Integrated Pest Management for sweetpotato in Eastern Africa

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Integrated Pest Management for sweetpotato in Eastern Africa

Proefschrift
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dr. C.M. Karssen,
in het openbaar te verdedigen
op vrijdag 13 juni 1997
des namiddags te vier uur in de Aula.

Aan de kleine boeren
in Oost Africa.

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The research described in this thesis was carried out between 1990 and 1995, while the author was working as an associate expert for the Directorate General for International Cooperation of the Ministry of Foreign Affairs of the Netherlands. She was detached to the International Potato Center (CIP). Duty stations were the Mbita Point Field Station of the International Centre for Insect Physiology and Ecology (ICIPE) in South Western Kenya in the period 1990-1992 and from 1993 onwards the Namulonge Agricultural and Animal Production Research Institute (NAARI) near Kampala, Uganda. The research costs were covered by CIP and partly by the Overseas Development Organisation through project R6115H.

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Stellingen

1. Uit het oogpunt van effectieve bestrijding van snuitkevers in bataat hoeft "opslag-in-de-grond" gecombineerd met "stapsgewijs" oogsten (een traditionele teeltmaatregel) in oostelijk Afrika, niet te worden vervangen door tijdig, eenmalig oogsten (de "moderne" teeltmaatregel).
   Dit proefschrift

2. Het is onwaarschijnlijk dat een bodembehandeling met de pathogene schimmel *Beauveria bassiana* effectieve bescherming biedt tegen *Cylas* snuitkevers in bataat.
   Dit proefschrift

3. Resistentie tegen de batatensnuitkever bestaat wellicht niet in de waardsoort *Ipomoea batatas*, daar het insect met het voeden aan de knol nooit de groei, reproductie of overleving van de plant in gevaar brengt.
   Talekar, N.S., 1987. Insect Science and its Application 8:815-817

4. Het massaal vangen van mannelijke snuitkevers met sexferomonen heeft beperkte zin als bestrijdingsmaatregel indien de overgebleven mannetjes meerdere vrouwtjes kunnen bevruchten.
   Dit proefschrift; Birch, M.C. and K.F. Haynes, 1982. Insect pheromones. Edward Arnold, London

5. Voor een zelfvoorzieningsgewas als bataat zullen boeren alleen bereid zijn tijdrovende en arbeidsintensieve maatregelen ter bestrijding van plagen te nemen indien ze er van overtuigd zijn dat ze hiermee een breed scala van teelt- en gebruiksproblemen aanpakken.
   Dit proefschrift

6. Bataat is een onaangeboorde voedselbron
   Woolfe, J.A., 1992. Sweet potato an untapped food resource. Cambridge University Press.

7. Oeganda is een bataat-wereldmacht.
   Bashaasha, B., pers. comm.; FAO agricultural statistics.

8. Een positief aspect van bataat is dat, vergeleken met andere voedselgewassen in de Oost-Afrikaanse regio als banaan, gierst, sorghum en cassava, het niet op dorpsniveau tot een smakelijk alcoholisch produkt gebrouwen kan worden.

9. Zolang in oostelijk Afrika de bevolkingsgroei de toename van de landbouwproduktie overtreft, en geboortebeperking een lage prioriteit heeft, is het slechts beperkt zinvol om aan verbetering van de landbouwproduktie te werken.

10. Iedere Nederlander met politieke aspiraties zou een stageperiode van een half jaar in een ontwikkelingsland zoals bijvoorbeeld Oeganda door moeten brengen, zodat hij of zij het begrip armoede in Nederland zal kunnen relativeren.

11. Bij de beoordeling van bezwaren tegen geluidsoverlast van Schiphol dienen klachten van Air-miles-spaarders buiten beschouwing gelaten te worden.

Stellingen behorend bij het proefschrift van Nicole Smit, getiteld "Integrated Pest Management for Sweetpotato in Eastern Africa", te verdedigen op 13 juni 1997 in de Aula van de Landbouwuniversiteit te Wageningen.

Contents

PART I GENERAL INTRODUCTION

1. SWEETPOTATO AND ITS PEST PROBLEMS

1.1 Introduction

Sweetpotato weevils, *Cylas* spp., are the most destructive and widely distributed pest of sweetpotato (*Ipomoea batatas* (L) Lam) in tropical and subtropical areas of the world. Larvae of this pest tunnel through roots which results in major damage and economic yield loss (Chalfant et al., 1990). Weevil damage imparts a characteristic terpene odour to the roots, which renders damaged roots unfit for human consumption (Uritani et al., 1975).

Only one pest species is circumglobally distributed, *C. formicarius* Fab, although it is rare in continental Africa. Two other important species, *C. puncticollis* Bohe. and *C. brunneus* Fab. are restricted to Africa (Wolfe, 1991).

As a result of an International Conference on Sweet Potato Pest Management (1989, Miami, Florida, USA) the book "Sweet Potato Pest Management: A Global Perspective" (Jansson and Raman, eds., 1991) evolved. Until then, most research on Integrated Pest Management (IPM) strategies for sweetpotato pest had concentrated on *C. formicarius* and had been done in the United States and in Asia. In the USA research efforts concentrated on the use of sex pheromone (Jansson et al., 1991), biological control (Jansson, 1991) and breeding for host-plant resistance (Collins et al., 1991). At the Asian Vegetable Research and Development Center (AVRDC) host-plant resistance and cultural control practices were studied (Talekar, 1991). Information on the biology and management approaches for the African sweetpotato weevil species was very limited. The International Potato Center (CIP) had just taken over the mandate for the commodity sweetpotato within the Consultative Group on International Agricultural Research (CGIAR). CIP agreed to post an IPM researcher in Eastern Africa and the present PhD thesis is a result from this research.

The reported research work was undertaken in collaboration with the National Agricultural Research Systems (NARS) of Kenya and Uganda between 1990 and 1995. For the first three years research was conducted at and from the Mbita Point Field Station of the International Centre for Insect Physiology and Ecology (ICIPE) in South-Western Kenya. The last three years work was done at and from the Namulonge Agricultural and Animal Production

Research Institute (NAARI) in Central Uganda.

1.2 Origin, spread and importance of sweetpotato

Sweetpotato, *Ipomoea batatas* (L.) Lam., is the only important economic food plant of the family Convolvulaceae (Purseglove, 1968). Sweetpotato originated in or near Northwestern South America around 8,000-6,000 B.C. (Austin, 1988). The countries of Guatemala, Colombia, Ecuador, and Peru have the greatest diversity in sweetpotato germplasm (Austin, 1983). The crop spread in pre-Columbian times into Polynesia, and European explorers introduced the crop into Africa and Asia (Yen, 1982). Secondary centres of genetic variability are Papua New Guinea, the Philippines, and Eastern Africa (Yen, 1982).

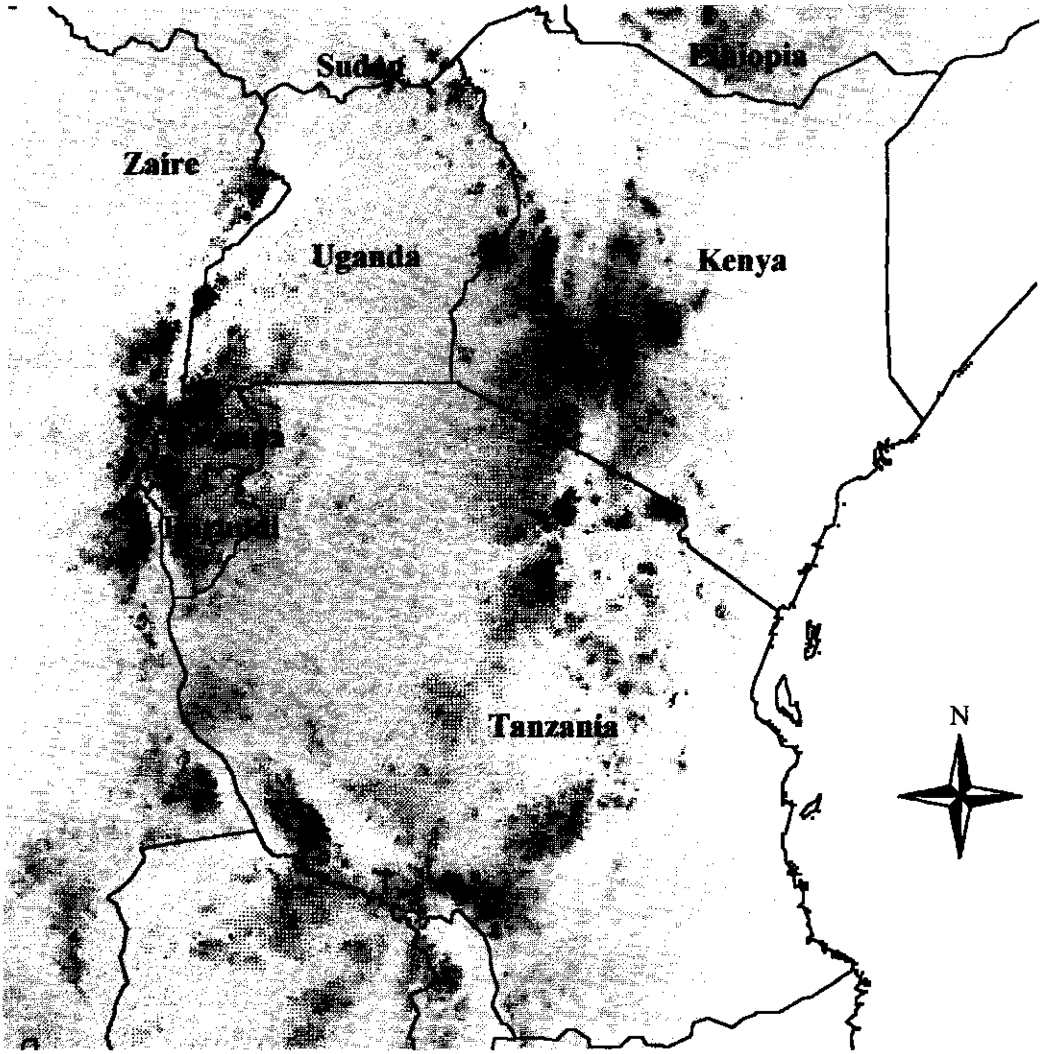
Sweetpotato ranks seventh among all food crops world-wide, with an annual production of 124 million metric tons (FAO, 1996; CIP, 1996). Of the root and tuber crops, sweetpotato ranks third in acreage (9.1 million ha) behind Irish potato, *Solanum tuberosum* L., (18.1 million ha) and cassava, *Manihot esculentum* Crantz, (16.0 million ha) (FAO, 1996). It is grown in more than 100 countries, and developing countries produce and consume nearly all of the world's sweetpotatoes (Horton et al., 1989; FAO, 1996). Approximately 92% of the world's sweetpotato is produced in Asia; 92% of this is found in China (CIP, 1996). Indonesia, Vietnam and Uganda follow China in production. Africa accounts for 5% of the total production and 15% of the total area under sweetpotato (Table 1.1). Several small countries, including some Pacific and Caribbean Islands, Rwanda and Burundi, have high levels of per capita production, with sweetpotato playing an important economic and dietary role (FAO, 1996).

Until recently sweetpotato received much less research-and-development attention than have other crops, work in China being the exception (Horton et al., 1989). A reason could be that sweetpotato is not a cash crop and is primarily a crop for poor farmers in developing areas. Since 1987 CIP has taken the lead to increase research efforts.

1.3 Sweetpotato in the food systems of Eastern Africa

1.3.1 Introduction

Sweetpotato is an important crop in two types of food systems in Eastern Africa. Throughout this document Eastern Africa is meant to include Kenya, Uganda, Tanzania, Rwanda and Burundi (Map 1.1). The term food system refers to the complex of



Map 1.1 Eastern African countries with altitude indications.

Table 1.1 Sweetpotato production from 1971 to 1993 in Africa and the world.

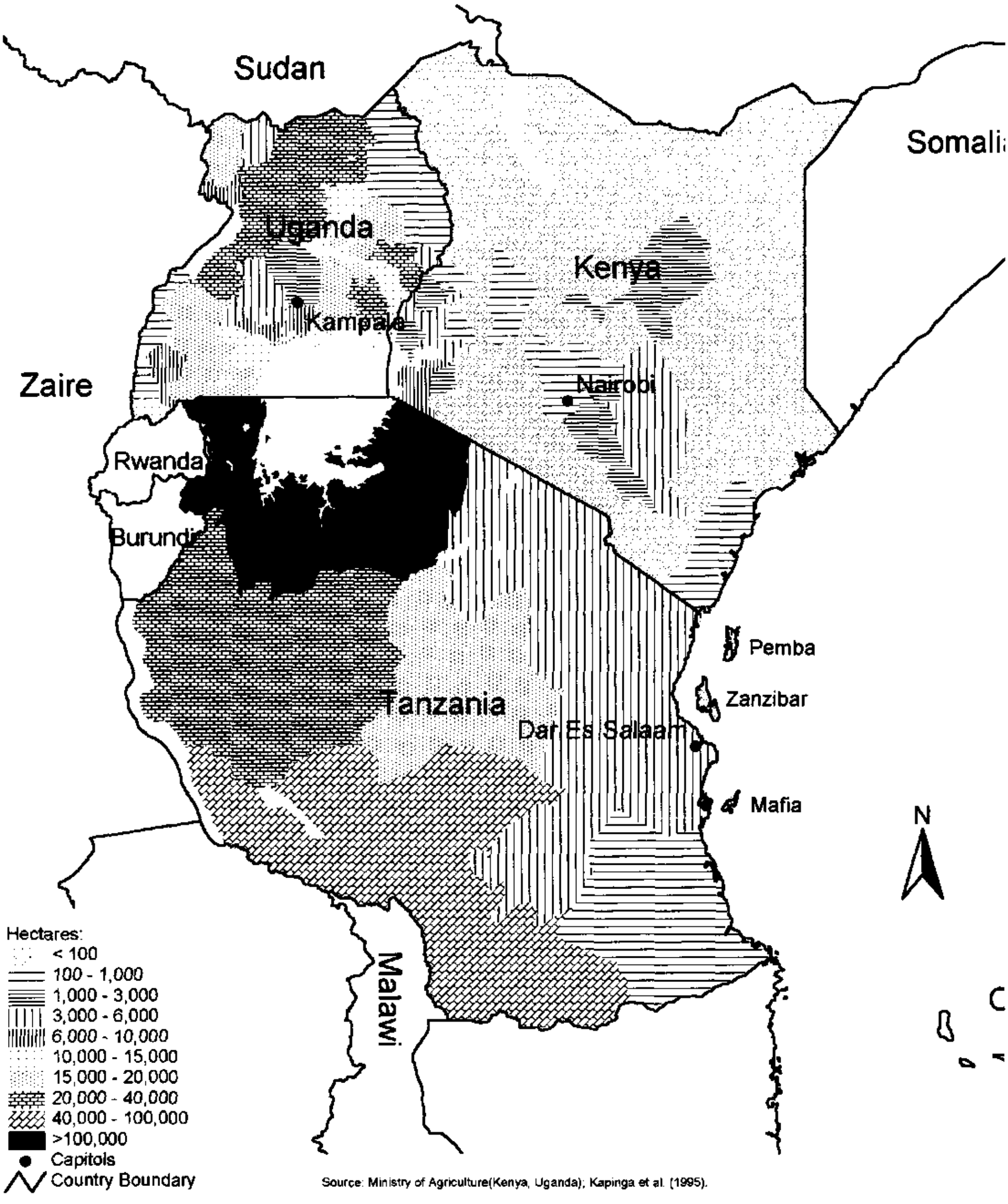
	1991/1993 average			1981/1983 average			1971/1973 average		
	Prod. (000t)	Area (000ha)	Yield (t/ha)	Prod. (000t)	Area (000ha)	Yield (t/ha)	Prod. (000t)	Area (000ha)	Yield (t/ha)
Uganda	1861	439	4.2	1543	393	3.9	1293	468	2.8
Rwanda	773	161	4.8	969	121	8.0	413	71	5.8
Burundi	687	108	6.4	496	78	6.4	380	60	6.3
Kenya	593	60	9.9	386	39	9.9	250	31	8.1
Tanzania	269	210	1.3	304	122	2.5	277	90	3.1
	----	----		----	----		----	---	
Sub-total	4183	978	4.3	3698	753	4.9	2613	720	3.6
Africa	6310	1352	4.7	5617	1093	5.1	4283	1030	4.1
China	105150	6228	16.9	111775	7099	15.8	114358	9085	12.6
Indonesia	2163	228	9.5	1994	258	7.7	2221	358	6.2
Vietnam	2437	387	6.3	2222	401	5.5	1133	229	5.0
World	123760	9109	13.6	131439	9969	13.2	134288	11953	11.2

Source: FAO AGROSTAT-PC, 1996

cropping patterns, production technologies, food consumption habits, and marketing links which determine what and how well people eat (Ewell and Mutuura, 1994).

The first type can be defined as food systems in which sweetpotato is a major staple in the diet, along with other starchy staples such as banana, potato, and cassava, plus beans. This pattern is found in the densely populated highlands (1,000 - 2,000 m) near Lake Victoria - in Uganda, Rwanda, Burundi, and adjacent parts of Zaïre and Tanzania (Ewell and Kirkby, 1991). In many of these regions very high and increasing population pressure on limited land resources is requiring the further intensification of production practices, which threatens the long-term productivity of the environment (Ewell and Mutuura, 1994).

The second type are food systems where maize and other grains are the basic staples, but where sweetpotato is an important secondary food. This pattern is found in Kenya, most of Tanzania and Ethiopia. Sweetpotato plays critical roles in rural diets in certain areas, in the "hungry months" when maize and other foods run short, and in years of drought and other catastrophe (Scott and Ewell, 1992).



Map 1.2 Sweetpotato Production in East Africa (1994 Hectares)

Sweetpotato grows in all arable agroecological zones in the region from semi-arid lowlands to high-altitude zones with near-temperate climates. Cultivation is most intense in a diverse set of environments located between 800 m and 1900 m (Scott and Ewell, 1992).

Five countries in Eastern Africa account for almost 70% of total sweetpotato production in Sub-Saharan Africa. Uganda alone registers an output of 1.9 million tons - nearly 30% of the total for Africa. Rwanda, Burundi, Kenya and Tanzania account for another 2.3 million tons (Table 1.1, Map 1.2). According to FAO estimates, world sweetpotato production fell in the last 20 years, although African production increased throughout the entire period (Table 1.1). Nevertheless, average reported yields in the continent and in Eastern Africa hardly increased in the same period.

Until the late 1980s, research investment by national and international agricultural institutes on sweetpotato in Eastern Africa was far below that received by crops such as maize, cassava, and potato. This disparity developed partly because the role and significance of sweetpotato in the region were not fully appreciated (Scott and Ewell, 1994). This changed when in 1988 the national agricultural research systems (NARS) of the region collaborated with the regional office of the CIP in Nairobi, Kenya on sweetpotato research. Baseline studies of the patterns of production and utilization were carried out in several countries (Mutuura et al., 1992; Bashaasha et al., 1995; Kapinga et al., 1995). The goal was to provide a users' perspective, -to identify areas where research is likely to have the most impact, and to respond to the priority needs of farmers, traders, consumers and processors of the commodity (Ewell and Mutuura, 1994).

1.3.2 Production systems

Sweetpotato is commonly produced in complex, mixed cropping systems. Eastern African sweetpotato producers are most often small, resource-poor farmers. Sweetpotato production is dominated by women (Mutuura et al., 1992; Bashaasha et al., 1995). Production practices are commonly carried out with hand tools. Production takes place on small plots, rarely more than half a hectare in size. Total area planted per farm per year is typically less than one hectare, although some larger scale commercial production exists (Mutuura et al., 1992; Smit and Matengo, 1994). Many small farmers manage the crop as a food reserve rather than for high yields. Sweetpotato is a sturdy crop, and farmers can choose relatively infertile soils, plant late after other more sensitive crops are safely in the ground, apply no fertilizer or manure, and pay little attention to weeding.

Most sweetpotato is grown in monoculture, but inter- and relay-cropping with maize, beans, cassava and a variety of other crops also exists (Mutuura et al., 1992; Bashaasha et al, 1995; Kapinga et al., 1995). In many areas sweetpotato is grown on upland plots during the rainy season, while in the dry season hydromorphic soils which do not dry out, usually on land near water sources or in inland valleys and small depressions, are planted with sweetpotato. These sites provide food when other crops are scarce, and serve as a source of planting material for upland fields when the rains begin (Ewell and Mutuura, 1994).

Sweetpotato is propagated from vines, which farmers most commonly obtain either from their own or neighbours' fields (Ewell and Mutuura, 1994). In certain drought-prone regions, and in other regions during extreme weather conditions, vines are bought and sold (Makula and Mazengo, 1994; Bashaasha et al., 1995). The crop is planted on ridges, mounds, or on flat ground. The choice of tillage method is in part a traditional habit which varies between regions, and in part a response to particular soil and drainage conditions (Ewell and Mutuura, 1994). In Uganda vines are usually planted on mounds, ridges are used in highland areas instead of mounds as a way to control soil erosion (Bashaasha et al., 1995). Farmers commonly plant a number of different varieties in the same plot. Varieties have different maturity periods, from 2.5 to 6 months or more, also depending on the altitude. Most of these varieties have been selected by farmers on the basis of factors such as yield; time until first harvest; drought tolerance; palatability; root colour, size and shape; root quality; sweetness; storability in the ground; pest and disease tolerance or resistance; or marketability. A mixture of varieties spreads the risk of any variety failing and varieties have varying degrees of useful characteristics (Hall, forthcoming). Another reason farmers commonly give for planting mixtures is that they cannot obtain enough planting material of the varieties they want or they like to try new varieties (Ewell and Mutuura, 1994). The identification of varieties by their local name is imprecise. A variety is often known by different names depending on the locality; different cultivars are also often known by the same name (Ewell and Mutuura, 1994). The use of chemical fertilizers or manure is uncommon (Bashaasha et al., 1995), although sweetpotato sometimes benefits from the residual effects of fertilizers applied to other crops planted earlier in rotation (Smit and Matengo, 1994). Sweetpotato vines quickly cover the ground suppressing weed growth; studies throughout the region indicate that most farmers weed once or twice, lightly hilling up the soil around the plants at the same time (Ewell and Mutuura, 1994).

An important advantage of sweetpotato in the cropping system is its flexible planting and harvesting period. Allowing for the length and severity of the dry season(s), sweetpotato is planted throughout the year in some regions (Tardiff-Douglin, 1992; Mutuura et al., 1992; Bashaasha et al., 1995). However, peaks commonly occur during the rainy season(s), especially in the latter half (Ewell and Mutuura, 1994; Mutuura et al., 1992; Smit and Matengo, 1995; Hall, forthcoming). Staggered planting allows sweetpotato to mature and become available for consumption sequentially. This avoids producing a glut of a crop which is difficult to store by conventional means (Hall, forthcoming). However, it is the storage of roots in the ground and the sequential or piecemeal harvesting of these roots which extends the period of availability the greatest. Piecemeal harvesting (the removal of mature roots without uprooting the plants, spread over a period of several months) is most common, while staggered harvesting (sequential uprooting of parts of the plot) is practised in certain regions and once-over harvesting by few commercial farmers. Depending on the length and severity of the dry season(s) and on the role of sweetpotato in the food system, fresh tubers are available for consumption from a few to all months of the year (Ewell and Mutuura, 1994).

1.3.3 Marketing, utilization and storage

Sweetpotato is overwhelmingly grown as a subsistence crop in Eastern Africa. Nevertheless, many households also utilize sweetpotato as a supplementary source of income and sell at local markets. A few roots are dug up and sold to cover expenses for household necessities or school fees (Scott and Ewell, 1994). The crop is also sold in urban markets, but its perishability and bulkiness cause losses and high marketing costs (Fowler and Stabrawa, 1992). Nevertheless, some farmers in particular areas have specialised in commercial production (Mutuura et al., 1992).

Sweetpotato roots are a good source of food energy and while their protein content is relatively low, the protein quality is extraordinary high (Woolfe, 1992). Sweetpotato crops produce large amounts of edible energy, protein, and vitamins per unit of land and time (Woolfe, 1992). In Rwanda it was estimated that average annual consumption was 203 kg per adult, and that sweetpotato was second in the provision of calories and protein, in both cases after beans (Tardiff-Douglin, 1992). In Eastern

Africa sweetpotato roots are cooked and prepared in a limited number of ways: most commonly just boiled or steamed. Home or village-level processing of sweetpotato is uncommon. In areas of Uganda and Tanzania with a long, hot dry season, when in-ground storage is impossible, farmers harvest, chip and sun-dry sweetpotato as a way to preserve and store the crop (Ewell and Mutuura, 1994; Hall, forthcoming; Kapinga et al., 1995). Sweetpotato consumption is seasonable and depends on its role in the food system. Bashaasha et al. (1995) report from Uganda that during the harvest period, people consume sweetpotatoes every day and sometimes every meal. Even in times of scarcity, they eat sweetpotatoes at least twice a week. Agro-ecological conditions and culturally-determined food preferences influence sweetpotato consumption patterns within Uganda (Hall, forthcoming). In Kenya (Mutuura et al., 1992) in the months of highest consumption in their households, 40 percent of the farmers reported eating sweetpotatoes 2 or 3 times a week. Consumption of the tender tips and young leaves of sweetpotato vines is very rare in the region, but takes place in Central and Southern Tanzania (Kapinga et al., 1995). Vines are sometimes fed to livestock, particularly in areas were small-scale dairying is developed (Ewell and Mutuura, 1994). The use of fresh roots for animal feed is very limited, but is expected to have potential (Scott and Ewell, 1992).

Fresh sweetpotatoes have a rather short shelf life and tend to deteriorate rapidly under ordinary conditions. Post harvest storage of fresh sweetpotatoes is very limited in the region, although storage of fresh roots in pits takes place in the Southern Highlands of Tanzania (Kapinga et al., 1995). Recent research in Uganda indicated the potential for storage of fresh roots in a pit or clamp (Anonymous, 1996). Farmers usually leave the roots in the field which can be called "in-ground storage on plants" (Bashaasha et al., 1995; Ewell and Mutuura, 1994). Storage of dried chips and flour mostly occurs in areas with dry periods lasting 5 months or more (Ewell and Mutuura, 1994).

1.4 Constraints

1.4.1 Introduction

The inferior status of sweetpotato as a "poor man's", a "famine" or a "fall-back" food has been cited by researchers as a significant constraint to increased sweetpotato consumption (Tsou and Villareal, 1982). In some Asian countries eating sweetpotato is associated with war and hardship, while in countries like Taiwan and Peru sweetpotato is regarded as an animal feed (Woolfe, 1992). In those parts of Eastern Africa where cereals are the preferred food, sweetpotato has a low social status. Even in some parts of Uganda sweetpotato is considered inferior to the preferred staple highland bananas. However, some ethnic groups recognise sweetpotato as their main food (Hall, forthcoming). Forty-nine percent of the 346 interviewed farmers in Uganda, mentioned sweetpotato as their first or second choice food among seven staple foods (Bashaasha et al., 1995).

In 1988, more than 60 sweetpotato researchers from 35 developing countries around the world provided their views on constraints to sweetpotato production and use in response to a CIP questionnaire distributed worldwide (Figure 1.1). The top-ranked constraints both related to post-harvest problems: unstable sweetpotato supplies and prices, and the lack of suitable processed products. The survey indicated that the leading production constraints were sweetpotato weevil, low soil fertility and drought. Production problems, in general, and pest problems, in particular, appear to be most severe in tropical and rainy climates. The sweetpotato weevil, *Cylas* spp., was considered to be the most important constraint to production of sweetpotato in the tropics (Horton & Ewell, 1991).

In Eastern Africa sweetpotato is generally considered a robust crop, without overwhelming problems like some other staple foods in the region. For instance, the maize crop regularly fails in parts of Kenya under drought conditions and the emergence of African Cassava Mosaic Virus (ACMV) has drastically reduced cassava production in Uganda. Nevertheless, sweetpotato yields in the region are low (Table 1.1) and if its major constraints could be overcome, the crop has the potential to play increasingly important roles in many areas (Ewell and Mutuura, 1994).

In 1989-1990 CIP and researchers of the Kenya Agricultural Research Institute (KARI) carried out a socio-economic survey of sweetpotato farmers in all regions of Kenya where the crop is important. In the farmer's perception moles and sweetpotato weevils (*Cylas* spp.) topped the list of constraints, both in frequency and severity (Figure 2). Problems vary between agro-ecological zones: In wet zones at higher elevations, moles are the most important problem. In drier low elevation regions, the major production constraints are sweetpotato weevils, drought and lack of planting material (Mutuura et al., 1992). These results were confirmed by Smit and Matengo (1995) and Low (1996), both interviewing farmers in South Nyanza District, Kenya's principal sweetpotato growing district. Low (1996) reported marketing

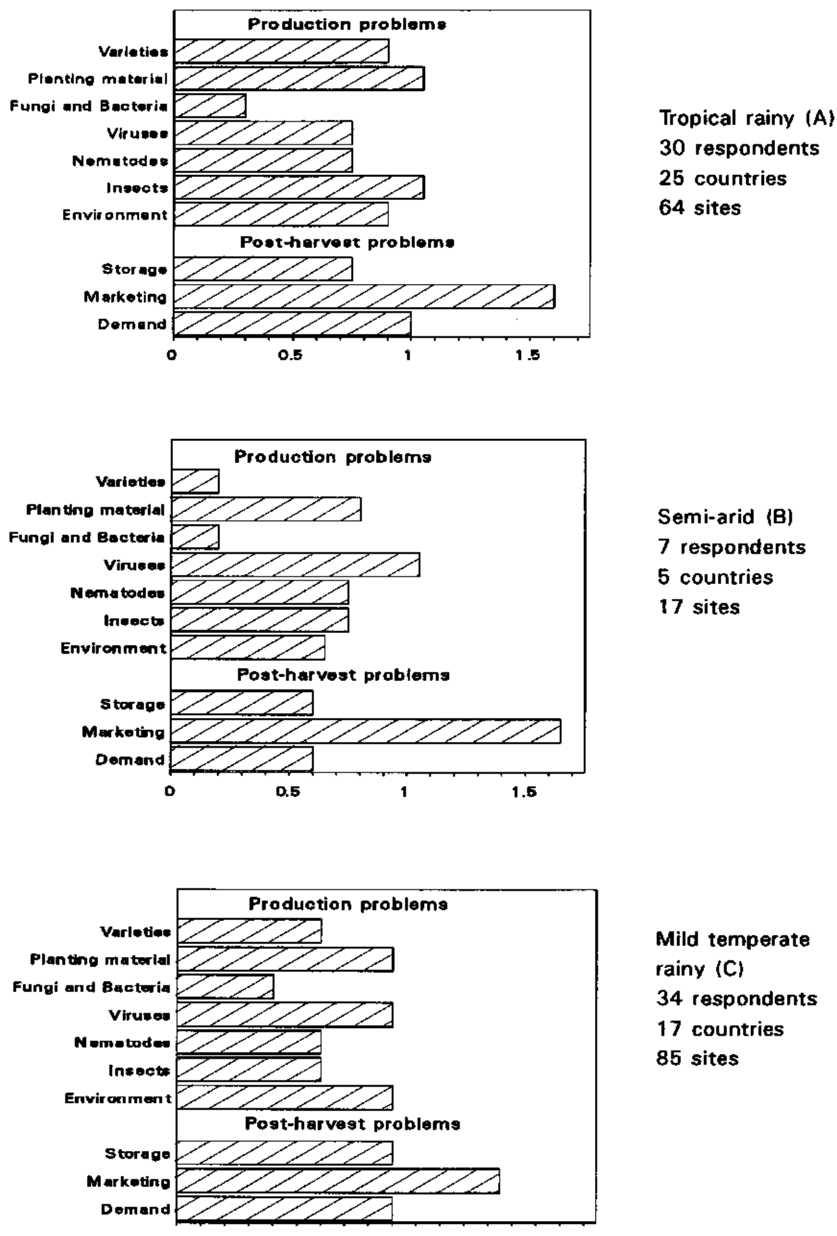


Figure 1.1 Mean scores for importance of various constraints to sweetpotato production and use in three climatological zones. Source: Horton and Ewell, 1991.

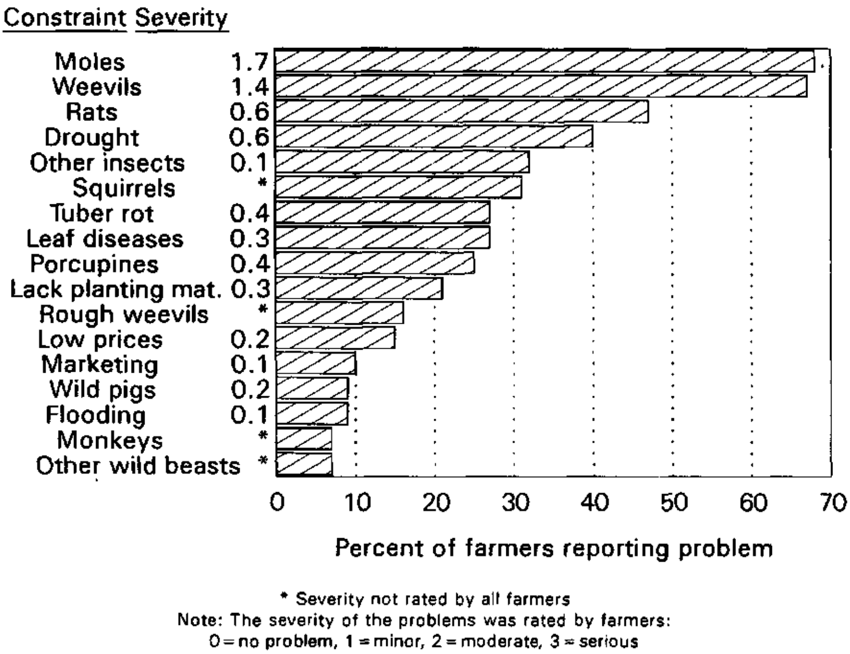


Figure 1.2 Frequency and average severity of major constraints in sweetpotato production reported by 208 farmers in Kenya. Source: Mutuura et al., 1992.

constraints as the most limiting factors to expanding sweetpotato production, especially lack of transport.

A sweetpotato baseline survey was conducted in seven districts of Uganda between 1989 and 1992 (Bashaasha et al., 1995). Farmers reported several biological, physical, and socio-economic constraints to increased production and use (Table 1.2). Farmers believed that vertebrate pests and insect pests, especially sweetpotato weevils and sweetpotato butterfly caterpillars, were the most important biological constraints they faced. The most important climatic constraint reported was drought, which apart from its direct effect on yield, reduces available planting material. Notable among socio-economic issues were high transport and labour costs, and the shortage (or price) of farm implements, this mainly in areas where land preparation is done with oxen ploughs. According to Hall (forthcoming) the major marketing constraint in Uganda is the fact that sweetpotato is a low value commodity. His conclusion is that there is a need to add value to the product or diversify its utilisation - so-called product development.

In Tanzania major constraints limiting production in the

Table 1.2 Farmers scoring of constraints to sweetpotato production averaged over seven districts (n=346).

Constraint	Score
High labour cost	2.32
High transport cost	2.31
Weevils	2.18
Sweetpotato butterfly	2.13
Lack of transport	2.12
Drought	1.95
Low market prices	1.95
Other rodents	1.91
Moles and rats	1.88
Shortage of farm implements	1.82
Lack of sacks	1.51
Tuber rot	1.49
Monkeys	1.48
Labour shortage	1.38
Lack of "clean material"	1.32
Virus	1.31
Land shortage	1.30
Lack of planting material	1.17
Porcupines	0.81
Wild pigs	0.53
Flooding	0.52
Mites	0.45
Squirrels	0.29

Scoring on a scale of 0 to 4, where 0 = not a problem, 1 = minor, 2 = moderate, 3 = serious, 4 = very serious
Source: Bashaasha et al., 1995.

order of importance mentioned by farmers include: sweetpotato weevils, drought, shortage of planting material, low root yield, vertebrate pests (moles, rats, pigs), viral and fungal diseases, poor market accessibility, storage pests, and low soil fertility (Kapinga et al., 1995).

Virus diseases are generally not recognized by farmers. However, they are considered by some national programmes in Eastern Africa to be an important constraint to sweetpotato production, the selection of varieties which are resistant to viruses being among the principal selection criteria of their breeding programmes (Wambugu et al., 1991; Carey et al., 1996). However, virus incidence varies greatly among regions and the overall importance of viruses might be limited due to the presence of resistant varieties (R. Gibson, personal communication).

The only fungal disease of some importance in the region is Alternariosis (*Alternaria* spp.). In high elevation regions this disease blackens and kills vines (Skoglund and Smit, 1994). Nematodes, especially *Meloidogyne* spp., have been found in association with sweetpotato, but there is no indication of an effect on root quality or yield (D. Coyne, personal communication).

1.4.2 Insect pests of sweetpotato in Eastern Africa

The above mentioned reviews indicate, that insect pests are considered the most important production constraint on sweetpotato worldwide as well as in Eastern Africa. Skoglund and Smit (1994) gave an overview of insect pests attacking sweetpotato in Eastern Africa, which is summarized in Table 3.

Table 1.3 Major sweetpotato insect pests in Eastern Africa

Type of pest	Order	Family	Species
Defoliators	Lepidoptera	Nymphalidae	*Acraea acerata* (Hew.)
		Sphingidae	*Agrius convolvuli* (L.)
	Coleoptera	Chrysomelidae	*Aspidomorpha* spp.
			Laccoptera spp.
			and others
Virus transmitters	Homoptera	Aphididae	*Aphis gossypii* (Glover) and others
		Aleyrodidae	*Bemisia tabaci* (Genn.)
Stem borers	Lepidoptera	Sesiidae	*Synanthedon* spp.
	Coleoptera	Curculionidae	*Alcidodes dentipes* (Oli.)
			A. erroneus (Thomson)
			Peloropus batatae (Marshall)
			Cylas puncticollis Boh.
			C. brunneus Fab.
Root feeders	Coleoptera	Curculionidae	*Blosyrus* spp.
			C. puncticollis
			C. brunneus

Source: Skoglund and Smit, 1994

To assess pest damage and pest incidence in farmers' sweetpotato fields a general survey form was developed in a joint effort by the International Institute for Biological Control (IIBC), regional NARS and CIP (Rangi et al., 1994). The standardised survey methods can be used on a regional and national basis and information can be stored in a computer database for easy access (Smit et al., 1994; Allard and Rangi, 1995). The survey method provides a general picture of the insect problems. However, in many regions farmers practice staggered planting and piecemeal harvesting of the sweetpotato crop, and as a result the once-a-season collected quantitative data on pest damage and pest incidence are of limited use. Season-long monitoring methods have been tested; they require a major time allocation of the researcher and a strong commitment of the farmer, but provide more accurate data.

The most important insect pests of sweetpotato in Eastern Africa are the sweetpotato weevils *C. puncticollis* and *C. brunneus*, which will be discussed throughout this thesis. Below, the other sweetpotato pests are reviewed. *Acraea acerata*, the sweetpotato butterfly, is a regionally important defoliating pest and is discussed in more detail.

Acraea acerata (Lepidoptera: Nymphalidae) has a pest status only in Eastern Africa. The sweetpotato butterfly is a serious constraint to sweetpotato production in parts of Uganda, Rwanda, Burundi, eastern Zaire and Southern Ethiopia (Lefèvre, 1948; Lenné, 1991; Ndamage et al, 1992; Girma, 1994; Smit et al., forthcoming). Among other constraints, sweetpotato butterfly damage was scored as a serious problem by farmers in Uganda (Table 2).

Mostly at the beginning of the dry season, a severe attack by the sweetpotato butterfly can result in extensive defoliation of the sweetpotato crop. Lefèvre (1948) mentions that in Kivu District in Zaire, serious attack resulted in a delayed and/or reduced production or complete crop failure. Lugojja (1996) simulated leaf injury of this insect by artificially defoliating plants in Uganda. Single defoliation at different growth stages did not effect the yield, but when plants were defoliated three times, at 1, 2 and 3 months after planting, a yield loss of 71% was registered. Farmers in some areas might overrate the importance of sweetpotato butterfly, as they do not realise that the dramatic, complete defoliation of their crop does not much effect its yield. However, in areas were repeated defoliation is common, serious yield reduction can be expected.

Female adult sweetpotato butterflies lay eggs on sweetpotato leaves in batches of 70 to 500 (Smit et al., forthcoming). For the first half of their life, the caterpillars are gregarious and feed together under a protective webbing. Next the larvae become solitary, and feed at night, eating the whole leaf lamina, except the primary midribs. For pupation the caterpillars crawl up a support close to the sweetpotato field. The development time from egg to egg can range from 27 to 55 days, depending on the temperature (Lefèvre, 1948; Smit et al., forthcoming).

The traditional method of controlling sweetpotato butterfly outbreaks has been to handpick and destroy nests of young caterpillars (Lefèvre, 1948). The limiting factor for this approach is often lack of labour. Insecticides are very effective against sweetpotato butterfly, but are costly compared to the low subsistence value of the crop. Also they are often not available in rural areas, can cause human health risks and have a negative effect on natural enemies of the pest (Smit et al., forthcoming). A review on the sweetpotato butterfly can be found in Smit et al. (forthcoming). Although sweetpotato butterfly is widespread in Eastern Africa, it appears to be a serious constraint only in higher altitude areas in the region.

The large caterpillars of the sweetpotato hornworm, *Agrius convolvuli*, feed on leaf blades, causing irregular holes. Sometimes they eat the entire blade, leaving only the petiole. Although widespread, it is usually not a serious pest. Handpicking the larvae from the leaves gives usually sufficient control. Ploughing the land between crops exposes the pupae to mortality factors like birds.

Seldom a serious pest, tortoise beetles (*Aspidomorpha* spp. and others) are widely distributed and often common, and their damage is quite conspicuous. Large round holes are eaten in the leaves by both adults and larvae. The pest does not usually warrant control measures.

Direct damage by leaf sucking of aphids is normally low. Aphids are however vectors of the sweetpotato feathery mottle virus. Whiteflies (*Bemisia tabaci*) are vectors of the "whitefly-born virus", which in combination with sweetpotato feathery mottle virus causes severe symptoms. Research on this virus complex is presently taking place in Uganda (Carey et al., 1996).

The larvae of clearwing moths (*Synanthedon* spp.) burrow into the vines and sometimes into the roots. The vine base is characteristically swollen and is traversed with feeding galleries. During heavy outbreaks, the vine easily breaks off at the base. Three closely related species of *Synanthedon* are regularly found in sweetpotato, but they are prominent pests only in some localities. Cultural control measures, such as rotation, earthing up and sanitation are recommended (Bradley, 1968).

Larvae of *Alcidodes* spp. bore into the vines, causing the vine base to swell up, and sometimes into the roots. Adult weevils girdle the vines, causing wilting. *Alcidodes* is a minor pest in most localities and control is not usually required.

A small weevil (*Peloropus batatae*) has been found inside stems and roots at some locations (Allard and Rangi, 1995). Control is usually not required.

Adult rough sweetpotato weevils (*Blosyrus* spp.) feed on foliage, but the larvae cause more serious damage. While feeding under the soil surface, they gouge shallow channels on the enlarging roots. These "grooves" reduce marketability and when extensively damaged, roots have to be peeled thickly. The weevil is a common pest in Eastern Africa, and is serious in some localities. Cultural control measures like rotation and sanitation are recommended.

In areas where farmers store sweetpotato in the form of dried sweetpotato chips, storage pests are a constraint. A survey in North-Eastern Uganda revealed that *Araecerus fasciculatus*, the coffee bean weevil, was the most common species among six storage insect species encountered. *Cylas* spp. were not retrieved from dried, stored sweetpotato (Agona, 1996).

1.5 Conclusions related to IPM for sweetpotato in Eastern Africa

Sweetpotato production in Eastern Africa can be summarized as follows:

1. Sweetpotato is mostly grown as a subsistence crop by resource-poor farmers, who do not use inputs.
2. Production takes place on small plots, rarely more than half a hectare in size.
3. The crop is grown in two types of food systems: a. Cereal-based, where sweetpotato is a food-security crop, e.g. in Kenya. b. Non-grain starchy staple based, where sweetpotato is one of several staples, e.g. in Uganda besides cooking banana and cassava.
4. There is almost no fresh storage of sweetpotato; farmers practice "in-ground" storage and piecemeal harvesting. As a consequence, in many regions sweetpotato crops can be found in the field throughout the year.
5. Sweetpotato weevils are considered a major constraint by farmers in areas with long dry seasons.
6. Other insect pests of sweetpotato are of regional importance, for instance the sweetpotato butterfly in parts of Uganda.
7. Because roots are preliminary destined for home consumption, quality demands are low and high pest level tolerance can be expected.

The above also indicates that the role of sweetpotato in the farming systems of Eastern Africa is very different from that of the USA or Taiwan, where most IPM research for sweetpotato took place. Production in the USA is highly commercialised, but of minor importance compared to other crops. Sweetpotato production in South-Eastern Asia is mostly commercialised, high levels of inputs are used and a large amount of production is for animal feed. Consequently, some of the management approaches for sweetpotato weevils developed in these continents might be inappropriate for Eastern Africa, and others will need adaptation so that they are compatible with the conditions in Eastern Africa. A critical evaluation of these management approaches was one of the tasks included in this research.

1.6 Research aims and structure of the thesis

The overall aim of this research project was to develop pest management programs on sweetpotato in Eastern Africa. To do this the biology and ecology of the pest species must be understood. Secondly, management approaches should be developed or adapted, which are compatible with the limitations of the agricultural systems in which the crop is grown. A further requirement is that farmers' needs and constraints must be considered in developing research priorities in sweetpotato IPM.

The first scientific aim was to define the role of sweetpotato in the farming systems and to know the crop's production constraints. In this introductory chapter, the implications for IPM research of the socio-economic and agroecological conditions, under which the crop is grown, are summarized.

The second scientific aim was to develop understanding on the weevils biology and ecology. Literature review revealed that almost no information on the biology, behaviour and ecology of the major insect pests, *C. puncticollis* and *C. brunneus*, was available. However, the related species *C. formicarius* was thoroughly studied. A hypothesis could be, that their are no major differences in biology, behaviour and ecology between the three *Cylas* pest species, so that certain management strategies, developed for *C. formicarius*, could also be applied for the other two species. This hypothesis will be tested in chapters 2 and 3. Aspects of the biology of the sweetpotato weevils *C. puncticollis* and *C. brunneus* are looked at and compared. Ecological, behavioural and biological traits are described and compared to those of *C. formicarius*. In the last part of this section, it is attempted to relate knowledge of sweetpotato weevil ecology, biology and behaviour to pest management considerations.

A third scientific aim of the research was to develop appropriate management components. The first question that has to be answered is, which control and/or cultural practices farmers presently use and why they are used. Survey results are presented in chapter 4. The survey indicated that it would be useful to study the effect of the indigenous cultural practices of in-ground storage and piecemeal harvesting on quality loss caused by sweetpotato weevil. This practice is investigated in chapter 5. The sex pheromone of *C. formicarius* proved a very useful component of an IPM programme for this insect. The sex pheromones for the African *Cylas* species had just been identified and many aspects of a trapping system based on these pheromones had to be researched, before its usefulness as a IPM component could be established. The development of optimal sex pheromone traps is described in chapter 6. An overview of all potential management components; cultural control, host plant resistance, biological control, sex pheromones and chemical control, is given in chapter 7. Comparisons to management of *C. formicarius* are made, the state of affairs is described and the potential of the different management components is evaluated critically.

In the concluding chapter the relevance of the findings are being discussed in the light of the socio-economic and agroecological conditions, under which the sweetpotato crop is grown in Eastern Africa. Questions such as this will be discussed: Will farmers be motivated to use labour-intensive cultural control practices for a low-value crop such as sweetpotato? Under which conditions could sex pheromone traps play a role? What role do different organisations or institutes play in IPM technology development and transfer?

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Chapter 1

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PART II BIOLOGY OF SWEETPOTATO WEEVILS

2. The biology of the African sweetpotato weevil species, *Cylas puncticollis* (Boheman) and *C. brunneus* (Fabricius) (Coleoptera: Apionidae).[1]

Abstract

The biology of two African sweetpotato weevil species, *Cylas puncticollis* and *C. brunneus*, were studied in laboratory experiments carried out at 27 ± 1°C, 45 ± 5% RH and a 12 h photophase. *C. puncticollis* females live longer than *C. brunneus* (141 ± 10 and 92 ± 12 days respectively), develop faster (egg to adult 20-28 days, and 32-41 days respectively) and have a lower oviposition rate (1.10 ± 0.04 and 1.53 ± 0.06 eggs per female per day respectively). The total egg production per female (average 101), sex ratio (1:1) and proportion of eggs surviving to adulthood (average 89%) were similar for both species. The intrinsic rate of increase was higher for *C. puncticollis* (0.553 per 10-day period compared to 0.521 for *C. brunneus*). Under field conditions *C. brunneus* will benefit from its higher oviposition rate during periods of favourable conditions for sweetpotato weevils, like dry spells which expose tubers for egg laying. *C. puncticollis* will benefit from its longer longevity during less favourable conditions, as females can survive extended periods when no oviposition sites are available and then resume egg laying when conditions improve.

2.1 Introduction

Sweetpotato (*Ipomoea batatas* (L.) Lam.) is one of the world's most widely grown crops. Farmers in more than 100 countries in tropical, sub-tropical and warm temperate areas rely on its ability to produce good yields on marginal lands with little investment (Horton et al., 1989). In East Africa sweetpotato is an important subsistence food crop, used as a staple, and as a famine reserve food supply (Scott and Ewell, 1992).

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Smit, N.E.J.M. and A. van Huis. The biology of the African sweetpotato weevil species, *Cylas puncticollis* (Boheman) and *C. brunneus* (Fabricius) (Coleoptera: Apionidae)

Sweetpotato weevils of the genus *Cylas* are considered to be the most destructive pest of sweetpotato in the world (Chalfant et al., 1990; Jansson & Raman, 1991). Even small populations reduce the quality of the roots (Proshold, 1983). In response to weevil feeding, the crop produces bitter-tasting and toxic sesquiterpenes which render storage roots unfit for human consumption (Akazawa et al., 1960). In Uganda crop losses up to 73% have been reported (Smit, 1996).

All known or suspected pest species of the genus *Cylas* occur in Africa and/or Madagascar, *C. puncticollis* (Boheman) and *C. brunneus* (Fabricius) being the major ones (Wolfe, 1991). Only *C. formicarius* (Fabricius) is found circumglobally outside Africa (Wolfe, 1991; CAB International, 1993). All current data indicate that the sweetpotato originated in or near northwestern South America (Austin, 1988). *C. puncticollis* and *C. brunneus* could not have evolved with the sweetpotato as Europeans brought the crop to the African continent. Therefore, the weevils must have originally been associated with other convolvulaceous host plants (Austin et al, 1991). Despite significant attempts to find *C. formicarius* in continental Africa, only two localities have been identified: Msabaha, Kenya and the Natal Province, South Africa (Wolfe, 1991; Parker et al, 1992). Numerous, recent, publications report the occurrence of *C. formicarius* in East Africa (Gowdey, 1912; Le Pelley, 1959; Ingram, 1967; Mwanga and Wanyera, 1988; Autrique & Perraeux, 1989; Lenné, 1991; CAB International, 1993). In most cases these reports are based on misidentifications of bicoloured specimens of *C. brunneus*.

IITA (1977) concentrated research on *C. puncticollis* after data from their research station in Ibadan, Nigeria, indicated that this was a more serious pest than *C. brunneus*. During a survey in South Nyanza, Kenya's principal sweetpotato-growing region, both African weevil species appeared to be of similar importance (Magenya & Smit, 1991). In Central Uganda infested sweetpotato roots were collected from experiments at a research station over a 2 year period. Although the proportions of *C. brunneus* and *C. puncticollis* emerging from incubated roots varied over the different harvest periods, the species were in general equally important (Smit, 1996). Therefore, both species need research attention in the development of an IPM strategy.

Virtually all information on the biology of *Cylas* weevils relates to *C. formicarius* (Mullen, 1981; Jansson & Hunsberger, 1991; and the references in Sutherland, 1986 and Chalfant et al., 1990). No published study on the biology of *C. brunneus* was retrieved, while only Nwana (1979), IITA (1982) and Anota & Odebiyi (1984) reported on the biology of *C. puncticollis*.

Biology of African Cylas spp.

Because basic biological information is essential for developing control strategies for insect pests, the present study concentrated on the comparison of the fecundity, longevity, development time, sex ratio and survival rate between *C. puncticollis* and *C. brunneus*. Based on this information it would be possible to compare the growth rates of their populations.

2.2 Material and methods

Four laboratory experiments were conducted between January 1991 and December 1992. Sweetpotato storage roots, infested with *C. puncticollis* and/or *C. brunneus*, were harvested from farmers' fields around the ICIPE Mbita Point Field Station, Mbita, South Nyanza, Kenya. Emerged adults, separated by species, were cultured on "Kalamb Nyerere" roots in a controlled environment chamber set at 27.0 ± 1.0°C, 45 ± 5% RH and a 12 h photophase. These conditions are comparable to the average ambient conditions at Mbita.

Experiment 1. Age-specific fecundity and longevity. Of each species fifteen newly eclosed (up to 24 h old) adult male and female pairs were collected from incubated pupae and placed in a square petri dish (9.0 cm, 1.5 cm high). One fresh, healthy sweetpotato (variety Kalamb Nyerere) root piece (about 3 by 2 cm) was placed in each petri dish with the periderm facing upwards. Freshly excised root pieces were provided daily. Used root parts were removed and examined under a stereo microscope. The periderm and cut surfaces were carefully peeled back with a razor blade in order to count the numbers of eggs laid per female. Female mortality was recorded daily. Dead males were replaced if they died before their mate had laid her first egg. Two out of the 15 test-females for each species produced an exceptionally low number of eggs and these data were not included. The experiment was terminated when all females died.

Experiment 2. Developmental period. Individual fresh, healthy, sweetpotato roots (variety Kalamb Nyerere) were exposed to 100 two-to-three week old adult weevils of either species for 24h. After exposure, the roots were incubated. Eggs were examined daily for hatching by carefully peeling back the periderm of two to four roots with a razor blade. After egg hatch was complete, roots were dissected every two to three days and the numbers of larvae, pupae and adults were counted until only adults were found. This destructive method had to be used because it is not possible to observe sweetpotato weevils developing in infested roots without disturbing them and was similar to the procedure used by Mullen (1981) for *C. formicarius*.

Experiment 3. Sex ratio. Twenty large-sized (> 300g) sweetpotato roots were exposed to adults of each species taken from the laboratory culture. After two days the adults were removed. The roots were labelled with the date of first exposure, and incubated until most individuals were in the pupal stage (see experiment 2). After dissecting the roots, all pupae were collected in a square petri dish (9.0 cm by 1.5 cm high) and counted. The incubated pupae were checked daily for emergence of males and females.

Experiment 4. Survival (proportion of eggs surviving to adulthood). Six or eight individual fresh, healthy, medium-sized sweetpotato roots (variety Kalamb Nyerere) were exposed to 50 pairs of two-to-three week old males and females of both species for 24h. Immediately after exposure, half the number of roots were dissected by carefully peeling back the periderm with a razor blade and the number of eggs were counted. This destructive method had to be used, as it was not possible to count eggs accurately based on observed oviposition sites. The remaining roots were incubated in individual containers for 26 days for *C. puncticollis* and 37 days for *C. brunneus*. Adults in the containers were counted and roots were dissected to count the remaining number of adults. The total number of adults retrieved after incubation was related to the number of eggs found directly after exposure in roots infested on the same day. The test was repeated three times for each species.

Calculation of the rate of increase. The first modification of the Leslie-Birch method, as described by Howe (1953) was used to calculate the intrinsic rate of increase (r_m) in this study. The unit period used for the calculation was ten days. The parameters in the calculation are: the number of female eggs, the proportion of eggs surviving to adulthood, the developmental time and the oviposition time. The rate of natural increase (λ) equals e^r.

2.3 Results

Fecundity and longevity. Percentage female survival decreased linearly with time for both species (Figure 2.1). Females of *C. puncticollis* lived significantly longer (48 days) than those of *C. brunneus* (Table 2.1).

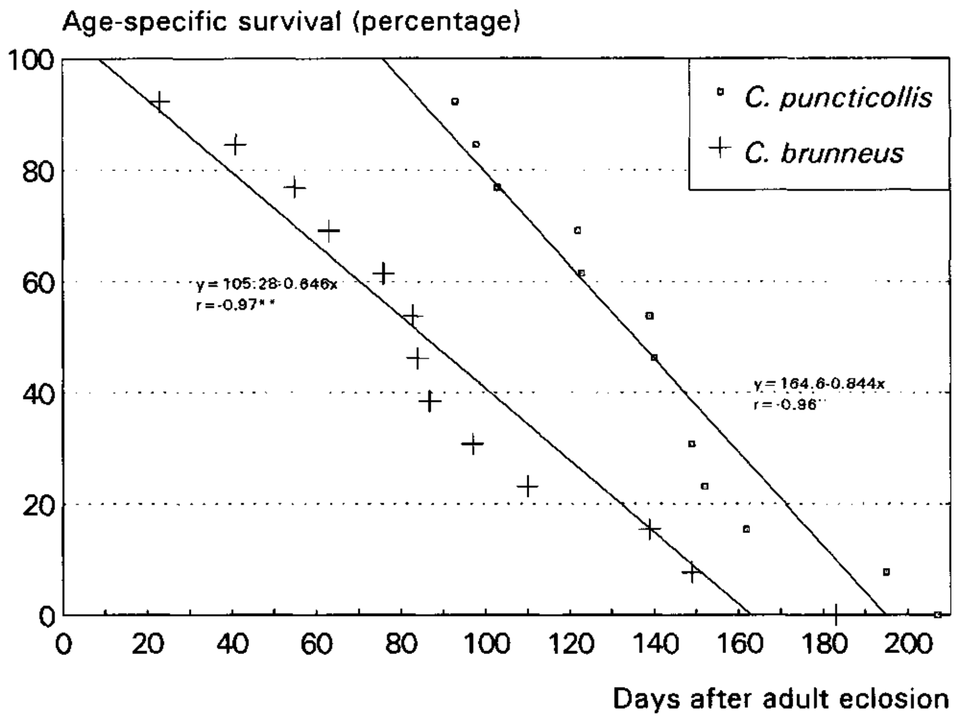

Figure 2.1 Longevity of *C. puncticollis* and *C. brunneus* females on "Kalamb Nyerere" sweetpotato root pieces at 27°C (n=13)

Table 2.1 Average duration (in days) of the longevity, and the pre-oviposition, oviposition and post-oviposition periods (±SEM) for 13 *C. puncticollis* and 13 *C. brunneus* females on "Kalamb Nyerere" storage root pieces (ranges in parentheses).

Cylas spp.	Longevity	Pre-oviposition	Oviposition	Post-oviposition
puncticollis	140±10a (93-207)	13.9±0.6a (9-16)	10±10a (67-171)	15.8±3.6a (0-37)
brunneus	92±12b (23-183)	11.4±0.6b (8-15)	74±12b (14-171)	7.0±2.4a (0-23)

Means within a column followed by different letters are significantly different by t-test ($p<0.01$ for longevity, $p<0.05$ for the rest)

For both species maximum oviposition occurred between day 15 and 85 after adult eclosion (Figure 2.2). After 85 days more than 60% of the *C. brunneus* females had died (Figure 2.1) and those that survived had a low oviposition rate. All *C. puncticollis* females were still alive on day 85, but the number of eggs oviposited per female per day dropped sharply. The duration of the pre-oviposition and oviposition periods differed significantly between the two species, and was respectively 2.5 and 36 days longer for *C. puncticollis* (Table 2.1). The total egg production was similar for both species, viz. about 100 (Table 2.2).

C. brunneus females laid their eggs just beneath the periderm of the root surface, while *C. puncticollis* females laid them slightly deeper. Very few eggs were laid on the cut surfaces of sweetpotato roots.

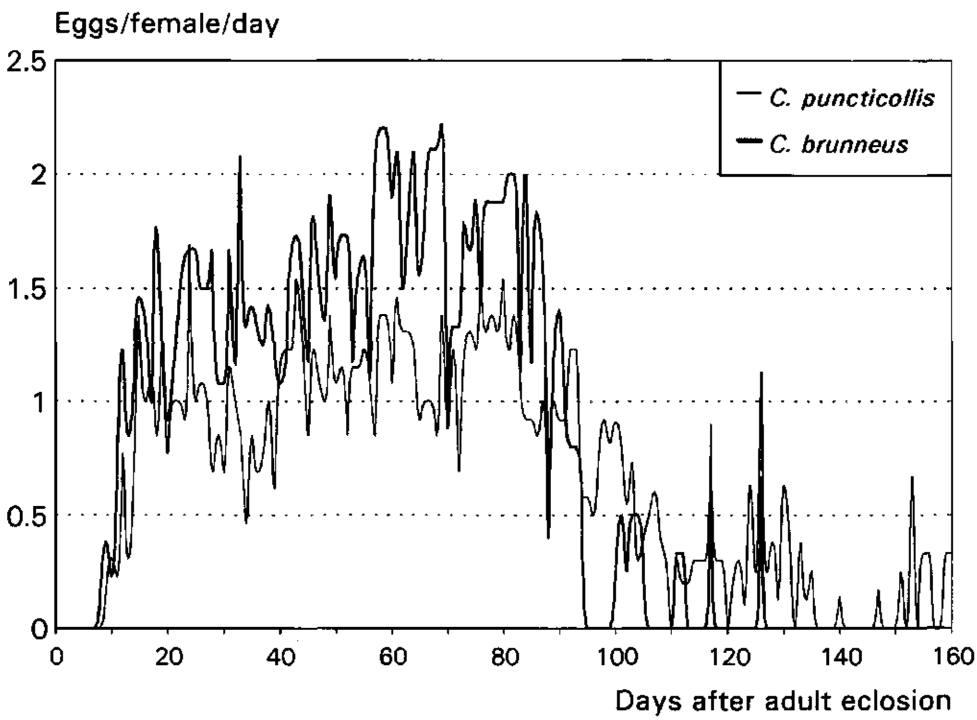

Figure 2.2 Daily oviposition by *C. puncticollis* and *C. brunneus* females on "Kalamb Nyerere" root pieces at 27°C (n=13)

Table 2.2 Average total (range in parenthesis) and daily (between 15 and 84 days) number of eggs per female (±SEM), survival (proportion of eggs surviving to adulthood) and sex ratio for *C. puncticollis* and *C. brunneus* on variety "Kalamb Nyerere".

Cylas spp.	Number of eggs per female	Number of eggs per female per day	Survival (% eggs)	Sex ratio (% females)
puncticollis	103±16a (44-230)	1.10±0.04b	91±4a	49.7
brunneus	100±18a (7-177)	1.53±0.06a	87±3a	51.5

Means within a column followed by different letters are significantly different by t-test ($p<0.05$)

Developmental period. Eggs, larvae and pupae of *C. puncticollis* developed faster than those of *C. brunneus* (Figure 2.3). The first adult weevils of *C. puncticollis* and *C. brunneus* emerged from the infested roots 24 and 34 days respectively after exposure of the roots to oviposition. Observations indicated that adult eclosion usually occurred 1 to 4 days before emergence from the root and was dependent on the proximity of the pupal chamber to the surface.

Sex ratio. For *C. puncticollis* 5501 pupae eclosed from 20 roots and for *C. brunneus* this figure was 3792. In both cases the sex ratio did not depart significantly from 1:1 (Table 2.2).

Survival. During the development of eggs into adults mortality was low, 9% for *C. puncticollis* and 13% for *C. brunneus*, the difference not being significant (Table 2.2).

Intrinsic rate of increase. The intrinsic rate of increase (r_m) for *C. puncticollis* was higher than for *C. brunneus* per 10-day period (Table 2.3).

2.4 Discussion

The longevity of *C. puncticollis* was 140 days, while Anota and Odebiyi (1979) reported a female longevity 59 days shorter (Table 3). However, they handled the females differently: couples were held in small cages pinned to whole sweetpotato roots. These conditions appear to be less ideal for female survival. We found that *C. brunneus* females lived an average of 92 days, which

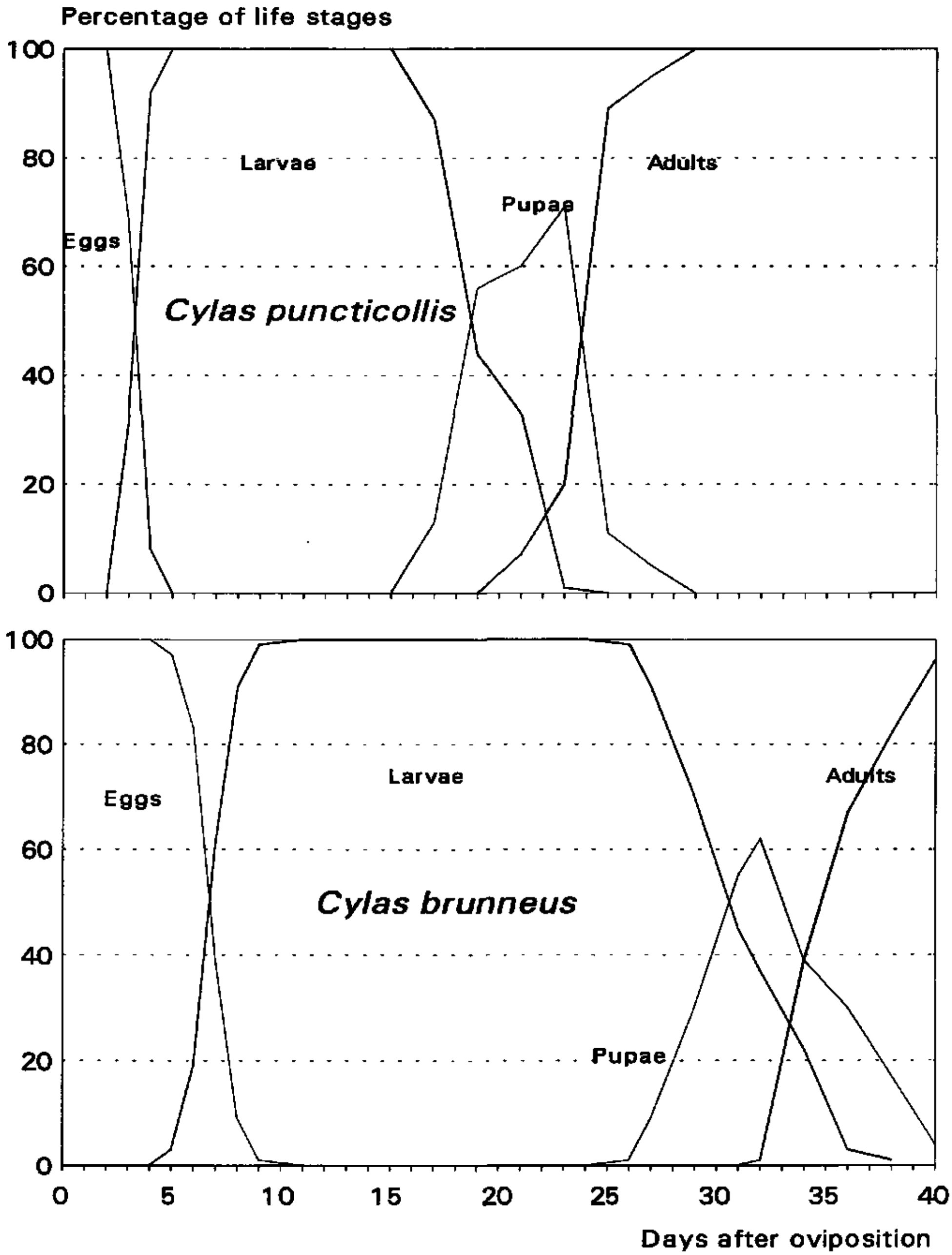

Figure 2.3 Development of *C. puncticollis* and *C. brunneus* in infested "Kalamb Nyerere" roots

Table 2.3 Data on longevity, fecundity, developmental period (egg to adult) and intrinsic rate of increase[1] of three *Cylas* spp., from different studies[2]

	Longevity	Average number eggs per female	Developmental period	Intr. rate of increase
C. puncticollis				
- This paper	140	103	20-28	0.553
- Nwana (1979)	-	-	22-32	-
- Anota & Odebiyi (1984)	81	308	19-25	1.05
C. formicarius				
- Mullen (1981)	79	88	25-31	0.82
- Jansson & Hunsberger (1991)	76	122	-	
C. brunneus				
- This paper	92	100	32-41	0.521

[1]In 10-day periods according to a modification of the Leslie-Birch method (Howe, 1953)

[2]Experimental conditions:

	Temp. (°C)	%RH	Photophase	Variety
This paper	27±1	45±5	12	Kalamb Nyerere
Nwana (1979)	22-31	63-94	?	?
Anota & Odebiyi (1984)	25-30	70	12	TIB4
Mullen (1981)	27±2	60±5	12	Jewel
Jansson & Hunsberger (1991)	27±3	60	12	Picadito

differs less with the average longevity of *C. formicarius* as reported by Mullen (1981) and Jansson and Hunsberger (1991), than with our longevity results of *C. puncticollis* (Table 2.3).

Fecundity as measured by Anota and Odebiyi (1984) was three times higher for *C. puncticollis* than our results (Table 2.3). This is probably due to the differences in experimental conditions. The containment of females in cages pinned on roots was probably more stressful for the females than containment in petri dishes. This may have induced oviposition. From the description given by Anota and Odebiyi (1984) it seems that they used the average number of viable offspring per female (oviposition x survivorship to adulthood), so that the actual fecundity was probably even higher. Our fecundity data for *C. puncticollis* and *C. brunneus* females are similar to those reported for *C. formicarius* (Table 2.3).

The pre-oviposition period for *C. puncticollis* as described by Anota and Odebiyi (1984) was 3.8 days, considerably shorter than the 13.9 days reported by us (Table 2.1). The authors do not describe how they obtained the virgin females. If they used newly emerged females (<24 h outside the root), the actual age of the females might have been older. This because not all females emerge on the day that they eclose; this may be 1-4 days later. Recently emerged adult weevils often "hide" in exit tunnels, as they appear to be attracted to dark places during the photophase. Therefore, the differences between the data on pre-oviposition by Anota and Odebiyi (1984) and ours may be an artefact.

The total developmental period (egg to adult) for *C. puncticollis* as described by Anota and Odebiyi (1984) (Table 2.3) is in accordance with results obtained in this study. Nwana (1979) reported a longer development time (Table 2.3). This might be due to the fact that the insects were dissected daily from root pieces, causing disturbance which may have slowed down their development. The development period of *C. puncticollis* is 20-28 days, for *C. brunneus* it is 32-41 days, and Mullen (1981) reported for *C. formicarius* 25-31 days. The development period for *C. brunneus* is 3 to 13 days longer than that of *C. puncticollis*.

Sex ratio of both *C. brunneus* and *C. puncticollis* is 1:1. Anota and Odebiyi (1984) and Mullen (1981) found the same value for *C. puncticollis* and *C. formicarius* respectively.

Mortality was low as only 10% of the eggs did not develop into adults. No information on the proportion of eggs surviving to adulthood was found in any of the references. Anota and Odebiyi (1984) probably included the proportion in their fecundity figures, as they were counting emerged adults.

The intrinsic rate of increase was higher for *C. puncticollis* than for *C. brunneus*. The two species did not differ in sex ratio, survivorship to adulthood and total egg production per female. *C. brunneus* has a longer development time and a shorter oviposition period than *C. puncticollis*. In the method used for calculating the intrinsic rate of increase, the longer development time of *C. brunneus* was more important than the higher oviposition rate per day. The data for *C. puncticollis* in Anota and Odebiji (1984) are sufficient to estimate an intrinsic rate of increase, although the daily oviposition pattern has to be estimated from the graph, and female survivorship has to be estimated from the average and range of longevity. The intrinsic rate of increase calculated this way, is much higher than the one obtained in this study (Table 2.3), mainly because they found a much higher fecundity. The difference in rate of increase between the *C. puncticollis* data documented in this paper and the results of Anota and Odebiji (1984) are expected to be due to differences in experimental conditions (method of confinement of couples, fitness of weevil culture, cultivar, etc). The data provided by Mullen (1981) and Jansson and Hunsberger (1991) allows the calculation of the intrinsic rate of increase for *C. formicarius* at 27°C (Table 2.3). The intrinsic rate of increase is higher than those obtained for *C. brunneus* and *C. puncticollis* in this paper. The probable reason for this is a higher oviposition rate during the first three weeks after sexual maturity of the females. It might be worthwhile to study if this is a major difference between the three *Cylas* species, or if this was induced by experimental conditions.

The difference in intrinsic rate of increase between *C. puncticollis* and *C. brunneus*, as recorded in this paper, results in a difference in population growth over a given period. Over a period of a year the population of *C. puncticollis* would be 672 times larger than that of *C. brunneus*. However, population increase is not merely dependent on the intrinsic rate of increase, especially as conditions in the field do not remain identical over a long period. For example, *C. brunneus'* higher oviposition rate will favour this species during short periods of favourable conditions for sweetpotato weevils, like dry spells which expose tubers for egg laying. *C. puncticollis'* longer longevity will favour this species during less favourable conditions, as females will still be alive and able to lay eggs once oviposition sites again become available. The fluctuating ratio between the two species, as observed over one growing season in sweetpotato crops (Smit, 1996), proves that other factors besides the r_m are important for population increase.

Acknowledgements

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Part II BIOLOGY OF SWEETPOTATO WEEVILS

3. Sweetpotato weevil (*Cylas* spp.) ecology, biology and behaviour, and control options

3.1 Introduction

A review is given on additional aspects of the sweetpotato weevil biology. Damage caused by sweetpotato weevils and their behaviour, dispersal and infestation are discussed. Almost all published studies deal with *C. formicarius*. I supplement this information with descriptions of own observations made on *C. brunneus* and *C. puncticollis* and with the results of experiments on behaviour. When no references are given for findings concerning *C. brunneus* and *C. puncticollis*, it are own, previously unpublished, observations.

Knowledge on the biology of pests and the kind of damage they inflict, together with knowledge on the key environmental factors that impinge (favourably or unfavourably) upon pest species in the ecosystem, is essential for setting up an IPM programme (Flint and van den Bosch, 1981). In the last part of the chapter, pest management considerations based on knowledge of sweetpotato weevil ecology, biology and behaviour will be presented.

3.2 Review and observations

3.2.1 Life cycle

Females of all three *Cylas* species lay yellowish eggs singly in a cavity excavated in either roots or stems and they seal the cavity with a faecal plug (Sutherland, 1986 and references therein). Roots are the preferred oviposition site. On stems, the woodier parts are favoured above new growth (Sutherland, 1986).

The larvae of all three *Cylas* species are creamy white and have a curved body. They feed and develop within the vines and roots of the sweetpotato. Pupation occurs inside the vine or root (Sutherland, 1986). The early instar larvae of *C. puncticollis* cannot be distinguished from *C. brunneus*, but the last larval instar, pre-pupal stage and pupae of *C. puncticollis* are larger.

After eclosing from the pupae, the adults remain in the vine or root for a few days before emerging (Sugimoto et al., 1996). Just-eclosed adults of *C. puncticollis* change from white, via grey, to completely black, while those of *C. brunneus* reach their final colouration via white and brown. Some *C. brunneus* specimens turn completely black like *C. puncticollis*, while other specimens become brownish (Wolfe, 1991). However, in Eastern Africa most *C. brunneus* are bicolored, having a black head, a reddish-brown thorax and black elytra, thus resembling *C. formicarius* (Wolfe, 1991). Average-sized adults of *C. brunneus* are smaller than adults of *C. puncticollis* and *C. formicarius*, resp. 5, 7 and 6 mm (Sherman and Tamashiro, 1954; own observations). The adults emerge from the root or vine after attaining full colouration. Like in *C. formicarius*, adults of *C. puncticollis* and *C. brunneus* may be conveniently sexed by the shape of the distal antennal segment, which is filiform in males and club-like in females (Sutherland, 1986).

3.2.2 Host range, infestation and dispersal

Although the preferred host plant of *C. formicarius* is *Ipomoea batatas*, 27 other *Ipomoea* spp. and a few related genera also serve as alternate hosts (Sutherland, 1986). According to Wolfe (1991), *C. formicarius* originated on the Indian subcontinent, and sweetpotato from the New World. *C. formicarius* could only have been involved with sweetpotato after Europeans brought the curculionid and this host plant geographically together (Austin, 1991). *C. puncticollis* and *C. brunneus* are restricted to the African continent (Wolfe, 1991). Before sweetpotato was introduced other plant species than sweetpotato must have been their host. A range of *Ipomoea* spp. is found in Eastern Africa, but no attempt has yet been made to verify whether *Cylas* spp. breed on any of these. In most cropping systems, sweetpotato plants or crop residues are available for the weevils throughout the year, therefore the need of alternate hosts for survival of *Cylas* spp. is probably limited. Besides, most other *Ipomoea* spp. do not form swollen storage roots, and population build-up on the vines is slow.

Larvae of the clearwing moth *Synanthedon* spp. and a small weevil *Peleropus batatae* infest storage roots via the root stalks. However, *C. brunneus* or *C. puncticollis* larvae do not tunnel down the vines into the roots; Sutherland (1986) also considered for *C. formicarius* this infestation mechanism insignificant. The principal mechanism of root infestation of *C. formicarius* is by females gaining access to the root, either when exposed on the soil surface or through soil cracks (Sutherland, 1986). Once at the root, oviposition follows. In laboratory tests in glass jars, *C. formicarius* females managed to reach roots and oviposit at a maximum depth of 2 to 2.5 cm, passing along the sides of the jars (Jayaramaiah, 1975b). No penetration through the soil was observed. Burdeos and Gapasin (1980) in a series of pot experiments, showed that the deeper the layer of soil above developing roots, the lower the infestation of *C. formicarius.* They did not mention if soil cracks aided the females to reach the roots.

C. formicarius can disperse by flying and crawling. Moriya (1995) studied the weevils flight ability using a flight mill. Nearly 50% of males and 95% of females never flew at all. The flight distance for females in 24 hours was an average 0.2 m and a maximum 17.5 m. He concluded that females disperse not by flying, but by crawling on the ground. This is difficult to measure, especially because for females there is no tool such as sex pheromones to measure dispersal distance. The flight distance for males in 24 hours is 40.8 m on average, and maximum 823 m (Moriya, 1995). These findings are consistent with values obtained by the mark-and-recapture experiments in the field using synthetic pheromone traps. Sugimoto et al. (1994) estimated the mean dispersal distance of male adults to be about 55 m/d in an area without sweetpotato. No males were recaptured at a distance of 1000 m downwind from the traps, while only one percent of males were recaptured at 500 m. The median dispersal distances per two days in Japan also depended on the season (Miyatake et al., 1995). It ranged from 326 m in September to less than 50 m in late October. The maximum dispersal distance is 500 m in fields with and 1000 m in fields without sweetpotato. Jansson et al. (1991) recaptured, in fields devoid of plants, about 10% of marked males in pheromone traps 16 hours after release from 280 m downwind of the pheromone.

Observations on females and males of *C. brunneus* and *C. puncticollis* also revealed that males fly more than females. Unmated males kept separate from females fly frequently.

3.2.3 Damage

Adults of all three *Cylas* species feed on the epidermis of vines and leaves, scraping oval patches off petioles, young vines and leaves. Yield loss is seldom serious (Sutherland, 1986 and references therein). Adults also feed on the external surfaces of roots causing round feeding punctures which can be distinguished from oviposition sites by their greater depth and the absence of a faecal plug. The developing larvae tunnel in the vines and roots causing significant damage. Frass is deposited in the tunnels (Sutherland, 1986). In response to the damage, the root produces terpenes which render the infested root part inedible (Sato et al, 1981). In Eastern Africa both *C. puncticollis* and *C. brunneus* can be found infesting the same root. When a root is exclusively infested by *C. puncticollis*, the core of the root might still be untouched; *C. brunneus* larvae seem to tunnel further inside the root. First signs of weevil injury are mostly observed at the root tips, being the parts that often are exposed and not covered by soil. Feeding inside the vines causes malformation, thickening and cracking of the affected vine. Early infestation might lead to poor establishment of the planting material. Foliage may become pale in colour and the growth and vigour of the plant can be affected (Sherman and Tamashiro, 1954). Heavy infestation of *C. formicarius* in the vines have been correlated with high damage levels in roots and reductions in total yields and root size, but that is not always the case (Sutherland, 1986). Jansson et al. (1990) found most *C. formicarius* life stages in the vines early in the season and in the roots late in the season. Weevil population grew 4.0 times more rapidly in the roots than in vines.

3.2.4 Behaviour

Adults of *C. formicarius* often feign death when disturbed (Jayaramaiah, 1975a). The same observation was made for *C. puncticollis* and *C. brunneus*. Especially males can run away at high speed from an apparently dead position.

C. formicarius weevil populations are highly clumped in sweetpotato fields (Jansson and McSorley, 1990). Besides that, between 82% and 91% of the total *C. formicarius* population is below the soil surface; and between 78 and 89% of the total population is found in the region extending from 10 cm above the ground to 15 cm below the ground (Jansson et al, 1990). In the laboratory aggregation behaviour of *C. puncticollis* is stronger than that of *C. brunneus*.

Diurnal patterns of *C. formicarius* activity were studied by Sakuratani et al. (1994) under laboratory conditions. Feeding, mating and oviposition activity peaked at night. *C. brunneus* is active in flying and mating during the photophase, while *C. puncticollis* aggregates during daylight in dark corners and is only seen mating and flying during the scotophase.

3.2.5 Sex pheromones

C. formicarius males are attracted to females suggesting the existence of a sex pheromone (AVRDC, 1976). Heath et al. (1986)

isolated, identified and synthesized the active, female-produced pheromone (Z)-3-dodecen-1-ol (E)-2-butenoate. Sathula (1993) and Smit et al. (1994) showed that female *C. puncticollis* and *C. brunneus* produce species-specific sex pheromones, and these were identified as decyl (E)-2-butenoate for *C. puncticollis* (Smith et al., forthcoming) and dodecyl (E)-2-butenoate for *C. brunneus* (Downham et al., forthcoming).

In an olfactometer experiment already-mated females of *C. formicarius* were not attractive for males in contrast to unmated females, probably because secretion of the pheromone ceases after mating (Sugimoto et al., 1996). However, for *C. puncticollis* in field-trapping experiments in Kenya male catches did not differ significantly between mated and unmated conspecific females (Smit et al., 1994). *C. brunneus* females attract males when mated, but significantly less than when unmated.

3.3 Experiments

3.3.1 Multiplication rate in roots compared to vines

The maximum number of *C. brunneus* that could develop per gram of initial root weight was compared with that of *C. puncticollis*. Also the numbers developing from roots were compared with those from vines. Eleven freshly harvested large-sized roots, ranging in weight from 293 to 841 grams, were separately presented to more than 500 weevils of each species in closed containers for oviposition for 24 hours. Ten vine parts (30 cm), placed in a tube with water, were offered to 20 female *C. brunneus* or *C. puncticollis* for oviposition for 72 hours.

A maximum of 1.4 adults per gram of initial root weight emerged from the root for *C. brunneus*, and 1.2 adults/g for *C. puncticollis*. Average numbers did not differ significantly between species and an average-sized root of 300 grams could easily harbour 250 adults. For *C. brunneus* the maximum number of adults retrieved from one vine part was 25, and the average over 18 vines was six adults per vine; for *C. puncticollis* these figures were 20 and 10 respectively.

These observations indicate that in the early stages of a crop, in the absence of storage roots, population build-up on stems will be slow. However, when roots are available for oviposition, populations increase rapidly.

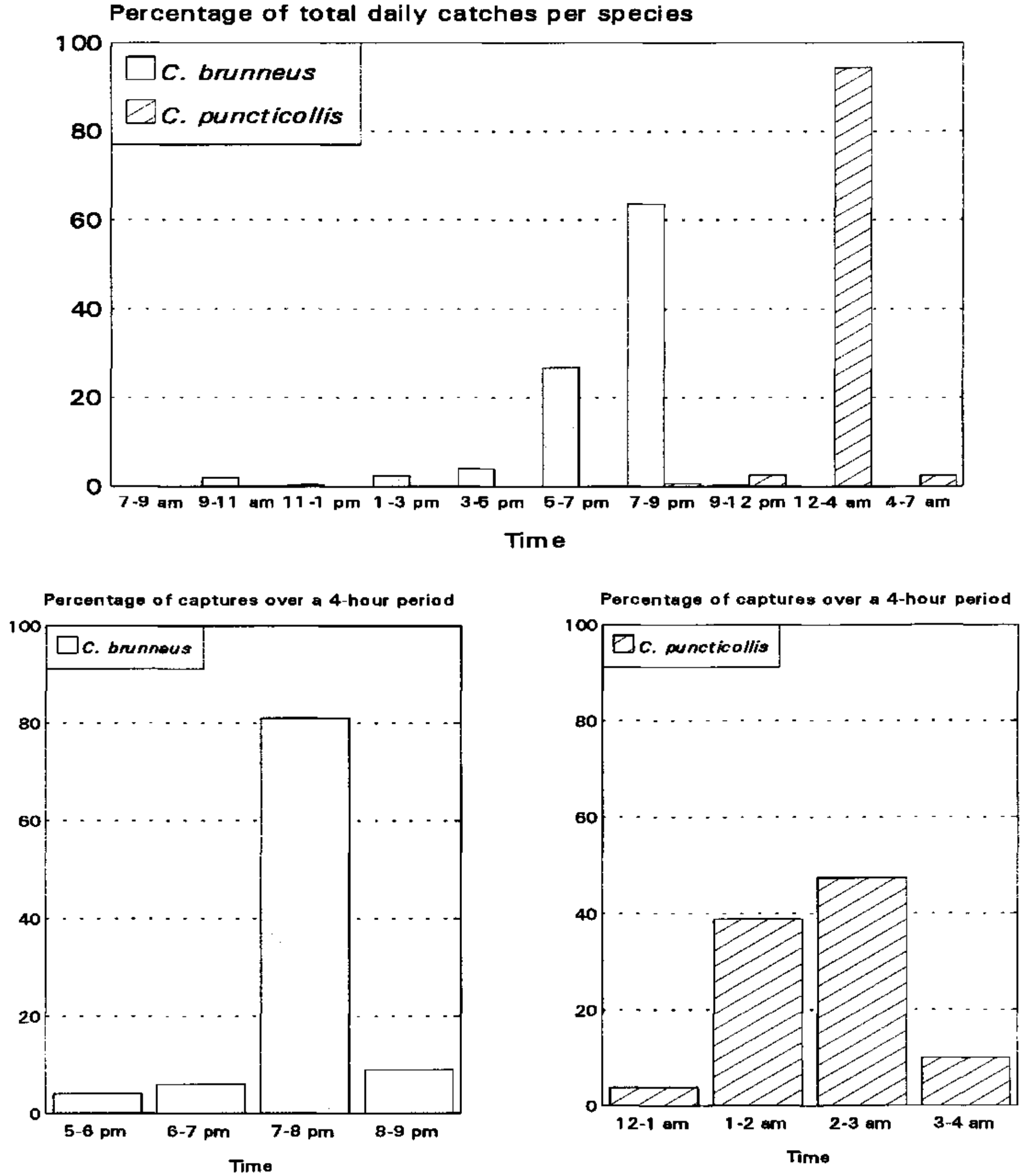

Figure 3.1 Diurnal timing of captures of *Cylas puncticollis* and *C. brunneus* males at traps baited with their respective pheromones (0.1 mg). Top graph based on separate experiments per species, each with four replications and over four nights. Bottom graphs based on other experiments, each with four replications and over four nights. Source: Downham, M.C.A., N.E.J.M. Smit, P.O. Laboke, D.R. Hall and B. Odongo, forthcoming.

3.3.2 Diurnal activity of males

Pheromone traps were used to determine diurnal timing of male *C. brunneus* and *C. puncticollis* activity (Downham et al., forthcoming). During four days pheromone traps (for material and methods see chapter 6) were checked on fixed times of the day; trapped weevils were removed and counted.

The peak period for catches of *C. puncticollis* males was 2-3 am and for *C. brunneus* 7-8 pm (Figure 3.1). The different period of sexual activity of males must be a major factor in ensuring conspecific mating even though the *C. brunneus* pheromone attracts *C. puncticollis* (see chapter 6). It is likely that production of pheromone by the females is synchronised with the conspecific male activity, reinforcing this effect. Jansson et al. (1991) in Southern Florida caught most male *C. formicarius* weevils a few hours after sunset in pheromone traps, and only a few during daylight. Of the three *Cylas* species, only *C. puncticollis* appears to be strictly nocturnal.

3.3.3 Effect of mixed pheromone lures

The effects on catches of mixing the two pheromone components were investigated, not only to determine whether more attractive and/or specific blends could be devised for either species, but also whether a single lure could be used to trap both species optimally.

Table 3.1 Mean no. (±SE) of males caught per trap per night in 5-l jerry can traps baited with decyl (E)-2-buteonate (*C. puncticollis* synthetic pheromone) and dodecyl (E)-2-buteonate (*C. brunneus* synthetic pheromone) or virgin female weevils (4 replicates; 5 nights)

Test	Lure Type[2]	decyl (E)-2-buteonate	dodecyl (E)-2-buteonate	Mean catch/trap/night[1] *C. puncticollis*	Mean catch/trap/night[1] *C. brunneus*	ratio target non-target
a	PV	0.1 mg	-	13.1(3.5)a	0.05(0.05)*	262
	PV	0.1 mg	0.1 mg	18.3(5.5)a	0.0	-
	PV	0.1 mg	0.01 mg	15.4(6.0)a	0.0	-
	C. puncticollis 10♀♀	-	-	4.1(1.2)b	0.05(0.05)	81
	control: root piece	-	-	0.4(0.2)c	0.0	-
b	RS	-	0.1 mg	12.5(5.0)b	14.7(3.0)a	1.2
	RS	0.1 mg	0.1 mg	29.8(6.4)a	0.1(0.1)b	0.002
	RS	0.01 mg	0.1 mg	6.5(1.4)b	0.1(0.1)b	0.015
	C. brunneus (10♀♀)	-	-	0.1(0.1)b	13.7(3.5)a	273
	control: root piece	-	-	0.0 c	0.5(0.1)b	-

[1] Means followed by same letter are not significantly different ($P<0.05$, Tukey; mean catches were transformed to $\log(x+1)$).
[2] PV = polythene vials, RS = rubber septa
* Due to low catches the data for *C. brunneus* in test a could not be analysed

Source: Downham, M.C.A., N.E.J.M. Smit, P.O. Laboke, D.R. Hall and B. Odongo, forthcoming.

The addition of the *C. brunneus* to the *C. puncticollis* synthetic pheromone component did not affect attractiveness to *C. puncticollis* males or lack of attractiveness to *C. brunneus* males (Table 3.1). Addition of the *C. puncticollis* to the *C. brunneus* component nullified the attractiveness of the latter to *C. brunneus* males even when the concentration of the first was only 10% of the latter (Table 3.1). In Electro Antenna Gram (EAG) studies both species gave responses to both decyl and dodecyl (E)-2-buteonate. However, these responses were significantly lower to the compound considered to be the pheromone of the other species. The results suggest that blends of the two pheromone components will not improve the attractiveness or the specificity of the single components, and also that lures for the two species cannot be combined in the same trap.

3.3.4 Movement in soil

Three tests were conducted to determine if African *Cylas* species can climb up to the soil surface from a soil-covered infested root, and if they can dig down through the soil to locate sweetpotato roots for oviposition. Four different soil conditions are used: sterilized sand and vertisol, either dry or water-saturated.

Test 1: A completely-infested root, either with *C. puncticollis* or with *C. brunneus*, is incubated. When all insects inside the root have reached the pupal or adult stage (see graph 3, chapter 2), the root is broken in two equal parts. Each part is laid on the bottom of a 30x15cm plastic jar. Both jars are filled with sterilised sand, one dry, the other water-saturated. In two other jars the same treatment is carried out with vertisol. The root parts are covered with two cm soil. Each treatment is replicated three times. Adults emerged above the soil are daily counted and removed. After two weeks the root is dug up and the remaining adults are counted.

Through both sand and vertisol, 98% of adults of both weevil species (in all cases >100) managed to climb up to the soil surface from a soil-covered infested root over a period of two weeks. The adults came up earlier through the dry materials than through the wet. Between seven and 14 days, when the wet material had started to dry up, most adults had emerged above the soil.

Test 2: Ten female and ten male weevils are put at the bottom of a plastic jar and covered with two cm of dry vertisol or sand. A small, fresh root is placed on top of the soil. The jars are inspected daily for adults that emerged from the soil and for feeding/egg laying signs on the root.

After two days all 20 adults of both species, which were covered with two cm of soil, had emerged from the soil and were feeding and ovipositing on a root.

Test 3: A clean, fresh root is laid on the bottom of one of four plastic jars. The jars are filled up either with dry or water-saturated sterilized sand, dry or water-saturated vertisol, such that the top of the root is covered with one cm of soil. Ten females and ten males are placed on the soil. After two weeks the root is dug up and inspected for feeding and oviposition holes. The roots are incubated for four weeks. Emergence of adult weevils is checked.

No weevils managed to dig down through one cm of sand or vertisol to locate a sweetpotato root for feeding and oviposition; no adults emerged after incubation of the roots. After two weeks, no soil cracks had formed in any of the treatments. Weevils remained on the soil surface. On the dry soil, they all died within two weeks, while on the wet soil only 20% (4 adults) survived.

Adult weevils of *C. brunneus* and *C. puncticollis* actively climb upward through a layer of soil or sand. However, they do not dig down to a root, even when the layer is only one cm of vertisol or sand. So, the principal mechanism of root infestation of *C. brunneus* and *C. puncticollis* (and *C. formicarius* (Sutherland, 1986)) is by females gaining access to the surface of the root, either when it is exposed on the surface of by passing through soil cracks.

3.3.5 Dispersal distance

To establish the dispersal distance of male sweetpotato weevils, mark-release-recapture experiments were carried out using bottle pheromone traps (ODA Holdback project, 1996; see chapter 6). Marked weevils (method described in chapter 6) were released at distances of 20, 50 and 80 m, or 35, 65 and 100 m in lines directly downwind from a trap and in lines at angles of 45° at either side, in open grassland. Percentage recaptures after 48 hours using 0.1 mg pheromone lures were measured.

A maximum of 14% recapture was recorded for *C. brunneus* males released 20 m from the trap. Recapture rates declined as release distance increased. The variable wind direction and speed, especially after midnight when *C. puncticollis* males are active, might be one reason for the low captures. No *C. brunneus* were recaptured from distances more than 80 m from the trap, while less than one percent of *C. puncticollis* were recaptured

Table 3.2 Sweetpotato weevil ecological, behavioural and biological traits and control considerations.

Ecological, behavioural or biological trait	**Control consideration**
Sweetpotato life stages are found in roots as well as vines.	Weevils of different life stages can be carried over within planting material.
Most life stages are found below the soil surface.	They are difficult to reach for parasitoids or aerial insecticide sprays. Fungi, bacteria or nematodes may be suitable biological control agents. Monitoring weevils by counting adults in field is misleading.
Sweet potato weevils have a limited host range and prefer sweetpotato above wild relatives.	Crop sanitation is an important control measure. The effect of removal of wild host weeds is less clear.
Weevils are most active at night.	Basing judgements on importance of weevils on numbers of adults counted in the field during day light can be misleading.
Female weevils produce sex pheromones which attract males of their own species.	Potential for lowering the population by mass trapping and/or mating disruption.
Weevils cannot dig down through soil. They reach roots through soil cracks or when roots are exposed above soil.	Deep-rooting varieties might escape weevil damage. Covering exposed roots with soil and filling soil cracks protect roots from weevil attack. Planting and harvesting dates could be adjusted, so that roots are not present in the dry season, when soil cracks are common.
Females fly infrequently, and seem to disperse by crawling.	A distance between sweetpotato crops, or a barrier crop, could prevent weevils to infest newly planted plots.
Under favourable conditions weevils have 9 to 13 generations a year, live three to four months, and produce an average of 100 eggs spread over a female's life.	Avoiding the continuous presence of weevil breeding sources is important. Crop debris and wild hosts should be removed and new plots planted away from old ones.

at 100 m. The maximum dispersal distances were 80 m and 120 m respectively. In all experiments a few unmarked weevils were trapped. These may have come from a sweetpotato plot at a distance of well over a hundred meters upwind, indicating that some dispersal from plots was occurring which was not exclusively the result of pheromone plume orientation (ODA Holdback project, 1996).

Until more is known about weevil dispersal by flight and crawling, it is difficult to recommend a safe distance of a new from an older, infested sweetpotato plot.

3.5 Conclusions related to management components

Knowledge of sweetpotato weevil ecology, biology and behaviour may give indications on how to manage the sweetpotato weevil. Details are presented in table 3.2. Some of the most important conclusions are: Ecological traits indicate that careful selection of planting material and crop sanitation are important control measures. Aspects of the weevils behaviour point towards potential for controlling them by covering exposed roots to avoid oviposition and by keeping a distance between sweetpotato plots. Biological traits indicate that the continuous presence of weevil breeding sources should be avoided. In chapter 7 potential management components for *Cylas* spp. are discussed separately.

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PART III IPM COMPONENTS FOR SWEETPOTATO WEEVILS

4. Farmers' cultural practices and their effects on pest control in sweetpotato in South Nyanza, Kenya[1]

Abstract.

Sweetpotato weevils (*Cylas puncticollis* (Bohe.) and *C. brunneus* (Fabr.) Coleoptera; Apionidae) are the most important insect pests in South Nyanza, Kenya's principal sweetpotato-growing district. A pest of secondary importance is the sweetpotato butterfly (*Acraea acerata* (Hew.) Lepidoptera; Nymphalidae). Cultural control is presently the most promising component of an integrated pest management strategy for subsistence sweetpotato farmers in Kenya. A survey of farmers' cultural practices in South Nyanza suggests that crop protection workers should concentrate their research and extension efforts on crop sanitation and the avoidance of adjacent planting of successive crops. The life cycle and behaviour of the sweetpotato weevils and butterfly should be explained to farmers, so that they better understand the insects' modes of dispersal and thus see the need for sanitation and avoidance of adjacent planting.

4.1 Introduction

South Nyanza, located on the shore of Lake Victoria in southwestern Kenya, is Kenya's principal sweetpotato-growing district. In 1990-91 about 13,000 ha of sweetpotato were grown, 52% of the total area under sweetpotato in the country (Kenya Ministry of Agriculture, 1992). The crop is important for food security in dry years and in months when other foods are scarce. Tubers are commonly sold for cash in local markets. Farmers in one area of South Nyanza have even specialized in growing sweetpotato as a cash crop for commercial markets. The staple food in Kenya is maize. For farmers this crop is far more valuable than sweetpotato.

Results of a socioeconomic survey throughout Kenya indicated that in dryer low elevation regions, the major production constraints are sweetpotato weevils and lack of planting material (Mutuura et al, 1992). In wet zones at higher elevations, moles

[1]A slightly different version of this chapter has been published as: Smit, N.E.J.M. and L.O. Matengo, 1995. Farmers' cultural practices and their effects on pest control in sweetpotato in South Nyanza, Kenya. International Journal of Pest Management, 41: 2-7.

are the most important problem.

A survey form to assess pest damage and pest incidence in farmers' sweetpotato fields was jointly developed by researchers from KARI (Kenyan Agricultural Research Institute), IIBC (International Institute for Biological Control) and CIP (International Potato Center) (Rangi et al, 1991). This form was used during pest surveys in South Nyanza. One of the conclusions from the surveys was that sweetpotato weevils (*Cylas* spp.) were the most damaging insect pest (Magenya and Smit, 1991).

Possible components of an integrated pest management (IPM) approach for sweetpotato weevils are resistant varieties, sex-pheromones and biological, chemical and cultural control (Talekar, 1991). Extensive research around the world has failed to identify varieties with resistance to sweetpotato weevil (Talekar, 1987). Several years of research is still needed before the sex-pheromones of the African sweetpotato weevil species can be used for control purposes. No cheap and efficient biological control techniques are expected in the near future (Jansson, 1991). Subsistence farmers cannot afford pesticides for a low-value crop like sweetpotato. This leads to the conclusion that cultural control is currently the most promising component of an IPM strategy for small-scale sweetpotato growers.

To increase food production in traditional agriculture, Glass and Thurston (1978) recommend determining what components of the system are essential to preserve or augment, and implementation of change in a rational manner consonant with the environment. Detailed studies should be made to learn the effect of existing traditional agricultural practices on pests and vice versa. Some cultural practices may have been developed and used as crop protection tactics (perhaps unrecognized) rather than for strictly agronomic reasons. There is a growing interest in starting from the "user's perspective" by documenting and analysing farmers' control strategies (Altieri, 1984; Brown, 1986; Ewell et al, 1990; Matteson et al, 1984; Thurston, 1992).

A survey was undertaken to document farmers' cultural practices and to learn why they were used. The survey indicated which practices should be studied in research on cultural control and emphasized in extension messages. When trying to understand the farmers' responses to the questionnaire, it is important to realise the relative importance of the crop compared to particularly maize.

4.2. Material and methods

4.2.1 Study regions

Three regions - differing in altitude, rainfall and soil type - were chosen in South Nyanza District, where the sweetpotato acreage is relatively high.

1. In Kabondo location, Oyugis division, located in the upper midland coffee zone (Jaetzold and Schmidt, 1982), sweetpotato is grown commercially. Rainfall is between 1400 and 1600 mm a year, the annual mean temperature is 21.1-19.3°C and the altitude ranges from 1450 to 1700 m. Soils are chromo-luvic phaeozems: well drained, deep, red, friable to firm clay, with a humic topsoil (Stroebel, 1987). Other major crops are maize and bananas; also grown are vegetables, beans, sorghum, coffee, tea and pineapple. This sample region will be referred to as "the high-potential zone".
2. Kamagambo location, Rongo division, is in the lower midland sugarcane zone. Rainfall is between 1600 and 1800 mm a year, the annual mean temperature is 21.7-20.5°C and the altitude ranges from 1350 to 1500 m. Soils are predominantly humic acrisols: well drained, deep, red, friable clay or sandy loam or sandy clay loam, with an acid humic topsoil. Major crops are maize and sugarcane; other crops are cassava, groundnuts, finger-millet, sorghum, beans and vegetables. This sample region will be referred to as "the medium-potential zone".
3. The third region covered parts of 3 locations: Kanyamwa and Kabuoch in Ndhiwa division and Kanyada in Rangwe division. The site is in the lower midland cotton zone and partly in the marginal sugarcane zone. Rainfall is between 1250 and 1450 mm a year, the annual mean temperature is 22.2-20.5°C and the altitude ranges from 1250 to 1450 m. Soils are vertisols: imperfectly drained, deep, dark grey, very firm, cracking clay (black cotton soils). Other major crops are sorghum and maize, planted with green grams, cassava and cowpea. This sample region will be referred to as "the marginal zone".

4.2.2 Sampling of farmers and general characteristics

We visited 85 farmers. Sweetpotato plots were spotted from the car or we were guided to them by people we met along the roads, tracks or in shopping centres. Care was taken that plots were evenly distributed over the sample regions. Whenever possible, we selected plots where farmers had already started harvesting.

The average estimated total farm size was 3.1 ha, ranging from 0.4 to 9.3 ha. Farms had 1 to 7 sweetpotato plots, with an average of 2.9. There were no differences in total farm size or the number of sweetpotato plots between sample regions. The average farm area under sweetpotato at the time of sampling was estimated at 0.4 ha (14% of total farm area). In the high-potential zone, the sweetpotato area was larger than in the medium-potential and marginal zones. Sweetpotato area ranged from <0.1 to 1.2 ha. Sample plots measured an average of 0.16 ha.

Of the 47% of farmers growing sweetpotato mainly for home consumption, 13% did not sell at all, while the rest sold surpluses on the local or commercial market. The remaining farmers (53%) grew sweetpotato primarily as a cash crop. More than half of these (32%) sold most tubers on local markets, and the rest (21%) were commercially oriented farmers who sold sweetpotatoes wholesale to large urban markets. All of the latter farmers were found in the high-potential zone.

Most of the farmers interviewed were female. Of the 10 males, 6 were involved in commercial farming. Most (85%) of the farmers had been growing sweetpotatoes for 10 years or more. The average farmer grew 2.3 different varieties in her plot. Names are confusing as the same local name may be given to different varieties, and the name of one variety can differ from farmer to farmer.

4.2.3 Short description of major insect pests

Sweetpotato weevil (*Cylas* spp.) adults are elongate and similar to ants in appearance. The female lays eggs singly in cavities excavated in vines or in tubers, preferring the latter. The developing larvae tunnel in the vine or tuber and are the most destructive stage. Pupation takes place within the larval tunnels. Adults develop inside the tuber or vine and emerge after a few days. The female finds tubers to lay her eggs in through soil cracks or when tubers are exposed above the soil, as she cannot dig. Sweetpotato weevils can infest a newly planted field by being introduced with planting material, by immigrating from neighbouring fields or by surviving in crop debris from a preceding crop (Talekar, 1988). Weevils fly infrequently and generally for short distances (Chalfant et al, 1990). Tubers with any sign of weevil infestation are considered unmarketable. When weevil damage is localized on the tuber, the good part is used for home consumption.

The female of the orange sweetpotato butterfly (*Acraea acerata*) lays pale yellow eggs in batches of 100-400 on the leaves. The caterpillars are greenish-black and spiny. They stay together for the first 2 weeks and feed on the upper leaf surface. Older larvae are solitary and eat the whole leaf. These insects can defoliate sweetpotato during outbreaks, as happens in southern Ethiopia and occasionally in Rwanda, Burundi, Uganda and Zaire (Girma, 1994; Lefèvre, 1948).

4.2.4 Cultural control

Cultural control covers management practices that make the environment less favourable to pest reproduction, dispersal and/or survival (Flint and van den Bosch, 1981). In the case of sweetpotato, cultural practices can reduce the number of weevils and butterflies invading a newly planted field and prevent weevils from access to tubers to lay eggs. Flint and van den Bosch (1981) mention that some of these practices, such as different cultivation techniques, have become so common among farmers that they are often not even recognized as control techniques. Examples of cultural practices are the use of clean planting material, keeping a distance between plots, rotation, suitable time of planting and harvesting, sanitation, planting methods, "hilling up" and fertilizer management.

4.3 Results and discussion

4.3.1 Farmers' cultural practices

4.3.1.1 Planting material

Almost all farmers (98%) mentioned that they only use vine tips (terminal cuttings) as planting material; two farmers also used vine cuttings in case of a shortage. Most farmers did not consider the availability of planting material a problem except in years of extreme drought. Many farmers (75%) had used planting material from their own plots and 25% had obtained cuttings from neighbours for free.

The probability of finding weevils inside the stems decreases in younger (tip) cuttings (AVRDC, 1991). Farmers in South Nyanza select this planting material; Trials comparing types of planting material are therefore not a priority. However farmers should be advised not to pick planting material from heavily infested fields, as adult weevils can hide among the leaves.

4.3.1.2 Distance between plots

In 48% of the cases, an older or younger sweetpotato plot, belonging to the same farmer or sometimes to a neighbour, was located directly next to or within 10 m of the sample plot. In 14% of the cases, the closest sweetpotato plot was more than 100 m away and in 38% of the cases another plot was 10 to 100 m from the sample plot.

When asked where farmers had planted or were planning to plant a new sweetpotato plot, 48% pointed out a plot within 10 m of the sample plot, 77% a plot within 100 m and 23% a plot at a distance of more than 100 m.. When asked if they had ever planted sweetpotato right next to an older plot, 96% answered positively. When asked if they had a special reason for that, none mentioned a reason which had to do with the sweetpotato crop. Some farmers had no reason at all, while others said that they had a shortage of land, that the crop fitted in their rotation, that it was good to plant sweetpotato after maize and sorghum because it suppressed striga weed, etc. Only 3 farmers mentioned that adjacent planting facilitated the spread of insects (and moles) from the old plot to the new plot.

Neighbouring fields may be the most important source of insect infestation for newly planted plots. Sweetpotato is grown year-round and there are always different plots of different ages present on one farm, very often at close distances. But even on a small farm it is possible to plant at least 50 m away or to ensure that there is a high barrier in between, such as sorghum or a hedge. Distance between successive sweetpotato plots is a key cultural practice and research is under way to establish the minimum distance for different agroecological zones.

4.3.1.3 Rotation

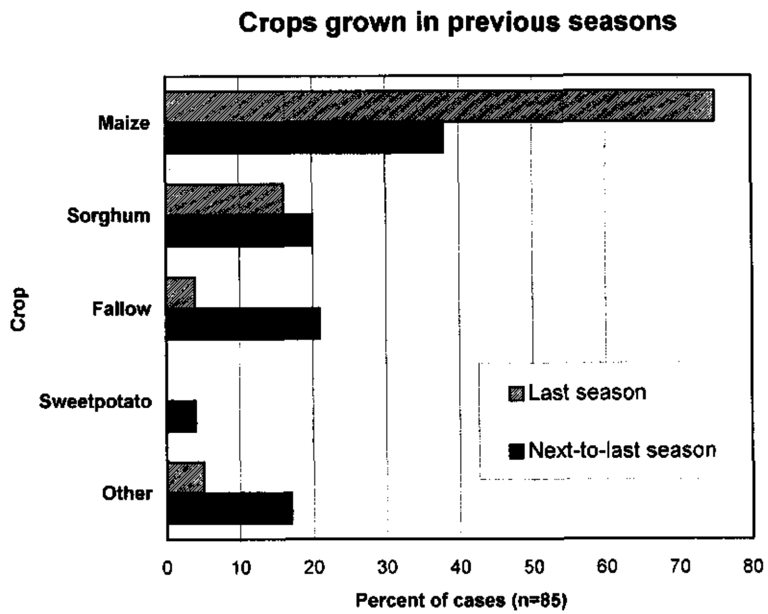
All of the sampled regions have 2 growing seasons per year: the short rains (Oct-Dec) and the long rains (Mar-May).

The previous crop on the sampled sweetpotato plot was often maize (75%) or in some cases a maize-legume intercrop (Figure 4.1). No previous crop of sweetpotato was mentioned. In the penultimate season 3 farmers grew sweetpotato.

One or 2 seasons occurred between 2 succeeding sweetpotato crops in 20% of the cases. Most of the farms with short rotations were in the high-potential zone. The rest of the farmers had more than 2 seasons between succeeding crops (Figure 4.1).

Most farmers (86%) believe that 2 sweetpotato crops should not succeed each other, because of low yields. An increase in insect damage was mentioned by 10% of the farmers.

In South Nyanza, farmers leave at least 2 seasons between succeeding crops of sweetpotato. Poor rotation is not a major concern, but research could establish the minimum number of seasons of rotation for the different agroecological zones.



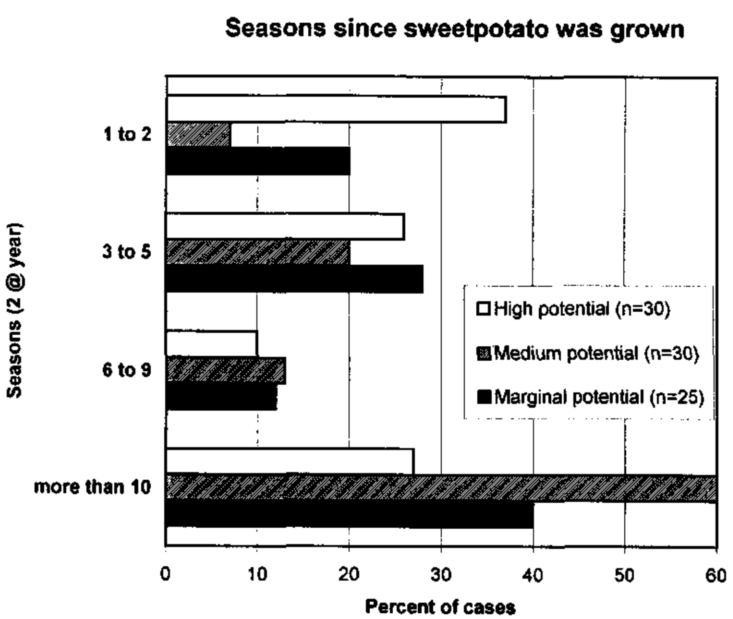


Figure 4.1 Rotation patterns in sample plots

4.3.1.4 Planting months

Sweetpotato was planted year-round, but most of the sample plots were planted in the later months of the rainy seasons, after other crops such as maize and sorghum. Most sweetpotato plots (80%) were planted either in October, November or December (short rains) or in April, May or June (long rains).

Farmers prefer to plant in the middle or at the end of the rainy season, which is an unrecognized but probably effective control practice against weevils. The plants establish well before the onset of the dry season. During the dry season, pest attack is high on the foliage, but no tubers have been formed yet. Tubers start to enlarge when it rains again, but few soil cracks are present. As a result, weevils cannot gain access to tubers and their numbers diminish. Most tubers are removed piecemeal before the onset of the next dry season. Research comparing different planting times could test the hypothesis that planting late in the season is advantageous.

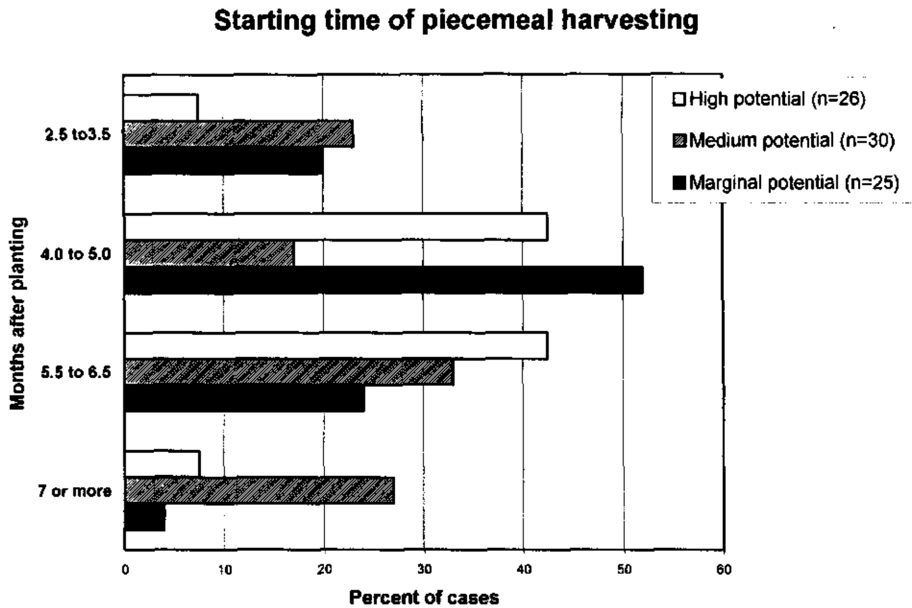
4.3.1.5 Harvesting

Except for 4 commercial farmers, who harvested the whole plot at once after about 8.5 months, all farmers mentioned that they practice piecemeal harvesting. This practice implies the careful removal of mature, enlarged tubers without uprooting the plant.

Piecemeal harvesting of the sample plots began about 5.2 months after planting (MAP) (Figure 4.2). However, the previous dry season had been extremely long and in "normal" years piecemeal harvesting starts slightly earlier.

Final harvesting of the plots with a hoe took place from 7 to 20 MAP with an average of 10.5 months. In the high-potential zone, farmers removed their sweetpotato plots significantly earlier than in the medium-potential and marginal zones. Many farmers in this zone are commercial farmers and need their plots for other cash-generating crops.

Piecemeal harvesting is probably a direct control method, because mature, enlarged tubers are removed when they are at greatest risk of attack by weevils. If tubers that mature at 5 MAP are left until a final harvest at 8 MAP, they will likely become infested. Many farmers also "hill up" during piecemeal harvesting, the effect of which is discussed later. Research comparing piecemeal harvesting and one-time harvesting will test the hypothesis that piecemeal harvesting is advantageous.



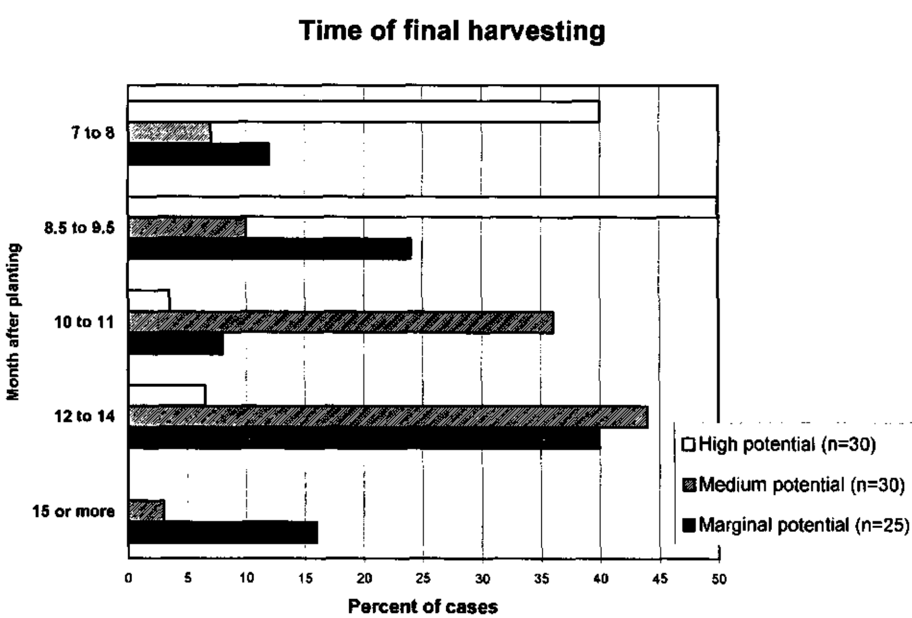


Figure 4.2 Harvest time in sample plots

4.3.1.5 Sanitation

Most farmers (71%) leave all or most of the vines in the field after the final harvest as soil fertilizer, 13% remove most of the vines, but leave a part on the field, and 16% remove all vines, mainly for animal fodder.

Newly rooted vines and sprouting, unharvested tubers will result in volunteer plants, which are sources of weevils. Farmers who have cattle should be encouraged not to leave vines in the field but to use them for animal fodder and to use the cow dung for fertilizing the soil. Farmers who have no alternative fertilizing source, should make sure that all sweetpotato vines dry completely in the field and remove volunteer plants regularly. It was commonly observed that farmers left weevil-infested tubers in the field after piecemeal harvesting. Farmers need to be told to remove these tubers and destroy them. Sanitation appears to be a key cultural practice. Demonstration plots should be established and research is needed on its control effect.

4.3.1.6 Planting method

All farmers planted on mounds, except one who planted on ridges. Mounds differed slightly in size, but most were not higher than about 20 cm. Two vine tips were usually planted per mound. Farmers practice relay cropping in maize (40%), but no intercropping.

Because only one planting method (mounds) was used in the district, IPM research on the effect of different planting methods is not a priority. The same can be said for intercropping trials, as this practice is not found in the study region.

4.3.1.7 "Hilling up"

All farmers added more soil around the base of the plant during weeding and 38% also mentioned "hilling up" during piecemeal harvesting. Most farmers weeded once.

"Hilling up" is a direct weevil control method: soil cracks are filled and exposed tubers covered, blocking the way for weevils. All farmers "hill up" at weeding. The advantage of further "hilling up" during piecemeal harvesting could be stressed in an extension message.

4.3.1.8 Fertilizing

One farmer applied farmyard manure before planting sweetpotato, but none of the others had fertilized the soil. The previous crop in the plot, especially maize, had been fertilized

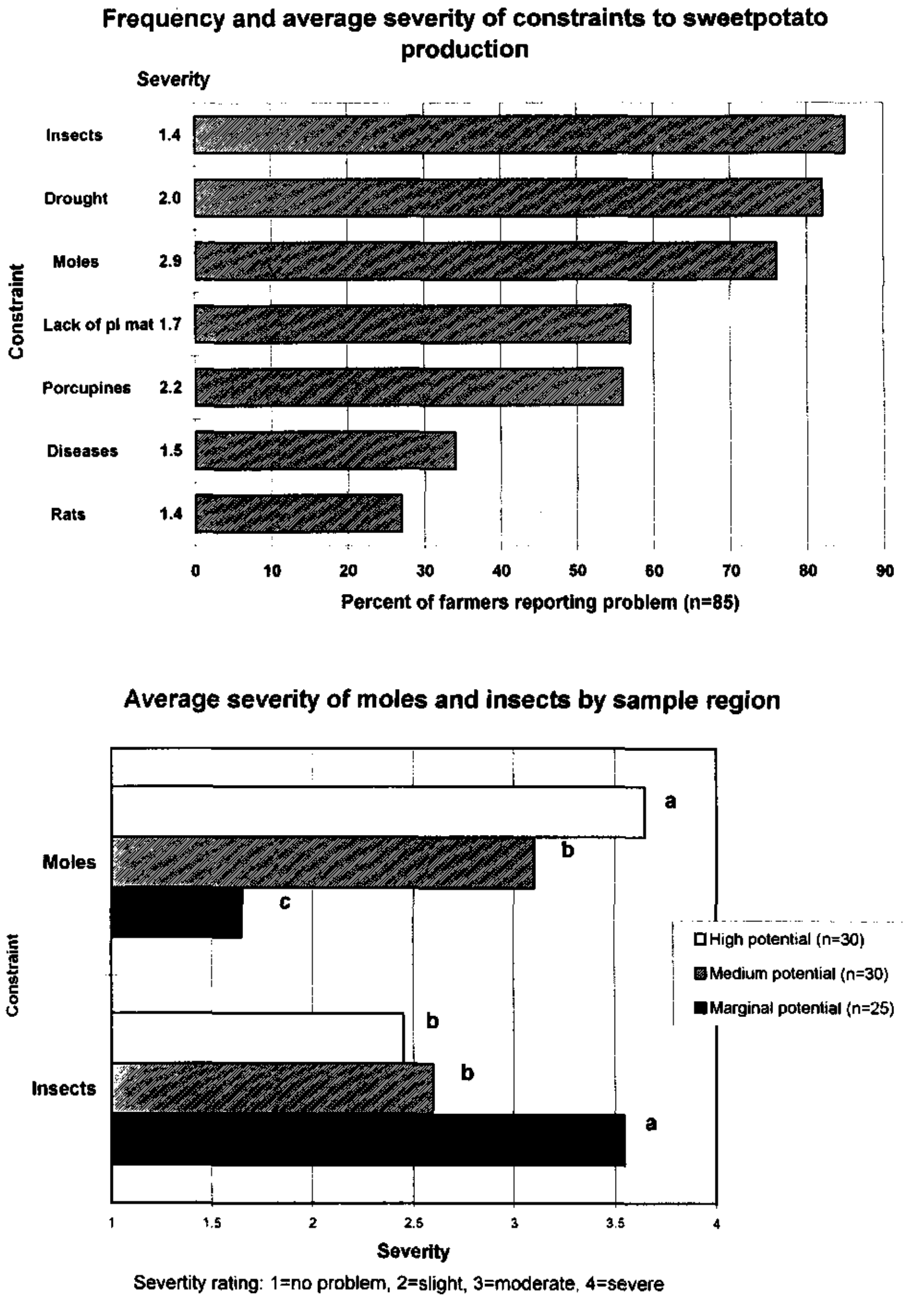


Figure 4.3 Severity of constraints

in most cases. Many farmers remarked that sweetpotato does not need any fertilizer, but rather adds fertility to the soil.

There is no immediate need for research on the effect of fertilizer on insect control, because farmers do not apply it.

4.3.2 Constraints

Farmers were asked to rate given constraints (Figure 4.3). Diseases referred mostly to viruses and were mentioned only in the high-potential zone. Drought was of unusual concern in the year of the survey, as the last dry season had been extremely long.

Moles and insects were clearly the most significant problems, but severity varied by sample region. Moles were a severe constraint in the high- and medium-potential zones, while insects were more serious in the marginal zone. Farmers' perceptions of mole damage might have been overrated as it is more dramatic than weevil damage.

Farmers were asked where insects caused damage to the leaves, to the stems or on the outside or inside of the tuber. Leaf damage, external and internal tuber damage were rated high in the marginal zone (Figure 4.4). Stem damage was not considered important.

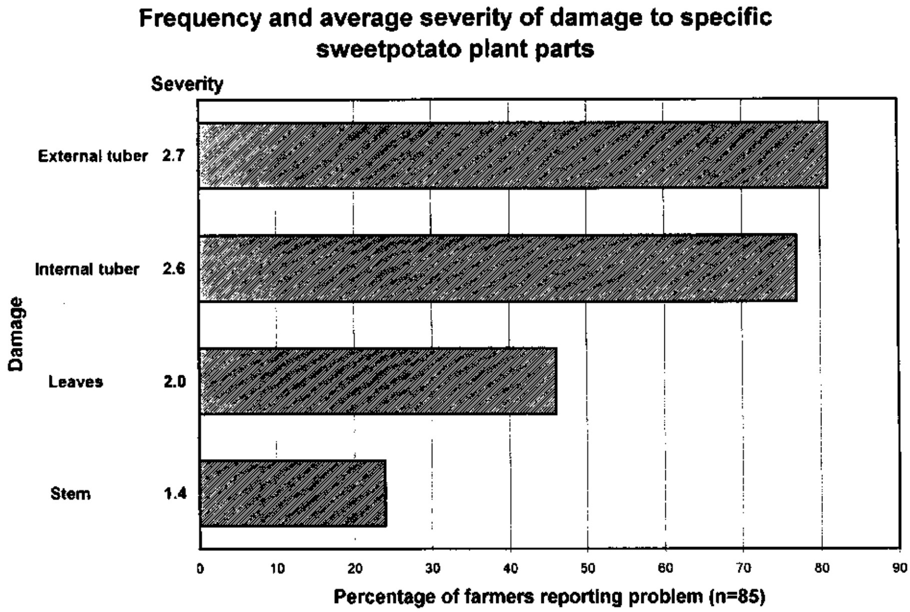
Most farmers (81%) who had cited insects as a problem recognized that most damage was done in the dry season. Farmers that saw more damage in the rainy season or saw no difference between seasons were not found in the marginal zone.

Insects were mentioned as a major constraint to sweetpotato production in the marginal zone, where rainfall is relatively low and the clay soil cracks easily. Farmers described sweetpotato weevil damage to tubers. During the survey, considerable damage to foliage caused by sweetpotato butterfly caterpillars was observed. Farmers also complained about this.

In the other two sample regions, insects were not a major constraint overall, but were a serious problem for individual farmers. Here, especially farmers with "poor" cultural practices complained about insect damage. IPM experiments should be carried out where insects are considered the major constraint.

4.3.3 Direct control and less susceptible varieties

Of the 74 farmers who considered insects to be a problem, 67% did not try to control the insects in any way, and the rest mentioned handpicking leaves with small caterpillars and destroying them.



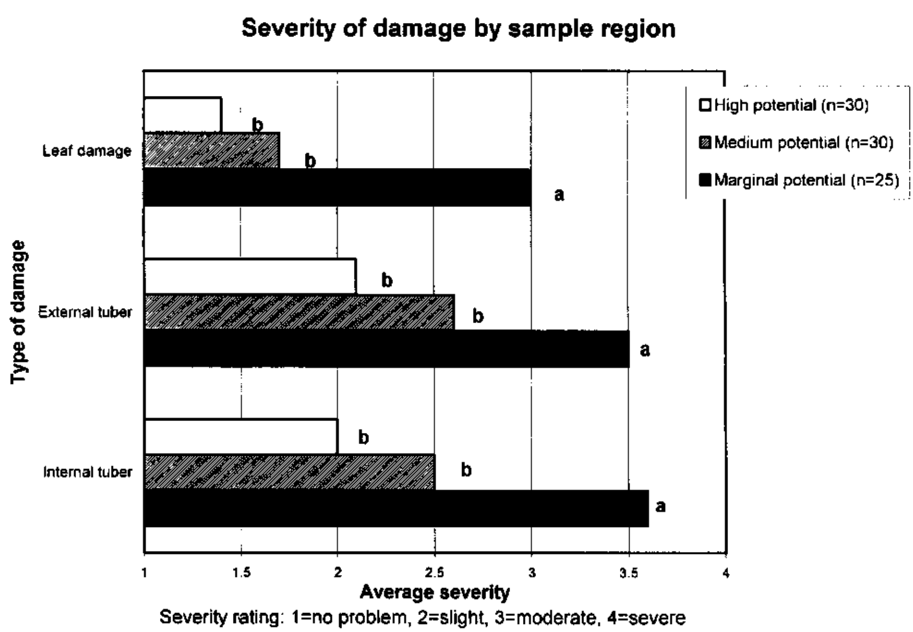


Figure 4.4 Average severity of damage to specific sweetpotato plant parts.

Most farmers (62%) were not familiar with weevil and/or butterfly "tolerant" varieties. Farmers that mentioned a less susceptible variety did not grow it themselves but had only heard about it. In total, 12 names of "tolerant" varieties were given. One variety named "Pokiluoro" was mentioned 7 times and is worth testing for resistance.

Handpicking of young caterpillars, the traditional control measure against sweetpotato butterfly, may be effective, as no severe outbreaks in South Nyanza were reported. Farmers did not mention any specific control techniques for sweetpotato weevils. They did not recognize that some of their cultural practices directly controlled weevils.

4.3.4 Recognition of insects

At the end of the interview, farmers were shown samples of insects in alcohol. They were asked if they were familiar with the insect, where it attacked and its name. Farmers, their children and neighbours cooperated enthusiastically.

Half of the farmers (51%) placed weevil larvae correctly inside a sweetpotato tuber or stem. The larvae were called "Orodho" by 26 farmers and no other names were given. Less than half of the farmers (42%) recognized adult weevils, 33% had seen them on sweetpotato leaves and 9% inside tubers. None of the farmers made the connection between larvae and adults; they saw them as different insects.

The sample of young caterpillars of sweetpotato butterfly was not shown to all farmers. About 70% of the farmers who saw the sample, placed the caterpillars on sweetpotato leaves, whereas 12% confused them with sweetpotato weevil larvae and said they had seen them inside the tuber. About 30% of the farmers called them "Orodho".

More farmers who rated insect damage as important recognized the samples than farmers who were not worried about insect damage. Many farmers declared that the caterpillars they saw eating leaves later went down to the tubers to tunnel through the inside. The damage symptoms of the tubers were referred to as "Orodho" as well. This name seems to be a general term both for insects that damage sweetpotato and for the damage they cause.

Farmers were not familiar with the life cycle of the insects and their means of dispersal and infestation. They did not establish the link between the mobile weevil adult and the white "worms" they found inside their tubers. Before being instructed on cultural control practices, they need to learn about pest biology and behaviour. After gaining this knowledge, they may be able to undertake cultural control methods themselves. The interviewers always described the weevil and butterfly life cycle after finishing the questionnaire and found farmers to be very interested.

4.4. Conclusions

Crop protection workers should concentrate their research and extension efforts on key cultural practices, which for this region are crop sanitation and the avoidance of adjacent planting of successive crops. It is important to realise that for the farmers sweetpotato is a less valuable crop than maize. Certain practices, that are advantageous for maize production, but effect pest control in sweetpotato negatively, might find no acceptability.

By gaining knowledge on the biology and behaviour of insect pests, farmers will be able to understand the effects of their agronomic practices. Empowering farmers through training will make it possible to improve some cultural practices.

Acknowledgements

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PART III IPM COMPONENTS FOR SWEETPOTATO WEEVILS

5. The effect of the indigenous cultural practices of in-ground storage and piecemeal harvesting of sweetpotato on yield and quality losses caused by sweetpotato weevil in Uganda[1]

Abstract

Traditionally, in Uganda most farmers growing sweetpotato practise in-ground storage combined with piecemeal harvesting. Several times during the growing period, between three and seven to twelve months after planting, large roots are removed from individual plants and small roots are allowed to remain in the ground to enlarge further. The overall aim of the practice is to maintain a supply of roots in the ground for the longest possible period. In a series of four trials, once-over harvests at different intervals after planting and a simulated piecemeal harvesting treatment are compared for yield and quality losses caused by sweetpotato weevils (*Cylas puncticollis* and *C. brunneus*). For the once-over harvests, the percentage of damaged roots increased linearly the longer the harvest was delayed. Losses ranged between 3% at a harvest 3½ months after planting (MAP) and 73% at 9½ MAP. The total yield and undamaged yield for the piecemeal harvesting treatments were comparable to the yields at the optimum harvest times for once-over harvesting at 6 to 7½ MAP. The results indicate that piecemeal harvesting is a practice with a controlling effect on sweetpotato weevil infestation.

5.1 Introduction

Sweetpotato (*Ipomoea batatas* (L.) Lam.) is a major food staple in Uganda. It is grown throughout the country both as a subsistence food crop and, increasingly, as a cash crop. It serves as a dietary staple for many rural and urban households (Bashaasha et al., 1995). Sweetpotato is predominantly grown by women. Production estimates suggest that 170,000 ha of the crop are cultivated annually, producing around 1.4 million tonnes (MAAIF, 1992).

Fresh sweetpotato roots are not stored in Uganda. However,

[1]A slightly different version of this chapter has been accepted in Agriculture, Ecosystem and Environment:
Smit, N.E.J.M. The effect of the indigenous cultural practices of in-ground storage and piecemeal harvesting of sweetpotato on yield and quality losses caused by sweetpotato weevil in Uganda.

many farmers producing for home consumption as well as small-scale trading practise a preharvest storage strategy, called in-ground storage, combined with piecemeal harvesting. The overall aim of in-ground storage is to maintain a supply of roots in the ground for the longest possible period (Hall, in prep.). Piecemeal harvesting concerns the removal of roots for immediate consumption only. Several times during the growing period, large roots are removed from individual plants leaving small roots in the ground to enlarge. The crop remains in the ground for seven to twelve months and sometimes even longer (Smit and Matengo, 1995). Once production declines or the field is needed for another crop, the plants are uprooted. Piecemeal harvesting is widespread: 93% of 346 farmers interviewed in seven districts spread over the country reported it (Bashaasha et al., 1995). Commercially oriented farmers practise a form of in-ground storage, as they leave the crop in the ground until they are sure of a ready market for the roots.

Sweetpotato weevils (*Cylas puncticollis* (Bohe.) and *C. brunneus* (Fabr.)) are one of the major constraints to sweetpotato production in eastern Africa. The females lay their eggs in vine bases and storage roots, which are reached through soil cracks or when exposed above the soil. Weevils do not dig down through soil. The larvae tunnel through vines and roots, which results in a significant quality loss and possibly a direct yield reduction. Infested roots cannot be sold on markets. Subsistence farmers use them for home consumption by cutting off infested parts of roots and eating the remainder.

Cultural control is a promising component of an integrated pest management strategy for subsistence farmers of sweetpotato (Talekar, 1991; Smit and Matengo, 1995). One of the cultural practices, which is recommended in sweetpotato-growing regions in Asia and America, is harvesting the crop early, as soon as roots are of acceptable size (Sanderson, 1912; Reinhard, 1923; Edwards, 1930; Holdaway, 1941; Sherman and Tamashiro, 1954; Sutherland, 1986a,b; Nawale, 1981; Talekar, 1991). The increase in damage occurs with time and delayed harvesting (Sherman and Tamashiro, 1954; Sutherland, 1986a). However, the traditional practice in eastern Africa is a non-destructive extended harvest, in which plants are allowed to remain in the field for prolonged periods. O'Hair (1991) remarks that piecemeal harvesting presents problems in weevil-infested areas by providing a continuum for the weevils. The strategy of in-ground storage combined with piecemeal harvesting seems to contain a trade-off between the availability of stored food and weevil attack; therefore, modifications or adaptations may be necessary. However, it could be hypothesized that piecemeal harvesting is advantageous for weevil control (Smit & Matengo, 1995) and overall yield.

In general, information and especially quantitative details are lacking on the effects of indigenous cultural practices on pest infestation (Altieri, 1993). Glass and Thurston (1978) recommended research into existing traditional cultural practices. They expected that some might have been developed and practised as crop protection tactics (perhaps unrecognized) rather than for strictly agronomic reasons.

Rose (1979) and Bourke (1985) describe sweetpotato trials in Papua New Guinea (PNG), in which piecemeal harvesting yields were compared with single harvest yields. However, they did not mention the effect on weevil infestation. No references to piecemeal harvesting in Africa were found. Ocitti p'Obwoya and Mwanga (1994) carried out strict in-ground storage trials with different varieties in Uganda. This also indicates a lack of agronomic data on in-ground storage and piecemeal harvesting.

The author compared the effect of destructive, once-over harvesting at different times after planting (in-ground storage per se) and in-ground storage combined with piecemeal harvesting on yield and quality loss caused by sweetpotato weevils. Several varieties were used in the trials, as varieties were expected to respond differently to piecemeal harvesting because of different agronomic characteristics (Hall, in prep.).

5.2 Materials and methods

Data were collected from four field trials conducted at the Namulonge Agricultural and Animal Science Research Institute (NAARI) (0'32"N, 32'35"E, 1128 m.a.s.l., mean annual rainfall 1270 mm spread over 2 seasons) between May 1993 and February 1995. Trial I contained one locally popular, high-yielding variety 'Tanzania'. In trials II and III five varieties were used, which were originally among 450 varieties collected in farmers' fields throughout Uganda: Tanzania, 'Tororo-3', 'New-Kawogo', # '29' and # '39'. Trial IV contained the same varieties, except Tanzania. Three cuttings (0.30 m) were planted at each planting point on mounds 1.0 x 0.9 m apart for trials I, II and III, and 1.0 x 1.0 m for trial IV. Plot sizes were 4.0 x 6.3 m (trial I), 5.0 x 5.4 m (trials II and III) and 5.0 x 6.0 m (trial IV). Areas for assessment in each plot were 2.0 x 4.5 m (trial I), 3.0 x 3.6 m (trials II and III) and 3.0 x 4.0 m (trial IV). Trial I had 6 harvest treatments and 4 replicates (24 plots); Trial II 8 harvest treatments and 3 replicates (120 plots); Trial III 7 harvest treatments and 3 replicates (105 plots); Trial IV 7 harvest treatments and 3 replicates (84 plots). The harvest treatments were subplots of varieties.

Each trial was planted on ground not used for sweetpotato during the past five years. No herbicides, fungicides, insecticides or fertilizers were used. The crops received no irrigation. Rainfall was recorded at a meteorological station within 1 km from each trial field. Weevil infestation was natural.

Harvest treatments were as follows: five once-over harvests at monthly intervals between 3½ and 7½ MAP (trial I), seven between 3½ and 9½ MAP (trial II), and six between 4 and 9 MAP (trials III and IV); each trial also had one treatment with piecemeal harvesting. The mounds of the piecemeal harvest plots were checked for roots of harvestable size on each once-over harvest date, and only roots weighing roughly more than 100 g were removed carefully. On the last date, simultaneous with the last once-over harvests, all roots were removed.

The following data on storage roots were taken at each harvest: total number and weight, number and weight of those of marketable size (roughly >100 g) and the number damaged by *Cylas*. The *Cylas*-infested roots were weighed. The infested parts of the partly edible roots were cut off and totally infested roots were discarded. The remaining edible roots and root parts were weighed.

One to 5 kg, depending on yield, of infested roots from each harvest were taken to the laboratory and kept in containers for one month. The emerging adult weevils were identified and counted. From each plot where plants were uprooted, 10 stem bases of approximately 15 cm length were collected. In the laboratory they were rated for external and internal stem damage and the insect specimens encountered were identified and counted. The damage rating scale was: 1 = no damage, 2 = 1-25% damage, 3 = 26-50% damage, 4 = 51-75% damage, 5 = 76-100% damage.

The total yield of the piecemeal harvested plots was calculated by summing up the yields at each monthly harvesting.

Normally distributed data were analyzed by analysis of variance, and means were separated by Duncan's Multiple Range Test ($p<0.05$). Non-normally distributed data were separated by square root transformation and then subjected to analysis of variance and Duncan's Multiple Range Test. Simple linear regression and correlation analysis was used for percentage damaged roots (in weight) on time after planting, and average piecemeal harvesting yield on rainfall during last month.

5.3 Results

Trials I and II received less rainfall than trials III and IV (Figure 5.1).

For percentage damaged roots (in weight), differences among varieties and varietal interactions with harvest treatments were not significant (analysis of variance, $P>0.10$), and therefore percentage of damaged roots was averaged over the different varieties (trials II, III and IV). For all trials, using the once-over harvest plots, percentage of damaged roots increased linearly with time (Figure 5.2).

There were no significant differences in total and clean yield between varieties at any harvest date, except for trial II at 3½ and 5½ MAP, when Tanzania and #29 had a higher total yield than the others (analysis of variance, $P>0.05$, data not shown). Therefore, the results of trials II, III and IV are averaged over the different varieties. The percentage of edible parts of the infested yield was similar for all four trials and ranged from 50.0% in trial III to 69.5% in trial IV. There was no trend in

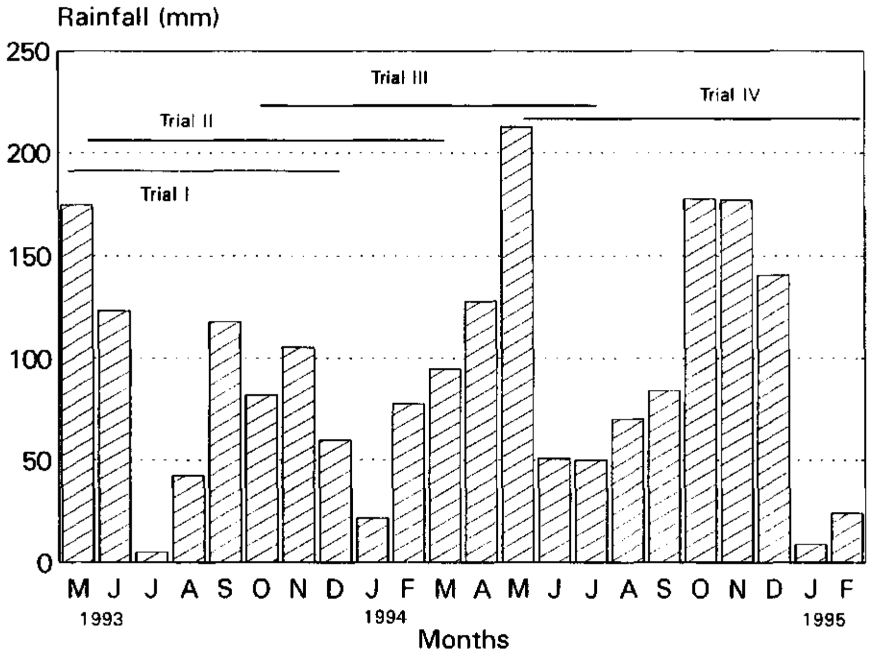

Figure 5.1. Monthly rainfall data and experimental periods.

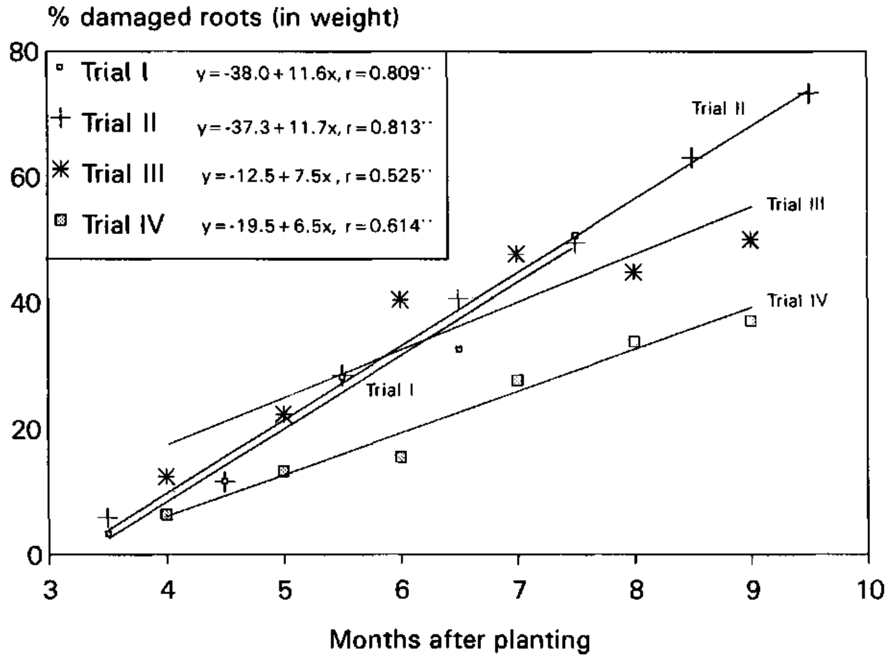

Figure 5.2 Increase in weevil damage to roots with time.

percentage of edible parts of the infested yield according to harvest time; therefore, these data are not shown for every trial.

Results of trials I and II (conducted in the same season) show a similar trend when comparing once-over harvests (Figure 5.3). Total yield increased the longer harvesting was delayed, although increases were not significant from 7½ months onward. Clean yield reached its maximum at 6½ months after planting. Yield data of trial III are not shown, as thieves disturbed the trial and caused yield data to be unreliable. Total yield in trial IV (Figure 5.4) increased with harvesting time, but the increase between 8 and 9 MAP was not significant. Clean yield did not increase after 6 MAP.

The total yield of piecemeal harvests is comparable to once-over harvests at 6 to 7½ MAP (Figures 5.3 + 5.4). Percentage of damaged roots is in all cases lower for the accumulated piecemeal harvests than for the last once-over harvest, which was removed from the field at the same time as the final harvest of the

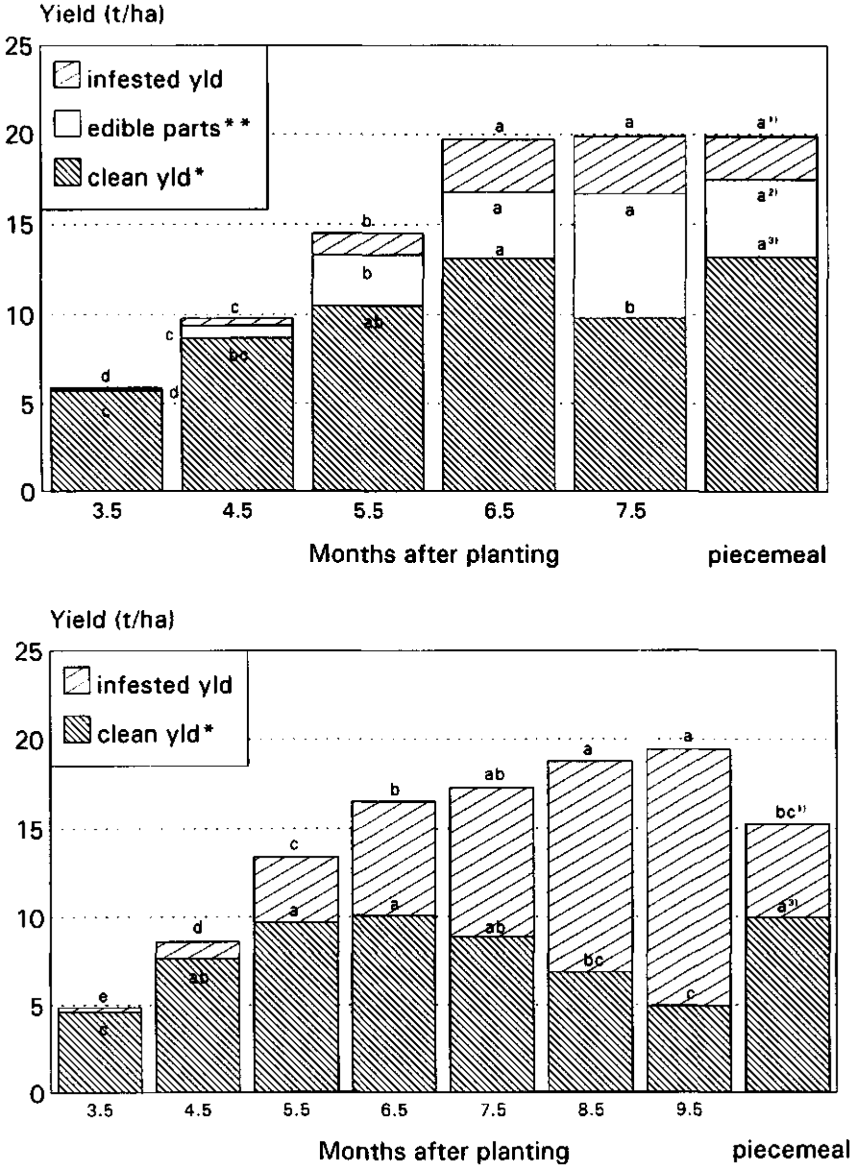

Figure 5.3. Yield and quality losses caused by sweetpotato weevils under different harvest treatments for variety Tanzania (top, Trial I) and averaged over five varieties (bottom, Trial II). **Edible parts = edible yield of infested roots, * Clean yield = roots without weevil damage; Different letters show significant differencs (Duncan's multiple range test $P<0.05$) between harvest treatments. 1) Total yield, 2) Edible yield (clean yield + edible parts of infested roots), 3) Clean yield

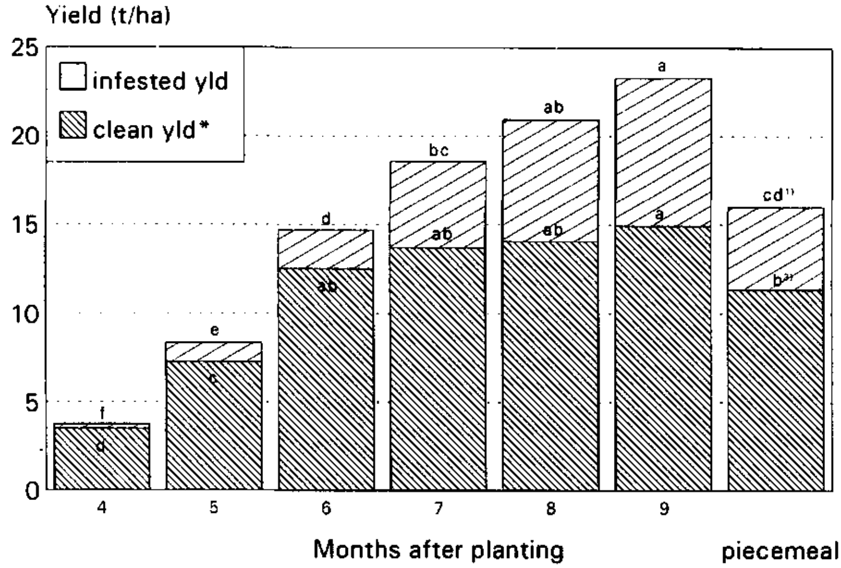

Figure 5.4. Yield and quality losses caused by sweetpotato weevils under different harvest treatments averaged over four varieties (Trial IV). For footnotes see Figure 5.3.

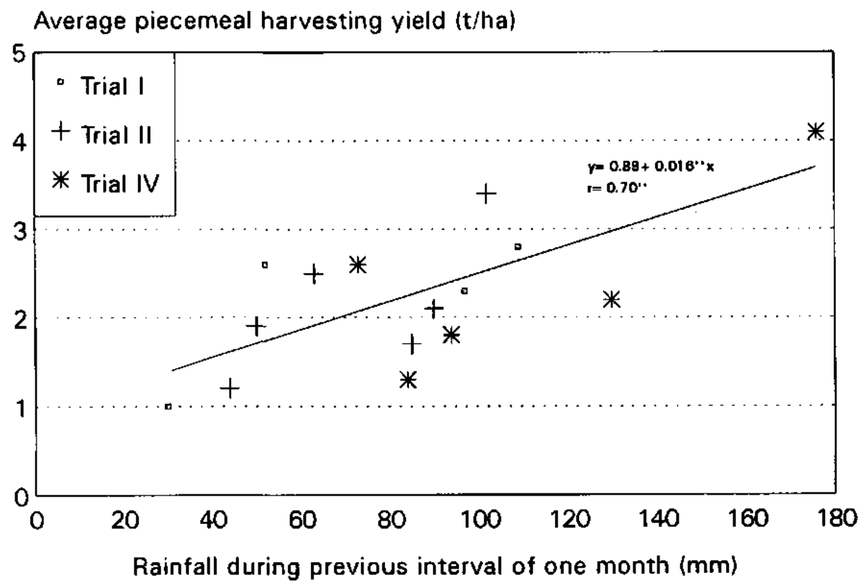

Figure 5.5 Relationship between rainfall and piecemeal harvesting yields. Piecemeal harvests were made at monthly intervals, starting at 3.5 to 4 MAP and ending at 7.5 to 9.5 MAP. Final harvest left out

piecemeal treatment (Trial I: 33% versus 51%, Trial II: 35% versus 73%, Trial IV: 29% versus 37%). In trials I and II the clean yields for the piecemeal treatments are not significantly different from the maximum clean yields obtained at once-over harvests at 6½ MAP.

There was a positive linear relationship between the amount of rainfall that fell from one piecemeal harvest to the next and the yield of the latter (Figure 5.5). Results of final harvests were not incorporated, as their yields were relatively higher because all roots, regardless of size, were uprooted.

The piecemeal harvesting treatment had a higher root number and lower average root weight per m^2 compared with the once-over treatments (Table 5.1). This pattern was consistent over the three trials.

Table 5.1 Number of roots per m^2 and average root weight (grams) compared between the last once-over harvest and the piecemeal harvesting treatments for three trials. Data are averaged over the different varieties for trials II and IV.

	Trial I*		Trial II		Trial IV	
	7½ MAP	piece	9½ MAP	piece	9 MAP	piece
Number of roots/m^2	16.0a	18.7a	7.6a	8.6a	5.8b	7.9a
Weight/ root (g)	124a	107b	254a	178b	401a	202b

Means within a row per trial followed by the same letter are not significantly different (Duncan's multiple range test; $P<0.05$)

* Tanzania, the only variety used in trial I, has in the other trials a significantly higher root number and a lower average root weight than the other varieties.

Averaged over all harvest times, the percentage emergence from infested roots of *C. brunneus* of both *Cylas* species was 50% in trial I (total 2494 insects), 50% in trial II (total 6233 insects), 61% in trial III (total 6870 insects) and 60% in trial IV (total 1708 insects). The proportions varied over the different harvest times within each trial, but differences were not significant.

Damage to the vine base in Uganda is not caused exclusively by *Cylas* spp. The average number of *Cylas* specimens per vine base ranged from 0.36 in trial IV to 0.66 for trial III. The other vine-damaging species were: clearwing moth (*Synanthedon* spp.), ranging from 0.07 to 0.25 specimen per vine in trials I and IV, respectively; *Peleropus batatas* (Marshall), ranging from 0.10 to 0.12 specimen per vine; and striped sweetpotato weevil (*Alcidodes dentipes* Oliv.), with less than 0.01 specimen per vine. It is not possible to differentiate external and internal vine damage caused by the different species. In many cases more than one species were found in the same vine base, or extensive internal damage was noticed when the causal insects had emerged from the stem. External and internal vine damage increased significantly the longer harvesting was delayed. The vines in the piecemeal harvesting treatments were damaged at the same level as in the last once-over harvest. The highest average vine damage score did surpass 3.5. Mortality of plants caused by vine infestation was low; in all trials the number of harvested plants was 94%, or higher, of the originally planted number.

5.4 Discussion

High rainfall precludes crack formation in the soil, which prevents or reduces root accessibility to ovipositing female weevils. Rainfall is one of the factors determining the amount of root damage (Sutherland, 1986b). Because rainfall was below average during the second half of 1993 (Figure 5.1), this partly explains why percentage of damaged roots increased more rapidly in trials I and II than in trials III and IV (Figure 5.2).

The fact that percentage of damaged roots did not differ among varieties was not unexpected. In areas where high weevil densities occur, differences in susceptibility to sweetpotato weevils might go undetected (Collins et al., 1991). Talekar (1987) suggested that adequate sources of resistance in sweetpotato roots may not exist in sweetpotato germplasm.

Sutherland (1986b) also reported a linear relationship between the increase in percentage of damaged roots and time. The relationships for trials I and II are very similar ($y=-38.0+11.6x$ and $y=-37.3+11.7x$, respectively). The reason for this could be that these trials were planted adjacently and grew simultaneously for a large part of the growing season (Figure 5.1). It is expected that the graphs would look different in agro-zones with extended dry seasons with very little or no rainfall. Damage might increase exponentially there. No data in the literature prove whether or not this is the case, but work in Hawaii suggested that damage increases sharply between 5½ and 7 MAP (Sherman and Tamashiro, 1954).

In-ground storage and piecemeal harvesting

Some commercial farmers in agro-zones similar to that of the trial practise in-ground storage but harvest only once. They could take samples early in the season, such as at 3, 4 and 5 MAP, to calculate percentage of damaged roots. From these figures, assuming a linear relationship, they could estimate percentage damage later in the growing season and decide at what stage they should harvest, considering the expected damage.

The trial methods on piecemeal harvesting only partly simulated normal farmers' practices. During informal surveys and on-farm trials, information on piecemeal harvesting was gathered from farmers. One observation was that a farmer does not harvest on an exact monthly schedule; instead the decision to harvest depends on the rainfall during the past weeks, apart from the need for food. When rainfall is sufficient, roots are expected to have grown. Besides, harvesting in wet soil is easier and does not damage the feeder roots as much. In the trials rainfall and wetness of the soil were taken into account only for the first (piecemeal) harvest. This is why harvests in some trials start at 3½ MAP and others at 4 MAP. Some piecemeal harvests were conducted in very dry soil and feeder roots might have been disturbed. A farmer would rather wait for a rainy day. That the farmer's decision-making concerning harvesting intervals is based on rationale is proven by the results in Figure 5.5. Noticing the extent of weevil damage in trial II, a farmer would have decided to do the final harvest earlier than the 9½ MAP in the trial.

The absence of yield differences among varieties harvested piecemeal in any of the trials might be explained by the fact that all five varieties had been selected at the research station under once-over harvesting conditions. The major selection criterion was yield. Varieties with characteristics favourable for piecemeal harvesting, such as spread timing of storage root initiation and enlargement, were not identified through this selection process. During a needs assessment survey (Hall, in prep.), it was often observed that farmers grow a range of varieties with varying degrees of useful characteristics, such as early and late maturity, good storability in the ground and high yield.

No significant differences in yield among varieties in trials II, III and IV were observed at any specific once-over harvest. This is probably also because varieties were selected at the research station under the same once-over harvesting regime, usually 5-6 months after planting. For trial purposes, it would probably have been better to use at least one farmers' variety, characterised by a spread timing of root initiation and enlargement.

The results of trials I, II and IV indicate that for once-over harvesting optimum harvesting times for all varieties are between 6½ and 7½ MAP for total, clean and edible yield. Ocitti p'Obwoya and Mwanga (1994) tested varieties Tanzania and Tororo-3, among others, for in-ground storage and reported similar optimum harvesting dates of 6 and 7 MAP, respectively.

Piecemeal harvesting gave comparable total and clean yields with the optimum once-over harvests at 6 to 7½ MAP. The bulking rate (g/week/m^2) was lower for the piecemeal harvest, as the crop stayed in the ground longer. For subsistence farmers, the advantage of the piecemeal harvesting system is that a supply of fresh roots is available over an extended period of time. The fact that land is occupied for a longer period is not (yet?) a concern. Bourke (1985) mentions in his review of sweetpotato research in PNG that three comparisons have been made of single harvesting versus progressive harvesting. In one case the single harvest technique gave higher yields than progressive harvesting. In the second case total and daily yields from the two techniques were similar. The third comparison (Rose, 1979) showed a greater total yield for progressive harvesting, with a larger proportion of smaller roots (under 100 g). The last observation is in agreement with the findings reported in this paper. All trials in PNG were conducted in the highlands (over 1600 m.a.s.l.). It is possible that sweetpotato weevils are not a major constraint there, so that no observations on insect damage were reported.

The fact that percentage of damaged roots is lower for piecemeal harvests than for once-over harvests, the crop having stayed in the ground for the same period of time, may be explained as follows. During piecemeal harvesting, farmers remove roots protruding from the ground that are just getting infested or are likely to become infested with sweetpotato weevil. By digging in the mound where cracks are visible, farmers locate mature roots and also fill the cracks so that smaller roots are no longer accessible to weevils. Most farmers also add more soil to the mound after removal of roots, so that it becomes even more difficult for weevils to locate roots. This suggests that, although piecemeal harvesting is primarily a method for sequential consumption of a "stored" crop, it also incorporates a practice that is essentially a process of storage maintenance or a (perhaps unrecognized) cultural control practice (Hall, in prep.).

Talekar (1982) in Taiwan, Mullen (1984) in the USA and Sutherland (1986b) in PNG studied the relationship between vine damage caused by sweetpotato weevils (*C. formicarius*) and root yield reductions. None mentions the presence of other vine-damaging species. Mullen (1984) concluded that severe damage to the vine base may result in mortality of infested plants with a corresponding reduction in yield. Talekar (1982) found that yields were not affected by the number of weevils feeding within vines. According to Sutherland (1986b) infestations of vines by weevils reduced foliage vigour and resulted in reduced yields. In the trials described in this paper, plant mortality was low, and lowered quality of roots was undoubtably more important than direct yield reduction.

5.5 Conclusion

In-ground storage combined with piecemeal harvesting is a traditional cultural practice that should not be replaced by prompt harvesting from the point of view of weevil control. During in-ground storage per se, weevil damage increases linearly the longer harvesting is delayed. In-ground storage combined with piecemeal harvesting is a sensible practice for small-scale farmers in this agro-ecological zone because it guarantees a continuous supply of fresh roots with a low percentage of weevil-damaged roots.

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PART III IPM COMPONENTS FOR SWEETPOTATO WEEVIL

6. Development of pheromone traps for control and monitoring of sweetpotato weevils, *Cylas puncticollis* (Bohe.) and *C. brunneus* (F.), in Uganda.[1]

Abstract

Experiments were carried out in Uganda to optimise pheromone traps for the African sweetpotato weevil species, *Cylas puncticollis* Bohe. and *C. brunneus* F. (Coleoptera: Apionidae). Various designs of funnel, water and sticky traps were compared and a 5-l plastic jerry can trap was the most appropriate design for effectiveness and practicability. A solution of Omo detergent in water was found to be the most effective trapping agent. Fewer weevils were caught in red traps than in yellow, white, green or blue traps. Catches of *C. puncticollis* increased when the trap was raised above crop height, but catches of *C. brunneus* were unaffected. When marked weevils were dropped onto the trap, 36% of *C. puncticollis* and 23% of *C. brunneus* were captured, and, of weevils placed in the trap, 88% and 92%, respectively, of the two species remained overnight. Lures for the two species showed no significant loss in attractiveness after eight weeks in the field, and chemical analysis showed 19% of the *C. puncticollis* pheromone and 72% of the *C. brunneus* pheromone remaining after this time.

6.1 Introduction

Sweetpotato weevils of the genus *Cylas* are the most devastating pests of sweetpotato, *Ipomoea batatas* (L.) Lam., worldwide (Jansson and Raman, 1991). The cryptic feeding habits of the larvae and the nocturnal activity of the adults make detection and control of infestations difficult. Major damage to the roots results from larval feeding through tunnels which are filled with frass, and this damage gives the roots a terpenoid odour which makes them unacceptable for human or even animal consumption (Uritani *et al.*, 1975).

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[1]A slightly different version of this chapter has been accepted in Entomologia Experimentalis et Applicata as:
Smit, N.E.J.M., M.C.A. Downham, B. Odongo, D.R. Hall and P.O. Laboke. Development of pheromone traps for control and monitoring of sweetpotato weevils *C. puncticollis* and *C. brunneus* in Uganda.

Cylas formicarius F. is present in sweetpotato-producing countries of Asia and North America, part of Central and South America, and some Pacific islands. Specimens of this species are known from only two coastal localities in continental Africa - Msabaha, Kenya, and Natal Province, South Africa (Wolfe, 1991; Parker *et al.*, 1992). *C. puncticollis* Bohe. and *C. brunneus* F. are the major pest species in Africa and are restricted to this continent (Wolfe, 1991; CAB International, 1993). In Kenya and Uganda, the two species are of similar importance (Magenya & Smit, 1991; Smit, forthcoming).

Heath *et al.* (1986) isolated, identified, and synthesized the female-produced pheromone of *C. formicarius*, (*Z*)-3-dodecen-1-ol (*E*)-2-butenoate. Use of the pheromone in pest management is being investigated (Heath *et al.*, 1991; Jansson *et al.*, 1991). In East Africa, pheromone traps helped confirm that *C. formicarius* was absent from all but one location (Parker *et al.*, 1992). Mass-trapping of males with the pheromone has been shown to suppress populations of *C. formicarius* in Taiwan (Hwang & Hung, 1991), India (Pillai *et al.*, 1993) and Japan (Yasuda, 1995), and CIP is collaborating with several national programmes to explore this potential (CIP, 1995). In the Dominican Republic, the use of pheromone traps significantly reduced the damaged yield from *Cylas* infestation (Alvarez *et al.*, 1996). Use of the pheromone in mating disruption of *C. formicarius* has also been reported (Mason & Jansson, 1991).

Sathula (1993) and Smit *et al.* (1994) showed that female *C. puncticollis* and *C. brunneus* produce species-specific sex pheromones. These were identified as decyl (*E*)-2-butenoate for *C. puncticollis* (Smith *et al.*, forthcoming) and dodecyl (*E*)-2-butenoate for *C. brunneus* (Downham *et al.*, forthcoming). In field tests, the synthetic lures proved to be highly attractive to conspecific males, but the synthetic lure for *C. brunneus* also attracted significant numbers of *C. puncticollis* males (Downham *et al.*, forthcoming).

This paper describes work aimed at developing a practical trapping system for *C. puncticollis* and *C. brunneus* in Uganda. This was part of a collaborative project to develop pheromones for monitoring and controlling these pests and involved the National Agricultural Research Organisation (NARO), the Natural Resources Institute (NRI) and the International Potato Center (CIP).

6.2 Materials and Methods

Experimental sites

Experiments were carried out between February 1995 and February 1996 on five sweetpotato fields at the Namulonge Agricultural and Animal Science Research Institute (NAARI) (0'32" N, 32'35" E, 1128 m above sea level, mean annual rainfall 1270 mm spread over two seasons). Two fields of 0.5 ha were specifically planted with variety "Tanzania" for the trapping experiments and each plant was artificially infested with one or two weevils of each species from a laboratory rearing. Another three fields of 0.3 to 0.5 ha with variety-comparison experiments and natural weevil infestations were also used for trapping experiments. Cultural practices were similar in all five fields. Crops were rainfed and no herbicides, fungicides, insecticides or fertilizers were used.

Traps

Seven trap designs were evaluated for their effectiveness in trapping *C. puncticollis* and *C. brunneus* males: a plastic funnel trap, a 1-l plastic bottle/funnel trap, a 2-l jerry can trap, a 5-l jerry can trap, a 4-l oil can trap, a Uni-trap and a sticky disc trap (Figure 6.1). All except the Uni-trap were constructed at NAARI from locally available materials. The plastic funnel trap (Figure 6.1a) was a slight modification of that used in studies in southern Florida, USA, by Jansson *et al.* (1989), with a galvanised iron sheet as a weather guard instead of a plexiglas sheet and a 1-l plastic bottle instead of a 140-ml plastic vial for collecting the weevils. The 1-l bottle/funnel trap was a modification of that described by Hwang *et al.* (1989) (Figure 6.1b) with a polystyrene round petri dish as a weather guard instead of the bottle top and four round holes of 4 cm diameter cut out in the top of the trap at the level of the suspended lure. The 2-l plastic jerry can trap was made from a yellow plastic jerry can with four square holes (4x4 cm) cut in the four sides of the upper third (Figure 6.1c). The 5-l plastic jerry can trap was white with rectangular openings (11x5 and 6x5 cm) cut in all four sides (Figure 6.1d). The 4-l metal oil can trap had windows (10x5 and 6x5 cm) cut out in a fashion similar to the 5-l jerry can trap (Figure 6.1e). The lures hung on a paperclip from the screw-type lid of all three "can" traps. The Uni-trap (Figure 6.1f) (International Pheromone Systems Ltd., South Wirral, L65 4EW, U.K.) consisted of a green moulded plastic funnel and yellow collecting box (15 cm outside diameter) with

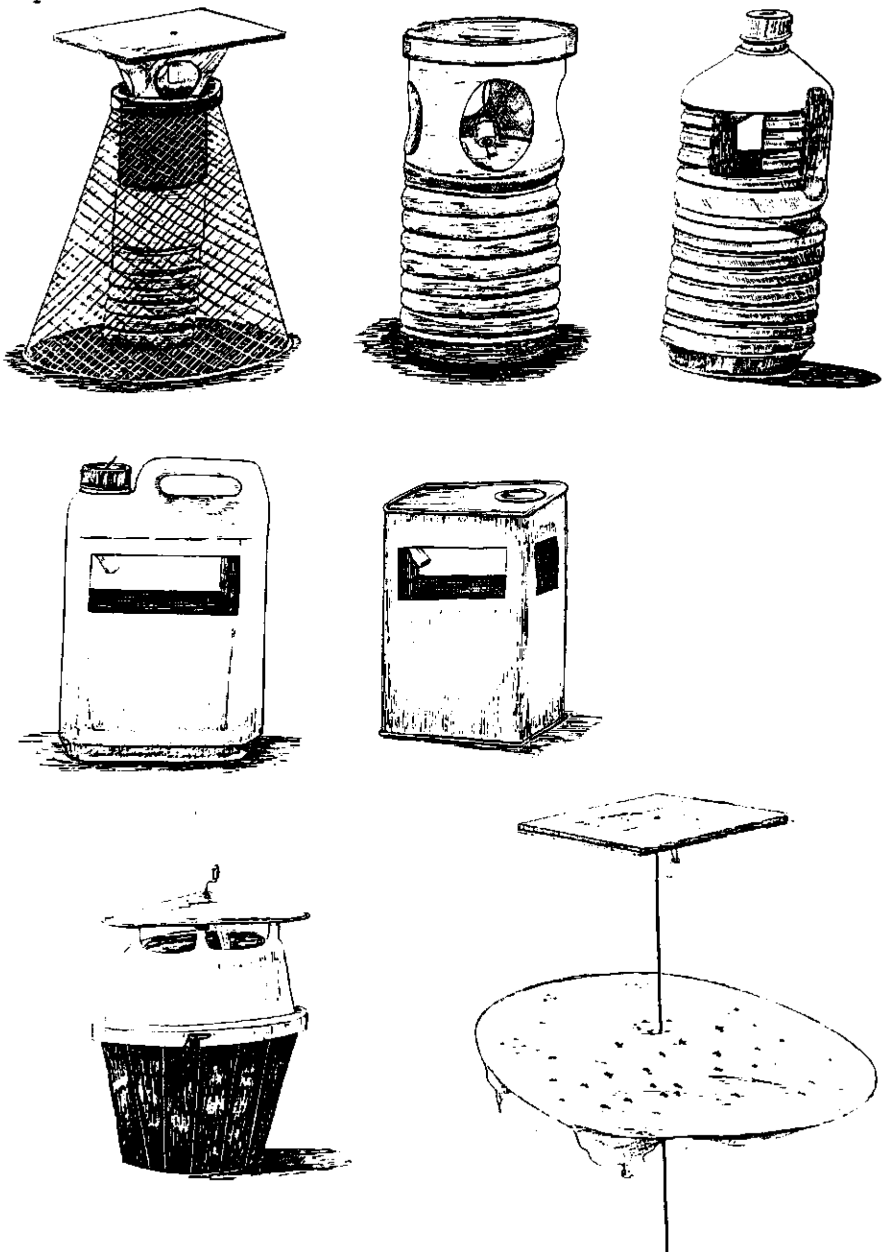

Figure 6.1 Seven pheromone trap types tested in Uganda: a. plastic funnel trap, b. 1-l bottle/funnel trap, c. 2-l plastic jerry can trap, d. 5-l plastic jerry can trap, e. 4-l metal oil can trap, f. Uni-trap, g. sticky disc trap.

a roof 3 cm above the funnel rim. Unless otherwise stated, in the above six trap types, a dilute detergent solution was used as a trapping and killing agent with 0.5 l in the 5-l jerry can trap and the 4-l oil can trap and 0.25 l of solution in the other four. The seventh trap was a sticky disc trap (Figure 6.1g) as used in Malawi by Sathula (1993) for trapping *C. puncticollis* and Marks (1976) for trapping armyworm moths, *Spodoptera exempta* Wlk. (Lepidoptera: Noctuidae). The trap consisted of a plywood disc (60 cm diameter) fixed horizontally to a steel rod (90 cm). A sheet of galvanised iron (30x20 cm), welded to the upper end of the rod 20 cm above the plywood disc, acted as a weather guard, and the lure was suspended from this 10-12 cm above the disc. The disc was covered with a polyethylene sheet smeared with polybutene sticker (Tanglefoot).

Unless otherwise stated, all trap types were placed on the ridges in the field such that the lures were hanging just above the canopy level of the crop, except for the sticky-disc trap which was positioned 50 cm above the crop canopy.

Pheromone lures

Decyl (*E*)-2-butenoate and dodecyl (*E*)-2-butenoate were synthesised from (*E*)-2-butenoyl chloride and the appropriate alcohol as described (Smith *et al.*, forthcoming; Downham *et al.*, forthcoming) and were at least 98% pure by gas chromatography (GC) analysis.

Pheromone dispensers were polyethylene vials (23 mm x 9 mm x 1.5 mm thick; Just Plastics, London E10 7PY, U.K.) or white rubber septa (part no. Z10,072-2; Aldrich Chemical Company Ltd., Gillingham, Dorset, U.K.). These were impregnated by adding the pheromone dissolved in hexane (0.1 ml) containing an equal weight of 2,6-di-*tert*-butyl-4-methylphenol (BHT) as antioxidant, and allowing the solvent to evaporate. Lures were polyethylene vials impregnated with 0.1 mg of decyl (*E*)-2-butenoate for *C. puncticollis* or rubber septa impregnated with 0.1 mg of dodecyl (*E*)-2-butenoate for *C. brunneus*.

The amount of pheromone remaining in lures returned from Uganda after field exposure was determined by extracting the pheromone at room temperature overnight with hexane (5 ml) containing an amount of hexadecyl acetate equal to the initial pheromone loading as an internal standard. The solution was analysed by GC using a fused silica capillary column (25 m x 0.32 mm i.d.) coated with CP Wax 52 CB (chemically bonded Carbowax 20M equivalent; Chrompack UK), with oven temperature held at 120°C for 2 min and then programmed at 6°C/min to 230°C. Samples were injected by autosampler (AS 200S) and data captured and processed with EZChrom 6.5 data handling hardware and software.

Weevil entry and retention

The rate of weevil entry into the 5-l jerry can trap was compared with that of the 1-l bottle trap. Fifty adult males were marked with enamel paint and released at dusk on the top and sides of the two trap types. The numbers and percentages of marked males captured were recorded the next morning. To test whether paint marking of weevils had an adverse effect on weevil capture, trap entry was compared between marked and unmarked weevils in a confirmed weevil-free environment. Marked (25) and unmarked (25) *C. brunneus* or *C. puncticollis* males were released at dusk onto the top and sides of four jerry can traps. The numbers of males captured were recorded the next morning.

The percentages of weevils that escaped from the two types of traps overnight were compared by placing 50 marked adult males inside each trap and recording the numbers remaining the next morning.

Experimental design and analysis

Experiments compared four or five treatments in at least four replicates. Treatments were separated by 10-25 m within replicates and replicates were separated by at least 50 m, typically with one field comprising one replicate. Treatments were moved around one position on four or five sample dates so that each treatment was present at each position within each replicate one time in each experiment. The number and species caught per trap were recorded on each sample date in the morning hours.

Data were analysed using three-way analysis of variance (Gomez & Gomez, 1984), using treatment, day and position, without taking interactions into account. Percentage of total catch per replicate per night and total weevil catch per trap were transformed to $\arcsin\sqrt{x}$ and $\log(x+1)$, respectively. Weevil entry and retention data were compared for the two trap types by pooling the data for the three experiments and conducting a t-test on the transformed mean percentages. In experiments involving more than two treatments, means were compared using the Tukey studentized range test (Gomez & Gomez, 1984).

6.3 Results

Trap design

Comparison of the plastic funnel trap used for *C. formicarius* with 2-l and 5-l jerry can traps and the 1-l bottle trap showed that with the *C. puncticollis* pheromone, catches of *C. puncticollis* males were significantly higher in the 1-l bottle trap than in the other three types (Table 6.1a). With the *C. brunneus* pheromone, there were no significant differences in catches of *C. brunneus* males in the four trap types, although catches were low in the 2-l jerry cans. When analysed as percentage catch per night, catches with the 2-l jerry can were significantly lower than in the funnel trap. Catches of *C. puncticollis* with the *C. brunneus* pheromone were also the highest in the 1-l bottle trap and the lowest in the 2-l jerry can (Table 6.1a).

In a second set of experiments, the 5-l jerry can and 1-l bottle were compared with the 4-l oil can and the sticky disc (Table 6.1b). Using the *C. puncticollis* lure, the sticky disc trap was significantly better than the other three trap types, and the 1-l bottle caught significantly higher numbers of weevils than the 5-l jerry can trap, as in the first set of experiments. Using the *C. brunneus* lure, the 1-l bottle and the sticky disc trap caught significantly more *C. brunneus* males than the 5-l jerry can and the oil can trap. Catches of *C. puncticollis* males with the *C. brunneus* pheromone were low, and only the oil can trap differed from the other three traps in having a significantly lower catch.

Comparison of catches in the Uni-trap, 5-l jerry can and 1-l bottle showed that catches of both species were significantly lower in the Uni-trap (Table 6.1c). As previously, catches of *C. puncticollis* males were significantly higher in the 1-l bottle trap than in the 5-l jerry can trap, regardless of the pheromone type, whereas catches of *C. brunneus* males were not significantly different in these two traps.

Trapping agent

Four trapping agents were evaluated in 5-l jerry can traps with *C. brunneus* lures. For both species, a solution of Omo detergent in water (1 g/l) was more effective than a solution of washing-up liquid (1 ml/l), a solution of salt (1 g/l) or two Vapona strips (DDVP) (Table 6.2a). However, when weevils were removed from traps with the Omo solution, even after 15-24 h in the field, more than half of the apparently dead weevils

Table 6.1 Mean no. (±SE) of males caught per trap per night and percentage total catch per replicate per night in 4 different experiments comparing different trap types at NAARI, Uganda, in 1995

Set	Trap type	Exp. I *C. puncticollis* lur		Exp. II *C. brunneus* lure			
		C. puncticollis		*C. puncticollis*		*C. brunneus*	
		males/night	% catch/night	males/night	% catch/night	males/night	%catch/night
a	Funnel	10.9(2.5)b	23.6(4.1)b	13.6(3.0)ab	19.3(3.2)bc	16.3(6.7)a	35.5(6.2)a
	2-1 Jerry	4.8(1.0)b	12.4(2.7)b	8.8(1.7)b	13.9(2.1)c	6.8(2.7)a	14.7(3.7)b
	5-1 Jerry	9.8(2.6)b	19.2(2.6)b	18.9(3.5)a	32.1(3.9)ab	7.4(2.5)a	23.5(5.0)ab
	1-1 Bottle	21.8(4.9)a	45.0(3.9)a	23.1(4.5)a	34.7(3.4)a	6.1(1.8)a	26.6(5.7)ab
b	5-1 Jerry	17.1(7.2)c	9.4(2.0)bc	6.8(2.1)a	29.3(6.0)a	9.0(2.4)b	15.6(3.6)b
	1-1 Bottle	34.8(12.7)b	21.9(4.1)b	9.0(2.3)a	33.8(6.2)a	29.6(6.3)a	38.0(4.1)a
	Sticky dis	59.2(10.3)a	65.4(6.0)a	5.3(1.2)a	33.7(7.4)a	28.1(7.8)a	34.6(3.5)a
	Oil can	14.8(12.2)d	3.4(1.9)c	0.8(0.4)b	3.1(1.6)b	8.8(2.2)b	11.8(2.2)b
c	Uni-trap	8.2(1.7)c	10.7(1.7)c	3.3(1.0)c	8.4(2.1)c	12.5(2.9)b	9.0(1.4)b
	5-1 Jerry	27.6(4.9)b	34.5(3.8)b	14.0(2.9)b	34.7(5.2)b	63.2(17.5)a	44.5(3.3)a
	1-1 Bottle	38.9(4.2)a	55.1(3.9)a	23.4(4.8)a	57.3(5.5)a	63.5(13.1)a	46.5(3.3)a

Means in the same column within each experiment followed by the same letter do not differ among trap types ($p<0.05$, Tukey's Honestly Significant Difference Test)

Table 6.2 Mean no. (±SE) of males caught per 5-l jerry can trap per night and percentage total catch per replicate per night in 5 different experiments at NAARI, Uganda, in 1995

Set	Treatment	Exp. I *C. puncticollis* lur		Exp. II *C. brunneus* lure			
		C. puncticollis		*C. puncticollis*		*C. brunneus*	
		males/night	% catch/night	males/night	% catch/night	males/night	%catch/night
d	Trapping agents						
	OMO solution	na	na	12.4(3.3)a	67.3(7.7)a	7.1(2.0)a	42.2(7.6)a
	Dish washing	na	na	2.3(0.5)b	20.2(5.8)b	6.0(1.7)a	29.6(5.1)ab
	Salt	na	na	1.1(0.5)b	9.5(5.4)bc	3.9(1.5)ab	17.4(3.9)b
	Insecticide	na	na	0.6(0.4)b	3.1(1.8)c	1.4(0.3)b	10.8(3.3)b
e	Trap colours						
	White	6.0(2.6)ab	16.7(4.1)b	2.4(0.6)a	21.6(4.4)a	12.2(3.4)a	28.3(4.2)a
	Yellow	5.6(1.5)ab	23.8(4.6)ab	1.6(0.5)a	26.3(7.0)a	8.6(1.8)ab	22.2(3.6)ab
	Green	6.6(1.9)a	35.6(5.3)a	2.7(1.5)a	23.5(5.8)a	8.0(2.2)ab	16.9(3.1)ab
	Blue	3.7(1.3)bc	13.6(2.8)b	1.6(0.6)a	13.7(3.7)a	9.1(2.8)ab	20.0(2.7)ab
	Red	2.3(1.3)c	10.3(5.0)b	2.2(0.8)a	14.9(3.8)a	6.7(2.0)b	12.5(3.2)b
f	Trap heights						
	- 15 cm	1.3(0.8)c	1.1(0.6)c	0.9(0.4)c	0.9(0.5)c	13.3(5.9)a	19.8(4.8)a
	standard	7.9(2.0)b	16.8(3.8)b	6.9(3.3)b	22.4(7.4)b	9.6(3.2)a	22.8(6.0)a
	+ 15 cm	21.9(6.3)a	39.5(6.0)a	17.8(8.2)ab	26.6(6.8)b	11.9(2.9)a	25.4(4.6)a
	+ 30 cm	19.9(4.3)a	42.6(5.2)a	14.5(4.8)a	50.1(8.0)a	9.4(1.8)a	32.0(6.2)a

Means in the same column within each experiment followed by the same letter do not differ among treatments ($p<0.05$, Tukey's Honestly Significant Difference Test)
na = not applicable, experiment not carried out

recovered and were mobile within 1 hour. This effect was more marked for *C. puncticollis* than for *C. brunneus*.

Trap colour

Yellow, green, blue and red 5-l jerry can traps were compared with the standard white. For both species, catches were the lowest in the red traps, with very few significant differences in catches for the other four colours (Table 6.2b).

Trap height

Increasing the height of the 5-l jerry can trap so that the lure was 15 cm or 30 cm above the canopy of the sweetpotato crop significantly increased trap catches of *C. puncticollis* but had no effect on catches of *C. brunneus* (Table 6.2c). Lowering the position of the trap so that the lure was 15 cm below the canopy reduced *C. puncticollis* catches, but did not affect those of *C. brunneus*.

Weevil entry and retention

When marked weevils were dropped on the top and sides of traps, in four replicates repeated over three nights the 1-l bottle trap and the 5-l jerry can trap captured 22.0±2.4% and 35.5±4.4% respectively, of the marked *C. puncticollis* and 16.0±1.8% and 23.0±3.3%, respectively, of the marked *C. brunneus*. The 5-l jerry can captured more of both species than the 1-l bottle trap, but the difference was significant only for *C. puncticollis*. There were no significant differences in weevil entry between marked and unmarked weevils. For *C. puncticollis*, 33.3% and 23.0%, respectively, of marked and unmarked weevils were caught, whereas for *C. brunneus* these figures were 31.5% and 37.0%.

No weevils of either species escaped from the 1-l bottle traps overnight. Significant but low numbers were found to escape from the 5-l jerry can traps, with percentages remaining after one night of 87.8±3.0% for *C. puncticollis* and 92.3±1.9% for *C. brunneus*.

Longevity of lures

Lures were aged outdoors in Uganda in plastic funnel traps, then stored wrapped in aluminium foil and in a sealed polyethylene bag at -4±1°C. In a first set of experiments, lures containing 1.0 mg or 0.1 mg of pheromone and exposed for 0, 1, 2, 3 and 4 weeks were compared in 5-l jerry can traps for both species (Table 6.3a+b). At both loadings, there were no significant differences in catches of either target species with

Table 6.3. Mean no. (±SE) of males caught per night and percentage total catch per replicate per night in 5-l jerry can traps baited with lures that were aged outdoors for different durations in 6 different experiments at NAARI, Uganda, in 1995

			Exp. I *C. puncticollis* lure		Exp. II *C. brunneus* lure			
			C. puncticollis		*C. puncticollis*		*C. brunneus*	
Exp Set	Lure dose (mg)	Age (w)	males/night	% catch/night	males/night	% catch/night	males/night	%catch/night
g	1.0	0	13.7(2.3)a	22.7(3.2)a	21.5(3.0)a	28.6(2.3)a	2.6(0.6)a	16.8(2.8)a
		1	11.6(2.5)a	17.9(2.1)a	12.1(1.9)b	17.0(2.4)b	5.3(1.5)a	25.3(3.4)a
		2	16.1(4.0)a	20.6(2.7)a	12.1(1.8)b	16.8(2.0)b	3.8(0.9)a	24.2(3.5)a
		3	16.5(3.7)a	21.1(2.5)a	14.3(2.4)b	18.8(2.2)b	3.1(0.8)a	19.0(3.3)a
		4	10.4(1.8)a	17.7(2.2)a	15.1(2.9)b	18.9(2.1)b	2.8(0.9)a	14.7(3.4)a
h	0.1	0	12.3(2.8)a	17.0(2.2)a	19.2(5.5)a	28.7(3.3)a	13.3(4.4)b	16.7(3.2)b
		1	19.6(6.8)a	22.5(3.2)a	9.6(2.0)a	14.8(2.6)b	19.8(5.9)ab	15.4(2.7)b
		2	15.0(4.3)a	19.2(2.4)a	13.6(3.7)a	19.3(3.4)ab	21.4(5.7)ab	21.7(2.5)ab
		3	15.0(4.9)a	19.3(2.2)a	11.5(2.4)a	18.8(3.8)ab	23.2(7.2)ab	14.5(2.7)b
		4	14.3(3.0)a	21.9(3.4)a	9.1(1.9)a	18.7(3.0)ab	31.7(7.2)a	31.7(3.8)a
i	0.1	0	5.8(1.6)a	21.2(3.5)a	12.6(3.1)*	47.5(4.6)a	9.5(3.5)ab	17.4(3.2)ab
		2	6.4(1.7)a	18.9(3.8)a	6.7(2.6)	20.4(3.5)b	5.2(1.9) b	12.2(3.1)b
		4	4.3(1.2)a	16.8(4.1)a	3.4(1.0)	16.2(3.4)b	7.8(3.4)ab	24.1(3.4)ab
		6	10.6(3.3)a	28.1(4.2)a	1.8(0.6)	7.4(2.1)b	11.1(5.9)ab	19.9(3.3)ab
		8	3.3(0.6)a	15.1(2.4)a	1.1(0.4)	8.5(2.9)b	9.3(2.8)a	26.4(5.1)a

Means in the same column within each experiment followed by the same letter do not differ among treatments ($p<0.05$, Tukey's Honestly Significant Difference Test)
* Data in this column were not analysed due to heterogeneity of variance

the aged lures. There was some indication that catches of *C. puncticollis* with the *C. brunneus* lures decreased immediately after the first exposure of the lures.

In a second set of experiments, 0.1 mg lures for both species were aged for 0, 2, 4, 6 and 8 weeks, and even after 8 weeks exposure catches of the target species were not significantly different from those with fresh lures (Table 6.3c). As above, catches of *C. puncticollis* with the *C. brunneus* lures decreased after initial exposure of the lures.

Analysis of pheromone remaining in the lures after different exposure periods showed that the amount declined exponentially with time (Figure 6.2), with 19% and 72% remaining in the *C. puncticollis* vials and *C. brunneus* septa, respectively, after 8 weeks in the second set of experiments. In the first set of experiments, amounts of *C. puncticollis* pheromone remaining after 4 weeks were 51% and 63% for 1.0 mg and 0.1 mg loadings, respectively, and 86% and 84% for the *C. brunneus* lures.

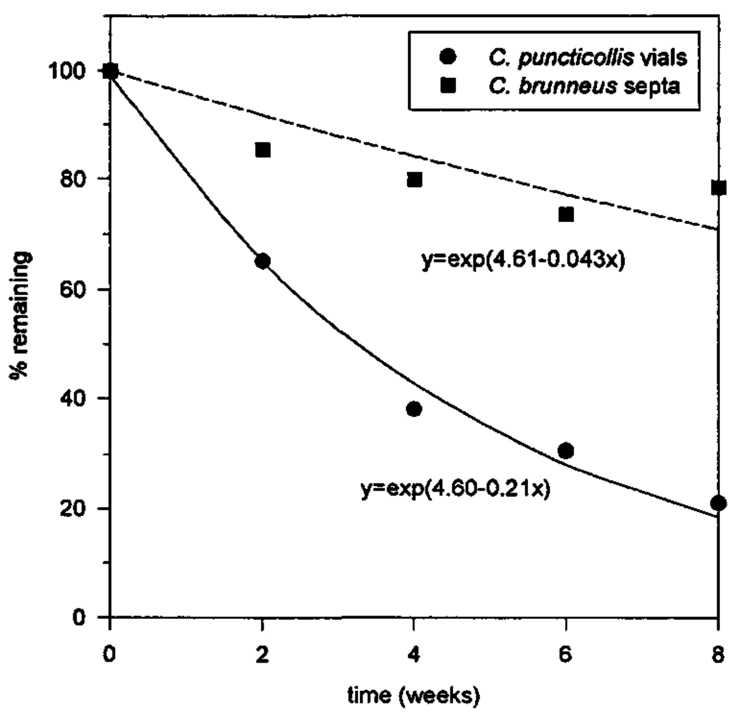

Figure 6.2 Release of pheromone from 0.1 mg dispensers exposed in the field.

6.4 Discussion

In much of the work on pheromone trapping of *C. formicarius*, plastic funnel traps with a lid and mesh skirt have been used as originally recommended by Proshold *et al.* (1986) and modified by Jansson *et al.* (1989). This proved to be more effective than the commercially available Universal moth trap (Uni-trap) and a screen-cone boll weevil trap at high weevil densities; at low densities, differences between traps were less marked (Jansson *et al.*, 1989, 1992). In Japan, Yasuda *et al.* (1992) compared the plastic funnel trap with a skirted water-pan trap, a Steiner trap, a sticky delta trap and a cup trap, and the most weevils were caught in the funnel trap. As pointed out by Jansson *et al.* (1991), the funnel trap and Uni-trap may not be suitable for use in developing countries, and Talekar & Lee (1989) and Pillai *et al.* (1993) reported use of water-trough traps made out of a basin or oil can in Taiwan and India, respectively. Hwang *et al.* (1989) tested three designs of funnel traps constructed from polyethylene terephthalate (PET) drink bottles. They proposed a single funnel design which was subsequently also used in trials by Hwang & Hung (1991) and Lo *et al.* (1992), although no comparison with other designs was reported. In the Dominican Republic, a trap made out of a plastic gallon jug proved effective and cheap (CIP, 1992; Alvarez *et al.*, 1996).

In this work with the African sweetpotato weevil species, *C. puncticollis* and *C. brunneus*, the plastic funnel trap did not catch significantly more weevils. This trap requires more materials and labour than other trap designs tested. The Uni-trap performed relatively poorly for both species, and, although it is commercially available, it is too expensive for routine use in Uganda. The bottle trap performed well, but, as the PET bottles used by Hwang *et al.* (1989) are not available in Uganda, a locally available substitute had to be used. The resulting trap was not easy to construct and not so robust in use. The sticky disc trap also performed well, although this may have been due at least in part to the height of the catching surface above the crop canopy. This trap also required a regular supply of polybutene to recoat the catching surface because it loses effectiveness due to saturation with insects and dust.

The 5-l jerry can traps gave the best compromise of ease of construction, robustness and effectiveness. Omo solution was the most effective trapping agent. Although this prevented escape, it did not kill weevils overnight. However, when pheromone traps are used for mass trapping purposes, there is no need to remove weevils daily. Trap colour was not critical except for red traps which caught fewer weevils than yellow, green or blue traps or the white traps used as a standard. Raising the trap so that the entrance holes were 15 cm or 30 cm above the canopy increased catches of *C. puncticollis* significantly, whereas catches of *C. brunneus* were similar to those with the entrance holes at crop height. This may have contributed to the high catches of *C. puncticollis* in the sticky disc traps which were approximately 50 cm above crop height. It is in marked contrast to results with *C. formicarius* (Proshold *et al.*, 1986) where raising the trap above crop height greatly reduced catches. Lowering the trap entrance below crop height significantly reduced catches of *C. puncticollis* but did not affect catches of *C. brunneus*. Proshold *et al.* (1986) also found that it did not greatly reduce catches of *C. formicarius*. These results suggest that *C. puncticollis* relies more on flying to reach a trap than *C. formicarius* and *C. brunneus*.

The number of insects caught in a trap depends on the number attracted, the number entering and the number retained (Sanders, 1989). The 5-l jerry can trap was more efficient than the 1-l bottle trap at capturing weevils dropped on the tops and sides of the traps. However, the actual values, 36% and 23% recapture for *C. puncticollis* and *C. brunneus*, respectively, were much lower than the 73% and 58% recapture reported by Jansson *et al.* (1992) for *C. formicarius* in funnel traps and Uni-traps, respectively, and further work is planned to investigate the reason for this. Jansson *et al.* (1992) found a 2% escape rate for *C. formicarius* from plastic funnel traps and Uni-traps and a 43% escape rate with boll weevil traps. Whereas no weevils escaped from the 1-l bottle trap, approximately 10% of weevils escaped from the 5-l jerry can trap in one night.

Previous work (Downham *et al.*, forthcoming) showed that for the *C. puncticollis* pheromone, polyethylene vials were the most effective dispensers. For the *C. brunneus* pheromone, catches of *C. puncticollis* males were significantly lower with rubber septa than with polyethylene vials, whereas catches of *C. brunneus* males were not significantly different with the two types of dispenser. Based on these results, polyethylene vials and rubber septa were recommended for the *C. puncticollis* and *C. brunneus* pheromones, respectively. Results presented in this paper demonstrated that these lures showed no loss of attractiveness after eight weeks of exposure in the field.

The release rate of pheromone from "monolithic" dispensers such as polyethylene vials and rubber septa is proportional to the amount of pheromone remaining, and hence the amount of residual pheromone and the release rate decline exponentially with time (Butler & McDonough, 1979). Fitting exponential curves to the results of analyses of residual pheromone (Figure 6.2) gave half lives for the *C. puncticollis* vials and *C. brunneus* septa of 3.3 and 91.0 weeks, respectively, and these results indicated that loss of attractiveness of the *C. puncticollis* vials might be anticipated after eight weeks of exposure, although the *C. brunneus* septa should remain effective for much longer.

The pheromone of *C. brunneus*, dodecyl (*E*)-2-butenoate, is similar in structure and volatility to that of *C. formicarius*, (*Z*)-3-dodecen-1-ol (*E*)-2-butenoate. Jansson *et al.* (1990; 1993) found that there was little loss of attractiveness to *C. formicarius* of Wheaton rubber septa loaded with 0.01 mg of the pheromone after 80 days of field exposure, although the attractiveness of Thomas septa extracted with dichloromethane declined significantly with age. Yasuda *et al.* (1992) also reported a halving of the numbers of *C. formicarius* caught over 60 days with pheromone dispensed from Aldrich rubber septa, but it is not clear whether this was caused by a declining population or a loss of attractiveness of the lures.

Under Ugandan conditions, lures for both *C. puncticollis* and *C. brunneus* can be used for two months. With the *C. brunneus* lures, relatively fewer *C. puncticollis* males were caught with increasing age of the septum, particularly at the 0.1 mg loading. The release rate from these dispensers declines exponentially with age, and this observation would further substantiate the hypothesis of Downham *et al.* (forthcoming) that cross attraction of *C. puncticollis* to the *C. brunneus* pheromone is greater at higher release rates.

The 5-l jerry can pheromone traps are now used in mass trapping experiments and monitoring experiments in Uganda. The traps will be useful for detecting the distribution of the two *Cylas* spp. over the African continent.

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PART III IPM COMPONENTS FOR SWEETPOTATO WEEVILS

7. Management components for *Cylas*: an overview

7.1 Introduction

Management of *C. formicarius* has been studied extensively, mainly in the USA, the Caribbean and Asia (Talekar, 1991; Jansson and Raman, 1991; Cisneros et al., 1995). Limited research on IPM of *Cylas* spp. had taken place in the Eastern African region until recently. Older references stress the use of chemical control (Wheatley, 1969; Ingram, 1961; Kibata, 1979). The International Institute for Tropical Agriculture (IITA) concentrated on breeding for resistance (Hahn et al., 1990). The International Institute for Biological Control (IIBC) worked on integrated control of arthropod pests for root crops in Eastern and Southern Africa from 1989 to 1995 (Allard and Rangi, 1995). The International Potato Center (CIP) works on IPM for sweetpotato in the region since 1988 (Smit, 1995). National Agricultural Research Systems (NARS) payed limited attention to the subject and only few reports on *Cylas* management can be found (Muhanna, 1994; Girma, 1994; Makame, 1994).

The technological options for an IPM programme include host-plant resistance, biological control, cultural control, chemical control and behaviour-influencing techniques such as pheromones, sticky traps and repellents. In this chapter I review the potential management components for *Cylas* species and incorporate the research results described in the previous three chapters.

7.2 Cultural control

7.2.1 State of affairs

Cultural control or habitat management covers practices that make the environment less favourable to pest reproduction, dispersal and/or survival (Flint and van den Bosch, 1981) and more favourable for natural enemies. Integration of different cultural practices has specific potential for managing *C. formicarius*, taken into account that the insect has a limited flight activity, a restricted host range and a characteristic mode of entry into the plant (Talekar, 1991). Principal sources of weevils infesting new sweetpotato plantings are: carry-over of weevils when cuttings are taken from old infested fields; emergence of weevils from crop residues; and immigration of weevils from alternate host plants and weevil-infested neighbouring crops. Cultural practices such as crop rotation, sanitation, use of clean planting material, and others were the earliest control measures advocated for reducing damage by *C. formicarius* (e.g. Franssen, 1934; Holdaway, 1941). Nowadays the recommended cultural practices include crop rotation, sanitation, use of clean tip cuttings as planting material, planting away from weevil-infested fields, hilling-up to reduce soil cracking, intercropping, mulching, sanitation, removal of alternate hosts and prompt harvesting (Talekar, 1991). Their mode of action against the different sources of weevil infestation are explained in table 7.1. Most experiments on cultural control were conducted in Taiwan at the Asian Vegetable Research and Development Centre (AVRDC) or in other Asian countries (Singh et al., 1984; Talekar, 1983, 1987a; Pardales and Cerna, 1987; AVRDC, 1990, 1991, 1992). At AVRDC (1990), for instance, research results indicated that cuttings (25-30 cm long) taken from the fresh terminal growth, even from an infested crop, were rarely infested with weevils; while older portions of the stem were infested with weevils. So, recommending to select the right planting material makes sense. In other experiments the management practice of rotating sweetpotato with rice, combined with isolating the field from other, weevil-infested sweetpotato fields, was able to reduce weevil infestation satisfactory (Talekar, 1983). Thus, crop rotation, may not only be a useful agronomic practice to maintain soil fertility, but will also help to control sweetpotato weevil if integrated with other management approaches.

The ecology and behaviour of *C. puncticollis* and *C. brunneus* is similar to that of *C. formicarius* considering flight activity, host range and mode of entry into the plant (chapter 3). In principal, the cultural control practices advocated for reducing damage by *C. formicarius*, apply also for the African weevil species. However, the production systems of sweetpotato in Africa are very different from those in the USA and Asia (chapter 1). Surveys on existing cultural practices (chapter 4), research to evaluate these practices (chapter 5), and research to test "new" practices in the African context, appeared necessary before recommendations for Eastern Africa could be made.

7.2.2 Cultural control in the light of information on African *Cylas* spp.

Because agro-ecological and socio-economic conditions in the region are very diverse, appropriate cultural control practices have to be site-specific. Some cultural control practices are

Management components for Cylas: an overview.

Table 7.1 Overview of cultural control practices to reduce damage of *C. formicarius*, their mode of action and their potential for control of the African weevil species.

Practice	Mode of action	Potential in Eastern Africa
Selection of clean tip cuttings as planting material from little-infested fields	Reduces initial weevil population	Good potential, often practised but in areas where planting material is scarce, farmers might have little choice what to use.
Crop rotation	Avoidance of weevil emergence from infested crop residues	Good potential, often practised, but in areas with high land pressure and few crops, rotation of 2-3 seasons might be maximum.
Sanitation: destruction of crop debris at (piecemeal) harvesting	Avoidance of weevil emergence from infested crop residues	Good potential, but not wide-spread out of ignorance? In some regions crop residues are important for maintaining soil fertility.
Planting away from weevil-infested fields	Avoidance of immigration	The practice of staggered planting and the close proximity of farms in some areas make it unpractical. In less-populated areas this practice has a high potential.
Hilling-up and filling of soil-cracks	Denying females access to roots for reproduction	Often already practised during piecemeal harvesting. Labour intensive.
Intercropping	Reduce the accessibility of host plants	Intercropping not widely practised, mostly with short-season crops. Effect doubtful.
Mulching	Denying females access to roots for reproduction	Not practised. Labour intensive Mulching material might not be easily available. Potential low.
Removal of alternate hosts	Removal of source of infestation	In many areas sweetpotato is grown year-round. Wild hosts are not important, as sweetpotato is a preferred host.
Timely planting	Avoidance of dry season when weevil pressure is highest	Some potential, but limited in areas where staggered planting is practised, so as to ensure a fresh supply of roots for the longest period.
Timely harvesting	Limiting the exposure time of roots and avoidance of dry season	Some potential, but limited in areas where piecemeal harvesting is practised, so as to ensure a fresh supply of roots for the longest time (see chapter 5).

already in use by farmers, and have been (consciously or unconsciously) incorporated into the production system. These traditional methods of crop protection were developed empirically through centuries of trial and error, natural selection and keen observation (Glass and Thurston, 1978). Other cultural practices can be identified, that could be adapted or improved for better pest management. In chapter 5 one of the standard-recommended cultural control practices, "prompt harvesting", is compared to the traditional cultural practice of "in-ground storage and piecemeal harvesting". The results show that considering yield and quality loss due to weevils, piecemeal harvesting is a sensible option for farmers in the region studied.

Research results of trials on cultural control practices of NARS in Eastern Africa are generally not published in refereed journals. Muhanna (1994) concluded from trials in Mwanza, Tanzania, that sweetpotato tillage methods (mounding, ridging and no heaping) had no effect on quality, yield and sweetpotato weevil damage. His data suggested that application of cow manure can increase sweetpotato yields and reduce root damage by the weevil on some soils. Longer cropping periods were associated with higher weevil damage, suggesting that early harvesting may reduce sweetpotato weevil damage in farmers' fields (Muhanna, 1994).

In different regions of Uganda a series of experiments focus on the effect of different planting dates on the extent of weevil damage. Preliminary results indicate that many vines are killed by weevils just after planting early in the rainy season causing poor crop establishment (Odongo and Smit, unpublished). This could mean that planting very early in the rainy season, so that harvesting could take place before weevil pressure gets high in the dry season, is not a feasible option.

An experiment to determine the effect of adjacent and staggered planting on quality loss due to weevils was conducted at the Namulonge Agricultural and Animal Production Research Institute (NAARI) in Uganda (Smit, unpublished). The experiment was situated in an isolated part of the station. There were no sweetpotato fields within a distance of one km, that could act as a source of weevil infestation. Plots were artificially infested with weevils reared in the laboratory. Treatment plots were planted 3 months later, either adjacent to a weevil-infested plot or separated by 22 m band of wild grasses. However, when harvesting the treatment plots, less than one percent of the roots showed weevil damage. The results could not be used to draw conclusions about the effect of adjacent and staggered planting on quality loss due to weevils. The reason of the failure of the artificial infestation is unknown; the release technique proved very effective in other types of experiments. The trial showed however, that planting sweetpotato in locations isolated from older, infested fields, on a plot that has not been planted with sweetpotato for several years, and using relatively clean planting material, can reduce weevil damage to very low levels.

Two subsequent experiments at NAARI focused on the effect of extra hilling-up of mounds and filling of soil cracks. These practices would prevent female weevils to have access to roots for oviposition. However, no significant differences in root damage between treatments and control were observed. Talekar (1987a) described the failure of a cultural control experiment concerning crop rotation due to the vicinity of a weevil source, being an older sweetpotato plot. In later experiments, he made use of 5m wide channels filled with water, on the four sides of the entire experimental field, to prevent weevils from outside sources invading the planting, and he artificially infested the field (AVRDC, 1990). In these experiments treatment plots with rotation or clean planting material showed significant less weevil damage than control plots. However, such experimental conditions are difficult to obtain in Africa, where often no irrigation facilities are available.

7.2.3 Prospects

Cultural control practices are appropriate for the management of sweetpotato weevils in Africa, as they do not require costly inputs. Some control practices against one pest affect management of other pests and diseases. For example, selection of healthy-looking planting material also reduces virus incidence. Some practices might be useful from an agronomic point of view, such as crop rotation to maintain soil fertility. In densely populated parts of Eastern Africa, where farms are closely spaced, some practices might require a community effort. An example is the avoidance of staggered and adjacent planting. Some of the cultural control practices, such as extra hilling-up of mounds and filling of soil cracks, are very labour intensive. Farmers may not be willing to provide extra labour, especially during periods when other crops also require care, or when the sweetpotato crop is considered to be of minor importance.

Knowledge on the biology and behaviour of weevils, will give farmers insight into the rationale behind cultural control practices. As was mentioned in chapter 4, farmers often do not lay the link between the larvae in the root and the mobile, adult weevils on the leaves.

For NARS to further develop technology on cultural control practices, a site-specific, participatory approach involving farmers appears essential (see chapter 8).

7.3 Sex pheromones

7.3.1 State of affairs

Heath et al. (1986) isolated, identified , and synthesized the female-produced pheromone of *C. formicarius*, (Z)-3-dodecen-1-ol(E)-2-butenoate. Use of the pheromone in pest management (monitoring; mass trapping and mating disruption) is being investigated (Heath et al., 1991; Jansson et al., 1991). Pheromone traps were used as monitoring tools in Eastern Africa. The results of the catches confirmed that *C. formicarius* was absent from all but one coastal location (Parker et al., 1992). According to Jansson et al. (1991) the sex pheromone has great potential as a monitoring tool in regions where *C. formicarius* is the pest species, and may help growers select and time management tactics to reduce weevil densities in either seedbed, field, or storage. It may also help growers to assess the success of current management programs for this weevil. Further, pheromone traps are important training tools, enlightening farmers on the number of mobile, adult weevils in their fields. Experience in Cuba indicated that pheromone traps greatly improved the credibility of the management recommendations delivered by extension staff and other trainers (Cisneros, pers. comm.).

Use of pheromones for mating disruption and/or mass trapping has potential as an IPM component. Mass-trapping of males with the pheromone has suppressed populations of *C. formicarius* in Taiwan (Hwang et Hung, 1991), India (Pillai et al., 1993) and Japan (Yasuda, 1995). CIP collaborates with several national programmes to explore the potential of this method (CIP, 1995). In the Dominican Republic mass trapping with pheromone traps is considered an essential component of the IPM approach (Alvarez et al., 1996). Use of the pheromone in mating disruption has also been reported (Mason and Jansson, 1991). Male counts in pheromone traps were considerably lower in fields in which the air was presumably permeated with synthetic sex pheromone than in control fields. However, populations of *C. formicarius* and their damage to roots were not measured in this experiment.

7.3.2 Sex pheromones for African sweetpotato weevil species

The sex pheromones of the African sweetpotato weevil species have been identified recently as decyl (E)-2-buteonate for *C. puncticollis* (Smith et al., in preparation) and dodecyl (E)-2-buteonate for *C. brunneus* (Downham et al., in preparation).

In chapter 6, experiments were described concerning the development of pheromone traps for *C. puncticollis* and *C. brunneus*. Various designs of funnel, water and sticky traps were compared and a 5-l plastic jerry can trap was adopted as the most practical design. In chapter 3, Smith et al. (in preparation) and Downham et al (in preparation) further experiments are discussed on pheromone dose, mixtures, lure type and attraction distance.

As an aspect of monitoring, the pheromone lures will be send to various countries within Sub-Saharan Africa to verify the distribution of the two species over the continent.

To determine whether pheromone traps for *C. brunneus* and *C. puncticollis* can be used to reduce weevil populations and subsequent root infestation, large mass trapping experiments in main season crops have been established at different locations in Uganda and are also planned in smaller, dry-season plots, which would simulate the farmer's planting material nurseries in moist areas.

7.3.3 Prospects

A restriction of the use of the weevil pheromones as a management tool is, that only male weevils are attracted to the traps. There is no information on the mating behaviour of *Cylas* spp., including *C. formicarius*. In case one male is able to fertilize a large amount of females and these females have a high fecundity, the potential of mass trapping males might be restricted. Therefore, experiments are being conducted to verify how many females a male weevil can fertilize. In other experiments, the fecundity of once-mated females is compared with that of females with continuous opportunities for mating.

Another restriction of the pheromone approach is the availability and price of pheromone lures. Concerning *C. formicarius*, there is one laboratory in Vietnam were pheromones can be synthesized at a cheap rate for local use (Braun, pers. comm.). In other countries with active IPM for sweetpotato programmes, Cuba and Indonesia, the sustainable availability of pheromone lures at an affordable price is still a constraint (Cisneros, pers. comm.). In the case of the Dominican Republic, formulation is carried out at CIP in Lima, Peru. Since two years, farmers have paid for 90% of the pheromone dispensers, priced at

$2.00 each; 10% was provided free of charge. The proceeds of these sales are deposited into a rotating fund destined for the future purchase of more concentrated pheromone (Alvarez et al., 1996). A price of $2.00 per lure would be a restriction for resource-poor farmers in Eastern Africa. Presently the pheromone lures for *C. puncticollis* and *C. brunneus* are produced in UK for experimental purposes only. In case pheromones prove a useful IPM component in Eastern Africa, a study should be conducted about the feasibility of producing pheromones within Africa.

7.4 Host-plant resistance

7.4.1 State of affairs *C. formicarius*

Numerous studies have been conducted during the last 50 years to identify sweetpotato resistance to *C. formicarius* (see for an overview Collins et al., 1991). Breeding of sweetpotato for weevil resistance has been conducted at AVRDC in Taiwan (Talekar, 1987b,c) and in the USA (especially in South Carolina and Puerto Rico) (Martin, 1984; Mullen et al., 1985). Many NARS researchers have screened and evaluated local germplasm for resistance (among others Jayaramaiah, 1975; Pillai and Nair, 1981; Pole, 1988; Faleiro and Mathew, 1991).

While no germplasm immune to *C. formicarius* has been identified, research suggests that sweetpotato clones differ in their level of resistance. These levels are low and do not stand up under high weevil pressure (Collins and Mendoza, 1991). The possibility that sweetpotato weevil resistance does not exist in sweetpotato germplasm is suggested by some researchers (Talekar, 1987c; Sutherland, pers. comm.). Talekar (1987c) argues that the weevil never endangers the growth, reproduction, or survival of the sweetpotato plant. Therefore, natural selection for plants with a defensive mechanism did not occur.

Several strategies have been suggested in order to progress towards higher levels of weevil resistance in sweetpotato, through conventional and non-conventional breeding techniques. However, considerable effort is required if successes with conventional breeding should be obtained. A multidisciplinary research team should at least involve a breeder, an entomologist and a bio-chemist. Biochemical and bioassay methodologies need to be developed for identification of resistance mechanisms and the biochemical compounds involved, and a methodology for accurate selection of resistant lines. Another approach is crossing sweetpotato with wild relatives, which show stem resistance (Collins and Mendoza, 1991). A third approach is the development of transgenic sweetpotato with proteinase inhibitors for *Cylas* spp. The non-existence of biosafety regulations in many developing countries might delay the field-testing of transgenic plants.

Some varieties are less susceptible to weevil damage than others due to an escape mechanism. Short-season varieties can be harvested early before the weevil population has built up (Collins et al., 1991). Deep-rooted varieties escape weevil damage because their roots are less accessible for females to lay eggs in. In Cuba specifically selected, deep-rooted, early-maturing varieties are an important component of an IPM approach (CIP, 1995). Escaping weevil damage through deeper root formation and early-maturity, can be considered as pseudo-resistance.

7.4.2 State of affairs African *Cylas* species

IITA was involved in breeding for sweetpotato weevil resistance from 1971 to 1987 (IITA, 1971), and concentrated research on *C. puncticollis* as data from their research station in Ibadan, Nigeria, indicated that this was a more serious pest than *C. brunneus* (IITA, 1977). Four promising clones were selected and resistance characteristics were incorporated into the breeding populations. Highly significant correlation was found between *C. puncticollis* damage ratings of storage roots and damage ratings of shoots. The heritabilities of resistance to weevils were estimated at 84 percent in the storage root test and 79 percent in the shoot test (Hahn and Leuschner, 1981). Anota and Odebiyi (1984) compared five field-resistant varieties to IITA's standard susceptible check, TIb4. The number of adults emerging from the susceptible check was significantly higher, indicating a higher survival rate than on the resistant varieties. There were no significant differences in developmental time of the weevils within the six varieties. Anota and Odebiyi (1984) categorized four out of the five field-resistant varieties as resistant, and concluded that the resistant varieties contain some components of antibiosis, which were reflected mainly in low survival rates of life stages.

These four resistant varieties were among those sent to national programmes in many countries around the world. When tested against *C. formicarius*, they were susceptible in Tonga (pers. observations), Taiwan (Collins et al., 1991) and showed some resistance in the USA (Rolston et al., 1979). In Kenya the varieties were susceptible to natural populations of *C. brunneus* and *C. puncticollis* (Shakoor, pers. comm.).

At IITA the four resistant varieties were consistently compared to the susceptible check TIb4. It appeared, that TIb4 can be considered a very susceptible variety, while the "resistant" varieties belong to the category of less susceptible ones. Under high weevil pressure this "resistance" is, however, of little value.

National programmes in Eastern Africa have screened and evaluated local and introduced germplasm for resistance, sometimes in collaboration with CIP. Results are mostly published in annual reports (Makame, 1994; Girma, 1994; CIP, internal reports; Magenya and Smit, 1994). However, results of field resistance tests were inconclusive. No-choice laboratory resistance tests also failed to identify any reliable resistance. Differences in field-susceptibility are noticed due to the rooting characteristics of varieties, which is based on an escape mechanism and not on resistance in the strict sense. In Uganda a popular local variety, Tanzania, is known to be very weevil-susceptible due to it protruding roots. Among six recently released varieties, two are characterized as highly susceptible and four as moderately susceptible.

7.4.3 Prospects

Breeding for weevil resistance is presently considered low-priority research at CIP, as other, more-promising IPM components are available. However, the biotechnological approach is presently explored and a project seeks to develop transgenic sweetpotato with proteinase inhibitors, resistant to *Cylas* spp.

To detect pseudo-resistant varieties with deep-rooting or early maturity, it is useful to continue scoring germplasm for weevil damage as part of a standard germplasm evaluation procedure, but not in specially-designed resistance experiments.

7.5 Biological control

7.5.1 State of affairs

Nine parasitic wasps have been reported to attack *C. formicarius* in Asia and the USA, but none is effective at sufficiently suppressing weevil populations (Jansson, 1991). Jansson (1991) lists 6 parasitoids of *C. puncticollis* in Africa (Table 7.2). Allard and Rangi (1995) report on several Hymenopteran and Dipteran natural enemies of *Cylas* spp. in Eastern Africa (Table 7.2). The fact that only few specimen were recovered from an extensive number of samples, indicates that parasitoids do not play an important role in control of *Cylas*

Table 7.2 Parasitoids of *Cylas* spp. in Africa

Host	Parasitoid species	Order: Family	Location	Reference
C. puncticollis	*Bracon* sp. (as *Microbracon* sp.)	Hym.: Braconidae	Africa*	Risbec 1947
	Macreupelmus sp.	Hym.: Braconidae		
	Cheiloneurus sp. (as *Chiloneurus* sp.)	Hym.: Encyrtidae		
	Eurytoma sp.	Hym.: Eurytomidae		
	Dinarmus sp. (as *Bruchobias* sp.)	Hym.: Pteromalidae		
	Rhaconotus menippus var. africana Nixon	Hym.: Braconidae		
Cylas spp. infested roots	idem		Kenya Uganda	Allard & Rangi 1995
	Cardiochiles enderleini Szepl.	Hym.: Braconidae	Kenya	
	Eumenis pipiszodes Speiser (?)	Dipt.: Syrphidae		

* No details on country

spp. in Eastern Africa. Because several life stages of sweetpotato weevils are completed underground, within the roots, it is apparently difficult for parasitoids to locate them.

Ground-dwelling insect predators, entomopathogenic fungi, nematodes and bacteria may be better suited to the underground conditions, and may have greater potential as biological control agents.

At least five predators of *C. formicarius* have been reported (Jansson, 1991) of which the ants *Pheiodole megacephala* and *Tetramorium guineense*, are used as biological control agents in Cuba (Castineiras et al., 1982; Morales, 1994; CIP, 1995). Ants, which are abundant in banana plantations, are offered wrapped banana leaves for nesting (INIVIT, 1995). When the parcels have been colonised, they are brought over to a sweetpotato crop, where the ants predate on sweetpotato weevils. In Indonesia the importance of generalist predators such as spiders, ants, staphylids and earwigs is under investigation (Braun, pers. comm.). Preliminary studies have started on predators of the African *Cylas* species (Smit, unpublished).

Of all known fungal pathogens reported to attack *C. formicarius*, *Beauveria bassiana* is the predominant species (Jansson, 1991). In Cuba *B. bassiana* suspension is used as a component of the IPM programme: 1) as a pre-plant dip for planting material, 2) sprayed around sex-pheromone units, or 3) used as a foliar spray (Castellon et al., 1993; CIP, 1995; INIVIT, 1995). An isolate of *B. bassiana*, naturally occurring in Taiwanese soils, was very pathogenic to *C. formicarius* (Su et al., 1988).

Many indigenous isolates of entomopathogens infecting *Cylas* spp. were found in Rwanda, Burundi, Uganda and Kenya, and cultures of isolates are held in dry storage in Kenya (Allard and Rangi, 1995). *Beauveria bassiana* was the predominant entomopathogenic species. Field experiments in East Africa with the most pathogenic strains as soil applications showed that it is difficult to create the right conditions for the fungus to have a controlling effect. No significant control effects were obtained. However, most experiments proved that the fungus is able to persist in the soil for over a year and that after treatment, a larger percentage of *Cylas* weevils are infected with *Beauveria* than before treatment (Allard and Rangi, 1995). *Beauveria* might have a limited niche in IPM for sweetpotato.

Field research on entomopathogenic nematodes of *C. formicarius* was conducted in the USA, but results were inconsistent (Jansson, 1991; Jansson et al., 1993). Two unidentified strains of entomopathogenic nematodes were recovered from soils in Kenya, which killed *C. puncticollis* larvae within four days under laboratory conditions (Allard and Rangi, 1995).

Jansson (1991) also tested the toxicity of a commercially available formulation (FOIL™) of the bacterium *Bacillus thuringiengis* (Bt), and found that it had no activity against *C. formicarius*. Bt was isolated from infected *C. formicarius* larvae in the Philippines (Amalin and Vasquez, 1993). According to Jansson (1991) further surveys to isolate bacteria-infected *C. formicarius* should be conducted, as these isolates will also be useful for developing transgenic sweetpotato plants resistant to *C. formicarius*. In Kenya, preliminary experiments with commercially available formulations of Bt, viz. FOIL™ and Novodor, on adults and larvae of *C. brunneus* and *C. puncticollis*, did not show an effect on adult and larval mortality of the *Cylas* spp. (N. Smit, unpubl. data).

7.5.2 Prospects

Very few results have been obtained with biological control of sweetpotato weevils up to date. The biological control agent with the most potential might be *B. bassiana*. The integration of the entomopathogenic fungus with pheromone traps, or using a *Beauveria* solution as a pre-plant dip might have some potential in Eastern Africa. Nursery beds for planting material in swampy areas, where the moist conditions might create the right conditions for the fungus to multiply and persist in the soil, appear to be appropriate places to try out these techniques. A restriction of a microbial control agent like *B. bassiana* is that it needs to be produced and formulated.

Given the importance of predatory ants in the Cuban IPM programme, the identification of predators and their impact on the African *Cylas* spp. should be further investigated.

7.6 Chemical control

7.6.1 State of affairs

In some areas in Southeast Asia and the Caribbean insecticide use in sweetpotato is or was relatively commonplace (Braun, pers. comm.; Cisneros et al., 1995). Numerous chemical insecticides have been tested for the control of *C. formicarius*, although exposure of the weevil to the chemicals is limited due to the cryptic behaviour of the insect. Sutherland (1986a) tested 59 different insecticides, most of which applied as post-planting foliar sprays, which resulted in varying levels of control. Weevil control after planting is difficult with conventional spraying, as only above-soil adults are killed, and repeated applications would be necessary to kill newly-emerged adults.

Systemic insecticides have been used to control weevils in planting material. By dipping vine cuttings in these insecticides, weevil life stages within the vine are killed and the plant is protected for at least one month after planting in the field (Talekar, 1991). This type of treatment is usually more economical than post-plant insecticide applications, but the systemic insecticides are highly toxic bringing about health risks. In older references from Eastern Africa (Wheatley, 1961; Ingram, 1967) it was advised to use DDT for the treatment of planting material.

7.6.2 Prospects

Frequent spraying of insecticides is not cost-effective for subsistence farmers and small-scale commercial farmers in many developing countries. Dipping planting material in insecticide can play a role in large multiplication projects. Suitable insecticides, which are generally available in Eastern Africa, have been listed in Skoglund and Smit (1994).

7.7 The integration of control components

Implementation of IPM in pilot units is an essential part of an IPM strategy. IPM programmes for *Cylas* weevils have taken off in a limited number of countries. Some experiences are described below.

Talekar et al. (1989) described a case study of integrated management of *C. formicarius* on an island of Taiwan. The programme included crop rotation, dipping cuttings in carbofuran solution before planting, elimination of wild *Ipomoea* species from the field borders, hilling of soil to fill in soil cracks, and continuous trapping of male weevils in pheromone traps from planting until harvest. Weevil damage to roots was reduced from 75% to 4% over a three year period. Cooperation of each farmer proved to be essential for the success of IPM. The IPM programme did not take off in Taiwan, supposedly because of the limited involvement of farmers in the technology development (Braun, pers. comm.).

In Indonesia and Vietnam, technology for sweetpotato IPM is developed by using the Farmer's Field School concept, a model originally developed for rice. Through hands-on experience, farmers in pilot units learn to analyze pest problems within the context of overall crop health. Concepts such as insect life cycles, the role of natural enemies, and the action of sex pheromones are introduced in the field schools, and farmers learn to recognize and distinguish the different roles that insects play in the crop ecosystem. The logic underlying pest/crop management options is discovered by the participants themselves through a non-formal education process (Braun, 1995).

In the Cuban IPM programme for *C. formicarius* cultural control, biological control and sex pheromonal control are integrated and have been very successful in reducing the use of insecticides (Figure 7.1, Table 7.3, Cisneros et al., 1995). In the Dominican Republic cultural and pheromonal control are used. The programme generated an internal rate of return on research and extension investment of 27%, which is economically attractive (Alvarez et al., 1996).

In Eastern Africa IPM research has not yet reached the phase of integration of management components. From the preceding pages can be concluded that cultural control practices and possibly mass trapping with sex pheromones are the management approaches that would presently be available for testing with farmers.

Table 7.3 Results of management of sweetpotato weevil in the Dominican Republic and Cuba (started in 1993, results up to July 1995).

Pilot Unit	Infested roots (%) Before IPM	IPM	Control practices Before IPM	IPM components
Vega, Dom. Rep.	25	5.4	Insecticides (3 sprays)	3,8,9,10,12[a] (1 spr)
Cienfuego, Cuba	44	8.0	Insecticides (10-12 sprays)	1,2,3,4,5,7,8,9,10, 11,12 (no sprays)

[a] Practices indicated in the IPM diagram (Figure 7.1)

Source: Cisneros et al., 1995

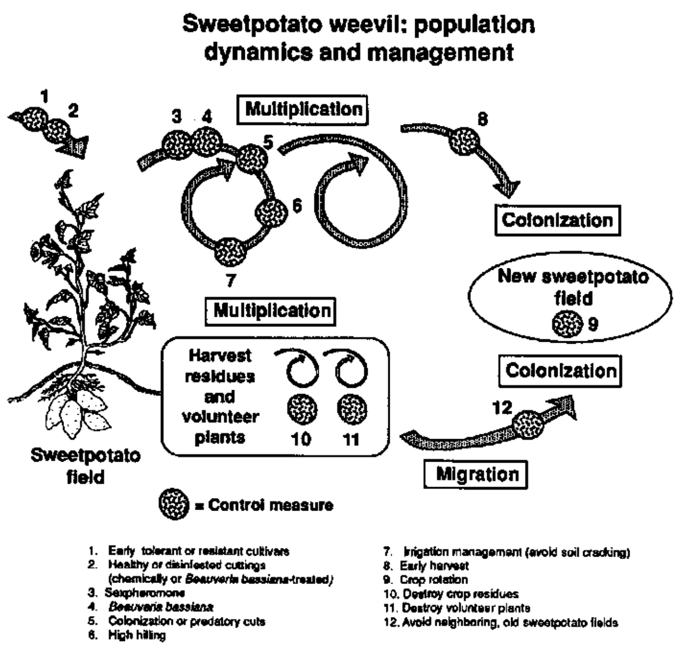

Figure 7.1 Sweetpotato weevil (*C. formicarius*): population dynamics and management.
Source: Cisneros et al., 1995)

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PART IV - SYNTHESIS

8. IPM for sweetpotato weevils in Eastern Africa

8.1 IPM concepts

The concept of Integrated Pest Management (IPM) emerged during the 1960s in response to problems associated with almost exclusive reliance on insecticides for pest control. A number of negative side effects became apparent: environmental and human health hazards, development of pesticide resistance, resurgence and secondary insect pest outbreaks. The first publication clearly defining "integrated control" and using economic threshold as an operational concept was that of Stern et al. (1959), which is considered the starting point of IPM. In 1968, IPM was defined by the UN's Food and Agricultural Organisation as "a pest management system that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible, and maintains the pest population at levels below those causing economic injury" (FAO, 1968).

IPM developed as a strategy to control pests by relying on natural control factors such as host plant resistance, natural enemies and cultural control methods, and using pesticides as a last resort. Crops were scouted to assess population levels of pests in order to decide whether to spray or not. The application of the economic threshold level at farm level turned out to be impractical for numerous reasons, an example is the complexity and labour-intensity of the required observation techniques (van de Fliert, 1993).

According to Barfield and Swisher (1994) IPM is geographically specific and based on a thorough knowledge of the ecology of regional agro-ecosystems, including the role of the arthropod fauna. In the late 1980s the FAO's Inter-country IPM Programme in Asia introduced four principles to rice farmers: 1. grow a healthy crop; 2. conserve natural enemies; 3. observe the field regularly; 4. become IPM experts (Indonesian National IPM Program, 1990; Kenmore, 1991). New developments towards sustainable crop protection might be called integrated crop management (ICM) (Zadoks, 1993 and references therein). ICM embraces all activities in the production system and focuses on solving particular constraints, such as integrated pest management (IPM), integrated nutrient management (INM), integrated water management (IWM), etc. ICM is concerned with managing a production system to optimize the use of natural resources, reduce environmental risk and maximize output. The goals of a particular management system are dependent upon natural, socio-economic and technological resources and their relationships.

8.2 IPM for resource poor farmers in sub-Saharan Africa

Chambers (1993) describes three types of agriculture: "Industrial" agriculture consisting of large fields under monoculture or plantations; "Green Revolution" agriculture mainly practised on irrigated plains in Asia; and a "complex, diverse and risk-prone" agriculture practised by most resource-poor farmers. The IPM concept emerged in industrialized countries as a technical alternative for resource-rich farmers. The experiences with IPM programmes in "Green Revolution" agriculture in Asia with relative resource-rich farmers were positive. However, developing and implementing IPM programmes in complex, diverse and risk-prone agriculture has not yet been a success (van Huis and Meerman, in prep.).

Most farmers in sub-Saharan Africa are resource-poor in terms of access to natural resources, credit, information and external inputs. Their main driving force is to secure food supply at farm level. Quality demands are generally low and levels of pest tolerance can therefore be higher (van Huis and Meerman, in prep.).

Traditional farmers rely on a variety of management practices to deal with agricultural pest problems. Two main strategies can be distinguished. One is the use of direct, non-chemical pest control methods (cultural, mechanical and physical practices). The second is reliance on built-in pest control mechanisms inherent to the biotic and structural diversity of complex farming systems commonly used by traditional farmers (Altieri, 1993).

Agricultural practices of resource-poor farmers are often well adapted to the agroecological and socio-economic conditions, and farming systems are flexible and responsive to all kinds of risks, including those of pests. The scientific community has devoted relatively little attention to understanding or improving traditional practices. To devise better crop protection methods it is important to rescue, understand and apply traditional farming knowledge concerning agricultural and pest problems (Altieri, 1993).

The low-input systems of resource-poor farmers usually operate near the optimum, but do not generally produce high yields. These low yields often become insufficient for farm families experiencing changed and/or adverse conditions. For example an increased human/land ratio forces a farm family to produce more per unit land. At the same time reduced availability of land per family forces farmers to move into increasingly marginal lands, less appropriate for agriculture. Farmers would like to produce both enough to eat and to sell, as nowadays almost all farmers need money for school fees, salt, etc. (Barfield and Swisher, 1994).

To increase yields and reduce crop losses in sub-Saharan Africa, agricultural development programmes have been launched. In many cases the technology transfer model has been used, relying on the use of extension services to disseminate the results of formal research. Unfortunately, this model has taken insufficiently into account the agro-ecological, human health, environmental and social factors that influence farmer behaviour (van Huis and Meerman, in prep.). The move is now towards a more participatory approach, sometimes referred to as "Farmer-first" (FF) (Chambers, 1993) or "Training-driven" (Barfield and Swisher, 1994). This approach requires a site-specific and multidisciplinary effort. It puts the end-users of a technology in the centre of the picture during the technology development process. It stresses the importance of understanding and building on local people's skills and knowledge (Croxton, 1994).

According to van Huis and Meerman (in prep.) the informal research and development capacity in Africa should be the basis for this approach. In partnership with research organisations and after training, the staff can do site-specific research, identify effective endogenous technologies and validate existing experiment station-derived technologies under the farmers' real-world conditions. According to Bentley (1990) perhaps the key to farmer participation is that scientists should work with farmers through intermediaries who live in remote villages and can serve as information brokers between scientists and farmers. Van Huis and Meerman (in prep.) are of the opinion that International Agricultural Research Centers (IARCs), such as CIP, should be involved in developing methods and techniques for FF research rather than developing site-specific technologies themselves. Moreover IARCs could play an important role in training scientists of NARS in the FF model for agricultural research.

8.3 Strategies for developing and implementing IPM

CIP's IPM research programme uses a scheme for the development of IPM from the initial pest problem assessment to the large-scale implementation of IPM in farmers' fields (Cisneros and Gregory, 1994; Cisneros et al., 1995). IPM development can be divided into five distinct, consecutive phases, which may overlap (Figure 8.1):

* pest problem assessment and characterization;
* development of management components;
* integration of key components;
* implementation of IPM in pilot units;
* implementation of IPM on a large scale.

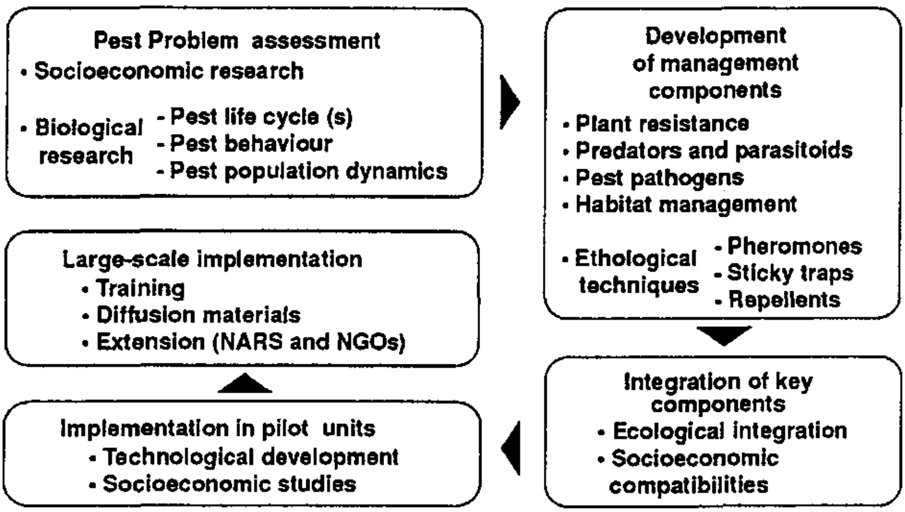

Figure 8.1 CIP's IPM Research and Implementation Strategy. Source: Cisneros et al., 1995.

This strategy has proven to be very successful in management of potato tuber moth (*Phthorimaea operculella*) in the Andean Region and in Tunisia and Egypt, in management of the Andean potato weevil (*Premnotrypes* spp.) in Peru and Ecuador, and in management of the sweetpotato weevil (*C. formicarius*) in the Caribbean (Cisneros et al., 1995). Through collaboration with NARS and NGOs the phase of large scale implementation has been reached in all target countries.

However, these successes were obtained with commercial crops, intensively grown by relatively resource-rich farmers, who commonly used insecticides to protect their crops. Sweetpotato crop management by subsistence farmers in Eastern Africa is very extensive (chapter 1).

IPM for sweetpotato research in Eastern Africa was conducted on aspects of pest problem assessment and development of management components (see previous chapters). The most-promising management components at this moment, cultural control practices and sex pheromones, both require adaptations by the farmers. The input of farmers at an early stage would alert researchers of any major unforeseen constraints to the eventual adoption of management components. Research on other management components, such as host-plant resistance and biological control, for which on-the-shelf technologies do not yet exist, can continue at the research stations. To increase the likelihood of practical success of the programme, some modification of the CIP IPM model is required. At this point in time, a pilot area should be selected, where further studies on pest problem assessment take place and where farmer participatory research into development and integration of management components is conducted. Experiences from the pilot unit can be used in the formal, research-station research, and as soon as promising results are obtained, the farmers' reaction on them can be obtained at the pilot areas.

However, interest in technologies covering a "narrow" topic may be limited. For example, managing sweetpotato weevils may not be perceived as a main issue or problem by a farmer. Zethner (1995), reviewing IPM in Sub-Saharan Africa, stated that in crops primarily grown for subsistence with little or no use of pesticides, projects should not be labelled as "IPM projects", but rather projects in which IPM is seen as a strategy to improve agriculture and farmers' income as a whole. Schulten and van der Graaff (1990) warned that IPM programmes in subsistence crops need a very long time to develop and would have to go hand-in-hand with general crop improvement; and with upgrading farmers awareness of IPM principles and their capacity as managers (van de Fliert, 1993).

8.4 Criteria conditional for the success of a sweetpotato IPM programme in Eastern Africa

8.4.1 Introduction

In chapter 1 an overview was given of the results of baseline studies of the patterns of production and utilization of sweetpotato, carried out in several countries (Mutuura et al., 1992; Bashaasha et al., 1995; Kapinga et al., 1995). One of the goals of the surveys was to identify areas where research is likely to have most impact. Sweetpotato growers in Eastern Africa experience a wide range of agroecological and socio-economic conditions, and face diverse constraints. To solve crop protection problems in sweetpotato will not be a priority for all farmers. According to van de Fliert (in prep.) IPM in developing countries is characterised as being knowledge- and skill-intensive, location-specific, aiming at sustainability, requiring group action, and having low observability. For that reason IPM demands dedication from farmers in training and implementation, which will not be found everywhere. The next paragraphs describe conditions and opportunities that create a favourable environment for setting up an IPM programme for sweetpotato in Eastern Africa. This can direct us to a suitable pilot area for farmer participatory research.

8.4.2 Agro-ecological conditions

Sweetpotato weevils are more abundant and injurious during the dry growing season than during the wet season because of higher temperatures and more soil cracking which expose fleshy roots to oviposition by the weevil (Chalfant et al., 1990 and references therein, chapters 1 and 3). Mutuura et al. (1992) and Smit and Matengo (1995) reported from Kenya that farmers considered rodents the most important constraint in wet zones at higher elevations, while in drier low elevation regions, the major production constraint were sweetpotato weevils. Sweetpotatoes are grown in a wide range of agroecological zones in the region, but farmers will only be motivated to deal with sweetpotato weevils in those regions with long dry periods. In other regions higher yields might by easier to obtain by using improved varieties or agronomic practices than by using strict IPM technologies. In areas with well-distributed rainfall, the strategy of "in-ground storage and piecemeal harvesting" (chapter 5; Hall, in prep. a) is used by the majority of farmers. This practice acts as a cultural control practice for weevils. In dry agroecological zones it is not used during the dry season as there is not enough soil moisture to keep sweetpotato vines alive, and the crop is extremely susceptible to sweetpotato weevils during this period.

8.4.3 Socio-economic conditions

Conelly (1987) worked on pest management of maize and sorghum, basic staple foods in South Nyanza, Kenya. In the low rainfall areas of this district, farmers do recognize insects as a serious pest, yet take little action to control them. In these areas, where maize and sorghum is largely for subsistence, farmers may be willing to tolerate quite high losses to insects, given the high cost in cash (e.g. insecticides) and/or labour (certain cultural practices) required for control. If farmers regularly suffer major yield losses to drought, as in these areas, and have alternative sources of subsistence and income such as livestock and fishing, then even substantial yield losses to insects may not justify the use of "costly" pest control measures. In this setting IPM components, which do not require cash or labour from the farmers, such as resistant varieties or classical biological control, are the few IPM technologies that remain.

Sweetpotato is an important crop in two types of food systems in Eastern Africa. In the first type, sweetpotato is a major staple in the diet, along with other non-grain starchy staples. In the second type, maize and other grains are the basic staples, and sweetpotato is an important secondary food. In the latter food system, pest management in sweetpotato will not be a priority for resource-poor farmers. Non-commodity specific surveys and need assessment through participatory rural appraisal would likely give this outcome. Pests in a relatively minor crop like sweetpotato, are but one of the many risks for the farmers. Success with IPM for sweetpotato can initially only be expected in those areas where the crop is a major staple and the safeguarding or the protection of the yield a major concern to the farmer.

However, even in areas, where sweetpotato is a basic food, pest management may not be the farmers' priority. Some farmers in Eastern Africa may face other, more important risks, such as violence.

When yields are primarily destined for home consumption, quality demands are lower and therefore levels of pest tolerance higher. Farmers are used to a certain yield reduction from sweetpotato weevils and may use the principle "plant enough for the pests, too" (Barfield and Swisher, 1994). Besides, in the just described areas, farmers are not dependent on sweetpotato alone. They plant a diversity of crops, including for instance cassava and millet. In years when sweetpotato weevil damage is very serious, the farm family will still survive; although they might not enjoy their preferred mix of diet. When there is a dramatic increase in the role of sweetpotato in the food system, traditional practices will not be sufficient to cope with the situation, and farmers may become interested in improved pest management.

Many households in Eastern Africa utilize sweetpotato as a supplementary source of income. They sell small quantities at local markets over an extended period. Quality standards in the rural markets are generally low, although obviously-weevil damaged roots will not be sold. This type of marketing will not encourage the adoption of labour- or cash-intensive pest management practices. Some farmers in particular areas have specialised in commercial sweetpotato production and these farmers might consider improved management of sweetpotato weevils a priority.

8.4.4 Selection of a pilot area

A combination of the following socio-economic and agroecological conditions appears conditional for conducting an IPM pilot programme in Eastern Africa:

1. Sweetpotato is a basic staple food and/or a major cash crop.
2. Rainfall is low and/or poorly spread with one or two long dry seasons.
3. Sweetpotato production becomes more important and intensive because: a. other staple and/or cash crop(s) have declined in importance due to e.g. the emergence of African Cassava Mosaic Virus Disease (ACMVD), which in Uganda dramatically reduced cassava production; b. the crop's economic value increased, for instance after successful product development, and therefore there is a substantial increase in the market and quality demands for sweetpotato.

Soroti and surrounding districts in North Eastern Uganda is a region within Eastern Africa fulfilling all three conditions and would be suitable as a pilot area for sweetpotato IPM. Another candidate region would be Mwanza and Shinyanga districts in Lake Zone Tanzania. Smaller suitable regions are found in other parts of Eastern Africa.

In Soroti District, sweetpotato is the predominant staple crop, providing the majority of dietary starch throughout the year. It is an important cash crop for the Kampala market during the major harvest months. Urban consumers prefer one variety, Tanzania, which is early-maturing and highly susceptible to weevil attack due to its rooting characteristics. Farmers also like this variety for its taste and high yield. The dry season is long, lasting from November to mid March. The preferred staple and important cash crop cassava has virtually disappeared from the area due to ACMVD since 1986. Sweetpotato has taken over most of its role as a crop for cash and food security (Hall, in prep. a.)

For similar reasons Hall (in prep. a) identified this region as suitable for testing out storage technology of fresh roots. This would offer the opportunity to extend the period of availability of the crop. He pointed out that before the onslaught of ACMVD, fresh cassava roots were available more or less throughout the year, as these can be stored "in-ground" on the plants. Sweetpotato plots, however, have to be dug up at the beginning or towards the middle of the dry season, because sweetpotato weevil damage increases rapidly to unacceptable levels. At that time of the year, sweetpotato is dried and stored, to provide food during the long dry season. However, the product cannot be stored very long due to common storage pests. Therefore, sweetpotato cannot completely replace cassava and a period of insufficient food availability occurs nearly every year just before the harvest of cereal crops. When final harvesting of sweetpotato could be delayed with one month, by reducing the incidence of sweetpotato weevil, this would already be of large benefit. IPM for sweetpotato weevils and storage of fresh roots are complementary in extending the period of availability of the fresh produce.

8.5 Development of a pilot IPM methodology for sweetpotato

8.5.1 Introduction

Based on information given in this thesis and experiences from other projects, as narrated in this chapter, a pilot IPM (or rather ICM) methodology for sweetpotato could be developed. To discuss it from a practical point of view, reference will be made to the situation in a pilot area: the Soroti District in Uganda.

The organisational aspects of the programme will be discussed first. In the next paragraphs the phases of pest problem assessment and development of management components are discussed. Criteria for evaluating the success of the programme are outlined. The aspect of technology transfer will be dealt with. Constraints and benefits of the described IPM approach close this chapter.

An integrated pest and crop management pilot programme for sweetpotato in Java, Indonesia is described in Braun et al. (1995) and van de Fliert (in prep.). Although the socio-economic and agroecological conditions for sweetpotato production are very different from those in Eastern Africa, the basic participatory approach of this programme can be used.

8.5.2 Organisational aspects

A NARS/IARC-backstopped national researcher based in the pilot area could do the day-to-day management concerning the farmer participatory research, and work closely together with the extension service (e.g. the Subject Matter Specialist root crops) and farm community leaders. NGO's working in the pilot area should be kept informed of the activities and should be given the opportunity to join in the project in case they are interested.

A IARC's role (CIP, 1995) is, among others, making appropriate information available through its cooperative linkages, encouraging the pursuit of necessary research in other institutions and initiating specialized research in the Center's areas of comparative advantage. Assisting NARS in writing appropriate research proposals for funding is a major task. The approach also involves conducting appropriate research in cooperation with NARS colleagues (CIP, 1995). Within Eastern Africa, where NARS research on sweetpotato has started only recently, the IARC could play a leading role in collaborative site-specific research, by training inexperienced research partners on-the-job and by catalyzing and fostering collaboration between different partners.

In the end, the responsibility for the diffusion of IPM technology does not lay directly with NARS or IARCs, but with extension officers, NGO staff and farmers. Researchers are involved in three activities related to diffusion of technology (Cisneros et al, 1995):

1. training of personnel who will act as farmer trainers;
2. producing IPM extension material;
3. acting as consultants.

8.5.3 Pest problem assessment

An evaluation of the perceived impact of sweetpotato pests, an assessment of farmers' knowledge of pests (and natural enemies), and an inventory of current crop and pest management practices is necessary in order to device appropriate control strategies. This can be obtained through Participatory Rural Appraisal (PRA) methods (Chambers, 1993; Nabasa et al., 1995), formal questionnaires and year-long record keeping in farmers' fields. Sweetpotato production constraints should be compared and related to constraints in other crops and to the general economic and social situation in the area, so as to arrive at a realistic interpretation of problems and possible solutions and opportunities.

8.5.4 Development of management components

We assume that during the pest problem assessment phase, farmers have expressed an interest in and need for management of sweetpotato weevils. Two sweetpotato weevil management components, cultural control and sex pheromonal control, are "on-the-shelf" technologies, which could be tried out through farmer participatory research. In the target villages, farmer-experimenters, should be selected from and appointed by the farmers involved in the pest problem assessment. They should be trained on the biology and behaviour of the insect pests, the ecological basis for pest outbreaks and the rationale for the control measures to be tested. According to Bentley and Andrews (1991) increasing the knowledge base of farmers makes them better experimenters and inventors, who learn and generate their own technology.

Besides IPM components, research on other aspects of sweetpotato production and post-harvest could be undertaken in partnership with researchers from other disciplines, depending on the constraints experienced by farmers. Testing of new varieties, methods for storing fresh roots and the production of sweetpotato flour could be possibilities.

According to Malena (1994), women farmers are the principal agents of pest management on food crops in Africa. Women's busy daily and seasonal time schedules make it difficult for them to adopt labour-intensive and time-consuming IPM technologies. However, until present no "farmer-friendly" management technologies for sweetpotato weevils are available, such as resistant varieties and classical biological control agents, which do not require major adaptations by the farmers. A cultural control practice that might play a key role in good weevil management, such as good field-sanitation, would require extra labour. Farmers in Soroti District commented that the yield of some sweetpotato varieties had improved since the disappearance of cassava (Hall, in prep. b). A possible explanation could be that sweetpotato is grown on more fertile lands (Hall, in prep. b), but it could also indicate that farmers have improved their agronomic practices since the importance of the crop increased. This might indicate that further improvements in cultural practices are feasible, when the benefits to the farmers are clear.

Research results with *C. formicarius* to date indicate that continuous trapping of males with the sex pheromone reduces weevil populations, but whether this results in diminished root infestation has not been sufficiently verified. Preliminary mass trapping experiments with the *C. puncticollis* and *C. brunneus* pheromones indicate little effect on actual root damage. However, combining this method with cultural control practices may prove to be effective. Moreover the traps have demonstrated to generate farmer's interest and enthusiasm as they learn about insect behaviour. The price and availability of sex pheromone lures might be constraints for wider adoption by farmers. Currently, lures are provided via the programme and unless large numbers of farmers were willing and able to buy the pheromone, the possibilities for commercialization of this product are limited. Continuous mass trapping of male weevils might be most useful during the dry season, when sweetpotato plots are restricted to small, moist areas in swamps or under trees. An advantage is that few traps are needed because of the small sizes of the plots. Moreover, in this way it can be achieved that planting material derived from these plots will be more or less free of weevil life stages.

Research on other weevil management components, which are still at the exploratory stage, should continue on research stations (see chapter 7).

8.5.5 Evaluation

When asked what measures they use to control sweetpotato weevils, most farmers will only mention early harvesting, so as to get the crop out of the soil before too many roots show weevil damage. Early harvesting also has disadvantages: 1. the actual crop yield is lower due to a shorter growing season, 2. everybody harvests early resulting in a glut of produce, for which there is not enough use or market, 3. later in the year there is food shortage. If the harvest of the crop, thanks to the "new" pest management practices, could be delayed with a few weeks, than this could be perceived by the farmers as a major advantage. The ultimate date of harvest of sweetpotato plots would be a criterion to evaluate the success of the weevil management. It will be necessary to establish during the pilot programme which levels of weevil damage are still acceptable to farmers. Farmers might still have other criteria, that we are presently unaware of. The PRA exercises will hopefully shed light on this.

8.5.6 Technology Transfer

The concept of IPM farmer field schools was developed for rice in Indonesia, and proved very effective for a group of relatively resource-rich farmers. Farmers participated in a tailored curriculum to prepare them in IPM techniques during a season-long field school, which they attended weekly for half a day. The objective of the field schools was to build farmer capacity to collect, analyze, and interpret information, make decisions based on the analysis, and evaluate the results; by doing so they would be better able to make future decisions (Kenmore, 1991). In Uganda such an approach does not seem appropriate for a single commodity, as farmers in most areas rely on a range of food crops for their subsistence. In the future the idea of farmer field schools might be feasible on ICM of all important crops within a target region.

8.5.7 Restrictions to the IPM approach

IARC's and NARS' programmes are commodity orientated, and may have a disciplinary orientation, like weevil management. The organisations dealing with farmers may have different interests: all aspects of farmers' crops or even the whole farming system. Out of the Participatory Rural Appraisal exercise it may become clear that farmers' major concern in Soroti District is to obtain planting material of ACMVD-resistant cassava varieties or an ox for land preparation. Our experience has shown that farmers and extension staff are so accustomed to sweetpotato weevil damage, that they can't imagine that something could be done to reduce it. After explaining possibilities for weevil control and the possible impact it might have, they get enthusiastic about the ideas. ACMVD and the disappearance of their draught animals due to civil unrest and theft are rather new problems, which come first to mind. It will be important to stay well informed about other IPM or farming systems projects in the region, in order to build on their experiences. Linking IPM for sweetpotato with other development efforts on the crop, such as testing of new germplasm, storage of fresh roots and product development, may prove to be very beneficial. An increase in the market and quality demand for sweetpotato through for instance product development, would make management of sweetpotato weevils more important for farmers.

The personnel of NARS and extension services are often only trained in the Transfer of Technology concept. Researchers sometimes express the misconception that subsistence farmers are slaves of inherited practices and hesitant innovators. Interest in and respect for indigenous technical knowledge is often limited. IARCs could assist in modifying this attitude by providing training and arrange visits to other countries with successful IPM programmes based on participatory methods. NGO and extension staff with experience in farmer participatory research are scarce. Specific training of these people who will be in close contact with the farmers will be necessary.

In Figure 8.1 socio-economic studies are mentioned in three out of five phases of IPM development. Although the scheme is not followed strictly, socio-economic research stays crucial. It is doubtful whether sufficient socio-economic support can be provided by IARCs or NARS. Not enough people are available or concentrate their efforts in other agro-ecological zones. However, through self-study, biological scientists can familiarize themselves with the new concepts and methodologies in IPM development and implementation and accomplish a great part of the socio-economic work, although cross-checking with socio-economists should always take place.

Commodity and disciplinary-orientated researchers from IARCs and NARS have to safeguard themselves from trying to promote their commodity and specialisation, instead of concentrating on farmer's needs. When farmers have no genuine interest in their topic, they should not be forced into activities for which they have limited time or interest.

8.5.8 Factors which increase the probability of success of the approach

Uganda is the only country in the region with a strong, multidisciplinary sweetpotato research team. In Kenya and Tanzania no NARS researchers are involved full time with sweetpotato, but rather divide their research time over a number of crops. Rwanda and to a lesser extend Burundi used to have a strong sweetpotato programme, but this has disintegrated. The commitment of the Ugandan national research programme to the crop sweetpotato indicates that it is the right country to start a pilot project.

The regional network of sweetpotato research programmes is based in Uganda. CIP is involved worldwide with six networks consisting of NARS potato and/or sweetpotato research programmes. The network model is based on sharing responsibilities among countries within a geographical area to economize on the costs of certain priority research tasks and on facilitating transfer of technology (CIP, 1995). In Africa the PRAPACE network (Programme Regional de l'Amelioration de la Culture de la Pomme de Terre et de la Patate Douce en Afrique Centrale et de l'Est) consists of Burundi, Eritrea, Ethiopia, Kenya, Rwanda, Uganda and Zaire. The national programmes have divided research tasks and Uganda has the mandate for IPM research. This implies that if positive results are obtained in the pilot area, it will be relatively easy to transfer ideas and experiences to other areas within the network region, where management of sweetpotato weevil might be a priority for farmers.

Representatives of some NGOs and research organisations are setting up networks on PRA and IPM in Uganda. This will facilitate the selection of suitable collaborators, exchange of experiences etc.

We can not expect quick results from the development of an IPM programme for the subsistence crop sweetpotato, but the present holistic approach with involvement of farmers holds promise to improve their living conditions.

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Summary

Sweetpotato is an important crop in Eastern Africa. Sweetpotato weevils (*Cylas puncticollis* Boheman and *C. brunneus* Fabricius; Coleoptera: Apionidae) cause damage to roots and vines throughout the crop's production area. Other insect pests of sweetpotato are of regional importance. The aim of the research project was to gain insight in the biology and ecology of sweetpotato weevils and, based on this insight, develop pest management programmes on sweetpotato in Eastern Africa.

In **Chapter 1**, the role of sweetpotato in the food systems in Eastern Africa is described. The importance of sweetpotato and the way it is produced can be summarized as follows:
1. Sweetpotato is mostly grown as a subsistence crop by resource-poor farmers, who cannot afford inputs, such as fertilizer and pesticides.
2. Production occurs on small plots, rarely more than 0.5 ha in size.
3. In some regions sweetpotato is grown for food security, while in others it is one of several staple foods.
4. Sweetpotato is grown under diverse agro-ecological conditions, ranging from semi-arid to high altitude temperate climates.
5. There is almost no storage of fresh sweetpotato roots; farmers practice "in-ground" storage and piecemeal harvesting. As a consequence, in many regions sweetpotato crops can be found in the field throughout the year.
6. Among biotic production constraints, insect pests are considered to be most serious.
7. Sweetpotato weevils (*Cylas* spp.) are the most widespread and damaging insect pest, but they are not everywhere a key pest. Farmers in areas with long dry seasons consider the weevils a major constraint.
8. Because roots are primarily destined for home consumption, quality demands are low and high pest levels are tolerated. Until recently, most research on IPM for sweetpotato took place in the USA and Taiwan. In these countries sweetpotato is produced for the market and modern inputs are used. Therefore, a research programme was developed taking into consideration the specific conditions in Eastern Africa.

The sweetpotato weevil species *C. puncticollis* and *C. brunneus* are unique to Africa. *C. formicarius* is the pest species in the USA, Asia and some Caribbean Islands. There are only two records of the occurrence of *C. formicarius* in continental Africa: Msabaha in coastal Kenya, and Natal Province in South

Africa. In Kenya and Uganda *C. puncticollis* and *C. brunneus* are of equal importance.

Virtually all available information on the biology of *Cylas* weevils relates to *C. formicarius*. Therefore, the biology of the African *Cylas* species was studied under laboratory conditions **(Chapter 2)**. *C. puncticollis* females live longer, develop faster, and have a lower oviposition rate than *C. brunneus* females. The total egg production per female, sex ratio and proportion of eggs surviving to adulthood were similar for both species. During periods of favourable conditions for sweetpotato weevils, such as dry spells which expose roots for egg laying, *C. brunneus* populations will grow faster than *C. puncticollis* because of its higher oviposition rate. *C. puncticollis* seems to be a better competitor during less favourable conditions due to its longer longevity. Females can survive extended periods when no oviposition sites are available and then resume egg laying when conditions improve.

In **Chapter 3** a review is given on the biology (additional aspects), behaviour, dispersal, and mode of infestation of the sweetpotato weevils and the damage caused. Allmost all published studies deal with *C. formicarius*. This information is supplemented with results of own observations and experiments on the African *Cylas* species. In the last part of the chapter, pest management considerations based on knowledge of sweetpotato weevil ecology, biology and behaviour are presented. For example, laboratory experiments revealed that weevils cannot dig down through soil. Under field conditions females will reach roots for oviposition through soil cracks or when roots are exposed above soil. Three management options could be considered: a. to plant deep-rooting varieties. b. to cover exposed roots with soil and to fill soil cracks. c. to adjust planting and harvesting dates, so that roots are not present in the dry season, when soil cracks are common.

The next part of the thesis deals with the development of appropriate management components. A first step was to make an inventory of traditional agricultural practices and control strategies. A survey, described in **Chapter 4**, was undertaken in South Nyanza District in Kenya, to document farmers' cultural practices and to learn why they were used. Common farmers' practices, which are expected to have a positive influence on pest control, were selection of healthy planting material, crop rotation and earthening up of mounds during weeding and "piecemeal" harvesting. Farmers' practices, which are expected to have a negative influence on pest control, were poor crop sanitation and adjacent planting of successive crops. Farmers were not familiar with the life cycle of the insects and their means of dispersal and infestation. By gaining knowledge on the biology and behaviour of insects, farmers will be able to understand the effects of their agronomic practices.

Traditionally, in most agro-ecologies in Uganda, farmers growing sweetpotato practise in-ground storage combined with piecemeal harvesting. In **Chapter 5** the effect of this indigenous cultural practice on yield and quality loss by sweetpotato weevils is described. Several times during the growing period, between three and seven to twelve months after planting, large roots are removed from individual plants and small roots are allowed to remain in the ground to grow. The overall aim of the practice is to maintain a supply of roots in the ground for the longest possible period. In a series of four trials, once-over harvests at different intervals after planting and a simulated piecemeal harvesting treatment are compared for yield and quality loss caused by sweetpotato weevils. For the once-over harvests, the percentage of damaged roots increased linearly with time, losses ranging between 3% when harvested 3½ months after planting (MAP) to 73% at 9½ MAP. The total yield and undamaged yield for the piecemeal harvesting treatments, which lasted until 9-9½ MAP, were comparable to the yields at the optimum harvest times for once-over harvesting at 6 to 7½ MAP. In-ground storage combined with piecemeal harvesting is a traditional cultural practice that should not be replaced by prompt harvesting from the point of view of weevil control. It is a sensible practice for small-scale farmers because it guarantees a continuous supply of fresh roots with a low percentage of weevil-damaged roots.

In **Chapter 6** research on sex pheromones of *C. puncticollis* and *C. brunneus* is described. In 1994 the female-produced sex pheromones of the two African *Cylas* species were identified. In field tests, the synthetic pheromone lures proved to be highly attractive to conspecific males, but the synthetic lures for *C. brunneus* also attracted significant numbers of *C. puncticollis*. Work aimed at developing a practical trapping system for *C. puncticollis* and *C. brunneus* in Uganda is described. Various designs of funnel, water and sticky traps were compared. A 5-liter plastic jerry can trap was the most appropriate design for effectiveness and practicality. A solution of detergent in water was found to be the most effective trapping agent. Fewer weevils were caught in red traps than in yellow, white, green or blue traps. Catches of *C. puncticollis* increased when the trap was raised above crop height, but catches of *C. brunneus* were unaffected. When marked weevils were dropped onto the trap, 36% of *C. puncticollis* and 23% of *C. brunneus* were captured, and, of weevils placed in the trap, 88% and 92%, respectively, of the two species remained overnight. Lures for the two species showed no significant loss in attractiveness after eight weeks in the field. Chemical analysis showed 19% of the *C. puncticollis* pheromone and 72% of the *C. brunneus* pheromone remaining after this time.

In **Chapter 7** an overview is given of all potential management components for sweetpotato weevil: cultural control, host plant resistance, biological control, sex pheromones and chemical control. Comparisons to management of *C. formicarius* are made, the state of affairs is described and the potential of the different management components is evaluated critically.

Integrating different **cultural control** practices has specific potential for managing *Cylas* weevils, taken into account that the insects have a limited flight activity, a restricted host range and a characteristic mode of entry into the plant. A list of potential practices, their mode of action and their potential for use in Eastern Africa, are presented. The following should be taken into consideration, when selecting cultural practices for testing with farmers: a. in general suitable cultural control practices are site-specific and depend on the agro-ecological and socio-economic conditions; b. some practices would require more labour from farm families, which might be a constraint; c. in densely populated areas some practices might require community effort; d. training farmers on the biology and behaviour of weevils is essential to give them insight into the rationale behind cultural control practices.

Use of the **sex pheromone** of *C. formicarius* in pest management has been investigated for the last ten years. The sex pheromone has proven to be a good monitoring and training tool. In some countries, mass trapping of males with pheromone traps is considered an essential component of the IPM approach to *C. formicarius*. Research on sex pheromones for the African *Cylas* species is at an early stage. Experiments to determine whether pheromone traps for *C. puncticollis* and *C. brunneus* can be used to reduce weevil populations and subsequent root infestation are ongoing. Restrictions to the approach could be: the availability and price of pheromone lures, the low percentage of males that is caught per night, and the fact that few males might be able to fertilize most females. All aspects are under research presently.

In spite of the considerable effort made to identify sweetpotato **host plant resistance** to *C. formicarius*, no germplasm immune to the insect has been identified. Research suggests that sweetpotato clones differ in their level of resistance, but these levels are low and do not stand up under high weevil pressure.

Similar results were obtained when germplasm was tested against *C. puncticollis* and *C. brunneus* in Africa. The biotechnological approach is presently explored to develop transgenic sweetpotato with proteinase inhibitors, resistant to *Cylas* spp. Some varieties are less susceptible to weevil damage than others based on pseudo-resistance: Short-season varieties can be harvested early before the weevil population has built up. Deep-rooted varieties escape weevil damage because their roots are less accessible for females to lay eggs in.

Biological control of *Cylas* species seems to have limited potential. Few parasitic wasps have been reported to attack *Cylas* species and none sufficiently suppresses host populations, probably due to the weevil's cryptic behaviour. Two predatory ants species are used as biological control agents for *C. formicarius* in Cuba. Preliminary studies have been started on predators of the African *Cylas* species. *Beauveria bassiana* is the predominant fungal pathogen infecting *Cylas* species. Field experiments have been conducted in Eastern Africa applying the most pathogenic indigenous strains to the soil. However, control was not successful, probably due to lack of appropriate environmental conditions. Field research on entomopathogenic nematodes of *C. formicarius* was conducted in the USA, but results were inconsistent. Commercially available formulations of the bacterium *Bacillus thuringiengis* (Bt) showed no effect on adult and larval mortality of *Cylas* species.

The role for **chemical control** of *Cylas* weevils in Eastern Africa is very limited. Weevil control after planting is difficult with conventional spraying, as only above-soil adults are killed, and repeated applications would be necessary to kill newly-emerged adults. Systemic insecticides have been used successfully as a dip to control weevils in planting material. However these chemicals are highly toxic and too expensive for subsistence farmers and small-scale commercial farmers.

In conclusion cultural control is presently the most sustainable and promising IPM component for *Cylas* species in Eastern Africa.

In the concluding chapter (**Chapter 8**) the relevance of the findings are being discussed in the light of the socio-economic and agroecological conditions, under which the sweetpotato crop is grown in Eastern Africa. The chapter starts with an explanation of the IPM concept and its relevance to resource poor farmers in sub-Saharan Africa. Strategies for developing and implementing IPM are compared. A "farmer-participatory-research" approach seems to be the most appropriate strategy. Criteria conditional for the success of a sweetpotato IPM programme in Eastern Africa are: 1. sweetpotato should be a basic staple food and/or major cash crop; and 2. *Cylas* attack is important, which can be expected with low rainfall and a long dry season. Such conditions exist in the proposed pilot area in Uganda. In this area sweetpotato production recently became more important and intensive, because the supply of other staple and/or cash crops declined, and demand for sweetpotato increased. For this pilot area organisational aspects are discussed, pest problem assessed and management components developed. We can not expect quick results in developing an IPM programme for the subsistence crop sweetpotato. A holistic approach is necessary involving research, extension and the farming community and considering the whole cropping and farming system.

Samenvatting

Bataat (zoete aardappel) is een belangrijk gewas in oostelijk Afrika. Snuitkevers (*Cylas puncticollis* Boheman en *C. brunneus* Fabricius; Coleoptera: Apionidae) beschadigen wortels en ranken van het gewas in het gehele produktiegebied. Andere insectenplagen van bataat zijn slechts van regionaal belang. Het doel van het onderzoeksprojekt was om inzicht te verwerven in de biologie en ecologie van batatensnuitkevers en, gebaseerd op dit inzicht, geïntegreerde plaagbestrijdingsprogrammas voor deze plaag in oostelijk Afrika te ontwikkelen.

In **Hoofdstuk 1** wordt de rol van de bataat in het voedselsysteem in oostelijk Afrika beschreven. Het belang van het gewas en van de teelt laat zich als volgt omschrijven:

1. Bataat wordt vooral verbouwd voor zelfvoorziening door kleine boeren die zich geen kunstmest of bestrijdingsmiddelen kunnen veroorloven.
2. De teelt vindt plaats op kleine percelen die zelden meer dan een halve hectare groot zijn.
3. In sommige regio's wordt bataat verbouwd als buffergewas in tijden van schaarste; in andere gebieden is het één van de basisvoedselgewassen.
4. Het gewas wordt verbouwd onder verschillende agro-ecologische omstandigheden, uiteenlopend van semi-aride tot gematigde klimaten op grotere hoogten.
5. Zoete aardappelen worden vrijwel nooit in opslag bewaard. In plaats daarvan laten de boeren de wortels gewoon in de grond. Ze oogsten de wortels beetje bij beetje al naar gelang de behoefte. Daarom wordt in vele regio's het gewas gedurende het hele jaar door in het veld aangetroffen.
6. Insectenplagen worden over het algemeen beschouwd als het belangrijkste probleem voor de teelt van bataat.
7. Batatensnuitkever (*Cylas* spp.) is de meest wijdverspreide en de meest schadelijke insectenplaag, maar is niet overal even belangrijk. Het zijn vooral de boeren in gebieden met lange droge seizoenen die snuitkevers als een heel belangrijk probleem beschouwen.
8. Omdat de aardappelen vooral zijn bedoeld voor eigen consumptie, zijn de kwaliteitsnormen laag en worden hoge plaagdichtheden getolereerd. Tot voor kort vond in Afrika nauwelijks onderzoek naar bestrijding van de batatensnuitkevers plaats. Wel werd veel onderzoek naar geïntegreerde bestrijding van bataat uitgevoerd in de Verenigde Staten en Taiwan. In deze landen wordt dit gewas commercieel geteeld en worden moderne teelttechnieken gebruikt. Het in dit

proefschrift beschreven onderzoek werd speciaal ontwikkelt voor de specifieke omstandigheden in oostelijk Afrika.

De snuitkeversoorten van bataat, *C. puncticollis* en *C. brunneus,* komen uitsluitend in Afrika voor. *C. formicarius* is de soort die aangetroffen wordt in de VS, Azië en op enkele Caribische eilanden. Er zijn slechts twee meldingen van *C. formicarius* in continentaal Afrika: Msabaha aan de Keniaanse kust, en de provincie Natal in Zuid Afrika. In Kenia en Oeganda blijken *C. puncticollis* en *C. brunneus* evenveel voor te komen.

Bijna alle beschikbare informatie over de biologie van *Cylas* betreft *C. formicarius.* Daarom werd voor dit project eerst de biologie van de Afrikaanse *Cylas* soorten bestudeerd in het laboratorium **(Hoofdstuk 2)**. *C. puncticollis* vrouwtjes leven langer, ontwikkelen zich sneller, en hebben een lagere ovipositiesnelheid dan *C. brunneus* vrouwtjes. De totale ei-produktie per vrouwtje, de verhouding tussen het aantal mannelijke en vrouwelijke nakomelingen, en het gedeelte van de eieren dat zich ontwikkelt tot adult zijn voor beide soorten vergelijkbaar. *C. brunneus* heeft echter een hogere ovipositie-snelheid en bij korte droogteperiodes, waarbij wortels blootgesteld worden aan ovipositie door de kever, zal de populatie van *C. brunneus* zich sneller ontwikkelen dan die van *C. puncticollis*. Maar onder minder gunstige omstandigheden zal de populatie van *C. puncticollis* zich beter ontwikkelen dan die van *C. brunneus* omdat ze gedurende langere periodes kunnen overleven als er geen ovipositiemogelijkheden zijn.

In **Hoofdstuk 3** wordt een overzicht gegeven van verschillende aspecten van de snuitkevers: de biologie, het gedrag, de verspreiding, de manier waarop ze de aardappelen aantasten, en van de veroorzaakte schade. Vrijwel alle eerder gepubliceerde gegevens betreffen weer *C. formicarius*. Die informatie wordt aangevuld met resultaten verkregen uit eigen waarnemingen en experimenten gedaan met de Afrikaanse *Cylas* soorten. Het hoofdstuk eindigt met een aantal overwegingen voor een manier van bestrijding die gebaseerd is op kennis van ecologie, biologie en gedrag van de batatensnuitkever. Een voorbeeld: laboratorium experimenten gaven aan dat de snuitkevers niet in staat zijn de wortels te bereiken door naar beneden te graven. De vrouwtjes kunnen de wortels dus alleen bereiken via scheuren in de grond en wanneer de wortels boven de grond uitsteken. Drie mogelijkheden voor bestrijding kunnen nu worden overwogen: 1. het planten van diep-wortelende variëteiten. 2. het bedekken met aarde van blootgestelde wortels en het dichten van scheuren in de grond. 3. het aanpassen van plant- en oogsttijden, zodat gedurende de droge tijd wanneer er veel scheuren in de grond voorkomen, er geen wortels zijn.

In het volgende gedeelte van het proefschrift wordt de ontwikkeling van geschikte bestrijdingsmethoden behandeld. Traditionele teeltmethoden van bataat en van bestrijding van plagen staan beschreven in **Hoofdstuk 4**. In het South Nyanza District in Kenia werd een enquête gehouden om de teeltmaatregelen van de boeren te beschrijven en er achter te komen waarom deze teeltmaatregelen werden gebruikt. Teeltmaatregelen waarvan verwacht mag worden dat die een positieve invloed hebben op de plaagbestrijding, zijn: de selectie van schoon plantmateriaal, gewasrotatie en het extra aanaarden van de plantheuveltjes tijdens het wieden en stapsgewijs oogsten. Teeltmaatregelen waarvan verwacht mag worden dat die een negatieve invloed hebben op de *Cylas* bestrijding, zijn: geen gewashygiëne, het niet saneren van oude percelen, en het planten van bataat in aangrenzende percelen. De boeren bleken niet op de hoogte te zijn van de levenscyclus van de insecten, hun manier van verspreiden en de wijze van aantasting. Voorlichting over de biologie en het gedrag van de snuitkever kan hen de noodzaak doen inzien van sanitaire maatregelen en het vermijden van het planten van bataat in aangrenzende percelen.

In de meeste agro-ecologische zones in Oeganda gebruiken boeren een traditionele methode die "opslag-in-de-grond" combineert met "stapsgewijs oogsten". In **Hoofdstuk 5** wordt het effect van deze inheemse teeltmaatregel op de opbrengst en kwaliteitsderving door batatensnuitkevers beschreven. Verschillende keren gedurende het groeiseizoen, drie tot zeven à twaalf maanden na het planten, worden grote wortels verwijderd van individuele planten en kleine wortels krijgen de kans verder te groeien. Het voornaamste doel van deze behandeling is om een voorraad wortels in de grond te hebben voor een zo lang mogelijke periode. In een serie van vier experimenten worden eenmalige oogsten op verschillende intervallen na het planten met "stapsgewijs" oogsten vergeleken. Voor het eenmalige oogsten steeg het percentage beschadigde wortels lineair met de tijd; de verliezen varieerden van 3% bij een oogst 3½ maand na het planten tot 73% 9½ maand na het planten. De totale en onbeschadigde opbrengst voor de "stapsgewijs" geoogste behandelingen, die duurden tot 9 à 9½ maand na het planten, was vergelijkbaar met de opbrengst op de gunstigste tijdstippen voor het in één keer oogsten, nl. 6 tot 7½ maanden na het planten. "Opslag-in-de-grond" gecombineerd met "stapsgewijs" oogsten is een traditionele teeltmaatregel die niet hoeft te worden vervangen door vlot, eenmalig oogsten vanuit het standpunt van snuitkeverbestrijding. Het is een uitstekende teeltmaatregel voor kleine boeren, omdat het een continue voorraad aan verse wortels garandeert met een laag percentage beschadiging door snuitkevers.

In **Hoofdstuk 6** wordt het onderzoek aan sex-feromonen van *C. puncticollis* en *C. brunneus* beschreven. In 1994 werden de door de vrouwtjes geproduceerde sex feromonen van de twee Afrikaanse *Cylas* soorten geïdentificeerd. De synthetische sexlokstof van *C. puncticollis* bleek in veldproeven hoogst attractief voor mannetjes van dezelfde soort. De synthetische sexlokstof voor *C. brunneus* was niet alleen attractief voor de mannetjes van de eigen soort, maar trok ook flinke aantallen *C. puncticollis* aan. In dit hoofdstuk wordt werk beschreven dat tot doel had een praktisch vangsysteem voor *C. puncticollis* en *C. brunneus* in Oeganda te ontwikkelen. Verschillende ontwerpen van trechter-, water- en plakvallen werden vergeleken. Een val gemaakt van een 5-liter plastic jerrycan was het meest doeltreffend en praktisch. Een oplossing van zeeppoeder in water bleek het meest effectieve vangmiddel. In rode vallen werden minder kevers gevangen dan in gele, witte, groene of blauwe vallen. De vangst van *C. puncticollis* nam toe wanneer de val zich op 15-30 cm boven het gewas bevond. Op de vangst van *C. brunneus* had de hoogte van de val geen effect. Van gemerkte kevers die boven op een val werden geplaatst, bleek slechts 36% van *C. puncticollis* en 23% van *C. brunneus* in de val terecht te komen. Van de gemerkte kevers die rechtstreeks in de zeepoplossing binnen in de val waren geplaatst, werden de volgende dag 88% en 92% respectievelijk in de val teruggevonden. Het synthetische feromoon van de twee soorten vertoonde geen significante afname in aantrekkingskracht na acht weken in het veld. De chemische analyse liet echter zien dat na deze periode nog slechts 19% van het *C. puncticollis* pheromoon en 72% van het *C. brunneus* pheromoon aanwezig was.

In **Hoofdstuk 7** wordt een overzicht gegeven van alle potentiële methoden ter bestrijding van de batatensnuitkever: teeltmaatregelen, waardplantresistentie, biologische bestrijding, bestrijding met sexferomoon en chemische bestrijding. De methoden van bestrijding worden vergeleken met die van *C. formicarius*. De huidige stand van zaken wordt beschreven en potentiële mogelijkheden van de verschillende bestrijdingsmethoden worden kritisch geëvalueerd.

Verschillende **teeltmaatregelen** ter bestrijding van *Cylas* snuitkevers kunnen worden gecombineerd: de insecten hebben een geringe vliegcapaciteit, hun waardplantenassortiment is beperkt, en hun aantasting van de plant is heel karakteristiek. De verschillende teeltmaatregelen worden beschreven, alsmede de manier waarop ze werken en wat de vooruitzichten zijn om deze maatregelen in oostelijk Afrika toe te passen. De volgende punten zijn hierbij van belang als men deze methoden bij boeren wil uittesten: a. bepaalde teeltmaatregelen zijn slechts lokaal toepasbaar want ze zijn afhankelijk van de agro-ecologische en socio-economische omstandigheden; b. sommige teeltmaatregelen vereisen meer arbeid van boerenfamilies, wat een probleem kan zijn; c. bepaalde teeltmaatregelen vereisen een gezamelijke aanpak van de gehele boerengemeenschap met name in dichtbevolkte gebieden; d. voorlichting van boeren over de biologie en het gedrag van snuitkevers is essentieel, zodat inzicht wordt verkregen in de werking van de voorgestelde teeltmaatregelen.

Er is al tien jaar ervaring opgedaan met de bestrijding van *C. formicarius* door gebruik van sexlokstoffen. De sexferomoonvallen bleken een goed instrument te zijn voor zowel het uitvoeren van training als het bemonsteren van het insect. In sommige landen wordt het massaal vangen van mannetjes met feromoonvallen als een essentiele component van de geïntegreerde bestrijding van *C. formicarius* beschouwd. Het onderzoek aan sexferomonen voor de Afrikaanse *Cylas* soorten bevindt zich in een vroeg stadium. Er vinden nu experimenten plaats om vast te stellen of feromoonvallen voor *C. puncticollis* en *C. brunneus* kunnen worden gebruikt om de populaties snuitkevers te reduceren en de wortelschade te beperken. Problemen bij deze aanpak zouden kunnen zijn: de beperkte beschikbaarheid en hoge prijs van de sexlokstof, het lage percentage van de aanwezige mannetjes dat per nacht wordt gevangen, en de mogelijkheid dat een beperkt aantal mannetjes de meeste vrouwtjes bevruchten. Al deze aspecten worden op het moment onderzocht.

Ondanks een niet geringe inzet om resistentie in bataat tegen *C. formicarius* op te sporen, is het niet gelukt om immuniteit tegen dit insect te vinden. Onderzoeksresultaten doen vermoeden dat bataatklonen verschillen in hun niveau van resistentie, maar deze niveaus zijn laag en houden geen stand onder een hoge populatiedruk van snuitkevers. Vergelijkbare resultaten werden bereikt na het testen van genetisch materiaal van bataat tegen *C. puncticollis* en *C. brunneus* in Afrika. Op het moment wordt met een biotechnologische aanpak een transgenetische bataat met proteinase onderdrukkers ontwikkeld. Deze bataat zou resistent zijn tegen *Cylas* snuitkevers. Sommige variëteiten zijn minder vatbaar voor snuitkeverschade dan andere. Dit is gebaseerd op pseudo-resistentie: variëteiten met een kort groeiseizoen kunnen worden geoogst voordat de snuitkeverpopulatie zich heeft opgebouwd. Diep-wortelende variëteiten ontsnappen aan snuitkeverschade omdat de wortels minder toegankelijk zijn voor eileggende vrouwtjes.

Biologische bestrijding van *Cylas* soorten lijkt weinig weinig kans van slagen te hebben. Slechts enkele parasitaire wespen die *Cylas* soorten aantasten worden vermeld en geen daarvan onderdrukt de gastheerpopulaties voldoende. Dit houdt waarschijnlijk verband met het verborgen gedrag van de kevers. Twee mierensoorten worden gebruikt als predatoren in de biologische bestrijding van *C. formicarius* in Cuba. Inleidend onderzoek naar predatoren van de Afrikaanse *Cylas* soorten is gestart in Oeganda. *Beauveria bassiana* is de meest voorkomende pathogene schimmel van *Cylas* soorten. In oostelijk Afrika zijn veldexperimenten uitgevoerd waarbij de grond werd besmet met de meest pathogene inheemse isolaties. Er vond echter geen effektieve bestrijding van snuitkevers plaats, waarschijnlijk omdat de klimaats- en grondomstandigheden niet geschikt waren. In de VS is veldonderzoek naar entomopathogene nematoden van *C. formicarius* uitgevoerd, hetgeen niet-consistente resultaten opleverde. Commercieel beschikbare formuleringen van de bacterie *Bacillus thuringiengis* (Bt) veroorzaakten geen effect op de mortaliteit van *Cylas* larven en kevers.

De rol voor **chemische bestrijding** van *Cylas* soorten in oostelijk Afrika is erg beperkt. Het bestrijden van snuitkevers door spuiten is moeilijk. Alleen de volwassen insecten die zich boven de grond bevinden worden gedood. Er zou dus herhaaldelijk gespoten moet worden om alle adulten, die regelmatig naar boven komen, te doden. Het onderdompelen van plantmateriaal in een systemisch insecticide is effectief voor de bestrijding van snuitkevers. Deze middelen zijn echter erg giftig en te duur voor boeren die bataat verbouwen voor eigen consumptie of kleinschalige markten.

Concluderend kan gezegd worden dat beheersing van de plaag met teeltmaatregelen op het moment de meest veelbelovende component is voor geïntegreerde bestrijding van *Cylas* snuitkevers in oostelijk Afrika.

In het afsluitende **Hoofdstuk 8** wordt het belang van de bevindingen besproken in samenhang met de socio-economische en agro-ecologische omstandigheden waaronder de bataat in oostelijk Afrika wordt geteeld. Eerst wordt het principe van geïntegreerde plaagbestrijding uitgelegd en de betekenis daarvan voor kleine boeren in oostelijk Afrika. Strategieën voor de ontwikkeling en uitvoering van geïntegreerde bestrijding worden vergeleken. Een onderzoeksaanpak met deelname van boeren lijkt de meest geschikte strategie. Voorwaarden voor succes van geïntegreerde bestrijding van plagen in bataat in oostelijk Afrika, zijn: 1. bataat moet een basis voedselgewas en/of een belangrijk handelsgewas zijn; en 2. *Cylas* schade moet omvangrijk zijn hetgeen kan worden verwacht in streken met lage regenval en een lang droog seizoen. Deze voorwaarden komen voor in een gedeelte van Oeganda. De teelt van bataat nam hier recentelijk zowel in oppervlakte als intensiteit erg toe omdat andere voedsel- en handelsgewassen niet meer beschikbaar waren. Voor dit gebied worden aspecten besproken die samenhangen met de organisatie van een geïntegreerd bestrijdingsprogramma voor bataat, alsmede de verschillende mogelijkheden van bestrijding. Snelle resultaten bij de ontwikkeling en toepassing van geïntegreerde bestrijding van plagen kunen niet worden verwacht voor een zelfvoorzieningsgewas als bataat. Een holistische aanpak is nodig, waarbij onderzoek, voorlichting en de boerengemeenschap dient te worden betrokken. Hierbij dient het totale gewassysteem en gehele boerenbedrijf in beschouwing te worden genomen.

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List of publications

Some chapters in this thesis are or will be published (in a slightly different form) as:

Chapter: **Publication:**

2. Smit, N.E.J.M. and A. van Huis. The biology of the African sweetpotato weevil species, *Cylas puncticollis* (Boheman) and *C. brunneus* (Fabricius) (Coleoptera: Apionidaae). Submitted to Insect Science and its Application.

4. Smit, N.E.J.M. and L.O. Matengo, 1995. Farmers' cultural practices and their effects on pest control in sweetpotato in South Nyanza, Kenya. International Journal of Pest Management 41: 2-7.

5. Smit, N.E.J.M., 1997. The effect of the indigenous practices of in-ground storage and piecemeal harvesting of sweetpotato on yield and quality losses caused by sweetpotato weevil in Uganda. Agriculture, Ecosystem and Environment, *in press*.

6. Smit, N.E.J.M., M.C.A. Downham, B. Odongo, D.R. Hall and P.O. Laboke. Development of pheromone traps for control and monitoring of sweetpotato weevils, *Cylas puncticollis* (Bohe.) and *C. brunneus* (F.), in Uganda. Entomologia Experimentalis et Applicata, *in press*.

Additional publications related to the research described in this thesis:

Downham, M.C.A., N.E.J.M. Smit, P.O. Laboke, D.R. Hall and B. Odongo, in preparation. Specificity of response to sex pheromones among the sweetpotato weevils, *Cylas puncticollis* Boh. and *C. brunneus* F. (Coleoptera: Apionidae).

Magenya, O.E.V. and N.E.J.M. Smit, 1994. On-farm screening test for weevil (*Cylas* spp.) resistance among various sweetpotato cultivars in Kenya. In: G.B. Allard, L.G. Skoglund, P. Neuenschwander and R.J. Murphy (eds). Root and Tuber Crop Pest Management in East and Southern Africa. Proceedings of a Regional

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Curriculum Vitae

Nicole Eva Jacoba Maria Smit was born on May 1st 1961 in Koog aan de Zaan, the Netherlands. She graduated from Petrus Canisius College in Alkmaar in 1979. In the same year she started to study Plant Breeding at the Agricultural University, Wageningen. She did her practical training period on millet and sorghum breeding at the Katumani Dryland Farming Research Station in Machakos, Kenya. The degree of "Ingenieur" (comparable to Master of Science) was obtained in early 1986.

From April 1986 to August 1987 she was employed in a project funded by the University of Hawaii in Tonga, South Pacific. The project had as its major objective breeding sweetpotato for resistance to leaf scab disease. From September 1987 to June 1989 this research was extended with work on other root and tuber crops on a local contract for the GTZ Plant Protection Project in Tonga.

In late 1989 she started her contract as associate expert for the Directoraat Generaal Internationale Samenwerking (DGIS) of the Ministry of Foreign Affairs, Netherlands. She was allocated to work for the International Potato Center (CIP) and she was based at the Mbita Point Field Station of the International Centre for Insect Physiology and Ecology (ICIPE) in South Western Kenya. The research topic was Integrated Pest Management (IPM) for sweetpotato. In March 1993 the duty station was shifted to the Namulonge Agricultural and Animal Production Research Institute near Kampala in Central Uganda. The DGIS contract ended in March 1995 after which a study contract followed allowing time to write the thesis.

In June 1996 she joined CIP as a post-doc IPM specialist with responsibilities in Eastern Africa, based at Namulonge, Uganda.