laboratory were as follows: larval period ranged from 27-45 days for larvae, 30-48 for pupae and 30-51 days after eclosion to reach adult stage (Masanza et al., Chapter 4).

In banana fields, *C. sordidus* population build-up is slow due to high mortality of egg and first instar stages (Abera et al., 1999). However, this study indicates that during the rainy season, larval survivorship increases, so that new generations emerge from residues in about two months. Destruction of banana crop residues in the wet season by uprooting corms then greatly would reduce pest population and damage.

Corm damage in bananas is due to larvae that burrow into corms of standing plants. Consequently, plants become weak and may topple, snap, mature late and carry low bunch weights. In this study, corm damage reduced with better sanitation. Masanza et al. (Chapter 3 and 5) showed that corms hosted twice the number of weevils than pseudostems. Chopping corms and pseudostems after harvest to ground level, cutting them up and spreading them to dry-up kills eggs and larvae. Further, the continuous chopping and spreading of crop residues eventually provide mulch that improves the performance of the growing plants. Mulch encourages banana root development; water infiltration and percolation, hence increases water and nutrient uptake (Rukazambuga et al., 1998; McIntyre et al., 2000). Salau et al. (1992) in their studies on mulch on soil, growth and yield showed that this practice enhances vegetative growth and bunch yield. In this study, mulching increased plant girth and height. The effect of removing corms after harvest and mulching both reduce the population and damage of weevils and enhance plant growth and yield. Yield loss due to banana weevil is less in fields maintained at high sanitation, because corm damage is less allowing better nutrient flow and hence increased leaf formation, girth and plant height. More vigorous plants yield higher (Rukazambuga et al., 1998).

Although *C. sordidus* population densities increased with time, corm damage decreased even in farms maintained at low sanitation levels; the decrease was more pronounced at higher sanitation levels. There are two likely reasons for this trend. First, there was a problem of adoption and or consistency by farmers practicing a particular sanitation level. It was difficult for the farmers to strictly adhere to a sanitation level. As a result, even farmers at low sanitation level at one time or another tried to remove corms just as the others were doing. However, such farmers often reverted to low sanitation basically due to labour constraints. Secondly, it is possible that as corms were removed, eggs and larvae (damaging stages) were being destroyed. Consequently, damage on growing plants reduced with time though adult population remained fairly constant at high sanitation, while it increased at lower sanitation. A hypothesis is that crop residues are a trap crop and their destruction causes weevils attack plants (Gold et al., 1993). In this study, destruction of crop residues may have exposed growing plants to pest attack. However, the continued removal of post-harvest debris counteracts this danger as immature stages are killed in the process due to desiccation. Surviving adults will eventually die leading to reduced populations. Fields maintained at low sanitation are in danger since these populations in such fields explode as this study shows. It is obvious from this study that crop residues in the long run released teneral females that invaded growing suckers to cause higher populations and damage.

In the past two decades, banana production in the Central region of Uganda declined mainly due to poor soils, pests, diseases but also due to socio-economic problems (Gold et al., 1993). Production in south-western Uganda where this study was located is considered moderate, but with an increasing pest problem. During this trial, most farmers who could not practice higher sanitation levels were either poor or old and/or had other business they may have considered more profitable. Banana farms owned by such farmers will most likely have an accelerated weevil problem. Since most of these small-scale farms are contiguous, this problem will spread to other farms as *C. sordidus* may migrate to cleaner farms in the long run unless crop sanitation is adopted as a community effort.

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Chapter 7

Effect of crop residue removal on banana weevil, nematode and natural enemy incidence in young isolated banana stands

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Chapter 7

Effect of crop residue removal on banana weevil, nematode and natural enemy incidence in young isolated banana stands

M. Masanza, C.S. Gold, A. van Huis and A.K. Abera

Abstract

We evaluated the effect of crop residue removal on weevil population, weevil damage (over four crop cycles), nematode and arthropod natural enemy incidence in isolated young banana stands at Kawanda, near Kampala in Uganda. A closed banana weevil population assumes no emigration or immigration between plots. We infested isolated banana plots with 5-10 weevils and a complex of 3,000 nematodes per plant. As harvesting of the plant crop started, we subjected the plots to low, moderate and high crop sanitation levels. High sanitation levels reduced trap catch by up to 40%, and weevil population by up to 43%, seemed to expose standing plants to increased weevil attack causing up to 34% reduction in yield. Crop sanitation seemed to reduce nematode populations but not damage. Plant growth was not affected until the fourth crop cycle when girth reduced by 10% and height by 6% in plots under high sanitation compared to plants in low sanitation fields. Plant girth and height increased with crop cycle. Complete removal of crop residues resulted in a three-fold reduction in arthropod natural enemies compared to leaving the residues intact, but did not affect total oviposition on growing plants. In young banana stands with closed weevil populations, removal of crop residues exposes growing plants to increased weevil attack.

Introduction

The banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is the most important pest of highland cooking banana (*Musa* spp., genome group AAA-EA) in Eastern Africa. The insect oviposits in the base of the plant. The larvae tunnel through the corm, the true stem and, occasionally, the pseudostem. *Cosmopolites sordidus* attack weakens the stability of the plant and impedes water and nutrient uptake. Damage results in plant loss through snapping, toppling and mortality without developing a bunch, reduced bunch weights, mat die-out and shortened plantation life (Gold et al., 2003). Yield losses of up to 100 % have been reported (Sengooba, 1986). The insect is disseminated by infested planting material. Population build-up is slow and *C. sordidus* problems are most pronounced in ratoon crops (Rukazambuga et al., 1998).

Highland cooking banana is an important food and cash crop in Uganda. Most of the country's banana is grown in small plots by resource-poor farmers with limited inputs. As a perennial crop, it is important in reducing soil erosion on slopes. Well-maintained banana stands can last 50 or more years. In recent years, serious yield declines in the crop's traditional growing areas in central Uganda has led to the rapid disappearance of banana in this region (Gold et al., 1999a). Early stages of yield decline have also been reported in current commercial production zones in the country's southwest (Gold et al., 1999b).

Damage by *C. sordidus* has been implicated as a primary factor in the crop's decline in central Uganda (Gold et al., 1999a). Farmers in this region have associated high levels of *C. sordidus* with reduced levels of management, including abandonment of crop sanitation practices (i.e. removal or destruction of crop residues). In earlier times, sanitation (removal or destruction of crop residues) was regarded as a means of reducing *C. sordidus* levels, as crop residues were seen as offering a breeding ground and refuge for adults.

The biology of *C. sordidus* has been described by Gold et al. (2003). The adult lives up to four years. It remains reproductive throughout its lifetime, although it produces only a few eggs per week. The adult is free living and most often is found in or near banana plants and crop residues. Treverrow and Bedding (1993) found crop residues to host 60 % of *C. sordidus* adults in Australia. In Uganda, 25-32 % of adults were found in prostrate residues, while another 10-12 % were associated with standing stumps (Gold et al., 1999b). In another study in Uganda, Abera et al. (1999) found 33 % of *C. sordidus* oviposition on highland cooking banana was in the stumps, while Vilardebo (1960) reported that most infestation on Gros Michel (AAA) in Ecuador occurred in the residues. Gold and Bagabe (1997) found little infestation on recently harvested plants of the resistant cultivar Kisubi (Ney poovan subgroup, AB), but that infestation increased over time following harvest. As a result, population buildup in Kisubi plots may have served as a source of weevils for neighboring plots of the susceptible highland cooking banana cultivar Kibuzi. Similarly, no larvae were found in recently harvested Pisang awak (AB) plants in Sumatra, Indonesia, but high infestations were found on cut residues left prostrate in the field. Antibiosis has been reported as the major means of resistance to banana weevil (Kiggundu, 2000; Gold et al., 2003). These data suggest that antibiotic mechanisms may break down after harvest and that prostrate residues may suffer most attack because of increased exposure of the corm and true stem.

Crop sanitation has been widely recommended as a *C. sordidus* control measure in Uganda. A survey of banana farms in this country indeed suggested that crop sanitation reduced banana weevil damage (Gold et al., 1999b). Nevertheless, survey data for banana-based cropping systems are rarely conclusive because of the complexity and variability of even proximal banana stands including differences in topography, soils, intercrops, banana cultivars and management methods employed. Therefore further studies are needed to determine the role of crop sanitation on *C. sordidus* populations and damage. Crop residues might, in fact, reduce *C. sordidus* pressure by (1) acting as a "trap crop" for ovipositing *C. sordidus*, drawing them away from standing plants; and (2) serving as a habitat for natural enemies, especially arthropod predators that thrive in plant debris.

High levels of *C. sordidus* have often been associated with low levels of management and the presence of other plant stresses including low soil fertility, bad drainage, extended droughts and nematode infestation (Gold et al., 2003). Speijer et al. (1993) reported that bananas attacked by plant parasitic nematodes had increased susceptibility to *C. sordidus*, which was attributed to corm softness after nematode infestation. In addition, nematode-damaged corms may have been more attractive to gravid females.

A range of natural enemies of *C. sordidus*, including histerids, hydrophilids, staphylinids and dermaptera, have been reported in highland cooking banana systems in East Africa (Koppenhofer et al., 1992; Tinzaara et al., 1999). These are opportunistic predators that are often associated with crop residues, although some are able to remove *C. sordidus* eggs from standing plants. It is unclear how crop sanitation levels might affect populations of these natural enemies.

The objectives of this study were to study the effects of crop sanitation on *C. sordidus* population levels and damage to growing plants in unstressed and nematode-stressed systems. In addition, we were interested in natural enemy abundance in fields with and without crop residues and the effects of crop sanitation on nematode damage.

Materials and methods

Studies were conducted on a field trial planted in March-April 1999 and ran through February 2002 over four crop cycles.

Site description and experimental fields

The trial was conducted at the Kawanda Agricultural Research Institute (KARI) (0°25'N, 32°32'E, 1190 m above sea level), 13 km north of Kampala, Uganda, with mean precipitation of about 1190 mm per year, average daily temperatures of 16 °C minimum and 29 °C maximum. The soil is classified as an isohyperthermic Kandiudalfic Eutrodox (USDA taxonomy) with high water holding capacity, medium acidity (pH 5.9-6.3), low organic matter content, deficient in nitrogen and phosphorus (McIntyre et al., 2001; O. Semalulu, pers. comm.).

Four strips of land (approx. one hectare each) were used in the study. Two strips had been in fallow for two years, following earlier plantings of maize and beans. The other two strips had supported a banana germplasm collection for 10 years (i.e. 1989 to 1998). The plants were uprooted several months prior to our field trial and had a residual *C. sordidus* population prior to ploughing.

Experimental design

The trial had six treatments: (1) low sanitation, low plant stress; (2) moderate sanitation, low plant stress; (3) high sanitation, low plant stress; (4) low sanitation; high plant stress; (5); moderate sanitation, high plant stress; (6) high sanitation, high plant stress (Table 1).

Table 1. Treatments to study the effect of different levels of sanitation at and high densities of nematodes on banana weevil.

Sanitation			
Level	**Pseudostems**	**Stumps**	**Nematodes[1]**
Low	Present	Present	Low
Moderate	Chopped	Present	Low
High	Chopped	Removed	Low
Low	Present	Present	High
Moderate	Chopped	Present	High
High	Chopped	Removed	High

[1] Low: No inoculation of suckers with nematodes

High: Suckers inoculated with nematodes (*Helicotylechus multicinctus* and *Radopholus similis*, ratio 3:2) six months after planting.

Low levels of sanitation consisted of leaving both the residual pseudostems and corms in the field; moderate sanitation involved chopping up the residual pseudostems but leaving the corms; while high sanitation encompassed destruction of both the residual pseudostems and corms. High plant stress was created by infesting the plots with the banana nematodes *Heliocotylenchus multicinctus* and *Radopholus similis*. The trial employed a randomized complete block design with four replications. Each strip comprised a block.

Plots (787.5 - 900 m^2) consisted of 105 – 140 plants spaced at 3 × 2.5 m. Blocks and plots within blocks were separated by grass alleys of 11 to 15 m. Such alleys can minimize *C. sordidus* movement between plots (Gold et al., 1998) and created a near 'closed banana weevil population'. An additional fifth block was located near the four sanitation blocks. This block had four plots (each containing 120 mats) at KARI. The plots were maintained at "very low sanitation" levels. Plants were mulched using banana leaves and cut pseudostems were split in the middle and left on the ground. These plots were included because the practice is more comparable to what is commonly encountered on farmers' fields than plots in which pseudostems are chopped. Split pseudostems also persist longer than chopped pseudostems and therefore may provide a better habitat for natural enemies.

Planting and management

The four strips were ploughed in February 1999 with planting during the rains of March and April 1999. Two highland cooking banana cultivars, Atwalira and Namwezi, were selected from banana farms near to KARI. Both cultivars are susceptible to banana weevil (Kiggundu, 2000). The suckers were pared to remove nematodes and weevil eggs and later dipped in a solution of Chloropyriphos at the rate of 30 ml in 150 litres of water for one hour before planting. This was done to disinfest the suckers of weevils and nematodes. The two cultivars were planted alternately within and between the rows.

Stand management such as weeding, gap-filling, fertilizer application, desuckering, de-leafing, mulching and de-trashing were done uniformly for all the plots. Gap filling was continually done to replace young suckers that died due to weevil attack or drought. Soil analysis confirmed a low nitrogen and phosphorus status. Diammonium-phosphate fertilizer was applied three months after planting at the rate of 75 g per plant. Mulch material of a mixture of swamp grass *Miscanthidium violaceum* (K. Schum.) Robyns. (Poaceae) and spear grass *Imperata cylindrica* (L.) Beauv. (Poaceae), was applied six months after planting to conserve soil moisture.

Weevil infestation

Six months after planting (October 1999) (i.e. when all plants were well established), the plots were infested with mixed sex adult *C. sordidus* of unknown age distribution (collected from pseudostem traps of nearby farms) at the rate of 5-10 per mat in each plot, to establish a moderate weevil pressure. The weevils were released in the evening in small depressions made in the soil near the plants.

Nematode infestation

In treatments calling for high plant stress, nematode infestations were established six months after planting. Root segments originating from nematode-infested banana plants in fields at Semuto (50 km NW of Kampala) were used as a source of inoculum. Nematode-infested roots with necrotic discolouration were chopped into one-half-cm-lengths, mixed thoroughly to obtain a uniform concentration of nematodes, and placed in depressions dug at the base of banana mats near actively growing roots.

Sanitation treatments

Sanitation levels (i.e. treatments) were implemented at first harvest. In low sanitation treatments, pseudostems were cut into halves with one half lying flat on the ground while the other was left standing on the mat. In other words, these residues were neither split nor chopped; they were left lying in plots whole and allowed to accumulate with each harvest. In moderate sanitation treatments, the residues on the ground were chopped to fine pieces to allow them to dry up quickly, while those standing on stools were left untouched. This ensured that the amount of residues in this treatment were half those in low sanitation. At high sanitation level, all residues were cut to the ground level and were completely shredded to ensure fast drying.

Cosmopolites sordidus adult populations

Cosmopolites sordidus adult populations were monitored by pseudostem trapping and by mark and recapture methods. On a monthly basis from February 2001 to February 2002 (except for July and September 2001), a single split pseudostem trap (Mitchell, 1978) was placed with the cut face down against each banana mat in the trial. After two nights, the number of *C. sordidus* adults in each trap was counted.

Populations were also estimated in each plot by modified mark and recapture methods developed for *C. sordidus* by Price (1993) and Gold and Bagabe (1997). A baseline population was estimated in July 2000 (eight months after release) and then repeated six months later in January 2001. Thereafter, populations were estimated at three-month intervals until February 2002. During these sampling periods, adults collected in the pseudostem trapping described for *C. sordidus* monitoring above were marked by placing scratches on the elytra using distinct marks for each sampling period. Seven days later, a new set of traps (one per mat) were placed in the field and after three more days the number of marked and unmarked adults were recorded. For each plot, *C. sordidus* adult populations were estimated using the Lincoln index (Southwood, 1978)

$$N = (m*n)/r$$

where N is the population estimate, m the number of individuals that were marked and released, n the total number of individuals captured, and r the number of marked individuals recaptured. Population density (numbers/ha) were estimated for each plot using data on stand size.

Corm damage assessment

Corm damage was assessed weekly on plants that had been harvested in the past week. Thus, sampling was always within one to seven days of harvest. Superficial damage was assessed on the corm periphery, estimated through a modified percentage coefficient of infestation (PCI) (Mitchell, 1978) and peripheral damage (PD), which is an estimate of percentage surface tissue consumed by *C. sordidus* larvae in the upper 10 cm of the corm. Internal damage was estimated in the cortex and central cylinder of cross sections (at the collar and 10 cm below the collar) following the methods of Gold et al. (1994). Average corm damage was derived from the means of the cortex and central cylinder cross-section damage estimates. All measurements were expressed as percentages.

All described methods for evaluating *C. sordidus* damage, including the ones used in this study, entail destructive sampling (Gold et al., 2003) that would interfere with the imposed low- and moderate-sanitation treatments (i.e. leaving crop residues undisturbed). Therefore, damage assessment was taken on a sub-sample of ten plants per plot per sampling period for each of these treatments. All recently harvested plants were evaluated for *C. sordidus* damage in high sanitation plots.

Cosmopolites sordidus oviposition levels and larval numbers

The number of *C. sordidus* eggs and larvae were assessed on suckers and crop residues by destructive sampling in all plots. Ten maiden suckers and ten crop residues (i.e. those used in damage assessment) per plot were carefully pared to expose eggs. Further search for larvae was done by carefully dissecting the corms and pseudostems. The number of eggs per residue was estimated. This was continued at three-month intervals over a period of two years.

Nematode levels

Nematode levels were determined during the rainy seasons of November 2000, April 2001 and April 2002 for all plots. Sampling was carried out on five recently flowered plants (within 2 weeks after emergence of the flower) per plot. An area of 20 × 20 × 20 cm extending from the plant corm was dug up, and all the roots in this soil volume were removed.

The numbers of live (functional with at least some live tissue) and dead roots in this area were counted. Ten-cm lengths (one per root) were cut from each of five randomly selected live roots, split lengthwise and scored collectively for percentage root necrosis using the methods of Speijer and de Waele (1997).

The remaining roots for each plant were placed in bags and transported to the laboratory. For each plant, the roots were chopped into small pieces (i.e. 0.005-0.010- m segments) and thoroughly mixed. A sub-sample of five grams was weighed then blended using a kitchen blender with some water for five seconds. The homogenous mixture was poured on an extraction tissue that was mounted on a sieve resting on a shallow plate and left to stand for 12 hours. The solution was poured into vials and left for the nematodes to settle at the bottom. The suspension was then drained using a sucking bottle until 25 ml of suspension was left in the vial. The suspension was thoroughly stirred to homogenize the nematodes, from which 1 ml of aliquot was drawn and put on a counting slide to be observed under a compound microscope for counting the different nematodes at species level, including all stages and sexes, i.e. female, male, and juvenile. The nematode counts were extrapolated to numbers in 100 g of fresh root weight.

Natural enemies

Natural enemies of *C. sordidus* were monitored in the different treatments of the sanitation blocks after 25 % of the plants were harvested during the fourth crop cycle. Natural enemy populations were also assessed in the four additional banana plots of the fifth block. In each treatment we assessed residues according to their availability. In the low and moderate sanitation treatment, we cut 30 cm from the exposed ends of prostrate pseudostem residues. These were shredded into tiny pieces and any histerids, hydrophilids, staphylinids and dermaptera were recorded. Additionally, heaps of chopped residues in the moderate and high sanitation treatments were searched and any natural enemy groups encountered recorded. In the fourth "very low sanitation" treatment in the fifth block, decomposed parts of residues were entirely shredded and natural enemies found were recorded. Data were recorded bimonthly beginning 30 months after planting over a period of one year.

Growth and yield parameters

Data on banana plant growth and yield were collected across four crop cycles. Plants were observed daily for flowering (i.e. when the first bract leaf emerged from between the flag leaf and the last leaf), at which time leaf formation ceases. Plant girth, height and number of functional leaves were recorded for all plants within one week of flowering. Plant height was defined as the distance between the soil surface and the point where the top-most petioles join. Plant girth was measured 100 cm above ground level. Plants were harvested on reaching physiological maturity (i.e. first ripening of a finger). Bunch weight was measured in kilograms using a Salter balance (precision = 0.5 kg).

Data analysis

Plot means of trap catches, weevil populations and plant growth parameters, corm damage (over four crop cycles) and means of the number of eggs deposited on banana stumps and suckers were subjected to GLM procedures of SAS (SAS Inc., 1997). For corm damage, sanitation nested in crop cycle was considered a fixed effect and residuals as random effects. Least Square Means for parameters of subsequent crop cycles were compared with those for the plant crop and low sanitation, adjusted to Dunnet's Test (SAS Inc., 1997). Nematode data based on the number of different nematode species, root necrosis index and number of dead roots were subjected to analysis of variance using the GLM procedure of SAS (SAS Institute Inc., 1997). When analysis of variance of nematode numbers and root necrosis were significant, Student Newman Keul's Test was employed to separate means. Data on abundance of arthropod natural enemies for each treatment were subjected to GLM procedures of SAS. Means per plant residue were compared using pair-wise comparison t-test of least square means.

Results

***Cosmopolites sordidus* adult populations**

Mean *C. sordidus* trap catches fluctuated over time with treatment means ranging from 2 to 6 adults/trap (Figure 1). Trap catches were significantly lower ($P < 0.05$) in high sanitation plots than in moderate and low sanitation treatments for all but two sampling dates (i.e April and October 2001). Population densities, estimated by mark and recapture techniques, were also significantly lower ($P < 0.05$) in high sanitation than in low or medium sanitation plots for all sampling dates (Figure 2). For example, densities were 37 % lower in high than low sanitation in August 2001 and 43% lower in November 2001. Trap catches and population densities were similar in low and moderate sanitation plots

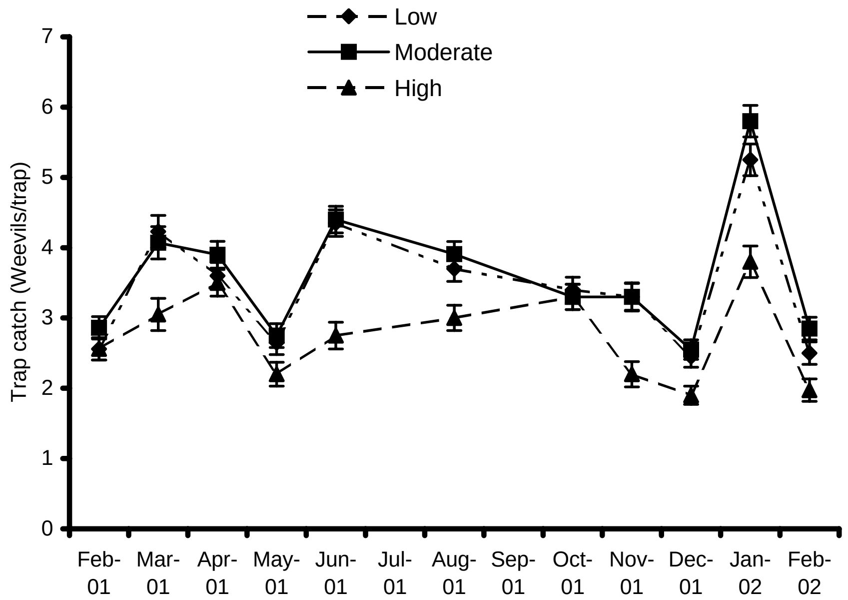

Figure 1. *C. sordidus* trap catch by sanitation level from February 2001 to February 2002 at Kawanda Agricultural Research Institute, Kampala, Uganda

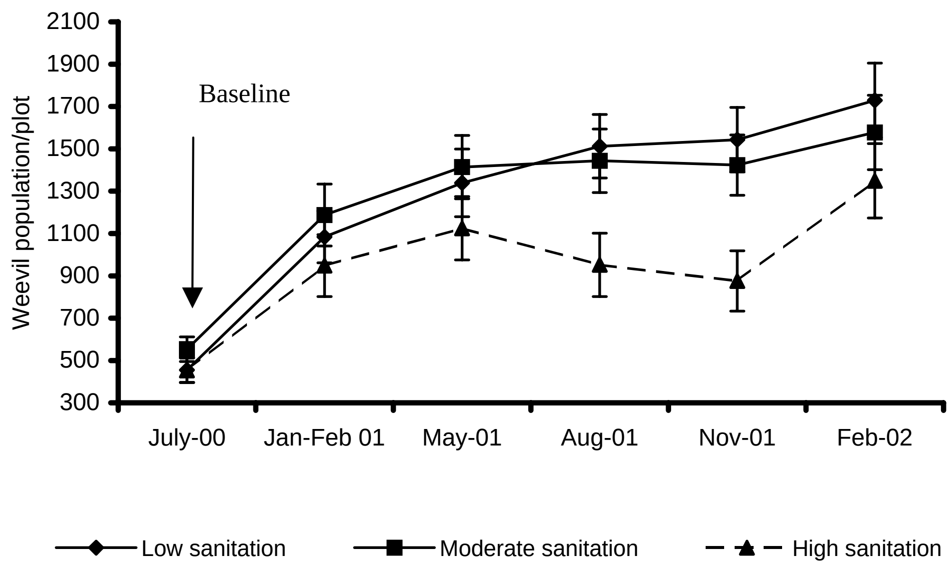

Figure 2. *C. sordidus* population estimates (weevils/plot) by mark recapture methods by sanitation level over sampling date in plots maintained at low, moderate and high sanitation levels at Kawanda Agricultural Research Institute, Kampala, Uganda from July 2000 to February 2002

throughout the trial. There was a general increase in population with time in all plots, but the rate was higher in plots maintained at low and moderate sanitation levels than in plots maintained at high sanitation. No significant inter-plot banana weevil migration was observed during the study (data not presented).

Corm damage

Crop sanitation did not have a significant effect (P > 0.05) on the coefficient of corm infestation for all crop cycles (Table 2). During the first three crop cycles, peripheral corm damage was highest in plots maintained at moderate sanitation, while in the fourth crop cycle it was highest on plants maintained at high sanitation. Damage to the central cylinder was greatest in moderate-sanitation treatments and lowest in low-sanitation plots, while damage to the cortex was highest in moderate-sanitation treatments in the second and fourth crop cycle. For all damage parameters, low-sanitation plots had similar damage scores during the first three crop cycles, and significantly lower damage scores than high sanitation plots during the fourth crop cycle (except that for the outer cortex).

Table 2. Damage by *C. sordidus* to banana during four crop cycles maintained at different sanitation levels: Coefficient of corm infestation, peripheral corm damage, outer and inner corm cortex damage at Kawanda Agricultural Research Institute, Kampala, Uganda, 1999-2002.

Corm Damage	Sanitation level	Crop cycle			
		1st	2nd	3rd	4th
a. Coefficient of infestation (%)	Low	8.4 ± 0.27	8.6 ± 0.27	9.0 ± 0.29	8.3 ± 0.38
	Moderate	8.7 ± 0.27	9.0 ± 0.27	9.3 ± 0.29	8.9 ± 0.38
	High	8.5 ± 0.27	8.5 ± 0.27	8.9 ± 0.27	9.3 ± 0.38
b. Peripheral damage	Low	14.4 ± 1.49	14.3 ± 1.49	15.2 ± 1.59	13.9 ± 2.09
	Moderate	17.3 ± 1.50*	17.9 ± 1.50*	19.1 ± 1.60*	16.6 ± 2.09
	High	14.3 ± 1.50	14.6 ± 1.50	15.3 ± 1.50	20.2 ± 2.11*
c. Inner damage	Low	5.5 ± 1.08	4.5 ± 1.08	4.3 ± 1.15	5.4 ± 1.52
	Moderate	8.2 ± 1.09*	8.6 ± 1.09*	7.4 ± 1.16*	8.1 ± 1.52*
	High	5.5 ± 1.09	5.3 ± 1.09	4.8 ± 1.09	8.7 ± 1.53*
d. Outer damage	Low	8.2 ± 0.94	7.4 ± 0.94	9.0 ± 1.00	8.5 ± 1.28
	Moderate	9.4 ± 0.95	11.0 ± 0.95*	9.3 ± 1.00	11.6 ± 1.28*
	High	9.0 ± 0.96	8.4 ± 0.96	8.7 ± 0.96	8.4 ± 1.30
e. Average damage	Low	6.8 ± 0.89	6.0 ± 0.89	6.6 ± 0.95	7.0 ± 1.23
	Moderate	8.8 ± 0.90*	9.8 ± 0.90*	8.4 ± 0.96*	9.8 ± 1.23*
	High	7.2 ± 0.91	6.8 ± 0.91	6.7 ± 0.91	8.5 ± 1.24*

*Significantly different (P ≤ 0.05) by Dunnett adjustment from low sanitation treatment within the column for each type of damage.

Oviposition levels on residues and suckers

At all sanitation levels, oviposition was significantly ($p < 0.05$) higher on banana stumps than on suckers (Table 3). Of the total eggs recovered, 81% were found on stumps and 19% on suckers. Although sanitation seemed to lower oviposition, differences were not significant ($P>0.05$).

Nematode numbers and damage

Radopholus similis appeared to establish in inoculated plots, but remained low for many months and did not reach appreciable levels until January 2002 (Table 4). *Helicotylenchus multicinctus* similarly established in inoculated plots, but also showed slow build up. Moreover, populations lagged behind in high sanitation treatments, while populations reached high numbers in untreated moderate sanitation plots by January 2002. The data suggest that high sanitation may have reduced *H. multicinctus*, but not *R. similis* abundance. For instance, in January 2002, the number of *H. multicinctus* was 64% lower in plots maintained at high sanitation compared to that in low sanitation fields. Root necrosis indices were only significantly different between inoculated and uninoculated plots during January 2002. Crop sanitation did not seem to show a consistent effect on root necrosis, nor did it significantly ($P > 0.05$) affect the number of dead roots. There was no effect of nematode incidence on weevil incidence (df = 5, F-value = 1.20, $P > 0.05$). This implies that there was no interactive effect between sanitation treatments and nematode presence.

Table 3. Mean number of eggs per banana stump/sucker by sanitation level at Kawanda Agricultural Research Institute, Kampala, Uganda

Sanitation level		Mean of eggs
Low	Stumps	3.9 ± 0.33a
	Suckers	0.8 ± 0.12 b
	Total	4.7 ± 0.37a
Moderate	Stumps	3.1 ± 0.30a
	Suckers	0.9 ± 0.26 b
	Total	4.0 ± 0.46a
High	Stumps	3.0 ± 0.41a
	Suckers	0.7 ± 0.14 b
	Total	3.7 ± 0.39a

In a column, means followed by the same letter are not significantly ($P>0.05$) different by pair-wise comparison t-test of Least Square Means.

Natural enemies

Increasing sanitation reduced the abundance of predaceous groups (i.e. histerids, hydrophilids, staphylinids, dermaptera) known to attack *Cosmopolites sordidus* in banana plots ($P < 0.05$) (Figure 3). Among these insects, Dermaptera were most abundant, followed by Staphylinidae, Hydrophilidae, and Histeridae.

Growth parameters

There were no significant ($P > 0.05$) differences in nematode and no nematode treatments (no table presented). We therefore pooled data and analysed as them against sanitation treatments only. Plant height and girth tended to increase with crop cycle. Plant height, girth and the number of functional leaves were not significantly affected by sanitation level during the first three crop cycles ($P > 0.05$) (Table 5). In the fourth crop cycle, plants were smaller (height and girth) and had fewer functional leaves in high sanitation treatments ($P < 0.05$).

Table 4. Nematodes population (*10^2) per 100 g live root weight, root necrosis index dead roots per 20-cm^3 volume of soil and weevil population density by sanitation level in inoculated and non-inoculated plots at three dates at Kawanda Agricultural Research Institute, Kampala, Uganda.

Sanitation level	Nematode Inoculated (October 1999)	Nematode population		Root Necrosis Index	Dead roots	Weevil density
		R. similis	*H. multicinctus*			
		November 2000				
Low	-	0.3 b	0.0 b	1.9 b	0.9	6794 ± 2279
Moderate	-	0.0 b	6.8 b	0.0 b	0.4	7139 ± 2279
High	-	10.9a	10.2a	5.0a	0.5	6181 ± 2279
Low	+	27.4a	19.0a	0.5 b	1.3	4725 ± 2279
Moderate	+	11.1a	7.1 b	0.0 b	0.8	6898 ± 2279
High	+	21.8a	15.7a	3.2a	0.7	5315 ± 2279
		April 2001				
Low	-	2.1 b	8.0 b	3.3a	0.7	15938 ± 1612
Moderate	-	2.3 b	4.4 b	3.0a	0.1	15541 ± 1612
High	-	5.5 b	4.2 b	3.1a	0.7	12073 ± 1612
Low	+	13.2a	26.4a	1.8a	0.3	12571 ± 1612
Moderate	+	18.5a	29.4a	3.2a	0.1	14565 ± 1612
High	+	18.8a	6.2 b	2.0a	0.3	13164 ± 1612
		January 2002				
Low	-	30.0 b	20.0 b	2.5 b	1.0	14740 ± 2279
Moderate	-	45.0 b	375.0a	2.0 b	1.0	19515 ± 2279
High	-	20.0 b	20.0 b	1.0 b	1.0	13260 ± 2279
Low	+	295.0a	235.0a	5.0a	1.0	21214 ± 2279
Moderate	+	130.0a	290.0a	5.0a	1.0	13128 ± 2279
High	+	200.0a	85.0 b	4.0a	2.0	14449 ± 2279

In columns, within each sampling date, means followed by the same letter are not significantly ($P>0.05$) different by Student Newman Keul's Test (for nematodes) and by pair-wise comparison t-test of Least Square Means (± s.e.) for weevil density. Where no letter is given, there are no significant differences.

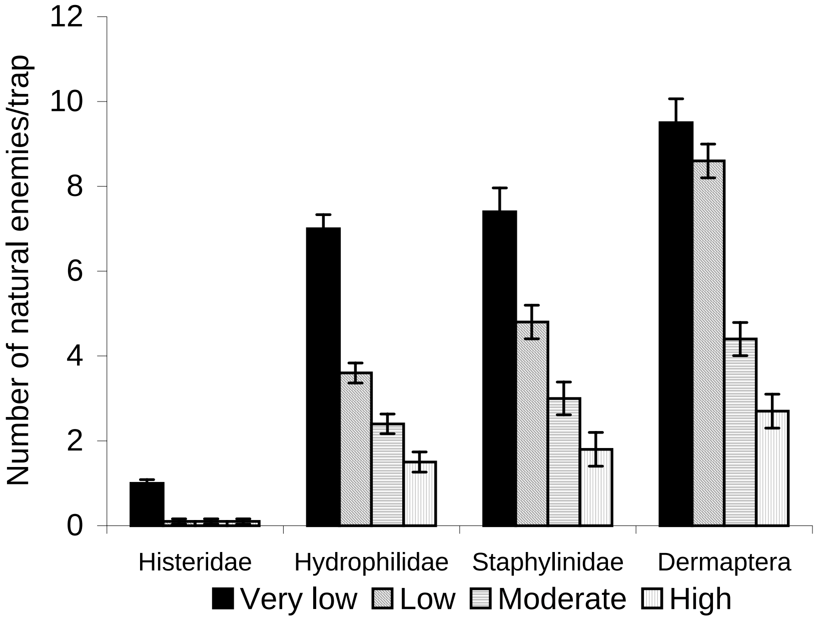

Figure 3. The number of natural enemies in banana plots maintained at various sanitation levels at Kawanda Agricultural Research Institute, Kampala, Uganda

Table 5. Growth parameters by sanitation level for bananas grown at the sanitation trial Kawanda Agricultural Research Institute, Kampala, Uganda

Parameter	Sanitation level	Crop cycle			
		1st	2nd	3rd	4th
Height	Low	242.7 ± 5.13aB	261.7 ± 5.13aA	269.6 ± 5.13aA	272.5 ± 5.48aA
	Moderate	234.5 ± 5.13aB	257.3 ± 5.13aA	264.5 ± 5.13aA	284.2 ± 5.92aA
	High	239.8 ± 5.13aB	257.8 ± 5.13aA	260.8 ± 5.13aA	256.8 ± 5.13 bA
Girth	Low	38.0 ± 1.09aB	42.4 ± 1.09aA	45.3 ± 1.09aA	46.8 ± 1.16aA
	Moderate	36.3 ± 1.09aB	41.1 ± 1.09aA	44.3 ± 1.09aA	48.5 ± 1.26aA
	High	37.5 ± 1.09aB	41.7 ± 1.09aA	43.9 ± 1.09aA	42.2 ± 1.09 bA
Functional leaves	Low	6.7 ± 0.09	6.8 ± 0.09	6.8 ± 0.10	6.6 ± 0.10a
	Moderate	6.4 ± 0.09	6.6 ± 0.09	6.6 ± 0.09	6.7 ± 0.10a
	High	6.6 ± 0.09A	6.6 ± 0.09A	6.6 ± 0.09A	6.1 ± 0.09 bB

For each parameter, means in columns followed by the same lowercase letters are not significantly ($P>0.05$) different by pair-wise comparison t-test of Least Square Means.
For each parameter, means in rows followed by the same uppercase letters are not significantly ($P<0.05$) different by pair-wise comparison t-test of Least Square Means.
Where no letter is given, there are no significant differences.

Yield

Nematode and no nematode treatments did not have significant (P>0.05) differences in yield. Therefore yield data were pooled and analysed against sanitation treatments. Crop sanitation level did not have a significant (P<0.05) effect on the number of bunches harvested across four crop cycles (Table 6). Yields tended to increase with crop cycle. Bunch weights in the third and fourth crop cycles were significantly lower for plants harvested from plots maintained at high sanitation than for those at low and moderate sanitation (P < 0.05). For example, in the fourth crop cycle, plants maintained at high sanitation yielded 34% lower than those maintained at low sanitation, while bunches from moderate sanitation plots weighed 20% less than those from low sanitation plots. A similar trend occurred with the number of hands per bunch, being significantly lower for bunches harvested from plots maintained at high sanitation compared to the other plots (P < 0.05). Yield loss due to toppling and stem breakage by wind across the four crop cycles was not significantly affected by sanitation level (P > 0.05).

Table 6. Yield and plant loss by sanitation treatment in plots of the sanitation trial at Kawanda Agricultural Research Institute, Kampala, Uganda

Parameter	Sanitation level	Crop cycle			
		1st	2nd	3rd	4th
a. Number of harvested plants per plot month	Low	9.9 ± 1.48	12.0 ± 1.48	12.6 ± 1.48	15.7 ± 1.95
	Moderate	8.5 ± 1.38	9.4 ± 1.38	11.5 ± 1.38	14.0 ± 1.95
	High	9.8 ± 1.38	9.8 ± 1.38	10.1 ± 1.38	12.0 ± 1.95
b. Bunch weight (kg)	Low	5.9 ± 0.41	8.1 ± 0.41	8.9 ± 0.41a	9.2 ± 0.55a
	Moderate	5.3 ± 0.39	7.4 ± 0.39	9.0 ± 0.39a	7.4 ± 0.39 b
	High	5.9 ± 0.39 B	7.3 ± 0.39A	7.4 ± 0.39Ab	6.1 ± 0.55 Bc
c. Hands per bunch	Low	5.3 ± 0.16	6.0 ± 0.16	6.3 ± 0.16a	6.5 ± 0.21a
	Moderate	5.0 ± 0.15	5.7 ± 0.16	6.2 ± 0.16a	6.2 ± 0.21a
	High	5.2 ± 0.15	5.7 ± 0.15	5.8 ± 0.15 b	5.3 ± 0.21 b
d. Plants toppled per plot	Low	4.4 ± 1.55 B	7.8 ± 1.34B	7.5 ± 1.10 B	11.0 ± 1.90A
	Moderate	7.7 ± 0.95	7.9 ± 1.01	8.7 ± 0.95	11.0 ± 1.90
	High	6.4 ± 1.10	7.8 ± 0.95	7.9 ± 1.02	9.5 ± 1.34
e. Plants broken by wind per plot	Low	9.3 ± 2.26	7.4 ± 3.19	16.6 ± 2.26	11.0 ± 5.53
	Moderate	7.7 ± 1.96	10.0 ± 2.26	13.2 ± 2.77	17.0 ± 5.53
	High	11.0 ± 2.26	9.8 ± 3.19	13.2 ± 2.77	15.0 ± 3.91

In columns for each parameter, means followed by the same lowercase letters are not significantly (P>0.05) different by pair-wise comparison t-test of Least Square Means.
In rows, for each parameter at a given sanitation level, means followed by the same uppercase letters are no significantly (P>0.05) different by pair-wise comparison t-test of Least Square Means. Where no letters are given, there are no significant differences.

Discussion

Weevil incidence

In this study removal of crop residues reduced *C. sordidus* populations. More weevils were caught in low and moderate sanitation plots than in those maintained at high sanitation. Several authors have reported the association between weevils and crop residues. Banana plantations littered with crop residues provide a suitable habitat for *C. sordidus* multiplication (Wallace, 1938; Abera, 1997; Gold et al., 1999). In a related study, crop residues had 50% more eggs than standing plants (Masanza et al., Chapter 3), while an earlier report indicated that 60% of weevils in a field come out of residues (Teverrow and Bedding, 1993). Cutting banana stumps, chopping and finally spreading them out to dry must have had the effect of killing eggs and larvae by desiccation of the residues. In addition, it is possible that developing larvae may have been more successful in crop residues than growing plants (Gold and Bagabe, 1997).

In general, trap catches appeared to be higher during and immediately after rainy seasons. This result seems to suggest greater *C. sordidus* activity when soils are moist and relative humidity is high. *C. sordidus* adults prefer moist places with high relative humidity (Roth and Willis, 1963; Ittyeipe, 1986). Sharp peaks in trap catch can therefore result from changes in moisture regime or relative humidity and temperatures when trapping was conducted that affected trap efficiency.

Weevil damage

We hypothesized that removal of crop residues would reduce *C. sordidus* populations with a resulting decrease in damage levels, as was found in on-farm studies (Masanza et al., Chapter 6). Contrary to expectation, corm damage in banana plots maintained at moderate and high sanitation levels was higher than in those maintained at low sanitation. Moreover, it was not clear why corm damage was highest at moderate sanitation. However, on the whole, these data suggest that removing of crop residues destroyed a preferred habitat for *C. sordidus*, leaving them no choice but to attack the standing plants. Whereas *C. sordidus* is relatively sedentary (Delattre, 1980; Gold et al., 1998, 2003) and migration was further reduced by the presence of inter-plot grass alleys, ovipositing females could only select among the possible hosts in the plots that they were in. In plots filled with crop residues, attack was most likely divided between the standing plants and crop residues. This may explain why the plants in plots with no crop residues suffered more attack. This suggests that residues may, in fact, act as a trap crop for ovipositing females.

The extent of damage was also reflected in yield. Bunches harvested from fields maintained at high sanitation had 34% lower bunch weight than those from low sanitation.

Weevil oviposition and natural enemies

Oviposition levels were higher on banana stumps than on corms of standing plants. There is a general belief that crop residues are more preferred as breeding sites than standing plants or freshly harvested plants because of break down resistance chemicals (Gold and Bagabe, 1997). It is also likely that cut residues were attacked more because they emitted more volatiles that attracted adults for feeding and breeding (Gold et al., 2003): damaged plants in other crops are known to emit more volatiles than intact ones (Dicke et al., 1990; Turlings and Tumlinson, 1992). In our study, crop sanitation seemed to have an effect on oviposition.

Moreover, the number of natural enemies was higher in low sanitation fields. Since corm damage was lower in fields that had crop residues, it is possible that many eggs and early instar larvae were eaten by Dermaptera, Staphylinidae and Hydrophilidae that were four times more abundant at low sanitation than at high sanitation. There is scanty information available about the efficacy of indigenous natural enemies (Koppenhofer et al., 1992; Gold et al., 2003). However, their role in reducing weevil populations by feeding on early development stages of *C. sordidus* is possible. Laboratory investigations on feeding and searching capabilities demonstrated that some of these predatory insects collected from banana fields in Kenya attack early stages of the banana weevil (Koppenhofer et al., 1992). The predators are capable of finding eggs hidden in banana rhizomes.

Nematode incidence

Nematode incidence increased with banana stand age, but it did not differ between crop sanitation levels despite the fact that *H. multicinctus* numbers seemed to be reduced by practicing high sanitation (Table 4). The nematode numbers were consistently higher in nematode inoculated fields. Speijer et al. (1994) made similar observations when they assessed nematode damage on suckers from farmers' fields maintained at different management levels. The reduction in *H. multicinctus* populations could have been due to corm removal. Corms with the roots growing on them can be a potential source of nematode inoculum for the growing plants. Speijer et al. (1993) found that nematode-infested bananas were more susceptible to weevil attack. This was attributed to attraction by volatiles emitted by damaged roots. However, in our study, there was no apparent effect of nematode infestation on weevil incidence implying that nematode damage in the experimental plots did not significantly affect root damage to cause the effects observed in the Speijer experiment. The difference in our results may be due to the different methodologies of achieving inoculum levels that caused different damage levels. In any case, their experiment was conducted in Kenya, which is environmentally different from Kawanda. These could also have brought the differences observed.

Conclusion

The question from these results is whether we should recommend sanitation at all. Basing on the results in this study, it is apparent that crop sanitation in young plantations helps reduce *C. sordidus* populations. However, complete removal of residues exposes growing plants to increased weevil attack. In the experimental plots, crop residues were destroyed immediately after harvest. Unlike the case of our on-station experimental fields, it is rare on farmers' fields to find such clean field, with all residues chopped to dry up quickly. For that matter, in farmers' fields, banana weevils still have some residues as alternative breeding sites, and there is possibility for the weevils to lay eggs, as well as the natural enemies to accumulate before the crop residues are destroyed. In isolated establishing banana plots, it might be advisable not to chop up crop residues immediately. It may be better to wait and chop them up after two to three weeks.

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Chapter 8

General discussion and conclusions

M. Masanza

Chapter 8

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To develop an integrated pest control strategy for the management of the banana weevil *Cosmopolites sordidus* in East Africa, research activities are conducted at the International Institute of Tropical Agriculture, East and Southern Africa Regional Centre (IITA-ESARC) and the National Banana Research Programme (NBRP) of the National Research Organization (NARO) Among the IPM options being emphasized is the use of cultural control or habitat management. Habitat management offers the first line of defence against herbivorous pests (Altieri & Letourneau, 1982). This is made possible by various mechanisms such as reduction of pest immigration, promotion of host plant vigour, tolerance to pest attack, and creating unfavourable environmental conditions to pest build-up. Habitat management options include planting clean material, crop sanitation, selection of an appropriate banana cropping system such as mixed cropping, improved agronomic practices and trapping of weevils (Gold et al., 2003). Crop sanitation as a banana weevil control strategy has been recommended, although there are no data available on the relationship between different methods of crop sanitation and the incidence of weevils (Gold & Messiaen, 2000). Therefore, we studied the effects of crop sanitation on *C. sordidus* populations and damage under field conditions. In particular, the research dealt with crop residue management to control this pest. Two hypotheses have been under scrutiny: 1) when crop residues act as a breeding site and source of food for *C. sordidus*, their destruction would lead to a reduction of pest population, and as alternative hypothesis 2) when crop residues would act as a 'trap crop', their destruction would expose standing plants to increased attack. Basis of this work formed a study on the various aspects of *C. sordidus* biology and ecology in the managed habitat, to obtain insight into the mechanisms of its population build-up and strategies for its control.

Biology of *C. sordidus*

Weevil population build up

The banana weevil typically exhibits a K-selected life cycle (Pianka, 1970). This is characterized by a long life span and low fecundity (Gold et al., 1999). Its population build-up in new banana fields is slow and the pest problem increases over crop cycles (Rukazambuga et al., 1998). In old plantations, we may have two situations: a) a clean field with no residues and b) an unclean field full of residues (but there can be intermediate situations). In the clean field, the insects present will have no choice but to attack standing plants causing damage and increasing their population on the standing plants. In a field without sanitation, crop residues accumulate in the banana stand.

Weevils will now have a choice and can either oviposit on residues or the standing plants. This choice may be influenced by the age of the residues.

Attraction, host acceptance and distribution of C. sordidus

One question is whether the age of crop residues would have an effect on the attraction of the banana weevil. When are the crop and the residues most vulnerable to pest attack? Knowledge of such information can provide insight into what the weevil is doing and can be used in timing sanitation measures for maximum effect to prevent weevil build-up and maximize wasted oviposition. The study was done in the laboratory on residues of different ages from various banana clones, and later also in the field in a banana system that comprised banana mats and different aged crop residues (Chapter 2 & 3). In the laboratory, adult *C. sordidus* were mainly attracted to banana corms (Chapter 2) (c.f. Cuille, 1950). In our studies, we measured the moisture of the crop residues. Corms more than 30 days after harvest were particularly attractive to adults most likely because first these residues were moist (see also Roth & Willis, 1963) and adults prefer moist and humid environments. Secondl6y, Tinzaara et al. (2003) reported that older corms emitted volatiles, suggesting in this study that it is the emitted volatiles that attracted *C. sordidus*.

In our field studies, most oviposition occurred on flowered plants and fresh corms up to 30 days after harvest (c.f. Abera et al., 1999), although weevils also can lay eggs on residues as old as 120 days. Our results indicate that oviposition reaches a peak about three weeks after harvest (chapter 3). Larvae and adults were more abundant in older residues. The results on attraction and oviposition together imply that it might be beneficial to destroy the residues at least one month after harvest to prevent the immatures from completing their life cycle and infest standing plants.

Some residues from different clones showed some resistance to weevil attack (Chapter 3). A farmer's field in Uganda normally is a complex cropping system with a wide range of banana cultivars (clones) of varying levels of tolerance and or resistance. Farming practices such as harvesting, crop residues management i.e. chopping them or leaving them intact at different levels of decomposition, detrashing and uprooting corms add to the complexity. Gold & Bagabe (1997) noted that in some banana stands, decomposed crop residues of a one resistant beer cultivar were infested more than freshly harvested ones. The next question to answer was whether survivorship on these residues varied with crop residue age.

Eclosion and survival rates on crop residues

We conducted another trial to investigate survival of *C. sordidus* on crop residues of different ages (Chapter 4). This would then help in understanding which crop residues to target for destruction in the control of *C. sordidus*. More weevils survived on fresh residues (c.f. Mesquita & Caldas, 1986). The adults from different aged residues were similar in weight and therefore probably equally fit.

Ecology of *C. sordidus*

Effect of crop sanitation on population dynamics and crop damage

To demonstrate the effect of crop sanitation on banana weevil population dynamics, we conducted on-farm and on-station field trials (Chapter 6 & 7). We evaluated the effect of crop sanitation on weevil population, weevil damage, and crop performance. These studies are difficult in a sense that confounding factors such as weather and soils may affect banana weevil populations. Further complications in studying this insect arise from the fact that the banana weevil is nocturnal and difficult to observe (Ittyeipe, 1986). However, our results were able to demonstrate that crop sanitation reduces banana weevil populations and damage (Chapter 6). The impact of crop sanitation was further evaluated with agronomic practices such as soil and water conservation practices that are thought to improve banana crop performance (see Gold et al., 2003), considered as covariates. Crop sanitation alone resulted in improved crop performance, and the covariates did not significantly affect banana yield parameters (Chapter 6).

In our on-farm trials, weevil populations fluctuated in all crop sanitation treatments depending on the season (Chapter 6). However, in general, populations remained lower where sanitation was practiced at higher levels. *C. sordidus* activity responds to various environmental conditions such as moisture regimes and relative humidity (see Roth & Willis, 1963).

In on-station trials, crop damage increased more in fields maintained at high than at low sanitation (Chapter 7). These are results from a controlled experiment in an isolated field (see below) aimed at providing deeper understanding of the mechanisms by which crop sanitation may influence weevil populations and damage. These findings seemed to support the hypothesis that destruction of crop residues (i.e. crop sanitation) removes hiding and breeding places for gravid females, in the process exposing growing banana plants to increased attack (Gold et al., 1993). The results obtained from the on-station trials would put in question the effectiveness of crop sanitation in reducing banana weevil damage.

Our on-farm and on-station trials presented different ecological environments for *C. sordidus*. The banana plots at the on-station trial were isolated by grass bands made them different and simulated a near closed population situation. Therefore, there was increased damage on plants located in plots where crop residues were destroyed. In Uganda, a study on the effect of *C. sordidus* on crop yield showed that the banana weevil pest problem becomes more pronounced with an increase in plantation age (Rukazambuga et al., 1998). Similarly, it is possible that the full benefits of crop sanitation become more evident when a plantation gets older rather than in young establishing ones.

Effect of crop sanitation on incidence of nematodes

At the beginning of the on-station trial, nematodes were used as a treatment to investigate its effect on weevil populations and their damage (chapter 7). However, analysis of the results indicated that nematodes had no effect *C. sordidus* incidence. We therefore investigated the effect of crop sanitation on nematode incidence. Habitat management as a pest control strategy also affects other organisms resident in the ecosystem. For example, crop sanitation tended to reduce nematode populations in the banana fields. The numbers of *H. multicinctu*s and *R. similis* were lower in plots maintained at high sanitation than in plots kept at low sanitation. However, there was no evidence that damage due to nematodes was reduced by higher sanitation levels (c.f. Speijer et al., 1999).

Effect of crop sanitation on incidence of natural enemies

Reported natural enemies of *C. sordidus* in East Africa include dermaptera, staphylinids, hydrophilids and histerids (Koppenhofer, 1993). These are generalist, opportunistic predators that are commonly associated with the banana mat and banana residues. In our study, we found higher incidence of these in fields with crop residues than in clean fields. Some of these arthropods are predacious to banana weevil immatures. Several authors have listed endemic arthropod natural enemies of *C. sordidus* in Africa (Koppenhofer 1993, Koppenhofer & Schumetter, 1993; Koppenhofer et al., 1992 and Tinzaara et al., 1999). Among those identified and tested in laboratory studies were *Thyreocephalus interocularis* (Epplesheim) (Coleoptera: Staphylinidae) and *Dactylosternum abdominale* (Fabr.) (Coleoptera: Hydrophilidae). These among others were predacious on weevil eggs and larvae. These findings do not in themselves negate the contribution of crop sanitation in pest control. What these results tell us is that there may be need to conduct further studies on the effect of crop sanitation on what would be beneficial organisms in banana systems, with the aim of maximizing the benefits of crop sanitation and at the same time trying to conserve the environment to protect the natural enemies.

Crop sanitation in integrated management of *C. sordidus*

The available methods for the control *C. sordidus* include cultural control, biological control, planting resistant varieties and application of chemicals. The use of crop sanitation for *C. sordidus* control has been widely recommended but with no data to support it. The contribution of crop sanitation as part of a wider IPM approach in pest control must be viewed in relation to its effect on banana weevil biology and ecology.

Use of clean planting material

For cultural control of *C. sordidus*, it is advisable to start with clean planting material (Peasely & Treverrow, 1986). Weevil-free suckers should be selected, for planting. Or, if the suckers are already infested, then precautions should be taken to ensure eggs and larvae on the suckers are removed by paring and hot water treatment (Gold et al., 1998). This delays pest population build-up in new banana fields. However, this method does not prevent later infestation by the pest from neighbouring fields. This is when other methods of control have to be applied to reduce *C. sordidus* population levels.

Crop sanitation

From our studies on *C. sordidus* distribution in banana fields, most oviposition occurred on corms of flowered and freshly harvested plants up to 30 days after harvest (Chapter 3). Therefore, residues should be left in the field up to a month before chopping them up. In this way, eggs and immatures will be killed and will not be able to develop to adults. Weevils lay eggs even on residues as old as 120 days. Also, since larvae and adults were more abundant in older residues, it might be beneficial to destroy all residues, as they are a potential source of infestation to standing plants.

Fresh residues had a higher number of eggs and the corm had more eggs than the pseudostems. Therefore, the part of the banana residue to destroy following harvest is the corm. After harvest, some farmers chop the pseudostem at ground level and place the pseudostems in the inter-mat alleys where they leave them intact or chopped and spread out. Farmers cut the remaining stump at various levels relative to the ground. In addition, a soil layer may be spread on the top of the banana stump, or the stump is left bare (Gold & Karamura, 2000). Our results indicate that deep cutting of the corm and its removal may be of benefit in reducing oviposition levels in the wet season (Chapter 5). This is because weevils are more active on the soil surface during the wet season. On the other hand, we found no differences in oviposition levels in the dry season. This suggested that in dry seasons, weevils burrow into the soil. Therefore, it may not be worth the trouble chopping banana stumps during dry periods, saving the farmers' precious labour for other farm activities.

Multiple cropping and agronomic practices

Multiple cropping and several agronomic practices can be used in pest management. For instance, intercropping systems may lower pest pressure by reducing insect immigration, interfering with host plant location and increasing emigration rates (Altieri & Letourneau, 1982). Some studies have been conducted on intercropping, using green manures (McIntyre et al., 2001). The effects of intercropping are limited presumably due to restricted mobility of *C. sordidus* and a narrow range of its natural enemies (Gold et al., 2003). We did not conduct a study on intercropping.

However, we did study the effects of some agronomic practices on weevil population and damage (Chapter 6). Construction of bunds and mulching to conserve soil moisture do not in themselves affect *C. sordidus* population and damage. Such practices are expected to enhance crop vigour so that plants withstand pest pressure. However, our study took hardly three years. Maybe the impact of these practices would have been more evident after having been applied for a longer time.

Trapping

Trapping of adults as a method to control *C. sordidus* populations has been used (Price, 1993). The traps employed comprise split pseudostem and disc-on-stump traps made out of post-harvest banana material whose effectiveness has been reviewed by Gold et al. (2003). Instead of chopping all the pseudostems and corms after harvest, some of these can be used to make traps while they are still fresh to trap adults, which can be collected after three days and killed. In Uganda, there have been reports of reduction of weevil populations using this method (Gold et al., 2002). However, because trapping using these kinds of traps is reportedly tedious, more efficient methods are being sought. For instance, kairomones and pheromones can be employed to aggregate the insects at delivery sites for biological control agents (Tinzaara et al., 2002). In our studies, crop residues aged more than 30 days after harvest were more attractive than fresh ones (Chapter 2). Such results suggest that plant extracts from these residues may be useful in improving trapping efficiency when they are used in combination with pheromones. Since the residues are attractive to *C. sordidus*, pheromone traps can be placed near them to help catch the adults.

Host plant resistance

Use of resistant varieties as a control strategy against the *C. sordidus* still has limited application in East Africa. This is because resistance is reported among the exotic bananas but none identified as being resistant to this pest among the commonly grown East African Highland banana and the plantains (Kiggundu, 2000). Our study on weevil distribution in banana fields in multi-cultivar stands showed that apart from one cultivar 'Entaragaza', all residues of the east African highland clones were equally susceptible to banana weevil attack (Chapter 3). Our laboratory bioassays on oviposition preferences did not show differences across the clones. We are not able to give conclusive recommendations on the resistant clones to farmers, because we only included nine cultivars and besides we did not evaluate the agronomic performance.

Biological control

Biological control agents such as the entomopathogenic fungi of the genera *Beauveria* and *Metarhizium* have a potential in the control *C. sordidus* in East Africa (Nankinga et al., 1994, 1999). However, one of the biggest challenges in using these microbial agents is to find an appropriate field delivery system, preferably based on the principle of contamination after the insects have been aggregated by kairomones and pheromones (Gold et al., 2003). In our studies on weevil distribution in farmers' fields (see Chapter 3), *C. sordidus* adults were more associated with cut residues. It may be possible to exploit this association by applying fungal spores on the residues so that adults can be infected as they feed and breed in the crop residues. Endemic arthropod natural enemies also thrive in these residues. Therefore, the residues should be left intact for a month to allow the build up natural enemy populations and then destroyed before *C. sordidus* completes its life cycle within the residues. Additionally, greater penetration of natural enemies may occur if the residues a split to allow them to enter.

Chemical control

Chemical control of *C. sordidus* control is mainly used on commercial farms and is usually successful (Gold et al., 1993; 1999). However, many small-scale farmers cannot afford these chemicals, and may also misuse them. *Cosmopolites sordidus* is reported to be resistant to many chemical compounds (Collins et al., 1991 and Gold et al., 1999). Because of pesticide resistance and the effect of chemicals to the environment, other forms of control are preferred.

Adoption of crop sanitation for *C. sordidus* control

The value of crop sanitation as a control strategy against *C. sordidus* has been debated over the years. For instance, some people have suggested that crop sanitation is a feasible long-term strategy to weevil control (Treverrow et al., 1992). Also, some authors, though with limited data have linked weevil control to crop sanitation (Nanne & Klink, 1975; Gold et al., 1997). A few authors have suggested that sanitation is too laborious and not worth the effort (e.g. Jones, 1968). In our study, we did not calculate the cost-effectiveness of crop sanitation; neither did we conduct a full study on its adoption. However, while at the beginning of the study in chapter 6 in July 1999, only five percent of the farmers in Ntungamo practiced high sanitation levels. By September 2001, this percentage had risen to 25%. Likewise, the percentage of farmers practicing low sanitation in 1999 was reduced to 20%. Most of these farmers were small-scale resource-constrained farmers. Therefore, it seems that crop sanitation is practicable and affordable to the small-scale farmer.

Conclusions

Although crop sanitation has been recommended over the years, there has been scanty data to demonstrate its effect on *C. sordidus* populations and damage. From our study, it appears that banana corms are most attractive to *C. sordidus*. Chopping banana crop residues and spreading them to dry reduces *C. sordidus* populations and damage. Crop sanitation, apart from keeping *C. sordidus* populations in banana fields low, may help in suppressing nematode incidence. *C. sordidus* can successfully complete their life cycle in crop residues and as such farmers should endeavour to keep banana fields clean in order to reduce weevil populations. The notion that crop sanitation is labour intensive may still hold, but many small-scale farmers in our study area adopted the method and successfully reduced weevil populations and damage, improving the banana yields on their farms. However, full benefits of crop sanitation may be realized if this method is adopted as a community effort. Judging from our results of the on-station trial (Chapter 7), complete removal of all crop residues in young banana stands may expose standing plants to increased attack. Finally, crop sanitation may contribute to suppressing weevil populations and damage but does not offer complete control. Therefore, for a long-term control strategy for *C. sordidus*, crop sanitation may work better in combination with biological control and the use of resistant cultivars.

The on-station trial was conducted under conditions of similar weevil pressure. It would be beneficial to conduct such a trial under various weevil pressure levels. This is because it is possible that the effects of crop sanitation in the on-station trials could have been masked by the high weevil incidence. Also, the real impact of crop sanitation on natural enemies needs to be assessed, coupled with studies on the effectiveness of the individual potential arthropod natural enemies found in the crop residues. A cost: benefit analysis study may be helpful in recommending a particular crop sanitation level to small-scale farmers. Because the full benefits of sanitation could be offset by immigration of weevils from nearby farms, studies on weevil migration among banana farms may be necessary. As a result of such studies, farmer communities could be advised on how to implement crop sanitation practices.

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English Summary

M. Masanza

Summary

Banana is an important food security crop in the East African Great Lakes region, but banana weevil (*Cosmopolites sordidus*) is a major constraint in its production. A review of the available control options showed that no single strategy has been effective in the control of the pest (**Chapter 1**). Cultural control strategies such as crop sanitation form the first line of defence against the pest and are the most readily available strategies to resource-poor banana farmers in East Africa. In this thesis, we report the effect of crop sanitation on *C. sordidus* population and damage in farmers' fields. Laboratory and field studies were conducted on the biology and ecology of *C. sordidus.* This provides insights into the mechanisms by which crop residues can be manipulated to control the pest.

Choice experiments were conducted in the laboratory in Uganda at Kawanda Agricultural Research Institute to determine attraction and acceptance of different aged crop residues to *C. sordidus* (**Chapter 2**). In the first experiment, studies focused on different types and ages of residues of one susceptible highland banana clone "Nabusa" (genome group AAA-EA). Corms attracted 65% of the test weevils, pseudostems 30%, and 5% were non-respondents. Females laid a higher number of eggs on young than old corms. In the second experiment, the same parameters were measured on banana residues of selected clones based on their levels of resistance and tolerance to banana weevil damage. Corms were more attractive to adults than pseudostems and flower stalks except for fresh residues of resistant clones. Pseudostems were more attractive than flower stalks with a few exceptions. The number of eggs per female did not differ across clones, but varied with residue age. The number of eggs per female was highest on flower stalks, followed by corms and pseudostems. On flower stalks, it was highest on old ones.

In **Chapter 3**, we report the results of on-station and on-farm trials, conducted in Uganda to investigate the effect of crop residue management on attack, oviposition and distribution of the *C. sordidus* on crop residues and growing plants. Oviposition and distribution were assessed on different aged standing and prostrate residues by destructive sampling. Similar data were collected from banana fields maintained at three sanitation levels. In the first experiment, oviposition occurred on residues as old as 120 days, but mainly between 0-30 days post-harvest. Weevil infestation varied among banana clones. In the second experiment, oviposition levels on standing residues were not significantly affected by age. Oviposition levels on prostrate four-week-old residues were two times higher than those on two-week-old residues, while the number of larvae on eight-week-old residues was three times higher than on two-week-old residues. The number of pupae did not differ at all ages of prostrate and standing residues. The number of adults on standing and prostrate 16-week-old residues was two times higher than that on two-week-old residues. In the third experiment, farmers' fields maintained at high sanitation level had 50% lower eggs per residue than those kept at low sanitation level. The number of immatures per residue was 50% higher on banana corms than on pseudostems. Larvae were three times more abundant at low than at high sanitation. The

number of pupae per residue at low sanitation was six times higher than at high sanitation level. Residues in fields at high sanitation hosted 50% less adults per residue than in fields at low sanitation. The results suggest that removal and splitting of corms after harvest is effective and practical in destroying immature growth stages of the pest.

The question arises if *C. sordidus* completes its life cycle in crop residues. We conducted laboratory trials to investigate *C. sordidus* eclosion success and larval survivorship on different aged banana residues at Kawanda in Uganda (**Chapter 4**). When we inserted less than 24-hour old eggs into corm pieces of four different aged susceptible banana cultivar "Kisansa" (genome group AAA-EA), eclosion rates were 66% in fresh, 67% in moderately old, 64% in old, and 58% in very old residues. To assess immature survival, less than 24-hour old larvae were put on banana corms of suckers and crop residues of the same cultivar "Kisansa" in single rearing chambers. The number of surviving individuals was recorded at three-day intervals until adults emerged. The proportion of surviving individuals 48 days after eclosion was 12% on sword suckers, 10% on maiden suckers, and 7% on flowered plants; after 51 days it was 12% on fresh, 8% on old, and 5% on very old corms. Larval development time and mean date of adult emergence increased with plant and crop residue age. Crop residue age did not affect adult weight, but the females were heavier than males. These results imply that fresh residues offer better nutrition for *C. sordidus* than old residues.

One of the cultural practices in controlling *C. sordidus* is the covering of banana stumps with soil after harvest. The effect of this practice on *C. sordidus* oviposition levels was investigated at Sendusu, Kawanda Agricultural Research Institute (KARI) and in the Ntungamo district of south-western Uganda (**Chapter 5**). In the first experiment we assessed oviposition levels in a banana system comprising growing plants and residues. Oviposition increased from sword suckers, reaching a peak 1 to 7 days after harvest, and it decreased thereafter. In the second experiment conducted on farmers' fields, corms received 70% of the eggs and pseudostems 30%. The area 5-10 cm below the collar received 27% of the eggs, the area 0-5 cm above the collar 30%, and the area 5-10 cm above the collar 0.3%. The remaining eggs (43%) were laid 0-5 cm below the collar. The effect of stump height and covering the stumps was evaluated in both the wet and dry seasons at Kawanda near Kampala and Ntungamo in the southwest of the country. Cutting stumps to ground level alone had no effect on oviposition. Covering post-harvest banana stumps reduced banana weevil oviposition in the wet but not in the dry season.

Apart from covering banana stumps, it is often recommended that post-harvest corms and pseudostems be removed to reduce weevil populations and damage. An on-farm study of the effect of crop sanitation on *C. sordidus* populations and corm damage was conducted in the Ntungamo district of south-western Uganda (**Chapter 6**). Farmers practiced sanitation levels that can be broadly defined as low, moderate and high. Soil conservation methods such as making bunds, mulching and application of manure were treated as covariates. Increase in sanitation level from low to high significantly reduced adult weevil population density from 52,000 to 13,000 ha^{-1}, lowered corm damage by 41% after three years, enhanced plant girth by 10% and plant height by 13% at flowering and increased yield by about 70%. There was a weak relationship between *C. sordidus* population density and plant damage. Shifting from a low to a high sanitation level significantly reduced corm damage. This study has demonstrated the great potential of crop sanitation in controlling *C. sordidus* populations, and reducing damage to the crop.

The on-farm study was complicated by farmer attrition and changes in management with time. So, we conducted a controlled experiment at Kawanda whose results are reported in **Chapter 7**. We evaluated the effect of crop residue removal on weevil population, weevil damage, nematode and arthropod natural enemy incidence in isolated young banana stands. A closed banana weevil population assumes no emigration or immigration between plots. We infested isolated banana plots with 5-10 weevils and a complex of 3,000 nematodes per plant. As harvesting started, we subjected the plots to low, moderate and high crop sanitation levels. High sanitation levels reduced trap catch by up to 40%, and weevil population by up to 43%. However, weevil attack increased on standing plants causing up to 34% yield reduction. Crop sanitation seemed to reduce nematode populations but not damage. Plant growth was not affected until the fourth crop cycle when girth reduced by 10% and height by 6% in plots under high sanitation compared to plants in low sanitation fields. Plant girth and height increased with crop cycle. Complete removal of crop residues resulted in a three-fold reduction in arthropod natural enemies compared to leaving the residues intact, but it did not affect total oviposition on growing plants. In young banana stands with closed weevil populations, removal of crop residues seems to expose growing plants to increased weevil attack.

A summary of our results on biology and ecology of *C. sordidus* is given (**Chapter 8**). The place of crop sanitation in an IPM framework with other control strategies is discussed. Conclusions from this thesis can be summarized as follows:

- Banana corms compared to pseudostems and other banana plant parts are more attractive to *C. sordidus.*
- Chopping banana crop residues and spreading them to dry up reduces *C. sordidus* populations and crop damage.
- Crop sanitation, apart from keeping *C. sordidus* populations in banana fields low, may help in suppressing nematode incidence.
- *Cosmopolites sordidus* can successfully complete its life cycle in crop residues and as such farmers should endeavour to keep banana fields clean in order to reduce weevil populations.
- The notion that crop sanitation is labour intensive may still hold, but many small-scale farmers in our study area adopted the method and successfully reduced weevil populations and damage, improving the banana yields.

- Full benefits of crop sanitation may be realized if this method is adopted as a community effort.
- Complete removal of all crop residues in young banana stands may expose standing plants to increased attack.
- Crop sanitation does not offer complete control. Therefore it should be combined with other methods that reduce or prevent an increase in weevil numbers, such as biological control and planting resistant cultivars in order to obtain a sustainable control of *C. sordidus*.

Future perspectives

- Since the on-station trial was conducted under conditions of similar weevil pressure, it would be beneficial to carry out such a trial under various levels of weevil pressure, because different weevil pressures may respond differently to crop sanitation.
- Studies on weevil migration among banana farms may be necessary so that farmer communities could be advised on how to better implement crop sanitation practices.
- A cost: benefit analysis study may be helpful in recommending a particular crop sanitation level to small-scale farmers.
- The impact of crop sanitation on a few selected arthropod natural enemies needs to be assessed, in order to find out whether crop sanitation enhances or frustrates biological control using them.

Samenvatting

M. Masanza

Samenvatting

Banaan is een belangrijke voedselbron in de oost-afrikaanse Great Lakes region, de bananen(snuit)kever (*Cosmopolites sordidus*) vormt echter een grote beperking voor de bananenproduktie. Een overzicht van alle beschikbare bestrijdingsmethoden liet zien dat niet één enkele strategie effectief is in het bestrijden van de pest (**Hoofdstuk 1**). Culturele bestrijdingsstrategiën zoals gewassanitatie vormen de eerste verdedigingslijn tegen de pest en zijn direkt beschikbaar voor arme bananentelende boeren in oost-afrika. In dit proefschrift richten wij ons op het effect van gewassanitatie op *C. sordidus* en de schade in de bananenvelden van de boeren. Laboratorium- en veldstudies naar de biologie en ecologie van *C. sordidus* werden uitgevoerd. Dit verschaft ons inzicht in de mechanismen waarmee gewasresiduen kunnen worden gemanipuleerd om de pest te bestrijden.

Keuzeexperimenten werden uitgevoerd in het laboratorium in Uganda bij het Kawanda Agricultural Research Institute om de aantrekkingskracht van gewasresiduen van verschillende leeftijden voor, en de acceptatie van deze residuen door, *C. sordidus* te bepalen (**Hoofdstuk 2**). In het eerste experiment richtte de studie zich op verschillende typen en leeftijden van residuen van een ontvankelijke hoogland bananencultivar "Nabusa" (genoom groep AAA-EA). Wortelstronken trokken 65% van de geteste snuitkevers aan, pseudostengels 30%, en 5% van de kevers reageerden niet. Vrouwtjes legden een groter aantal eieren op jonge wortelstronken i.v.m. oude wortelstronken. In het tweede experiment werden dezelfde parameters gemeten op bananenresiduen van verschillende cultivars geselecteerd op basis van hun resistentie en tolerantie tegen bananenkeverschade. Wortelstronken waren aantrekkelijker voor adulten dan pseudostengels en bloemenstelen behalve verse residuen van resistente cultivars. Pseudostengels waren aantrekkelijker dan bloemenstelen met een paar uitzonderingen. Het aantal eieren per vrouwtje verschilde niet tussen de verschillende cultivars, maar was wel verschillend tussen de verschillende residuleeftijden. Het aantal eieren per vrouwtje was het grootst op de bloemenstelen, gevolgd door wortelstronken en pseudostengels. Op de bloemenstelen was dit aantal het grootst op oude stelen.

In **Hoofdstuk 3** laten we de resultaten zien van "on-station" en "on-farm" proeven uitgevoerd in Uganda om het effect van gewasresidumanagement op de aanval, eileg en verspreiding van *C. sordidus* in gewasresiduen en groeiende planten te onderzoeken. Eileg en verspreiding werden beoordeeld op "standing" en "prostrate" residuen van verschillende leeftijd via destructief verzamelen. Vergelijkbare data werden verzameld in bananenvelden gehandhaaft op drie sanitatieniveau's. In het eerste experiment vond eileg plaats op residuen zo oud als 120 dagen, maar vooral tussen 0-30 dagen na de oogst. Keverinfectie varieerde tussen bananencultivars. In het tweede experiment werd eileg op "standing" residuen niet sigificant beïnvloedt door leeftijd. Eilegniveau's op vier weken oude "prostrate" residuen waren tweemaal hoger dan die op twee weken oude residuen, terwijl het aantal larven op acht weken oude residuen driemaal zo hoog was als op twee

weken oude residuen. Het aantal poppen was hetzelfde op “prostrate” en “standing” residuen van alle leeftijden. Het aantal adulten op 16 weken oude “standing” and “prostrate” residuen was tweemaal zo hoog als op twee weken oude residuen. In het derde experiment hadden bananenvelden gehandhaaft op een hoog sanitatieniveau 50% minder eieren per residu dan die gehandhaaft op een laag sanitatieniveau. Het aantal onvolwassen kevers per residu was 50% hoger op bananenwortelstronken dan op pseudostengels. Larven waren drie keer zo algemeen bij lage als bij hoge sanitatieniveau’s. Het aantal poppen per residu bij lage sanitatie was zes keer hoger dan bij een hoog sanitatieniveau. Residuen in velden gehandhaaft bij hoge sanitatie bevatten 50% minder adulten per residu dan die in velden met een lage sanitatie. De resultaten suggereren dat het verwijderen en opdelen van wortelstronken na de oogst een effectieve bestrijdingsmethode is tegen onvolwassen stadia van de pest.

De vraag doet zich voor of *C. sordidus* z’n levencyclus volbrengt in gewasresiduen. We hebben laboratorium proeven uitgevoerd om de fractie uitgekomen eieren (eclosie) en larvale overleving van *C. sordidus* op bananenresiduen van verschillende leeftijden in Kawanda (Uganda) te onderzoeken (**Hoofdstuk 4**). Als we minder dan 24 uur oude eieren tussen wortelstronken van vier verschillende leeftijden van de ontvankelijke bananencultivar “Kisansa” (genoom groep AAA-EA) voegden, waren de eclosiefrequenties 66% in verse, 67% in gematigd oude, 64% in oude, en 58% in zeer oude residuen. Om de overleving van onvolwassen stadia te bepalen werden minder dan 24 uur oude larven op banaanwortelstronken van jonge planten en gewasresiduen van dezelfde cultivar “Kisansa” uitgezet in enkele kweekkamers. Het aantal overlevende individuen werd, met intervals van drie dagen, geteld tot de adulten verschenen. De fractie overlevende individuen 48 dagen na eclosie was 12% op jonge “zwaard” planten, 10% op jonge “dames” planten, en 7% op bloeiende planten; na 51 dagen was dit 12% op verse, 8% op oude, en 5% op zeer oude wortelstronken. Larvale ontwikkelingstijd en gemiddelde datum van het verschijnen van de adulten namen toe met plant- en residuleeftijd. Residuleeftijd beïnvloedde het gewicht van de adulten niet, maar vrouwtjes wogen meer dan mannetjes. Deze resultaten impliceren dat verse residuen een betere voedselbron vormen voor *C. sordidus* dan oude residuen.

Eén van de culturele praktijken bij het bestrijden van *C. sordidus* is het, na de oogst, bedekken van bananenresiduen met aarde. Het effect hiervan op eileg van *C. sordidus* werd onderzocht in Sendusu, Kawanda Agricultural Research Institute (KARI) en in het Ntungamo district van zuid-west Uganda (**Hoofdstuk 5**). In het eerste experiment hebben we het eilegniveau bepaald in een bananensysteem bestaande uit groeiende planten en residuen. Eileg nam toe van jonge “zwaard” planten, met een piek bereikend 1 tot 7 dagen na de oogst, en daalde daarna. In het tweede experiment dat in de proefvelden werd uitgevoerd ontvingen de wortelstronken 70% van de eieren en pseudostengels 30%. Het oppervlak 5-10 cm onder de grens tussen wortelstronk en stengel ontving 27% van de eieren, het oppervlak 0-5 cm boven die grens 30%, en het oppervlak 5-10 cm boven die grens 0.3%. De rest van de eieren (43%) werden gelegd op

0-5 cm onder de grens tussen wortelstronk en stengel. Het effect van residuhoogte en het bedekken van de residuen werd onderzocht in zowel het droge als het natte seizoen in Kawanda nabij Kampala en Ntungamo in het zuid-westen van het land. Het alleen afsnijden van de residuen tot grondniveau had geen effect op eileg. Het bedekken van de residuen na de oogst reduceerde eileg in het natte, maar niet in het droge, seizoen.

Behalve het bedekken van bananenresiduen wordt er vaak aangeraden de wortelstronken en pseudostengels weg te halen om keverpopulaties en schade te reduceren. Een "on-farm" studie naar het effect van gewassanitatie op *C. sordidus* populaties en wortelstronkschade werd uitgevoerd in het Ntungamo district van zuid-west Uganda (**Hoofdstuk 6**). Boeren voerden sanitatieniveau's uit die gedefinieerd kunnen worden als laag, matig en hoog. Methoden van bodembeheer zoals het maken van "bunds" (gegraven kanalen met verhoogde bermen waarop gras is aangeplant), het bedekken van de bodem (bv. met grassen) om de vochtigheid te bewaren en bemesten werden als covariaten behandeld. Toename in sanitatieniveau van laag naar hoog reduceerde de adulte keverdichtheid significant van 52,000 tot 13,000 ha^{-1}, reduceerde schade aan wortelstronk met 41% na drie jaar, vergrootte plantomtrek met 10% en planthoogte met 13% tijdens bloeien en vergrootte de oogst met ongeveer 70%. Er was een zwakke relatie tussen de populatiedichtheid van *C. sordidus* en de schade aan de plant. Verandering van laag naar hoog sanitatieniveau reduceerde de wortelstronkschade significant. Deze studie laat het grote potentiaal zien van gewassanitatie in het bestrijden van *C. sordidus* populaties, en het reduceren van schade aan het gewas.

Deze "on-farm" studie werd bemoeilijkt door de vermoeidheid van de boeren en de veranderingen in management. Daarom voerden we een gecontroleerd experiment uit in Kawanda waarvan de resultaten beschreven zijn in **Hoofdstuk 7**. We evalueerden het effect van het verwijderen van de residuen op de keverpopulatie, keverschade en de aanwezigheid van nematoden en geleedpotige natuurlijke vijanden in geïsoleerde jonge bananenplantages. Een gesloten bananenkever populatie wil zeggen dat er geen emigratie of immigratie is tussen plots. We infecteerden geïsoleerde bananen plots met 5-10 kevers en een complex van 3000 nematoden per plant. Zodra het oogsten begon, verzorgden we een laag, matig of hoog sanitatieniveau in de plots. Hoge sanitatieniveau's reduceerden de vangst in de vallen tot 40%, en de keverpopulatie tot 43%. De aanval van kevers op staande planten zorgde echter voor een oogstreductie van 34%. Gewassanitatie leek de nematoden populaties te reduceren maar niet de schade. Plantengroei werd niet beïnvloedt tot de vierde plantencyclus als de omtrek met 10% was gereduceerd en hoogte met 6% in plots onder hoge sanitatie i.v.m. planten in velden met lage sanitatie. Plantenomtrek en hoogte namen toe met gewascyclus. Complete verwijdering van residuen resulteerde in een drievoudige reductie in arthropode natuurlijke vijanden i.v.m. het intact laten van de residuen, maar dit beïnvloedde de totale eileg op groeiende planten niet. In jonge bananenplantages met gesloten keverpopulaties lijkt het verwijderen van residuen te resulteren in een grotere aanval van kevers op groeiende planten.

Een samenvatting van onze resultaten over de biologie en ecologie van *C. sordidus* wordt gegeven (**Hoofdstuk 8**). De plaats van gewassanitatie in een IPM framework met andere bestrijdingsstrategiën wordt bediscussieerd. Conclusies uit dit proefschrift kunnen als volgt worden samengevat:

- Bananenwortelstronken zijn aantrekkelijker voor *C. sordidus* dan pseudostengels en andere delen van bananenplanten.
- Het afkappen en verdrogen van banananenresiduen reduceerd de *C. sordidus* populaties en de schade aan het gewas.
- Gewassanitatie, naast het laag houden van de *C. sordidus* populaties in bananenvelden, zou kunnen helpen tegen de aanwezigheid van nematoden .
- *Cosmopolites sordidus* kan zijn levenscyclus voltooien in residuen en boeren moeten daarom hun velden schoonhouden om keverpopulaies te reduceren.
- De notie dat gewassanitatie arbeidsintensief is mag dan nog steeds gelden, veel kleinschalige boeren in ons studiegebied hebben deze methode aangenomen en reduceren de keverpopulaties en schade met success, en verhogen daarbij de bananenoogst.
- Grote voordelen kunnen uit de toepassing van gewassanitatie gehaald worden als deze methode als een gemeenschappelijke inspanning gezien wordt.
- Complete verwijdering van alle residuen in jonge bananenplantages kan de planten blootstellen aan een grotere aanval van de pest.
- Gewassanitatie biedt geen volledige bestrijding. Daarom moet het gecombineerd worden met andere methoden die een toename in de aantallen kevers voorkomt of reduceerd zoals biologische bestrijding en het planten van resistente cultivars om een duurzame bestrijding van *C. sordidus* te bewerkstelligen.

Toekomstperspektieven

- Aangezien de “on-station” proef werd uitgevoerd onder gelijke keverdruk, zou het interessant zijn om een dergelijke proef uit te voeren onder een verschillende niveau’s van keverdruk, omdat verschillende niveau’s van keverdruk verschillend kunnen reageren op gewassanitatie.
- Studies naar de migratie van kevers tussen bananenboerderijen is noodzakelijk zodat boerengemeenschappen geadviseerd kunnen worden over hoe gewassanitatie beter geïmplementeerd kan worden.
- Een kosten-baten analyse zou nuttig kunnen zijn in het aanbevelen van een bepaald gewassanitatieniveau aan kleinschalige boeren.
- De impact van gewassanitatie op sommige geselecteerde arthropode natuurlijke vijanden moet bepaald worden om uit te vinden of gewassanitatie hun gebruik in de biologische bestrijding bevoor- of benadeeld.

Curriculum vitae

Michael Masanza was born in Bubulo, Mbale District in eastern Uganda on February 23, 1961. He attended Toma-Butta Primary School and later joined Nabumali High School where he completed Ordinary and Advanced level secondary education. He proceeded to the National Teachers' College in Nagongera where he obtained the Makerere University Diploma in Education in 1985. Thereafter, he taught Agriculture and Biology in Bubulo Girls' High School in Mbale District for three years before joining Makerere University in Kampala in 1989, where he obtained a B.Sc. in Agriculture (Crop Science option) in 1993. He worked as Assistant Project Manager in charge of crop protection and quality control for Nile Roses Ltd in Mukono (Uganda), a company that produced flowers for export to Europe. However, this was short-lived as the Makerere University Faculty of Agriculture and Forestry nominated him for a scholarship funded by the United States Agency for International Development/Manpower For Agricultural Development ((USAID/MFAD) to pursue a Masters of Science degree in Agriculture (Crop Protection). His thesis research was entitled "*Integrating pseudostem trapping, chemical and biological control for the management of the banana weevil Cosmopolites sordidus (Germar) (Coleoptera: Curculionidae)*. Among his duties was conducting practical lessons in entomology for undergraduate students at the Faculty of Agriculture and Forestry at Makerere University. He completed his M.Sc. degree in 1996. The same year he was offered the post of Research Assistant with the International Institute of Tropical Agriculture, Eastern and Southern Africa Regional Centre (IITA-ESARC) through September 1997. His work focused on the use habitat management/cultural strategies in the management of the banana weevil. In 1997, he was appointed a Research Fellow at IITA. The Rockeffelor Foundation funded his fellowship through the IITA to pursue doctoral studies at Wageningen University. The study was a sandwich construction with the first year 1997-1998 spent at Wageningen University where he did relevant courses in entomology, statistics and experimental design. This doctoral thesis is a result of the research conducted in Uganda between 1999 and 2002 at Kawanda Agricultural Research Institute (KARI), the IITA Sendusu station in Namulonge and in Ntungamo district on farmers' fields in a farmer participatory design.

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List of publications

M. Masanza, C.S. Gold and A. van Huis (to be submitted) Influence of different aged banana crop residues on attraction and host acceptance of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae)

M. Masanza, C.S. Gold and A. van Huis (to be submitted) Distribution, timing of attack and oviposition of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) on banana crop residues in Uganda

M. Masanza, C.S. Gold, A. van Huis ans P.E. Ragama (to be submitted). Influence of plant and residue age on egg eclosion and larval survival of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae)

M. Masanza, C.S. Gold and A. van Huis (to be submitted) Effects of covering post-harvest highland banana (AAA-EA) stumps with soil on banana weevil *Cosmopolites sordidus* oviposition

M. Masanza, C.S. Gold, A. van Huis, P.E. Ragama and S.O. Okech (to be submitted) Effect of crop sanitation on banana weevil *Cosmopolites sordidus,* (Germar) (Coleoptera: Curculionidae) populations and crop damage in Uganda

M. Masanza, C.S. Gold, A. van Huis and A.K. Abera (to be submitted) Effect of crop residue removal on banana weevil, nematode and natural enemy incidence in young isolated banana stands

Other publications

Masanza, M. (1999). Effects of crop sanitation on banana weevil *Cosmopolites sordidus*, Germar, (Coleoptera:Curculionidae) population and damage. A progress report. IITA. Kampala pp.43.

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