Are millipedes a pest in low-input crop production in north-eastern Uganda?
Farmers' perception and experimentation

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Abstract

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Between 2000 and 2003, various studies were conducted to assess the impact of millipedes as pests in the production of sweet potato and other major crops in north-eastern Uganda. The overall objective of the research was to generate basic knowledge about pest status, biology, ecology, and behaviour of millipedes. A strategy was recommended for integrated production and pest management in sweet potato and other major crops, serving the needs of resource-poor farmers in low-input agricultural systems in north-eastern Uganda and eastern Africa.

These studies included: (i) Field survey on farmers' knowledge on sweet potato production and perception of millipede infestation; (ii) Field assessment of pests in sweet potato and other major crops conducted in the planting seasons of 2000 – 2002; (iii) Feeding activity of the East African millipede *Omopyge sudanica* Kraus, based on no-choice laboratory experiments, and (iv) Comparison of the indigenous cultural practices of piecemeal harvesting and storage roots 'in-ground on plants' with one-time harvesting after crop senescence in trials conducted in the planting seasons of 2002 – 2003. There was inadequate information about millipedes in general and possible control strategies in East Africa. Therefore a literature study was also done to gain more knowledge about this animal.

From the 148 sweet potato (*Ipomoea batatas* (L.) Lam.) growers interviewed information was generated on sweet potato production and its constraints. Farmers considered sweet potato weevils (*Cylas* spp.) the most important pests, followed by rats (*Spalax* spp.) and millipedes. The impact of millipedes was also serious in other major food and cash crops, such as cassava (*Manihot esculenta* Crantz), groundnut (*Arachis hypogaea* L.) and maize (*Zea mays* L.). Separation of plots over time and space is often not practised. Millipede incidences depended on the frequency of millipede hosts in the crop rotation. Groundnut planted after sweet potato showed high levels of millipede attack. Millipede incidence was often associated with the incidence of sweet potato weevils. Measures to control sweet potato pests, like sanitation, were hardly implemented. Chemical insecticides were not used at all.

Field experiments showed that millipedes of the species *O. sudanica* caused damage on planting material of sweet potato and on germinating and podding groundnut early in the first rainy season (March/April). Damage in maize occurred in both rainy seasons. Storage roots of sweet potato were hardly affected by millipedes when harvested 5 months after planting. However, when storage roots were stored 'in-ground on plants' during the prolonged dry season sweet potato weevils facilitated millipede damage.

No-choice feeding activity laboratory experiments showed that *O. sudanica* efficiently utilized the grain crop diets groundnut and maize for its growth. The species also consumed storage roots of sweet potato. The research revealed how difficult it is to obtain reliable, quantitative data on the feeding habits of millipedes.

Piecemeal harvesting used to be done up to final harvest. It is revealed that this practice was only useful during a limited period of time. When piecemeal harvesting continued up to 5 months or more, it could coincide with the onset of the dry season, i.e. when sweet potato weevils invade the above-ground sweet potato plant parts. When the population of weevils is too high piecemeal harvesting can no longer be used as a control measure.

From the results in this thesis some important issues have arisen which can be implemented in a pest control programme of the sweet potato crop. The research activities presented in this thesis have led to recommendations for improving integrated sweet potato production and pest management aimed at the needs of the resource-poor farmers in low-input agricultural systems of East Africa.

Keywords: Crop rotation, farmers' knowledge of millipedes, host crops, integrated crop production and pest management, *Ipomoea batatas*, millipedes, no-choice feeding activity of millipedes, *Omopyge sudanica*, piecemeal harvesting, sweet potato, sweet potato weevils.

Preface

The research described in this thesis was carried out in north-eastern Uganda between 2000 and 2003. Without the support of the farmers, the research assistants in the field, and staff of the Arapai Agricultural College, it would not have been possible having conducted this work. A great many people, in Uganda and elsewhere, encouraged me to fulfil my endeavours. It is impossible to thank them all, but I would like to thank those who played a key role.

Without Dr. Benson Odongo from the Namulonge Agricultural and Animal Research Institute (NAARI) I would probably never had the chance to begin this undertaking. He guided me in setting up the research proposal and he was the person who discussed with me the experiments to be conducted and their loopholes. Thanks for all the hospitality I received from you and your wife during my stays at your residence.

Above all, I am deeply in debt with Prof. Paul C. Struik of the Crop and Weed Ecology Group, who supported, encouraged and supervised me from the very beginning. The door of your office was always open, encouraging me to enter without anxiety. You always took your time. After leaving your office I always had the exited feeling to be able to continue in my efforts to get the articles ready to be published. Your swiftness in going through drafts, even during your journeys to a far away destination, often surprised me, but is so much appreciated. I was very lucky having you as my supervisor.

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The support and help of Dr. C.A.W. Jeekel are never forgotten. He identified some millipede species, which affected the sweet potato, groundnut and maize. I enjoyed the ‘lectures’ and he triggered my interest to have a closer look at the anatomy of the millipede. He explained the complexity of distinguishing female from male millipedes, the tiny differences between species and the difficulty of identifying the larvae. The gained knowledge was very useful to give body to my articles and made it possible to pass it on to some of my research assistants, who never attended school. Dr. Jeekel also taught me a few important home truths. I got the message. I am grateful for that.

I would like to thank Ms Gon van Laar for editing the thesis, the layout and putting the chapters in the same format. I realize you were very busy with your own work, but still you were prepared to help me, as desperate I was in the final stadium of this thesis. Your work is highly appreciated. Please, continue to assist other students, as you play a crucial, and above all, an emotional role in the final steps of many years plodding and ‘sweet and tears’. Personally, I felt an enormous release when you said: “That ‘s it. Ready”. I am so grateful to you!

I would also like to thank my colleagues at Arapai Agricultural College. In the first place all my gratefulness goes to Aisu Jonathan Oumo. He was my main assistant and friend during the work. Especially for being my guide during the so many trips to the farmers and the translation work in the field. I also like to thank Francis Onyilo for assisting me during the interviews with farmers in Lira District. Despite the hardships, we had a wonderful time out there and I learned a lot about the Teso and the Lango. Dr. Morris Oĉweda is acknowledged for reviewing earlier versions of a number of scripts and being the ‘logistic officer’ for organizing the college truck. I also like to thank Morris for the friendship, which even continues to last, in spite of the great distance between us. And from here, I like to tell you, that this friendship is very special for my family. One day we will meet again.

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I am also very thankful to all the extension officers of Soroti, Katakwi, Kumi, Kaberamaido and Lira Districts, the agricultural specialist of SDDP, Dr. Mark Versteeg, the Principal of Arapai Agricultural College and the Directors of SAARI and NAARI.

The farmers of north-eastern Uganda should actually have been mentioned at first, but it must be clear to the reader that they played a crucial rule in the generation of information on sweet potato production and constraints, with emphasis on damage on millipedes. Due to their observation of millipede problems in a number of other main crops, they forced me to focus the research not only on sweet potato, but also on groundnut and maize. Because we were always most welcome at their farms I got a good picture on their way of living and all the hardships they face in their daily life.

Erna, you encouraged me to do my PhD. It was difficult to accept because of all the difficulties you were facing during your own research and all the lonely hours behind your computer. Still, I accepted it to give a trial and it was you who gave me all the support to continue and to follow the long road. Your skills and experience in analysing of research data helped me very much. We sat together many times until midnight seriously discussing and interpreting the results. Your support strongly contributed to the success in having all the articles published.

Marjolein, your father was often in the bush of Africa, but you managed to coop with it. I will not forget all the welcome balloons, which disappeared out of your tiny grip when meeting at arrival at Schiphol Airport.

And last but not least, my parents. When we wandered around the forbidden 'bush' of the Planken Wambuis, my mother welcomed enthusiastically the idea of conducting a PhD research. My (late) father, doubted because of my age, but realizing that Paul C. Struik had already agreed with the research proposal, he supported me to do what I wanted to do. Papa, you gave me the spirit and the means to fulfil my aspirations. A few days before you passed away you were still curious about the results. I know you would have enjoyed being present on the big day. But realizing that the fifth article was accepted by the journal and that the defence was fixed on 16 October, you concluded that it was too far ahead. You decided to undertake your journey to join my sister on her star. I dedicate this thesis to you!

Ernst Ebregt Wageningen, October 2007

Contents

CHAPTER 1

General introduction

The work described in this thesis was conducted in cooperation with the National Agricultural Research Organisation (NARO) of Uganda, Department of International Development (DFID), Arapai Agricultural College of Soroti, Wageningen University, local extension personnel and farmers. It was aimed at assisting the north-eastern Ugandan farmers, collecting information about millipedes and formulating an initial integrated management programme of millipede pests. Specifically, I used a farmer participatory approach during the collection of regional information on sweet potato production and constraints, with emphasis on damage by millipedes. I investigated the pest status of millipedes in sweet potato, groundnut and maize in field experiments. Laboratory experiments were conducted on the feeding activity of millipedes on potential host diets. Lastly, field experiments on the effect of piecemeal and one-time harvesting on the incidence of sweet potato pests were conducted. The work is reported in five research chapters of this thesis.

This introductory chapter describes the agricultural systems in north-eastern Uganda, and the crops sweet potato, cassava, groundnut and maize, with regard to their economic importance, their role in the cropping and food system, ecology and cultivation, and marketing. I also describe the constraints and research challenges on arthropoda pests, with emphasis on millipedes, in these crops and lay out the rationale and objectives of this thesis research.

Throughout this thesis north-eastern Uganda is meant to include Lira, Kaberamaido, Soroti, Katakwi and Kumi Districts.

Agricultural systems in north-eastern Uganda

North Uganda is broadly divided into three ecological zones, mainly based on soils, natural features of the surface, and rainfall distribution. A unimodal rainfall pattern is found above the 3° North latitude and a bimodal pattern south of this latitude. The area between latitude 1° and 3° North is characterized by transitional zones. A mountainous ecological zone is found around the highland areas of Mbale (Mount Elgon) and Kasese (Ruwenzori Mountains) (Musiitwa & Komutunga, 2001).

In this thesis the transitional zone of north-eastern Uganda will be of main interest, as the research carried out in the districts of Lira, Kaberamaido, Soroti, Katakwi and Kumi, was situated in this zone. Wortmann & Eledu (1999) classified this transitional zone into three agro-ecological zones (AEZs). These are the Northern Moist

Farmlands (Lira and Kaberamaido Districts), the Northern Central Farm-Bush Lands (Soroti and Katakwi Districts), and the Southern and Eastern Lake Kyoga Basin (Kumi District).

According to Bakema *et al*. (1994), the bimodal rainfall pattern is characterized by two rainy seasons of which the first season (April-June) has long rainy periods, while the second rainy season (August-November) has unreliable, shorter rains. However, since the last few years the duration of the two seasons has varied randomly. The long rains may be experienced in the first rainy season or in the second season (Musiitwa & Komutunga, 2001).

The farming systems in the three agro-ecological zones are the Lango and the Teso systems (Musiitwa & Komutunga, 2001). In recent years these farming systems in north-eastern Uganda have changed (Bashaasha *et al*., 1995; Musiitwa & Komutunga, 2001). The main factor contributing to these changes was the civil unrest of the 1980s, leading to cattle depletion and decline in cotton marketing systems and production (Bakema *et al*., 1994). The Sigatoka disease and banana weevil (*Cosmopolites sordidus* (Germar); Curculionidae) infestation (Tushemereirwe *et al*., 2001), the reduction of the cassava cultivation due to the African Cassava Mosaic Disease (ACMD) epidemic (Scott *et al*., 1999; Otim-Nape *et al*., 2001), the parasitic witchweed (*Striga* spp.) in sorghum and maize (Bakema *et al*., 1994; Kikafunda-Twine *et al*., 2001), and population pressure (Musiitwa & Komutunga, 2001) were other causes of these changes. Due to these profound changes, the sweet potato has become an important fallback crop in the food system in meeting people’s nutritional requirements and for covering recurrent household expenses (Scott & Ewell, 1992; Bakema *et al*., 1994; Scott *et al*., 1999).

There are seven predominant farming systems in Uganda (Ngategize *et al*., 2001). The Teso farming system is one of them, which is found in the transitional zone. Soroti, Katakwi, Kumi and partly Kaberamaido fall into this system. Until the civil strife the largest cattle population of Uganda was found in Teso (Musiitwa & Komutunga, 2001). Most farmers also kept goats, sheep, turkeys and chicken. Animal traction was common practice for ploughing (Anon., 1994). However, rustling during the insurgency left the farmers virtually without livestock (Anon., 1994; Bakema *et al*., 1994). The soils are light and loamy sands and can easily lose moisture. When precipitation ceases or during dry spells within a growing season, drought becomes severe. In general, rainfall is heavy during April-May and August-September. July is characterized by dry spells, while a severe dry season, with hot dry winds, lasts from December to March (Figure 1) (Musiitwa & Komutunga, 2001).

In the Teso farming system, the major food crop is finger millet (*Eleusine coracana* (L.) Gaertn.). Other important food crops are cassava, cowpea, groundnut, sorghum,

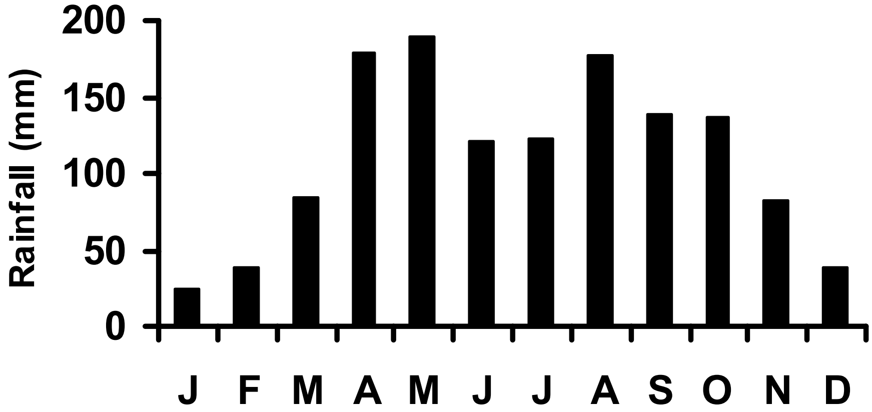

Figure 1. Average monthly rainfall (mm) in Soroti District (Soroti station, wmo no: 63658, 1943-1993) (Bakema *et al.*, 1994).

sesame and sweet potato. Surplus of mostly millet and groundnut is sold (Bakema *et al.*, 1994; Musiitwa & Komutunga, 2001). Maize is becoming increasingly important (Kikafunda-Twine, 2001). Cotton used to be an important cash crop before the 1980s. Crop rotation was practised with cotton as the first crop after bush clearing and opening the land, followed by millet (Musiitwa & Komutunga, 2001). The last crop before fallow was cassava (Anon., 1994). Although the cotton production declined, this crop is still considered the main cash crop (Musiitwa & Komutunga, 2001) and efforts are underway to revive the cotton production (Anon., 1994).

In the Lira District, the common farming system is called the Lango system and it is quite different from the Teso system. In this district the rainy seasons are a bit longer. The farmers are mainly cropsmen, although some cattle are kept. Animals are rarely used for ploughing. Instead, the hand hoe is used to cultivate the arable land. The major food crops are cassava, maize, millet, cowpea, groundnut, pigeon pea and sesame (Musiitwa & Komutunga, 2001).

Due to insurgency and cattle rustling, the Lango farming system has also greatly changed. Non-traditional cash crops, such as groundnut, millet and sweet potato are increasingly grown (Musiitwa & Komutunga, 2001).

Sweet potato

Economic importance

Sweet potato (*Ipomoea batatas* (L.) Lam.) ranks fifth among all staple crops world-wide (Anon., 2005). At present, the sweet potato is a low-input crop in many places in

Sub-Saharan Africa (Ewell & Mutuura, 1994; Bashaasha *et al*., 1995). In the densely populated highlands near Lake Victoria of Uganda, Rwanda, Burundi and adjacent parts of Congo and Tanzania, sweet potato is a major staple food, along with banana, Irish potato and cassava, often in combination with beans (Ewell & Mutuura, 1994). In Kenya, most of Tanzania and Ethiopia maize and other grains are the basic staple, while sweet potato is an important secondary food (Scott & Ewell, 1992). Currently, Uganda is the biggest sweet potato producer in Africa with an annual average of 2.7 million t and an average yield of 4.4 t ha^{-1}. Its yield in the region is below world average (14.8 t ha^{-1}) (Anon., 2005).

In north-eastern Uganda, sweet potato is also the major food staple and an increasingly important cash crop at subsistence level (Scott *et al*., 1999; Abidin, 2004). Both piecemeal and one-time harvesting are commonly practised (Abidin, 2004; Ebregt *et al*., 2004b, 2007b). A study in the Gweri sub-county (Soroti District) revealed, however, that land availability, farmers' pest knowledge, availability of information and labour were the major factors affecting use of improved practices (Okoth *et al*., 2000).

Role in the cropping and the food system

The sweet potato is mostly grown in small plots, < 0.5 ha, by subsistence farmers in low-input agricultural systems (Bashaasha *et al*., 1995; Carey *et al*., 1998, Ebregt *et al*., 2004a; Abidin, 2004; Abidin *et al*., 2005). Women play a major role in cultivating the sweet potato (Bashaasha *et al*., 1995). However, in north-eastern Uganda both genders play an important role (Abidin, 2004).

Sweet potato, is the third most cultivated starch crop after bananas and cassava, and is the widest adaptable crop in most of the Ugandan agro-ecological zones (Bashaasha *et al*., 1995; Mwanga *et al*., 2001b). However, in the northern and eastern regions of Uganda, sweet potato is second to finger millet (Bashaasha *et al*., 1995; Mwanga *et al*., 2001b).

Sweet potato is mainly cultivated as a monocrop (Gibbon & Pain, 1985; Mwanga *et al*., 2001b). In densely populated areas, intercropping is important because of population pressure (Bashaasha *et al*., 1995; Mwanga *et al*., 2001b). In Uganda, the sweet potato crop rotation systems are diverse (Bashaasha *et al*., 1995). In north-eastern Uganda, they vary among the AEZs and even within households. In a generalized rotation system for the area, sweet potato was often followed by finger millet or groundnut. In the Northern Moist Farmlands, maize was also grown after sweet potato. Moreover, sunflower, soya bean, kidney bean or other legumes, sesame and cassava are grown after sweet potato. Occasionally sweet potato was followed by a fallow period (Ebregt *et al*., 2004a).

In the Northern Moist Farmlands, the most common crop preceding sweet potato is cassava. Sorghum, millet, maize, beans, sesame and groundnut are also often cropped before sweet potato. In the Northern Central Farm-Bush Lands, the preceding crops are cassava, groundnut, sorghum, millet and sesame. In the Southern and Eastern Lake Kyoga Basin the preceding crops are cassava, groundnut, millet or sorghum, and sometimes cowpea and green gram (Ebregt *et al*., 2004a).

Sweet potato is cultivated for food security, as it stores well 'in-ground on plant' as a famine reserve crop (Scott & Ewell, 1992; Bashaasha *et al*., 1995; Scott *et al*., 1999; Abidin, 2004). Therefore it is also called the 'protector of the children', which title alludes to the vital role it fulfils during the harsh dry season when people depend on the crop to combat hunger (Anon., 1998).

Sweet potato storage roots are perishable and have a short shelf life. In north-eastern Uganda, therefore most farmers favour fresh consumption of sweet potato. In the dry season, people eat 'amukeke' (dried sliced storage roots) and inginyo (dried crushed storage roots) (Abidin, 2004). In South and West Uganda few farmers slice, dry and store their sweet potato (Bashaasha *et al*., 1995). Recently, sweet potato storage roots are also used to prepare potent gin. Apart from the use of storage roots, at some locations in Teso, farmers eat fresh young leaves of some varieties, such as Osukut/Tanzania, as fresh vegetable (Abidin, 2004).

Sliced and dried sweet potatoes can be stored reasonably well (Bashaasha *et al*., 1995; Abidin, 2004), but they are attacked by storage bruchids (Coleoptera: Bruchidae) and palatability is thereby affected (Bashaasha *et al*., 1995). More recently, farmers in Uganda copied the idea from farmers of the Southern Highlands of Tanzania of storing fresh roots in pits (Smit, 1997).

Besides the fact, that sweet potato has established itself in the food system of the people, income from sales of sweet potato has also helped many farmers in generating cash income and so their efforts to re-stock cattle herds in Teso (Bakema *et al*., 1994).

Ecology and cultural practice

Annual rainfalls of 750–1000 mm are considered suitable, with a minimum of 500 mm in the growing season. At the tuber initiation stage, 50–60 days after planting, the crop is sensitive to drought. Once established, the crop can tolerate dry periods of considerable lengths. It is not tolerant to water-logging (Gibbon and Pain, 1985; Bashaasha *et al*., 1995).

In Uganda, sweet potato is cultivated in all agro-ecological zones from semi-arid lowland to high-altitude zones with near-temperate climates (Bashaasha *et al.,* 1995; Smit, 1997). Farmers can choose relatively infertile soils, plant late after other crops with more strict demands to planting time are safely in the ground, apply no fertilizer or manure, and pay little attention to weeding, hence the crop is managed as a food reserve rather than for high yields (Smit, 1997).

Sweet potato is propagated from vines, hence most farmers raise their own planting material or obtain vines free from neighbours. Farmers also obtain volunteer vines, sprouting from tubers from previous crops (Bashaasha *et al*., 1995; Abidin, 2004, Ebregt *et al*., 2004a). Land near water sources or inland valley bottoms are often prepared for "vine storage" during the long dry season (Smit, 1997; Abidin, 2004; Ebregt *et al*., 2004a). When rains return, planting material will be obtained from these swamp nurseries (Ewell & Mutuura, 1994; Abidin, 2004; Ebregt *et al*., 2004a). When the village is far away from the swamp, nurseries are prepared under shade trees in the homestead area (Abidin, 2004). During extreme weather conditions vines are bought in the market (Abidin, 2004; Ebregt *et al*., 2004a).

The crop is planted on ridges, mounds or in flat ground, depending on traditional habits (Ewell & Mutuura, 1994). In north-eastern Uganda, vines are usually planted on mounds (Abidin, 2004; Ebregt *et al*., 2004a).

Farmers commonly plant different varieties of sweet potato in one plot, based on their preference. This strategy is used for providing a continuous food supply, and balancing out the risk of any failing due to drought, pests and diseases. Other reasons are trying out new varieties, culinary attributes and lack of planting material of preferred varieties (Bashaasha *et al*., 1995; Abidin, 2004).

In north-eastern Uganda, besides one-time harvesting, most farmers practice storage 'in-ground on plants' combined with piecemeal harvesting. This means that 3 months after planting, several times during the growing period, farmers remove 'mature', large storage roots from the plant without uprooting the plant itself (Bashaasha *et al*., 1995; Smit, 1997a, b; Abidin, 2004; Ebregt *et al*., 2004b, 2007b).

Marketing

In north-eastern Uganda, many rural households also utilize sweet potato as an additional source of income, as they do with other products, such as groundnut, maize and cassava. They sell the storage roots at local markets to cover expenses for household necessities and school fees (Scott & Ewell, 1994; Abidin, 2004).

In Kumi District, one of the major sweet potato growing areas of Uganda, some farmers have specialized in commercial production (Scott *et al*., 1999; Mudiope *et al*., 2000; Abidin, 2004; Ebregt *et al*., 2004a). A recent survey in this district indicated the adequacy of farmers' cultural practices. A number of production constraints, however, were hammering the production. Examples are shortage of labour and the lack of sufficient planting material with the onset of the growing season (Mudiope *et al*., 2000; Abidin, 2004). On top of that middlemen offered very low on-farm prices for the storage roots. Hence, the lack of a profitable market can be considered as another major constraint for sweet potato growers in the region. Besides, in relatively remote areas, traders will not risk their trucks on the bad and muddy roads hence farmers had problems selling their produce. The situation in the other districts of north-eastern Uganda is comparable. The greater distance to the big urban markets makes it even more difficult for these farmers to sell their produce (Abidin, 2004).

Cassava

Economic importance

After the sweet potato, cassava is the sixth major staple crop in the world (Anon., 2005). Approximately half of the global production is produced in Sub-Saharan Africa, of which Uganda is one of the big producers (Anon., 2002). In Uganda, cassava is almost exclusively grown for human consumption; it is considered by farmers as the most important staple crop (Otim-Nappe & Zziwa, 1990; Anon., 1996). Cassava ranks second to bananas (matoke) in total production (Anon., 1999).

The districts of Lira, Kaberamaido, Soroti, Katakwi and Kumi used to be the leading producers (Otim-Nape *et al*., 2001). However, starting in 1990, the epidemic of ACMD destroyed the crop or at least severely reduced productivity (Scott *et al*., 1999). In Kumi, for example, the production declined with 38% between 1987–1989 and 1995–1997. As a result, the per capita human consumption also declined (Otim-Nape *et al*., 2001). The International Institute of Tropical Agriculture (IITA) estimated the loss due to ACMD in Uganda up to 2002 at 720,000 t (Anon., 2002). In recent years, in eastern Uganda, there is an increased prevalence of the use of plants of local ACMD-susceptible cultivars infected with a mild strain of the East African cassava mosaic virus (EACMV-Uganda), as these plants yielded significantly more tuberous roots than initially healthy plants (Owor *et al*., 2004).

Role in the cropping and food system

Since cassava can be cultivated in an exhausted soil, it is typically grown last in a crop rotation (Gibbon & Pain, 1985). Therefore in the three agro-ecological zones of north-eastern Uganda, cassava is often grown as a 'resting crop', followed by sweet potato (Ebregt *et al*., 2004a).

In times of famine, cassava is regarded as a reserve crop, because of its ability to do well on marginal soils and stressed environments, and its capacity of storage 'in-ground on plant' for over two years (Jameson, 1970). Besides singly consuming the roots, either roasted or cooked, cassava is also used as an additive to sweet potato flour to make a local bread (atapa), which is eaten with peanut sauce, often cooked with dry leaves of cowpea. The roots are also used to prepare a local potent gin (waragi), which provides an important income for rural women.

Ecology and cultural practice

Cassava can be grown in areas of rainfall of 500-1500 mm. It grows best on sandy or sandy loam soils (Gibbon & Pain, 1985), and these are common in north-eastern Uganda (Wortmann & Eledu, 1999; Aniku, 2001; Ebregt *et al*., 2004a).

The crop has a wide extensive root system. Because of its capacity to use a large area for the uptake of water and nutrients, cassava can be cultivated under marginal conditions and/or on infertile soils. When cassava is planted as the first crop in the rotation, no extensive bush clearing is needed, as long as trees are removed to allow sunlight reaching the crop (Otim-Nape *et al*., 2001).

Cassava is propagated from stem cuttings, the so-called 'stakes'. Good planting material, i.e. free from diseases and pests, will lead to good sprouting ability, hence better yields. Timely planting of the stakes is important to ensure at least 2 months of sufficient soil moisture for proper crop establishment. In north-eastern Uganda, peak planting coincides with the rainfall seasonal patterns, i.e. April-May and August-September (Figure 1). Field observations showed that the entire cutting is commonly buried horizontally at a depth of 10 cm. Weed control during the first 3−4 months is critical (Otim-Nape *et al*., 2001).

Cassava is often intercropped with other crops, such as maize and cowpea. Intercropping with maize/sorghum, maize/millet or maize/okra/cowpea is also done. All these intercroppings have given consistent yield advantage (Otim-Nappe *et al*., 2001).

At approximately 18 months after planting, the starch content is optimal and harvesting can take place (Otim-Nappe *et al*., 2001). As tubers spoil quickly after harvest (Gibbon & Pain, 1985), the roots are often stored 'in-ground on plant' and can be available when other crops are not (Jameson, 1970).

Marketing

By over 71% of the farmers country-wide, cassava is regarded as the most important staple and subsistence crop. Some 19% of the farmers consider cassava as a cash crop (Otim-Nappe *et al*., 2001). It is mainly sold at the local markets, raw or roasted.

Groundnut

Economic importance

In Uganda, starting from 1980, the acreage and production of groundnut increased, both as a food crop and as a cash crop, because of increased awareness of its value as a source of protein and oil (Page *et al*., 2002). Soroti (including the later established Katakwi and Kaberamaido districts), Kumi and Lira are the main groundnut growing districts in north-eastern Uganda (Scott *et al*., 1999; Busolo-Bulafu & Obong, 2001). Despite its importance and the high local demand, yields continue to be low, averaging 0.56 t ha^{-1}. Adopting good management practices and the control of pests and diseases, such as groundnut rosette caused by the groundnut aphid (*Aphis craccivova*), would help to increase production considerably (Page *et al*., 2002).

Role in the cropping and food system

In north-eastern Uganda, farmers plant groundnut seeds at the beginning of the first rains because of the expectation of good rains and to reduce the risk of rosette infection, which increases as the season advances (Busolo-Bulafu & Obong, 2001). Groundnut is known for its capacity of generating residual nitrogen in the soil (Page *et al*., 2002).

A rotation of 3 years or longer is advisable in order to reduce disease, pest and weed incidences. Groundnut should not be grown after cotton. However, cotton can be grown in rotation after groundnut. Other legumes, tobacco and tomato should be avoided in the rotation, as they may cause a build-up of nematodes and soil-borne diseases that also affect groundnut. Maize, sorghum and millet are suitable in rotation with groundnut (Purseglove, 1991; Page *et al*., 2002), and other clean-weeded crops, such as cassava, sunflower and sweet potato (Page *et al*., 2002). In north-eastern Uganda, however, many farmers do not cultivate groundnut after sweet potato, because of the risk of millipede damage. Others do use groundnut as an 'after crop' of sweet potato. (Ebregt *et al*., 2004a).

Groundnut is an important source of protein (23−25% content) and oil (45−52% content). Kernels are roasted and crushed in order to be prepared into peanut butter or a sauce, which is mixed with traditional dishes, such as cowpea, smoked fish, boiled fresh sweet potato and amukeke. In this way it constitutes a valuable protein content of the diet of many Ugandans.

Ecology and cultural practice

Groundnut needs an annual rainfall of 400 mm or more under low evaporative demand. During the growing season a minimum rainfall of 200 mm is required. The spreading type, the Virginia variety, requires more rainfall than the upright sequential branched bunch type, the Spanish-Valencia variety. Dry spells during growth impair the vegetative growth. On top of that, drought hinders the penetration of the peg into the soil if the soil becomes dry and crusted, hence resulting in a low nut production. During ripening, harvesting and drying of the crop, dry conditions are needed.

Groundnut prefers a light sandy soil (Gibbon & Pain, 1985), which is generally the major soil type of the three AEZs of north-eastern Uganda (Bakema *et al*., 1994). Heavy or waterlogged soil will restrict the vegetative development and will reduce peg penetration and pod development (Gibbon & Pain, 1985).

Smooth seed bed preparation is a condition, before the first rains appear, so that sowing can take place with the onset of the first rains. Early planting is also advised, to reduce the risk of groundnut rosette infection, which increases in the course of the growing season. Crop residues of previous crops should be removed or buried (Page *et al*., 2002).

Seeds from the previous crop are normally used for sowing. They will be hand-shelled (Page *et al*., 2002). Therefore little damage is caused to the testa and seed is less prone to fungal infection (Carter, 1973). After shelling, groundnut seed may retain its germinating capacity for 6 months (Busolo-Bulafu & Obong, 2001). They are sown in grooves of 5−6 cm depth (Busolo-Bulafu & Obong, 2001, Page *et al*., 2002). Close spacing also assists in avoiding the groundnut aphid invading the crop and so upholding serious outbreaks of the groundnut rosette virus (Purseglove, 1991; Busolo-Bulafu & Obong, 2001; Page *et al*., 2002).

Marketing

From our observations, it seems that the main objective of growing groundnut is for home consumption. The surplus may be sold in local markets and helps the smallholders to improve their livelyhood (Busolo-Bulafu & Obong, 2001). On top of that, selling and buying of improved seeds by the Soroti District Farmers Association (SODIFA) helped the farmers with a ready market and made them less dependent on middlemen.

Maize

Economic importance

Maize can grow in most parts of Uganda (Kikafunda-Twine *et al*., 2001). During the period 1987–89 and 1995–97 the maize output increased with 70% country-wide. In the eastern region of Uganda, under which Soroti, Katakwi and Kumi reside, the maize output jumped 86%, while over the same period in the northern region, under which Lira falls, this figure was even reaching 150% (Scott *et al*., 1999). Factors contributing to this increase are the improvement of flour processing and an improved road infrastructure in the area. Also the introduction of new hybrids, with a moderate resistance to major pests and diseases, a shorter maturing period and a higher drought resistance, encouraged the farmer to grow maize (Kikafunda-Twine *et al*., 2001).

Role in the cropping and food system

Maize is planted in both seasons where rainfall is bimodal. However, the first rains are favoured for planting. The crop is commonly grown continuously for about 4 years, after which the land is either left under fallow or cassava (Kikafunda-Twine *et al*., 2001).

Maize is generally grown in rotation with other crops (Gibbon & Pain, 1985). In the sweet potato crop rotation in north-eastern Uganda, maize is grown after sweet potato, especially in the Lira District. In some localities of the same district, maize is the preceding crop of sweet potato (Ebregt *et al*., 2004a).

In north-eastern region Uganda, many people depend on cassava, millet and increasingly on sweet potato, as part of their diet. Because of the decline in the cassava production, many people had to adjust their feeding pattern. Besides the establishment of the sweet potato in the food system, maize production is quickly expanding. Many people have adopted the use of maize as the staple carbohydrate. Due to the improvement of flour processing people accepted posho, a firm maize porridge, as part of their diet (Kikafunda-Twine *et al*., 2001).

Ecology and cultural practice

Farmers in Uganda commonly plant maize by hand in a ‘chop and plant’ method. At planting and during the first four weeks after planting, soil moisture is critical for the early development of the root system and the subsequent development of the crop. Maize does not develop an extensive root system as sorghum does. For that reason maize is not able to make use of the full volume of soil moisture under conditions of water stress and consequently the plant may wilt and probably may not be able to survive (Gibbon & Pain, 1985).

Very little fertilizer/manure is used for maize production. When planted without fertilizer, the yield will be about half of what it could be, i.e. yields of 2.4–3.0 t ha^{-1} instead of about 6 t ha^{-1} (Kikafunda-Twine *et al*., 2001). However, this cereal is also often intercropped with nitrogen fixing crops, such as groundnut, soya bean or beans (kidney bean or other grain legumes). The companion crop is planted approximately one week after planting maize, i.e. when the maize starts to emerge (Kikafunda-Twine *et al*., 2001).

Marketing

Cobs have a long shelf life. Maize is stored ‘on cobs’ until there is a need for it, either for sale or to mill for home use. Because of its long storage life, it can supplement the diets of people, especially when other foods run short (Kikafunda-Twine *et al*., 2001).

While the maize marketing system used to be regulated by a governmental controlled Produce Marketing Board having the monopoly on trade and exports, the system has been completely liberalized. Nowadays, there are many millers in the countryside and with the World Food Programme purchasing maize flour, the farmers are encouraged to grow maize for their own consumption and to sell the surplus (Kikafunda-Twine *et al*., 2001).

Constraints and research challenges

The inferior status of sweet potato in parts of Eastern Africa as a "poor man's food" has been cited by researchers as a significant constraint to increase sweet potato consumption (Tsou & Villareal, 1982, in Smit, 1997). For that reason research on sweet potato was limited until 1982 (Hakiza *et al*., 2000). However, collaboration between the National Agricultural Research Systems (NARS) of the region and the International Potato Center (CIP) on sweet potato research caused an increase in the interest in constraints of sweet potato production (Smit, 1997). Work done so far has resulted in the release of high-yielding and disease-resistant varieties that meet the farmers' selection criteria. Also appropriate cultivation methods, control of sweet potato weevil and some diseases have been developed (Mwanga *et al*., 2001a) as well as the use of farmer participation on sweet potato germplasm selection (Abidin, 2004).

Cassava production is affected by the use of inferior and low yielding varieties and due to lack of good quality planting material, land availability and deteriorating soil conditions. Economic factors, such as low price incentives, poor cultural practices, bitterness and cyanogenic glucosides, bulkiness and perishability, poor methods of processing, and lack of credit facilities and farm inputs have also contributed to low production levels. Most farmers, however, have identified pests and diseases as the main hazards in cassava production (Ocitti p' Obwoya & Otim-Nape, 1986; Otim-Nape and Zziwa, 1990). In Uganda, intensive research has been done by the National Network of Cassava Workers (NANEC) (Otim-Nape *et al*., 2001), for example, in improving varieties with a cross protective effect against the ACMD (Owor *et al*., 2004).

Yields of groundnut continue to be low due to poor management, harvest, and storage and drying practices (Page *et al*., 2002). The groundnut rosette disease has been the subject of much research in East Africa (Busolo-Bulafu & Obong, 2001).

The production of maize is quickly expanding to non-traditionally growing areas due to improved road infrastructure and improvement in processing (Kikafunda-Twine *et al*., 2001). Unreliable weather conditions, lack of fertilizers and capital, and the incidence of pests and diseases are the main production constraints.

No research has been previously reported on millipedes for sweet potato, cassava, groundnut and maize in East Africa. However, possible biological production constraints caused by millipede infestation have recently been reported by Abidin (2004) and Ebregt *et al*. (2004a, b, 2005, 2007a). Millipede infestations also contributed to low yield and quality (Ebregt *et al*., 2005).

Arthropoda pests in sweet potato, cassava, groundnut and maize in north-eastern Uganda

The presence of the sweet potato crop and crop residues in the field throughout the year, generally favours multiplication of pests. Bashaasha *et al*. (1995), Smit (1997), Ebregt *et al*. (2004a, b, 2005) considered sweet potato weevils (*Cylas brunneus* and *C. puncticollis*) as the most important sweet potato pests. Another important pest is the sweet potato butterfly (*Acraea acerata*). The caterpillar of this butterfly is a serious constraint to sweet potato production in parts of Uganda, especially during dry spells (Bashaasha *et al*., 1995; Smit, 1997). However, in north-eastern Uganda, this pest was present, but considered by the farmers to be insignificant (Ebregt *et al*., 2004b). The clearwing moths, *Synanthedon* spp. (Lepidoptera: *Sesiidae*), striped sweet potato weevils, *Alcidodes* spp. (Coleoptera: *Curculionidae*), rough sweet potato weevils, *Blosyrus* spp. (Coleoptera: *Curculionidae*) are other pests, but their damage is less prominent (Ames *et al*., 1997). Millipedes (Diplopoda) are pests of economic importance (Abidin, 2004; Ebregt *et al*., 2004a, b, 2005, 2007a).

Millipede problems are usually aggravated by the onset of the growing season. They contribute to the perennial shortage of planting material of sweet potato (Abidin, 2004; Ebregt *et al*., 2004a, b; 2005) at the beginning of the first growing season. Damage on storage roots has not been observed at harvest, five months after planting (Ebregt *et al*., 2004b; 2005). However, when storage roots were stored 'in-ground on plant' during the dry season, and harvesting was done at the first rains of the new growing season, farmers risk imminent damage by millipedes (Ebregt *et al*., 2004a, b, 2005, 2007a).

In Uganda, direct serious damage to groundnut by pests was not mentioned by Busolo-Bulafu & Obong (2001) and Page *et al*. (2002), with the exception of some termite species (Busolo-Bulafu & Obong, 2001). However, germinating groundnut was found to be affected by millipedes (Ebregt *et al*., 2004a, b, 2005, 2007a, b). In the Lira District farmers noticed damage during pod development (Ebregt *et al*., 2004a). In groundnut trials at the Arapai Station, Soroti District, similar damage symptoms were observed (Ebregt *et al*., 2005).

Millipedes also feed on germinating/imbibing maize (Ebregt *et al*., 2004b, 2005, 2007a). Furthermore, farmers mentioned that millipedes can burrow over-mature cassava roots and can feed on the young sprouts of cassava cuttings (Ebregt *et al*., 2004b). Other crops affected by millipedes are germinating beans (mixture of kidney bean and other grain legumes), bambara groundnut, soya bean, cabbage, cotton, sunflower and the pseudo-stems of banana (Ebregt *et al*., 2004b).

Research aims and structure of the thesis

The overall objective of this research on millipedes in north-eastern Uganda was to assist the researchers of National Agricultural Research Organisation (NARO) of Uganda with their efforts to generate basic knowledge about pest status, biology, ecology and behaviour of the millipedes. The generated knowledge of this thesis work will help them to develop some production and pest management strategies, for reducing pest infestation and thereby increasing yield and quality of the crop and contribute to the poverty alleviation of resource-poor farmers.

A series of studies was carried out in north-eastern Uganda. There was inadequate information about the biology, ecology, behaviour, damage and possible control strategies of the East African millipedes. The scope of area is too broad to include all the topics in this PhD work. In order to get a proper knowledge about millipedes, a literature study was done and it is presented in Chapter 2. This chapter describes information about the taxonomy of millipedes, anatomy, reproduction, life cycle, feeding and digestion, pest status, natural enemies, and seasonal activity and dispersal. Furthermore this chapter also describes the role of the millipede in decomposition processes.

Chapter 3 through 7, all published in the NJAS – Wageningen Journal of Life Sciences, describe the results of the series of the studies concerning millipedes as a pest in a number of important crops in north-eastern Uganda.

The first objective of this study was to collect information from farmers using participatory rural appraisal approach. The results of farmers' interviews were analysed, aimed at establishing the relative importance of the millipede problem in sweet potato production and other crops. Topics concerned were the general agronomic practices, and sweet potato and crop rotation. Chapter 3 provides detailed information on this work

The second objective was to collect information from interviewed farmers about the relevance of pests, with the emphasis on the millipede problem, occurring in crops, and about the indigenous pest management and its constraints. After analysing the results, the different harvesting practices, pest management and its constraints, damage symptoms in sweet potato (in planting material as well as in storage roots), groundnut, maize and other crops were focused on. The result of this work is presented in Chapter 4.

The third objective was to determine, through a number of experiments in the field, the extent of damage and damage symptoms caused by pests, millipedes in particular, in sweet potato, groundnut and maize. After analysing the results, the damage in sweet potato during crop establishment, bulking, both from 5 locations with different soil textures in the Soroti District in north-eastern Uganda, and storage 'in-ground on plants' was determined. Damage by different sweet potato pests in non-established cuttings and storage roots in different sweet potato genotypes were also discussed. A number of millipede species collected from the 5 different locations, were identified and their occurrence on these locations were also verified.

Results from damage and the corresponding symptoms by millipedes and other soil pests of germinating groundnut seeds recorded 10 days after planting, and of pods found damaged at harvest were investigated. Furthermore, the results from damage and the corresponding symptoms of germinating maize were recorded and analysed. Millipede species found in both crops were identified. Chapter 5 presents results of this work.

The fourth objective was to collect quantitative information on intake of crop diets by and body weight gain of the millipede *Omopyge sudanica* in short-term no-choice feeding activity laboratory experiments. The diets were sweet potato (cv. Osukut/Tanzania) and cassava (cv. Nigeria) storage roots, groundnut seeds (cvs. RPM 12 and Rudu-Rudu), maize seeds (cv. Longe I). Parameters assessed included: (1) ingested crop product (intake), (2) body weight related to the intake and weight gain, (3) consumption index (i.e., the ratio between intake and body weight), and (4) the efficiency of conversion of ingested food into body substance. The result of this work is presented in Chapter 6.

The fifth objective was to compare the indigenous cultural practices of in-ground storage and piecemeal harvesting with one-time harvesting, with special reference to effects on damage done by the sweet potato weevil (*Cylas* spp.), the rough sweet potato weevil (*Blosyrus* spp.) and millipedes. The relation between time of piecemeal harvesting and (i) average number of soil cracks, number of mounds containing 'mature' storage roots and number of storage roots, (ii) average number of harvestable, non-harvestable and total storage roots, (iii) average weight of harvestable and non-harvestable storage roots and (iv) the percentage infested vines, were investigated. Furthermore, results of the number of vines and number of storage roots at final harvest of both harvesting practices were analysed and looked into the fitted and observed relationship across the two practices. The percentage of vines damaged by the sweet potato weevil and the percentage damaged storage roots by sweet potato weevils, rough sweet potato weevil, millipedes and nematodes in the two harvesting practices were also analysed. Lastly, a field assessment was conducted of vine and storage root damage by sweet potato weevils in three different planting seasons. Detailed information of this study will be found in Chapter 7.

Finally, in Chapter 8, the major findings of the studies are synthesized and their implications for the development of integrated production and pest management strategies for sweet potato improvement of north-eastern Uganda will be discussed.

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CHAPTER 2

Millipedes: a literature study

Taxonomy

In most languages, the millipede is called by names, which are derived from the (large) number of legs. Miljoenpoot (Dutch), milliped (French), quilópodo (Portuguese), Tausendfüssler (German), jongvoo (Swahili), songololo (Zulu/Xhosa) and kaki seribu (Indonesian) are a few examples.

Millipedes belong to the class of the Diplopoda (double-footed). This class is grouped together with the Chilopoda (centipedes), Paurapoda and the Symphyla as the Myriapoda (Lawrence, 1984; Blower, 1985). According to Marshall & Williams (1977) and Chiney (1986), the term 'Myriapoda' is retained for convenience and does not have any systematic significance, i.e. the groups are not closely related. The Paurapoda and the Symphyla are less known (Lawrence, 1984) and of no relevance for this thesis.

Several authors (e.g. Manton, 1977; Marshall & Williams, 1977) made systematic classifications within the Diplopoda, but recently these classifications have undergone a thorough update. Blower (1985) and Hopkin & Read (1992) constructed a classification of the Diplopoda based on Enghoff (1984), shown in Table 1.

The orders Polydesmida, Spirostreptida and Julida contain species, which attack a variety of crops (Lawrence, 1984). Two species played a significant role during the study: *Omopyge sudanica* Kraus (Spirostreptida: Odontopygidae) and *Spirostreptus ibanda* Silvestri (Spirostreptida: Spirostreptidae). Other species identified in the study were: *Tibiozus robustus* Attems, *Tibiomus* spp. (cfr. *ambitus*) Attems, *Prionopetalum* spp. (cfr. *xerophilum*) Carl, *P. xerophilum* Carl, *Haplothysanus emini* Carl, *Rhamphidarpe* spp. (cfr. *dorsosulcata*), *Rhamphidarpe* spp., *Xanthodesmus* vagans Carl and *Aulodesmus* spp. (C.A.W. Jeekel, personal communication).

Anatomy

Often people find it difficult to distinguish a millipede from a centipede. Table 2 gives an overview of a number of striking differences between these two classes of arthropoda (Lawrence, 1984; Blower, 1985).

Many features of millipedes are adaptations for defence and a saprophagous life style, although occasionally they feed on living plant parts. In contrast, the adaptations of a centipede are meant for offence and a carnivorous life style (Lawrence, 1984; Blower, 1985).

Table 1. The classification of the Class Diplopoda, based on the classification by Enghoff (Sources: Enghoff, 1984; Blower, 1985; Hopkin & Read, 1992).

CLASS DIPLOPODA

Subclass Penicillata ("bristly" millipedes)
Order: Polyxenida
Subclass Chilognatha
Infraclass Pentazonia
Order: Glomeridesmida
Order: Sphaerotheriida (giant pill millipedes)
Order: Glomerida (pill millipedes)
Infraclass Helminthomorpha
Helminthomorpha incertae sedis: Order Siphoniulida
Subterclass Colobognatha
Order: Platydesmida
Order: Siphonophorida
Order: Polyzoniida
Subterclass Eugnatha
Superorder Nematophora
Order: Stemmiulida
Order: Callipodida
Order: Chordeumatida
Superorder Merocheta
Order: Polydesmida (true flat-backed millipedes)
Superorder Juliformia ('snake millipedes')
Order: Spirobolida
Order: Spirostreptida
Order: Julida

Table 2. Anatomic differences between a millipede and a centipede.

Difference	Millipede	Centipede
Number of legs per body segment	2 pairs	1 pair
Skeleton	Inflexible calcified cuticle	Thin cover of fairly flexible chitin
Body shape in cross section	Round and cylindrical or hemispherical	Flat
Reaction on disturbance	Coils its body around its head	Will speed away
Movement	Gliding	S-like wave
Secretion of smelling substance	Present	Absent
Life style	Saprophagous	Carnivorous

The characteristic feature of a millipede is the exoskeleton, an almost rigid armoured covering, which is impregnated largely with calcium salts, making the millipede incompressible. The animal is often round and cylindrical or hemispherical in cross section (Lawrence, 1984). In north-eastern Uganda, the white bleached remains of dead specimens were often found in the field (observation by E. Ebregt). Other anatomic features are the head, with short elbowed antennae probing the substrate, robust mandibles of a very peculiar type, and just one pair of maxillae fused into a characteristic lower lip or gnathochilarium. The head is followed by the trunk, consisting of a collum or first trunk unit, three segments sharing three pairs of legs, and many (more than four) similar leg-bearing ring segments, with two pairs of legs on each segment, (Blower, 1985). From this the scientific name of the class, Diplopoda or double-footed is derived. Each ring segment or diplosomite actually consists of two fused segments. The various segments bear a number of hairs, sensitive to touch (Lawrence, 1984). Between the tail-piece, called the telson, and the last leg-bearing segments, there are one or two apodous rings. Between these apodous rings and the telson lies the growth zone, where new trunk units are initiated and grown. The terminal telson consists of a pre-anal ring, a pair of anal valves and a sub-anal scale (Blower, 1985). The telson often plays a key role in the identification of species (C.A.W. Jeekel, personal communication).

The short antennae are composed of eight segments. They carry the sense organs, which palpate the substrate immediately in front of the head (Blower, 1985). It can be noted that, when the millipede walks along, the tips of the antennae are constantly tapping against the ground (Lawrence, 1984).

The mouth-parts of millipedes consist of a pair of mandibles, of which, with a few exceptions (Hopkin & Read, 1992), the biting portion is armed with blunt and rather clumsy ‘teeth’. Their task is, to some extent, to break up and grind the bigger parts into smaller particles for swallowing (Lawrence, 1984; Hopkin & Read, 1992). The gnathochilarium, which forms the floor of the buccal cavity, is hardly involved in chewing. Along the front edge of the gnathochlilarium the taste organs are found. As the food passes into the mouth, these organs come first into direct contact with the food. The detailed shape of the gnathochilarium varies from order to order, and so, it can be used for identification. It carries the taste organs on its margin (Lawrence, 1984; Blower, 1985).

As millipedes live in dark places sight is not well developed and not much of importance to the animal in finding food (Lawrence, 1984). The members of the Polydesmida possess no ‘eyes’ at all (Lawrence, 1984; Blower, 1985), while in the majority of the superorder Juliformia a cluster of ocelli, just above the antennae, can be found (Lawrence, 1984; Hopkin & Read, 1992). They are somewhat difficult to distinguish from the surrounding cuticle (Lawrence, 1984).

On each side of the head, between the base of the antennae and the 'eye', the Tömösváry organs are visible. These are openings, which are hypothesized to be receptive to smell (Hopkin & Read, 1992). Touch and smell are the most highly developed senses in the millipede. The millipede probably also has some means of becoming aware of changes in the amount of surrounding moisture and temperature in the air (Lawrence, 1984).

The largest species of the Juliformia, the Spirostreptida may have as many as 70 pairs of legs, while the smallest species may have about 40 pairs (Lawrence, 1984). The millipede leg has a basic number of seven podomeres, in contrast to most insects, which have only five podomeres. Besides the trochanter, prefemur and femur, there is the extra postfemur, followed by the tibia, tarsus and tarsal claw. The position of the postfemur corresponds with the position of the 'knee', which gives an S-shaped bending to the leg. The legs of the Juliformia are positioned ventrally through the coxae to the sternite, although those of the Polydesmida are inserted more laterally (Blower, 1985).

Defensive systems

Millipedes have resorted to physical and chemical means of defence (Hopkin & Read, 1992). For most of the time they live hidden in the soil or surface litter, in order to protect themselves against heat and aridity. Besides the protection of the exoskeleton, millipedes of the Juliformia have the ability, when disturbed, to fall quickly on their sides and from this position they roll their bodies round their heads into a coil. In this position, the hard upper side of the body will protect the legs and the soft under-belly (Lawrence, 1984). During the study, it was noted that, when the millipede felt confident again, it uncoiled itself again and moved off, like a small train.

When irritated, the millipedes can discharge void liquid faeces (Lawrence, 1984). On top of that, all millipedes of the Spirobolida, Spirostreptida and the Julida also possess defensive glands. In the case of the millipedes of the order Julida, for example, they are located under minute pores, mid-laterally on the sixth to the last podous rings (Blower, 1985). When a millipede is handled roughly or when it is under attack, for example by ants, the animal will secrete a badly smelling brownish substance. The exudates from the glands stain the fingers and cause a burning pain in a cut finger or in the eyes (Lawrence, 1984). The chemical content of these defensive secretions from these glands is not uniform. Benzoquinones are the most common chemicals. They are found only in the orders Spirobolida, Spirostreptida and Julida (Hopkin & Read, 1992). The defensive glands of the Polydesmida are on the whole larger and better developed. They secrete extremely toxic prussic acids and, therefore, they are very effective against ants, toads, carabid beetles (Carabidae), some birds and some burrowing animals (Lawrence, 1984).

The millipede *Omopyge sudanica* of the family Odontopigidae, often encountered in the field and used in several experiments reported in this thesis, has a quite different defensive reaction. When handled, these millipedes react extremely lively and make violent snake-like movements with the body, while trying to escape (Lawrence, 1984). During the study it was often experienced that they were trying to 'bite' the fingers. This in contrast with the much larger millipede *Spirostreptus ibanda*, also often encountered in the field, but which was less active when captured.

Locomotion and burrowing

If a moving millipede is observed from its side, one can see what appears a little gliding train, for which the co-operation of the numerous legs is needed. Lawrence (1984) described that in 1742 a historical figure, Owen, compared the movement of legs with rolling on of the waves of the sea, moving along the rows of legs, from behind forwards. This is because the legs move in a group of 5 or 6 pairs of legs (Lawrence, 1984).

The ability to burrowing is a striking characteristic of the millipede. It cannot be compared with the tunnels and runways of mole crickets. Many millipedes have to find natural shelters, such as stones, trunks of fallen trees and sometimes deserted termite mounds. In general they stay in the shallow topsoil layer, but during the hot dry season they can burrow to greater depth (Lawrence, 1984). Dangerfield & Telford (1991) found millipedes 'overwintering' in burrows up to approximately 30 cm deep. Although millipedes lack the necessary 'digging' structures for burrowing (Lawrence, 1984), they have a remarkable ability to push, due to the many from behind forward moving legs and the possession of diplosegments (Blower, 1985), thus producing a large thrust for a relatively short body (Hopkin & Read, 1992). Besides, the head capsule is usually heavily calcified to facilitate burrowing (Hopkin & Read, 1992). On top of that, the ventral origin of the legs is seen as an adaptation to burrowing (Manton, 1958).

Reproduction

In insects, the reproductive openings occur at the extreme hind end of their abdomen. Millipedes, however, have the openings of the genital ducts of both sexes on the seventh segment ring of the trunk (Lawrence, 1984; Hopkin & Read, 1992; C.A.W. Jeekel, personal communication). In the Julida the pair of testes opens through gonopores on a double lobed penis just behind the second pair of legs. In the Polydesmida the external male organs, the so-called gonopodes, open through gonopores on the coxae of the second pair of legs, or through penises on them (Blower, 1985; Enghoff, 1990; Hopkin & Read, 1992). In all orders, the female millipedes have paired oviducts, which separately open through the vulvae, posterior to the second pair of legs (Blower, 1985; Enghoff, 1990; Hopkin & Read, 1992).

Berns (1968) showed that in the Spirobolida, following the moult to the fifth instar, the functional walking legs of the seventh ring segment are replaced ventrally by small bumps. In the next instars, these bumps will undergo morphological changes and will develop into gonopodes at maturity. From Berns' work it was concluded that gonopodes pass through a progressive growth and differentiation of their own and do not develop as a gradual modification of the walking legs (Hopkin & Read, 1992).

At maturity, each female species has a unique detailed structure of the vulvae and this may be of importance in identification (Kurnik, 1988). The external male sex organs can be easily detected on the seventh segment of the trunk. The shape of these male organs is also often very peculiar and is also often a helpful means to identify the species (C.A.W. Jeekel, personal communication). The male of the Julida can also often be identified by means of the two small fleshy pads under his feet to assist him to cling on the female during mating. Females do not have these pads (Lawrence, 1984; Blower, 1985).

After the process of insemination, the female stores the sperm in the so-called spermathecae. The eggs will only be fertilized when they leave the body at oviposition (Hopkin & Read, 1992).

In South Africa, from October to December, the males of certain species appear in the open, especially after the brief afternoon thunder showers. This is called the nuptial walk (Lawrence, 1984). It is thought that pheromones may play a role in the attraction between males and females. However, it is not clear over which distance these odours are effective (Hopkin & Read, 1992). In north-eastern Uganda, with the onset of the first rains, millipedes of the species *Omopyge sudanica* also appear massively, but males are not abundant (observation by E. Ebregt).

Life cycle

Several hundreds of quite yolk eggs are usually deposited at a time, often in specially constructed 'nests' made out of moistened earth. The outside of the 'nest' is often camouflaged with fragments of earth and dirt (Lawrence, 1984). A resistant capsule, moulded with saliva moistened earth, is prepared around the egg (Lawrence, 1984; Hopkin & Read, 1992). With the exception of male Platydesmida (Hofman, 1982), there are no reports of millipedes guarding their eggs (Hopkin & Read, 1992).

In north-eastern Uganda, it was observed that the *Spirostreptus ibanda* (Spirostreptida, Spirostreptidae) often makes specially prepared chambers in rotting wood, compost heaps and other places rich of somewhat moist organic soil, such as with earth vacated polythene bags, often found in tree nurseries (observation by E. Ebregt). After hatching, the embryo will feed on the walls of the capsule; these serve as its first nourishment until after the second moult (Lawrence, 1984; Hopkin & Read, 1992). The larva is born with only three pairs of legs and four fully developed ring segments. Posterior to these podous ring segments there are one to three apodous ring segments. It will soon shed its skin and after each moult it will initiate more ring segments and more legs, which appear in the proliferation zone, near the posterior end of the trunk. This mode of embryonic development is called anamorphosis. This is in contrast with the development of most insects, i.e. eggs hatch with the fully required number of their segments (epimorphosis). The young larvae are much lighter in colour than the more mature ones and it will take more than a year to reach full size of the grown millipede (Laurence, 1984; Blower, 1985).

Most millipedes undergo a purely anamorphic development. Following the first 6-legged stadium there will be 7 or 8 moults, resulting in 8 or 9 moults. However, there are also species, which undergo even 6 to 14 or 15 moults. For example, the Polydesmida has either 7 or 8 moults. The number of moults in the Julida is even more variable: from 6 to 15. In the Polydesmida at a given moult there is always an increase of a new podous ring segment, consequently the development stadium of any individual can be determined. In the Julida the increase of new ring segments at a given moult varies from one to eight, hence the development stadium cannot be determined by counting the number of ring segments (Blower, 1985).

The shedding of the skin also continues from time to time during the life of the adult (Lawrence, 1984; Blower, 1985; Hopkin & Read, 1992). The whole process of moulting, which will last approximately 3 weeks, is a dangerous period for the millipede. During some 7 days it is even immobile. The moulted skin is often eaten, as the cuticle contains valuable calcium salts, which can be used for hardening the new one (Lawrence, 1984).

Because of this vulnerability during moulting, most millipedes, like other arthropods, seek refuge, where they shed their exoskeleton. Some make just shallow depressions in the soil to moult in, but others, such as the larger Spirostreptida build elaborate chambers.

Feeding and digestion

Millipedes probably play an important mechanical role in breaking up the plant litter into smaller particles. Furthermore, it appears that millipedes only assimilate a very small part of the material they ingest (Blower, 1985). They do not have specific digestive enzymes in order to digest the leaf material itself. It is therefore assumed that the digestive system accommodates micro-organisms, which induce this process (Blower, 1985).

Millipedes deal with food in two stages. At first, after the mechanical break up by the mandibles, nutrients pass through the mid-gut epithelium and are quickly assimilated across the microvilli. Secondly, enzymes from the secretion of the salivary glands (Nunez & Crawford, 1977) and the mid-gut epithelium, and probably from the present micro-organisms mixed with the food in the mid-gut lumen, ensure that the products of digestion are assimilated by the body. The rectum is forming the faecal pellets. It is able to re-absorb water from a moist substrate (Hopkin & Read, 1992).

Coprophagy (i.e., the re-ingestion of excreta) is common among millipedes. However, it is not known whether it is essential for all millipedes to survive. It may be important, especially when nutrients are not yet available for assimilation in the mid-gut and nutrients are released at the end of the gut. On top of that, activities of the micro-organisms might also release valuable substances, which otherwise might be lost. Furthermore, it might be important, when the preferred food is not available (Hopkin & Read, 1992).

Natural enemies

Little quantitative information is available on the number of millipedes that fall victim to predators. In north-eastern Uganda, farm animals like chicken, ducks, turkeys and pigs feed on millipedes (Ebregt *et al.*, 2004b). Other birds and mammals kept in captivity, and reptiles can take millipedes. But these observations do not mean that millipedes are part of the habitual diet of the same predators in the wild (Hopkin & Read, 1992). The stomach of numerous South African birds contained millipedes, indicating that they can overcome the discouraging effects of the defensive glands. None of these birds are known to making millipedes their main menu (Hopkin & Read, 1992). It should be taken into account that many of these South African birds are also a part of the natural ecosystem in East Africa, permanently or during migration (Maclean, 1993; William & Arlot, 1995).

Nearly all millipede species, which are known to be eaten by the (larger) vertebrae, belong to the Juliformia. These are all middle-sized or larger species. Most likely mole rats (Muridae) and other small burrowing animals feed on millipedes during their underground activities (Lawrence, 1984). In north-eastern Uganda, crickets (Gryllidae) were seen feeding on millipedes and in a number of cases remains were found near the entrance of a cricket undergound burrow. It was also reported that millipedes fell victim to army ants and scorpions (Ebregt *et al.*, 1994b). Practically no records are available about the smaller millipede species (Lawrence, 1984). Soil scavengers must also prey on eggs and young larvae (Hopkin & Read, 1992).

In South Africa, assassin bugs (Hemiptera; Reduviidae) consume mostly larger species of the family Spirostreptidae, while some smaller species, such as the *Chersastus* (Spirobolidae), are not attacked at all. The same accounts for parasitic mites, which are feeding in large numbers on *Doratogonus* (Spirosteptidae), but are rarely found feeding on *Chersastus*. Another invertebrate predator is the South African scorpion (*Opisthacanthus leavipes*), which was found feeding on the *Doratogonus flavifilis* (Spirostreptida) (Lawrence, 1984).

Nematodes are considered to be the most common endoparasites of millipedes (Blower, 1985). In South Australia, the nematode *Rhabditis necromena* Sudhaus and Schulte has been used as a biological control agent against the accidentally introduced Portuguese millipede *Ommatoiulus moreleti* (Julidae), which had become a pest (McKillup & Bailey, 1990). However, field trials with the same nematode were not successful in Cape Verde Islands, West Africa (McKillup *et al*., 1991).

Some millipedes of the Julidae are fairly often affected by ectoparasitic fungi of the Laboulbeniales (Rossi & Balazuc, 1977). The branched hyphae infect the first three pairs of legs of females and the first seven pairs of legs of males. Restriction of their mobility is the result. This might be due to the fact that the millipede is no longer able to groom efficiently, or to the absence of defensive glands from the first five ring segments (Blower, 1985).

Distribution

In north-eastern Uganda, dead millipedes were often found in (dried up) water holes or other places where rain water temporarily accumulated (observations by E. Ebregt), clearly indicating that millipedes can not swim. When falling into water, they will sink straight to the bottom and die. This disability will restrict their geographical distribution, when large rivers form the natural boundaries of a given region. Other restrictions include their sensitivity to desiccation and their long periods required for moulting, during which they are completely helpless and very sensitive to changes in the environment (Lawrence, 1984). Some species, especially some originally European Julida species, have a world-wide distribution, but this is due to activities of man. *Ommatoiulus moreleti* (Julidae), for example, was introduced from Portugal into Australia and became a serious nuisance because of its habit of eating garden vegetables and invading houses (Baker, 1985). Another millipede, *Archiulus moreleti*, has been casually introduced into South Africa, probably also from Portugal, by shipping together with plants, fruits and some of the soil accompanying them. This millipede has become very common in greenhouses and gardens in Cape Town and they even enter houses and apartments in large numbers (Lawrence, 1984).

Seasonal activity and dispersal

Dangerfield & Telford (1991) reported that in Zimbabwe all millipedes of the Julidae have a seasonal pattern of surface activity, where the dispersal takes place primarily by walking (Hopkin & Read, 1992). With the exception of the southern African species *Gymnostreptus pyrrocephalus* (Spirostreptidae) (Lawrence, 1984) and the *Alloporus uncinatus* Attems (Spirostreptidae), of which the juvenile stadia form dense swarms, the dispersion pattern of the other African species is at near random (Dangerfield & Telford, 1993). With the onset of the first rains millipede activity peaked soon after emergence from their quiescence, and after some weeks this activity declined again. Moisture is the most likely clue to induce soil surface activity of millipedes (Dangerfield & Telford, 1991). In north-eastern Uganda a comparable phenomenon was observed. Following a 3−4 months dry season, this peak of activity occurred in March/April shortly after the first rains of the first rainy season appeared. It often happened early in the morning, especially on cloudy days. In the course of the growing season, this activity also declined rapidly. In the second rainy season, millipedes activity ceased before the end of the rains in anticipation of the coming dry season (observation by E. Ebregt). The upper horizons, mostly up to 30 cm deep, where the millipedes overcome the dry season in burrows, require sufficient rainfall in order to 'waken up' the millipedes out of their quiescence. Moreover, the soil should be soft enough for them to dig through to the soil surface (Dangerfield & Telford, 1991). In north-eastern Uganda, diurnal activity could rarely be seen in the course of the second rainy season (observation by E. Ebregt). Nonetheless, they were still found feeding on germinating maize (Ebregt *et al*., 2005).

Gillon & Gillon (1976) stated that millipedes are more commonly found under trees than in a more open habitat. The spatial patterns of abundance and biomass for many organisms, including millipedes, vary between and within habitat types (Dangerfield, 1990). In Dangerfield's comparison study in Zimbabwe between natural (Miombo) woodland and managed habitats (maize cultivated area, grassland fallow and a stand of eucalyptus trees), millipedes were abundant mostly in closed woodland habitats. No millipedes were recorded in the maize cultivated area (with plants between 2.0 and 2.5 m tall) and in the eucalyptus site. Nonetheless, it is expected that larger millipede species, members of the Odontopygidae and Spirostreptidae families, could be short-term migrants within the maize field from adjacent woodland habitats. A woodland habitat, which in general harbours larger populations of millipedes, may well act as a refuge and reservoir. From there millipedes can migrate as short-term migrants or re-colonize adjacent areas, such as cropping fields. The low pH values of the soil of the eucalyptus site may restrict the millipedes to temporary visits (Dangerfield, 1990).

The heterogeneity within habitat type is especially important for certain groups of soil macro-fauna, such as millipedes, which tend to form natural aggregations. The spatial variation with regard to habitat type is most clear for the macro-fauna that lives in the litter layer or at the soil-litter interface, such as millipedes. This suggests a strong influence of microclimate on patterns of distribution of millipedes. Such patterns of aggregation in soil fauna populations will increase the degree of spatial heterogeneity in decomposition processes (Dangerfield, 1990).

The role of millipedes in decomposition processes

The effects of soil fauna, with the possible exception of termites and earthworms, on decomposition in African tropical savannahs and the agricultural systems derived from them is still poorly understood, despite their importance in influencing nutrient release (Dangerfield, 1990). A study of the macro-fauna in savannah woodland and its associated managed habitats showed that millipedes account for 36% of the total density of soil fauna and up to 75% of the soil fauna biomass (Dangerfield, 1990). In another feeding activity study, Dangerfield (1993) suggested that millipedes are likely to ingest 88.1 g of dry matter m^{-2} and produce approximately 400 cm^3 of faecal pellets m^{-2} over one season.

Millipedes are not well equipped with specialized enzymes to enable them to digest the plant litter itself. It is suspected that micro-organisms in the alimentary channel play a crucial role in the digestion of food (Blower, 1985) and indirectly influence the fluxes of nutrients (Anderson *et al*., 1985; Blower, 1985; Anderson & Leonard, 1988; Hopkin & Read, 1992). Anderson & Bignell (1980) illustrated this by showing that millipedes (and other saprophages) are not directly responsible for more than 10 per cent of chemical decomposition. Nonetheless, because of their feeding activity the micro-organisms can carry out approximately 90 per cent of the chemical breakdown. Millipedes affect decomposition through the fragmentation and inoculation of organic matter with bacteria and fungal spores, and ultimately convert the organic matter into humus (Blower, 1985; Dangerfield, 1990). Change of the physical structure of the soil may also occur due to the millipedes burrowing activities, resulting in increasing porosity, changing soil moisture features and enhancing leaching of soluble materials by rainwater (Anderson & Leonard, 1988). Being mobile animals, they may also effect a net transfer of nutrients from edge habitats to the arable fields through the production of faecal pellets (Dangerfield, 1990).

In conclusion the millipede feeding activities may have considerable effects on the regulation of the decomposition process and may be beneficial to crop production by retarding nutrient release by locking up nutrients in persistent faecal material (Dangerfield, 1990).

Pest status

Millipedes are abundant in the tropics and dominate the biomass of soil fauna (Dangerfield, 1989). Nevertheless, millipedes are still among the less well-known arthropods in nearly all countries of the world (Lawrence, 1984). Although most of the millipedes are known to be saprophagous, several species are known to eat living plant parts. They usually ingest the soft and easily digestible parts, such as young shoots or fine roots (Hopkin & Read, 1992). There are many reports that millipedes can be destructive in crops. Kuria & Eijnatten (1981) listed millipedes with a pest status in crops in Ghana (guinea corn, cotton, millet and groundnut), Central African Republic (cotton and groundnut) and South Africa (Irish potato, beetroot, carrot, turnip and various ornamental plants). Mercer (1978) thought that millipedes were one of the culprits, which were responsible for the poor stands of groundnut fields in Malawi. More recently in India, Siddadappaji *et al*. (1979) described the impact of millipedes feeding on the inflorescence of green gram (*Vigna* spp.) surrounded by fallow land. Also cowpea (*Vigna unguiculata*) was affected. Alagesan & Ganga (1989) discussed a millipede as a potential pest in carrots, potato and cassava. In other parts of the world, the species *Blaniulus guttulatus* Fabricius (Julida, Blaniudae) and *Brachydesmus superus* Latzel (Polydesmida, Polydesmidae) may cause significant economic damage to root crops. They are often found in partly hollowed-out Irish potato tubers (Blower, 1985). Wightman & Wightman (1994) reported millipedes being active as pod borers in Zambia, Zimbabwe, Botswana, Malawi and Tanzania, although they were rarely present in sufficient quantities to warrant concern. In West Africa, millipedes (Odontopygidae) were considered a nuisance in groundnut (Demange, 1975; Johnson *et al*., 1981; Masses, 1981; Lynch *et al*., 1985; Umeh *et al*., 1999; Youm *et al*., 2000). Masses (1981) reported that the yield was even reduced by 30−40%.

Little documented reference was found about millipedes in Eastern Africa, although they form a major group of soil fauna. Kuria & Eijnatten (1981) reported that in the Coast Province (Kenya) until 1976 the millipede *Archispirostreptus gigas* Peters (Spirostreptida) was viewed with little or no economic concern, because it was not known to feed on crop plants. However, from that year onwards, its population built up to such an extent that it caused a nuisance in tree nurseries as it was seen cutting young emerging seedlings of various trees. Kuria & Eijnatten (1981) also reported that since then, young germinating plants, such as sesame, cotton and maize were cut. The pest had become unmanageable for the farmers. Another unidentified millipede was reported to cause damage by burrowing into carrots and potato tubers.

Earlier studies in Uganda showed that farmers consider arthropod pests as the most important biological constraint on sweet potato production (Bashaasha *et al*., 1995; Smit, 1997; Abidin, 2004; Ebregt *et al*., 2004a). After an outcry from farmers and agricultural officers, studies showed that sweet potato farmers from north-eastern Uganda considered millipedes the second most important arthropod pest after sweet potato weevils (Cylas *brunneus* and C. *puncticollis*, Coleoptera: Curculionidae) (Abidin, 2004; Ebregt *et al*., 2004a, b). Furthermore, it appeared that other important crops, such as groundnut, maize, cassava, beans (kidney beans and other grain legumes), sesame, cotton, cabbage, sunflower and banana pseudostems, were also affected (Ebregt *et al*., 2004a, b, 2005, 2007a, b).

Mwanga *et al*. (2001) stated that sweet potato weevils (*Cylas brunneus* and *C. puncticollis*) are more abundant in the storage roots during the dry season than in the rainy season. Ebregt *et al*. (2005, 2007b) found that there is a relationship between the presence of sweet potato weevils and millipedes. After being stored 'in-ground on plants' for more than 10 months, besides the sweet potato weevils, millipedes of the Odontipygidae (mainly *Omopyge sudanica*) affected the storage roots. Furthermore, Ebregt *et al*. (2005) suggested that, after the weevils have damaged the storage roots, millipedes can have access to the roots easily. Blower (1985) and Hopkin & Read (1992) already assumed that millipedes just worsen damage initiated by primary pests. Many millipedes are certainly also attracted to cut surfaces (Hopkin & Read, 1992).

In the following chapters of this thesis the knowledge of farmers on sweet potato production and millipede infestation in north-eastern Uganda is reported. Furthermore, a series of experiments and their results, for example on pest incidence in sweet potato, groundnut and maize, on feeding activity of the millipede *Omopyge sudanica* on different crop diets, and field observations on the indigenous piecemeal harvesting and one-time harvesting practices, are described.

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CHAPTER 3

Farmers' information on sweet potato production and millipede infestation in north-eastern Uganda.
I. Associations between spatial and temporal crop diversity and the level of pest infestation

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Farmers' information on sweet potato production and millipede infestation in north-eastern Uganda. I. Associations between spatial and temporal crop diversity and the level of pest infestation

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Abstract

Farmers in five districts of north-eastern Uganda were interviewed to generate information on sweet potato production and constraints, with emphasis on damage by millipedes. Participatory rural appraisal methodology was used to interview 148 farmers. The peak period of planting sweet potato was from the end of May till the beginning of July in order to produce dried form food (amukeke) for storage in the dry season, which sets in around November. Vine cuttings were usually planted on mounds and weeding was mostly done only once. Osukut, Araka Red and Araka White were the most popular varieties. Many respondents obtained planting material from volunteer plants. Separation of plots over time and in space was often not practised. Sweet potato crop rotations were diverse. Millet, groundnut and maize were commonly grown after sweet potato. Cassava, sweet potato, groundnut and maize are host crops for millipedes and were often grown in succession. Millipede incidences were not statistically different for the three agro-ecological zones of north-eastern Uganda, but depended on the frequency of millipede hosts (including sweet potato) in the crop rotations. Groundnut planted after sweet potato had high levels of millipede attack. Millipede incidence was often associated with the incidence of weevils. The results of this inventory show that most farmers consider millipedes as a pest of sweet potato and other major food and cash crops, but that many farmers lack the knowledge to control them.

Additional keywords: crop rotation, Diplopoda, farmer variety, host crop, *Ipomoea batatas*, participatory rural appraisal, planting material, spatial diversity.

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Introduction

Sweet potato (*Ipomoea batatas* (L.) Lamk) ranks fifth among the world's most important crops (Anon., 2002) and is important in all countries of eastern Africa. It is mostly grown as a subsistence crop by resource-poor farmers in a non-seed carbohydrate staple food system (Smit, 1997). In Uganda it is a major staple food, along with banana, cassava and Irish potato, often in combination with beans (kidney beans or another grain legume) (Ewell & Mutuura, 1994; Smit, 1997). It is cultivated in all agro-ecological zones and performs well in marginal soils (Bashaasha *et al.*, 1995; Smit, 1997). Sweet potato is high in carbohydrates and vitamin A and is crucial during the harsh dry periods when people depend on the crop to combat hunger (Anon., 1998).

In Uganda during the early 1990s, the production of cassava declined due to Cassava Mosaic Virus, and the production of banana dropped because of the Sigatoka disease and banana weevil infestation (Bashaasha *et al.*, 1995). So food supply was inadequate, often resulting in famine and dependence on relief aid for survival. Meanwhile, sweet potato established itself in the food system in meeting the people's nutritional requirements, and for covering recurrent household expenses (Scott & Ewell, 1992; Scott *et al.*, 1999). For example, many farmers in Kumi District grow sweet potato as a cash crop for commercial markets and are the main suppliers for the market of Kampala (Abidin, 2004). Income from sales of sweet potato also helped many farmers in their efforts to re-stock cattle herds in areas where stealing of cattle had taken place during the period of civil unrest (Bakema *et al.*, 1994).

Currently, Uganda is the largest producer of sweet potato in Africa (Anon., 2002). However, compared with Uganda's 4.4 t ha^{-1}, the yields of neighbouring countries are higher (Anon, 2002). This strongly suggests that there are constraints that require to be overcome urgently if the production of the crop is to increase, especially in north-eastern Uganda.

Farmers in north-eastern Uganda are poor (Anon., 1994; 1999) and inputs in sweet potato, such as fertilizers and pesticides, cannot be afforded. In a previous study only farmers in the village Aukot (Soroti District; Sub-county Gweri) were reported to apply pesticides or inorganic fertilizers (Abidin, 2004). Moreover, pesticides and inorganic fertilizers are not always available at the trading centres, or are only accessible for those who own transportation means.

Farmers in Uganda consider insect pests the most important production constraint in sweet potato (Smit, 1997; Abidin, 2004). They believe that the sweet potato weevils (*Cylas brunneus* and *C. puncticollis,* Coleoptera: Curculionidae) and the caterpillars of the sweet potato butterfly (*Acraea acerata,* Lepidoptera: Nymphalidae) are the main culprits (Bashaasha *et al.*, 1995; Smit, 1997). Also rats are important. Serious damage by millipedes (Diplopoda) was suggested by Abidin (2004). There is inadequate information at present about the identity, biology, ecology, behaviour, damage and possible control strategies of millipedes in Uganda and eastern Africa as a whole.

We are carrying out research to develop an appropriate integrated pest management package, with emphasis on millipedes, to minimize yield losses, particularly for the resource-poor farmers in north-eastern Uganda.

This paper analyses the results of farmers' interviews aimed at establishing the relative importance of the millipede problem in sweet potato production. A companion paper describes the indigenous control strategies in sweet potato production (Ebregt *et al.*, 2004).

Materials and methods

Interviews were conducted in Soroti, Kumi, Katakwi, Kaberamaido and Lira, the main sweet potato growing districts in north-eastern Uganda. According to reports received from farmers and agricultural extension agents, millipede problems in these regions were significant. Farmers' knowledge of general agronomic practices and pest management with emphasis on millipedes was assessed through participatory rural appraisal (Nabasa *et al.*, 1995; Anon., 1996).

Details on interview sites, methodology, data collection and processing are described in this paper.

Description of interview area

One hundred and forty eight farmers in 32 sub-counties were interviewed between 19 April 2001 and 7 April 2002. For the location of the households interviewed and the agro-ecological zones as classified by Wortmann & Eledu (1999) see Figure 1. This classification shows that farms where interviews took place were located in the Northern Moist Farmlands (Lira and Kaberamaido Districts), the North-central Farm-Bush Lands with sandy soils (Soroti and Katakwi Districts), and the Southern and Eastern Lake Kyoga Basin (Kumi District). The rainfall pattern has been described by Bakema *et al.* (1994) as bimodal. It is characterized by a long rainy season from March to June, which makes it possible to grow all major crops. A shorter rainy season follows from August to November but is less reliable, so that crop failure is quite common in this period. The maximum air temperatures for the three agro-ecological zones are more or less the same (above 30 °C), but rainfall distribution varies. In Lira, Kaberamaido and Soroti Districts annual rainfall is between 1000 and 1500 mm, in Katakwi District between 850 and 1500, whereas in Kumi District it is over 1500 mm (Rabwoogo, 1997).

Soil texture in the three agro-ecological zones varies from sandy loam to clay loam (Aniku, 2001). The proportion of land used for the cultivation of sweet potato varies from 1 to 5% in the first two zones. In the Southern and Eastern Lake Kyoga Basin this figure is between 5 and 15%. In the eastern part of this agro-ecological zone the proportion of land under sweet potato may even reach up to 35%. In the three zones, groundnut, millet, sorghum and cassava are the predominant crops (Bashaasha *et al.*, 1995; Mwanga *et al.*, 2001). In the three agro-ecological zones a number of broad valley bottoms occur with grassland communities consisting of *Echinochloa* and *Sorghastrum*, which are seasonally water-logged (Aluma, 2001). As the soils in these valley bottoms contain moisture during the dry season, farmers establish sweet potato nurseries in these swampy grasslands (Smit, 1997).

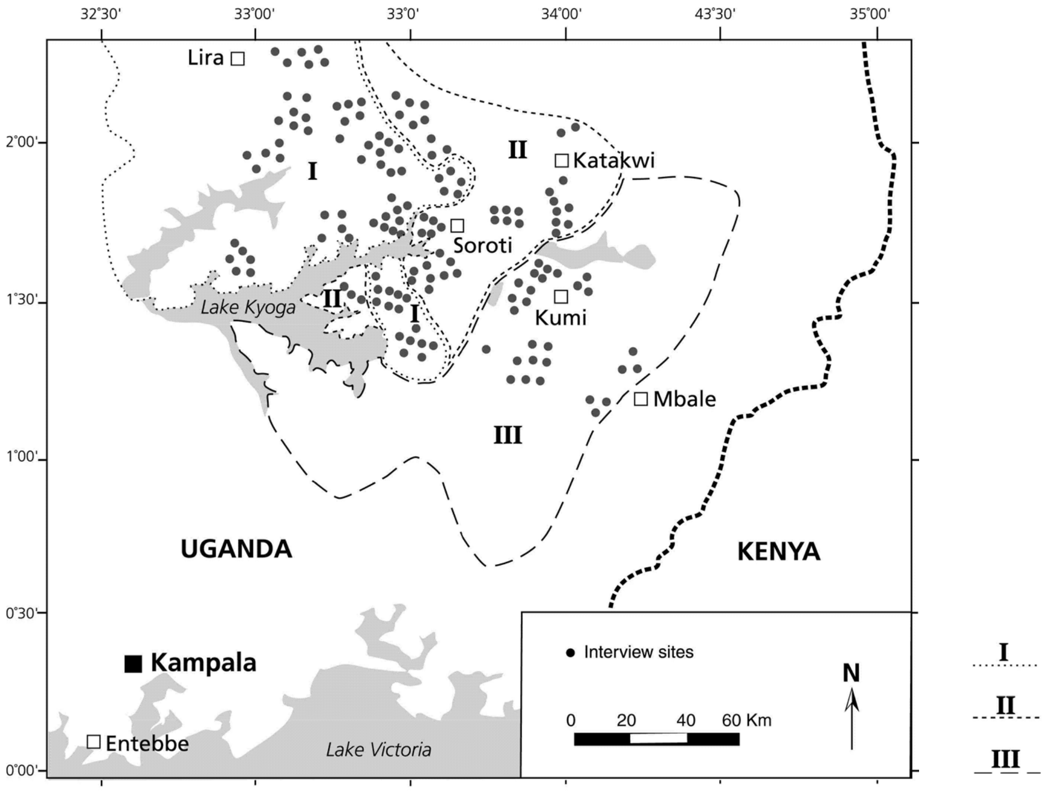

Figure 1. Map of north-eastern Uganda with location of the 3 agro-ecological zones (AEZ) and the households (black dots) where farmers were interviewed.
.... = Northern Moist Farmlands (AEZ I);
- - - - - = Northern Central Farm-Bush Lands with sandy soils (AEZ II);
– – – = Southern and Eastern Lake Kyoga Basin (AEZ III).

Interview methodology

With the assistance from extension workers and leading farmers, between five and nine sub-counties were selected per district. A preliminary survey was done to obtain information on the number of farmers in the area. Based on this information the number of interviews per sub-county was determined. Water bodies like swamps and streams were often the natural boundaries between the sub-counties and their presence might affect millipede dispersal as these insects cannot cross water.

A standard questionnaire – partly structured and partly open – for individual interviews was designed and administered. The following topics were targeted: (1) general sweet potato agronomic practices, (2) common sweet potato varieties and sources of planting material, (3) spatial dispersal of sweet potato plots, (4) type of cropping systems and sweet potato frequencies, and (5) crops not favoured after sweet potato.

Direct field observations in the presence of the farmers interviewed were made too, and interviewees were encouraged to give information freely. Farmers' crop management methods were noted. Each interview took about 1 hour and 45 minutes.

Data collection and processing

Answers from the respondents of different areas were tabled and analysed. Questions on preference for varieties and for origin of planting material included a rating. The rating was based on the preference of the most common sweet potato varieties and sources of planting material. The score decreased with decreasing preference, i.e., a score of 4 represented the first choice of farmers, a score of 3 the second, a score of 2 the third, and a score of 1 the last choice of farmers. Next, for each district, the overall score for each variable was calculated by using the formula $\Sigma\, n_i s_i \;/\; n_t$, where n_i is the number of farmers who gave score s_i and n_t is the total number of farmers interviewed.

Genstat (Anon., 1997) was used for general analysis of variance, the Kruskal-Wallis test, and matrix correlation. General analysis of variance was used to test the ranking of sweet potato varieties and source of planting material. The Kruskal-Wallis test was used to analyse the millipede and weevil incidences reported by farmers in sweet potato cropping systems, related to the three agro-ecological zones in north-eastern Uganda. The frequencies of sweet potato in the rotations were generated from the cropping systems mentioned by the respondents. Graphs were used to relate the incidences of millipedes and weevils to the interval between two sweet potato crops in the crop rotations across the agro-ecological zones. Relations were quantified using matrix correlation. Correlation coefficients (R^2) ≥ 0.25 (number of respondents in these cases 145) were considered statistically significant.

Results and discussion

General agronomic practices

Area and soils under production

Detailed information on the minimum and maximum area under sweet potato per farmer in each district is presented in Table 1.

The farmers interviewed did not apply inorganic fertilizers or available organic manure produced by their animals, and did not hesitate to grow sweet potato on less fertile, sometimes even nutrient-depleted soils. Sweet potato is known as a crop that can still do reasonably well on less fertile soils (Gibbon & Pain, 1985). Growing sweet potato on poor soils is typical for resource-poor farmers in low-input agricultural systems. However, the respondents of Lira District mostly grew their crops on loam, which generally is fertile (Table 2).

Seedbed management

In swamp areas ridges are used for nurseries, while in upland areas mounds are preferred. According to the respondents' information, ridges would enhance burrowing by rats. In the research area the number of vine cuttings planted per mound varied between 2 and 4 (Table 3), confirming earlier findings by Abidin (2004). The respondents indicated that the number of cuttings planted per mound depends on factors

Table 1. Land area per farmer under sweet potato in 5 districts of north-eastern Uganda. n = number of farmers.

District	n	Area		
		Minimum	Maximum	Mean
		(ha)		
Soroti	43	0.10	2.02	0.43
Kumi	28	0.20	1.62	0.59
Katakwi	24	0.10	2.02	0.57
Kaberamaido	23	0.20	0.81	0.39
Lira	30	0.10	1.01	0.39

Table 2. Soil texture of the farms in north-eastern Uganda (by district).

District	Soil texture			No. of farms not recorded
	Loam	Sandy loam	Clay	
Soroti	8	26	4	5
Kumi	3	18	1	6
Katakwi	3	18	0	3
Kabaramaido	15	5	0	3
Lira	21	6	0	3

Table 3. Number of sweet potato vines per mound in 5 districts of north-eastern Uganda. n = number of respondents.

District	n	Vines per mound		
		Minimum	Maximum	Mean
Soroti	38	2	4	2.5
Kumi	28	2	4	3.7
Katakwi	24	2	4	3.4
Kaberamaido	23	2	4	2.5
Lira	30	2	4	2.9

like soil fertility, availability and maturity of the vines, survival expectations, marketability and home consumption.

Weeding

Weeding is normally done one month after planting, sometimes followed by a second weeding a month later. However, the farmers interviewed underlined their experience that the vines may break if pushed aside during this second weeding. This is caused by sweet potato weevil larvae that attack the stem base causing it to swell, crack and break. To avoid this problem, many farmers do not weed a second time, hence their fields will look neglected, as noted by Smit (1997). During the process of weeding, the mound will be carefully loosened and earthed up with surrounding soil to allow water to penetrate, resulting in larger storage roots. As this earthing up of mounds also has a weed control effect and weeding close to the stem basis can disturb the storage root development, a second weeding is not really recommended by farmers. This was also reported by Abidin (2004). According to earlier research by Smit (1997), this cultivation practice could prevent sweet potato weevils from having easy access to the storage roots. On the other hand, millipedes now find a suitable environment to live in, although the respondents indicated that millipedes generally do not affect the roots until 5 months after planting. The farmers nevertheless did report weevil damage in non-mature storage roots, especially during a dry spell, confirming observations by Smit (1997).

Common varieties planted

The number of varieties reported in the study area ranged from 18 in Katakwi District to 36 in Lira District. According to farmers' information, Osukut was the most popular variety, followed – with the exception of Lira District – by Araka Red and Araka White. Osukut is an old farmer variety in the region (Smit, 1997; Abidin, 2004). The respondents in Kumi District significantly favoured Osukut, a variety wanted above all other varieties by the market in Kampala. Detailed information on varieties is presented in Table 4.

Most respondents preferred to plant a mixture of varieties, mostly based on yield performance, maturity, culinary values and tolerance to pests. According to Smit (1997) and Abidin (2004), this strategy evens out the risk of any failure and farmers have access to varieties with different useful characteristics.

Early maturing and late maturing varieties

In the interviews, the 148 respondents mentioned a total of 60 different varieties grown on their farms. Twenty-five of them were planted because they were early maturing. Nine varieties were reported to be late maturing. Also Abidin (2004) listed a number of early maturing and late maturing varieties reported by farmers in this region.

By planting early maturing varieties, farmers can harvest before the end of the growing season, and in that way can escape the risk of drought and consequently the damaging effect of weevils, which enter the soil through cracks. Farmers stated that when harvesting of sweet potato was delayed too much, millipedes affected the storage

Table 4. Some characteristics and mean scores[1] for importance of sweet potato varieties in 5 districts of north-eastern Uganda. n = number of farmers.

Variety	Characteristics	District				
		Soroti (n = 43)	Kumi (n = 28)	Katakwi (n = 24)	Kaberamaido (n = 23)	Lira (n = 30)
Osukut	Early maturing, good yield, sweet, good marketability.	2.3a[2]	3.6a	2.3a	1.3a	1.1b
Araka Red	Early maturing, good yield, tolerant to *Cylas* spp.	2.3a	1.5b	2.3a	1.8a	1.2b
Araka White	Early maturing, good yield.	2.3a	1.2b	2.6a	1.7a	1.3b
Lira Lira	Early maturing, good yield.	none[3]	none	none	1.5a	2.5a
Ateseke	Good yield.	1.3b	none	1.4b	1.7a	none
Igang Amalayan	Early maturing, good yield.	none	1.3b	1.6b	none	none
Latest	Early maturing, good yield, sweet.	1.3b	none	none	2.1a	1.4b
Osapat	Good yield.	none	1.4b	none	none	none
Ekampala	Good yield.	none	1.5b	none	none	none
Tedo Oloo Keren	Good yield, tolerant to *Cylas* spp.	none	none	none	none	1.4b
Odupa	Tolerant to *Cylas* spp.	none	none	1.3b	none	none
F-value		< 0.001	< 0.001	< 0.001	0.242	< 0.001
LSD[4]		0.5	0.5	0.7	0.7	0.5

[1] Scores on a scale of 1–4 (1 = not relevant; 4 = highly relevant). Data based on scores and numbers of respondents only.
[2] Mean scores in the same column, followed by a common letter are not statistically different ($P > 0.05$).
[3] none = no sample of this variety was found.
[4] LSD = least significant difference ($P > 0.05$).

roots, especially if the roots were stored 'in-ground on the plants' during the dry season and harvesting was done at the first rains of the new growing season. Farmers indicated that late maturing varieties were drought tolerant and could be stored 'in-ground on the plants' during the dry season. In general the crop was stored 'in-ground on the plants' a bit longer, but by the end of February most of the crop was harvested.

Table 5. Mean scores[1] of sources of sweet potato planting material for farmers in 5 districts in north-eastern Uganda. n = number of farmers.

Source of planting material	District					Across districts
	Soroti (n = 43)	Kumi (n = 28)	Katakwi (n = 24)	Kabaramaido (n = 23)	Lira (n = 30)	
Buying	1.7b[2]	2.3ab	1.7b	1.1c	1.3c	1.6b
Neighbours	1.6b	1.5cd	1.3bc	2.0b	2.3b	1.8b
Home nurseries	1.7b	2.6a	2.6a	1.2c	1.1c	1.8b
Swamp nurseries	1.6b	1.2d	1.3bc	1.1c	1.3c	1.3bc
Vines	1.1c	1.1d	1.0c	1.0c	1.0c	1.0c
Volunteers	2.8a	1.9bc	3.1a	3.4a	3.2a	2.9a
F-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
LSD[3]	0.5	0.6	0.7	0.5	0.7	0.6

[1] Scores on a scale of 1–4 (1 = not relevant; 4 = highly relevant). Data based on scores and number of respondents only.

[2] Means in the same column, followed by a common letter are not statistically different ($P > 0.05$).

[3] LSD = least significant difference ($P = 0.05$).

Sources of planting material and planting time

The sources of planting material across the districts, in order of importance, were (1) volunteer plants from previous gardens, (2) home nurseries, (3) neighbours, (4) sellers, and (5) swamp nurseries, with only the contrast between volunteer plants and the other categories being statistically significant (Table 5). With the exception of Kumi District and to some extent of Katakwi District, the use of planting material obtained from volunteer plants was often dominant (31 respondents; n = 148), especially in Kaberamaido District (43%). This corresponds with data obtained from other areas in Uganda (Gibbon & Pain, 1985; Ewell & Mutuura, 1994). With volunteers most farmers have access to their own favourite varieties. However, they can only plant if enough volunteer plants have established, which is about 6 weeks after the start of the first rains.

In order to secure enough planting material, farmers often combine a number of sources. The respondents indicated that they often supplement their planting material from volunteer plants with vine cuttings obtained from their nurseries and/or from their neighbours. The category 'buying vines' often correlated positively with the category 'from neighbours'.

Table 6 shows that planting took place from March to mid August, with a peak period from the end of May to the beginning of July. Most planting started about 2 months after the start of the growing season, after crops with a low evaporative

Table 6. Planting calendar for sweet potato in north-eastern Uganda (by agro-ecological zone (AEZ) and district). n = number of farmers.

Agro-ecological zone[1]/ District	n	Month of planting										No. of plots	No. of plantings per year (%)		
		March	April	May	June	July	Aug	Sept	Oct	Nov	Dec		1	2	3
AEZ I															
Soroti	18	5	6	1	6	3	4	0	1	0	0	26	56	44	0
Kaberamaido	23	2	3	9	8	8	6	1	1	0	0	38	48	43	9
Lira	30	2	9	6	9	4	2	3	3	1	1	40	70	27	3
Total AEZ I	71	9	18	16	23	15	12	4	5	1	1	104	59	37	4
AEZ II															
Soroti	25	2	6	8	4	5	4	1	0	0	0	30	56	44	0
Katakwi	24	1	5	10	8	5	3	1	2	0	1	36	63	35	2
Total AEZ II	49	3	11	18	12	10	7	2	2	0	1	66	59	37	4
AEZ III															
Kumi	28	10	2	12	9	6	3	1	1	1	1	46	50	39	11
Total AEZ I–III	148	22	31	46	44	31	22	7	8	2	3	216	57	37	6

[1] AEZ I = Northern Moist Farmlands; AEZ II = Northern Central Farm-Bush Lands with sandy soils; AEZ III = Southern and Eastern Lake Kyoga Basin.

demand, such as groundnut, had been planted. As long as the soil was moist enough for ridging or preparing mounds and for crop establishment, planting continued till October. However, many respondents said to prefer to plant in the first rainy season, as the rains of the second season are unreliable.

Farmers who are eager to plant in March–April for reasons of food security or to get a good price on the market, consider obtaining planting material at that time as a constraint (Abidin, 2004). Another constraint of planting early was considered the risk of losing planting material due to millipede activity.

To be able to plant at the onset of the first rains, farmers have to maintain a nursery during the dry season or obtain vine cuttings from neighbours' nurseries. About 15% of the respondents in Soroti, Kumi and Katakwi Districts have nurseries. For Kaberamaido and Lira Districts this figure is much lower, as farmers in these districts are less commercially orientated and obtain their planting material mainly from volunteer plants and neighbours.

Swamp nurseries score slightly but not statistically lower than home nurseries. The probable reason is that during the dry season many farmers drive their animals into the lower areas, where they can wander around and survive on the little available vegetation. The lush green vegetation of the sweet potato would be grazed off if the nursery is not well fenced. Ewell & Mutuura (1994) and Smit (1997) stated that there is a tendency to establish nurseries near the homesteads, because of the increasing animal pressure due to re-stocking.

During our field observations we noticed that home nurseries, which also function to supplement the families' scanty diet during the dry season, harbour relatively high populations of millipedes. This may be explained by the fact that such nurseries are often kept in shady environments (for example under a mango tree), by the role such nurseries play as a permanent food supply and by their relatively long lifetime (often more than two years).

Distance between fields

Table 7 lists farmers' statements on leaving a distance between sweet potato fields. In a number of cases few farmers maintained a reasonable distance between sweet potato fields. The most common reason for separating fields is to avoid pests, mainly weevils and millipedes (10 respondents). However, a large number of the farmers responding to this issue (116 out of 144) did not have any problem with establishing a new plot adjacent to a previous or existing one.

Infestation of sweet potato by soil pests like weevils, mostly originates from neighbouring fields, as sweet potato can be found in the field year-round. For that reason it has been suggested that spatial separation of fields or physical barriers (Smit, 1997) combined with cultivation practices like re-hilling of the mounds (Anon., 2000), could result in reduced pest infestation. However, the effects of such control strategies on millipedes need to be verified.

Life cycle and behaviour of weevils and millipedes

As biological information is essential to understand pest incidence, and for developing

Table 7. Farmers' statements on distances they leave between separate sweet potato fields in 5 districts of north-eastern Uganda. n = number of respondents.

District	n	Distance between fields (m)					No problem planting next to previous/other sweet potato field(s)
		0–10	10–25	25–50	> 50	Any	
Soroti	42	14	3	5	12	8	34
Kumi	28	14	1	2	10	1	25
Katakwi	24	13	1	3	7	0	22
Kabera-maido	20	6	0	1	7	6	16
Lira[1]							
– Bar and Amach	13	0	1	0	12	0	2
– Other	17	7	1	0	3	6	17
Total	144	54	7	11	51	21	116

[1] Bar and Amach are subdistricts.

control strategies, a short paragraph is included with a description of the life cycle and the behaviour of millipedes and weevils.

Millipedes

Millipedes are normally regarded as saprophytes, living in the soil or surface litter. They burrow through the soil and litter or penetrate underneath surface objects using the force of their legs. At night many become active on the soil surface (Marshall & Williams, 1977). The majority of millipedes eat dead plant material and fragments of organic matter. Some eat living plant parts but these usually consist of soft and easily digestible material such as young shoots, fine roots and groundnut pods (Hopkin & Read, 1992).

Eggs with large yolks are usually laid in a nest of earth (Marshall & Williams, 1977). After hatching, the minute larvae with only three pairs of legs shed their skins, acquiring more legs and more body rings after each moult. They take more than a year to reach the full size of the adult millipede. Because of their vulnerability during moulting (about three weeks in all), most millipedes seek refuge in specially constructed cells where they shed their exoskeleton (Lawrence, 1984; Hopkin & Read, 1992).

Weevils

Adult weevils are often found on the leaves, in the stem bases or in the storage roots. Eggs are laid in hollows on the stems, after which the larvae tunnel the stems downwards, causing thickening and cracking of the affected parts. Pupation takes place in the stems. When storage roots are exposed to the soil surface, weevils can lay their eggs directly into the roots. The larvae tunnel their way through the storage roots.

Debris is deposited in the tunnels. The roots respond by producing toxic terpenes, which render storage roots unpalatable. Weevils usually appear in the fields at the time when the storage roots start to develop. As planting is done during the whole growing season, populations can build up easily and the damage can be tremendous, especially during dry spells (Ames *et al.*, 1997; Smit, 1997).

Sweet potato and crop rotation

Types of cropping systems and cropping sequences

Table 8 lists the main rotation systems in the three agro-ecological zones of north-eastern Uganda. The cropping systems in these zones of the research area are diverse. Rotations vary among and even within households, depending on their requirements and priorities, as Bashaasha *et al.* (1995) noted before in other districts of Uganda. Table 9 shows that, averaged over the 3 agro-ecological zones, sweet potato most often was followed by millet (85 respondents out of 148) or groundnut (30 respondents out of 148). Also maize was grown after sweet potato, but this was, with one exception, only reported in the Northern Moist Farmlands (12 respondents out of 71). Detailed information is presented in Table 9. Also minor crops, such as sunflower, soya bean, kidney bean or another grain legume, sesame and cassava were grown after sweet

Table 8. Scheme of most common sweet potato crop rotations and the normal sweet potato frequencies (years) in the 3 agro-ecological zones (AEZ) of north-eastern Uganda.

AEZ I: Northern Moist Farmlands	Frequency
1. Sweet potato→millet→sorghum→any other crop(s) (predominantly cassava/fallow)	1 : 3
2. Sweet potato→millet→cassava/fallow→any other crop(s)	1 : 5
3. Sweet potato→millet→any other crop(s)→cassava/fallow	1 : 4
4. Sweet potato→groundnut→any other crop(s)	1 : 3
5. Sweet potato→maize→any other crop(s) (predominantly cassava/fallow)	1 : 5
AEZ II: Northern Central Farm-Bush Lands with sandy soils	
1. Sweet potato→millet→sorghum→any other crop(s)	1 : 3
2. Sweet potato→millet→cowpea→any other crop(s) (predominantly cassava/ fallow)	1 : 4
3. Sweet potato→millet→groundnut→any other crop(s) (predominantly cassava/fallow)	1 : 5
4. Sweet potato→millet→cassava/fallow→any other crops(s)	1 : 4
5. Sweet potato→groundnut→any other crop(s) (predominantly cassava→fallow)	1 : 4
AEZ III: Southern and Eastern Lake Kyoga Basin	
1. Sweet potato→millet→groundnut→predominantly cassava	1 : 4
2. Sweet potato→millet→cowpea→any other crop(s) (predominantly cassava)	1 : 3
3. Sweet potato→millet→any other crop(s)→cassava/fallow	1 : 4
4. Sweet potato→groundnut→any other cop(s) (predominantly cassava/fallow)	1 : 3

Table 9. Number of farmers planting millet, groundnut or maize after sweet potato in north-eastern Uganda, by agro-ecological zone (AEZ) and district. n = number of farmers.

Agro-ecological zone[1]/ District	n	Crop following sweet potato			
		Millet	Groundnut	Maize	Other
AEZ I					
Soroti	18	8	6	0	4
Kaberamaido	23	15	7	1	0
Lira	30	11	0	11	8
Total AEZ I	71	34	13	12	12
AEZ II					
Soroti	25	15	6	0	4
Katakwi	24	19	3	0	2
Total AEZ II	49	34	9	0	6
AEZ III					
Kumi	28	17	8	1	2
Total AEZ I–III	148	85	30	13	20

[1] See Table 6.

potato. Occasionally sweet potato was followed by a fallow period.

As for crops preceding sweet potato, in the Northern Moist Farmlands (71 respondents), 50% of the respondents grew sweet potato following a 'resting period' of 1 to 3 years under cassava or fallow. Also sorghum, millet and maize were often the preceding crop (15, 8, 5%, respectively). Beans (kidney bean or other grain legumes), sesame and groundnut scored around 5% each. In the Northern Central Farm-Bush Lands with sandy soils (49 respondents) the major preceding crops were cassava (28%), which usually lasted 2 years, groundnut (17%), the cereals sorghum (8%) and millet (7%), and sesame (8%). In this zone also sorghum or groundnut was grown before sweet potato and sometimes maize or leguminous crops preceded it (data not shown). In the Southern and Eastern Lake Kyoga Basin the preceding crops were cassava (39%), groundnut (3%), millet (10%) or sorghum (7%). In the group of 'sweet potato-groundnut' rotations sometimes also cowpea and green gram were grown before sweet potato.

Comparing the above results on the 'after-crop' with the findings of Bashaasha *et al.* (1995), it is remarkable that these authors do not mention groundnut at all, whereas our respondents often cultivated it after sweet potato.

It is striking that no respondents from Lira District grew groundnut after sweet potato (Tabel 9). The reason mentioned by the farmers was that millipedes affect groundnut during germination and pod development. The farmers in Katakwi District were of the same opinion.

Many of the farmers interviewed grew sweet potato after a 1-year fallow period or left the field under cassava, as this crop is also considered by the farmers as a 'resting crop', after which they burned the vines. In both cases the soil will recover little of its lost fertility. Cassava is well known for its potential to draw on the last resources of the soil. The short burning period leaves little organic material to decompose. Nutrients are lost due to leaching and some, particularly N and S, are easily lost to the atmosphere (Ames *et al.*, 1997). This suggests that the farmers' perception of the role of cassava and fallow in north-eastern Uganda will add to the depletion of the soil in that area. The increasing population pressure will intensify land use and so adds to the non-sustainability of the traditional cropping system.

Crops not planted after sweet potato

Table 10 presents a list of crops that are not favoured by farmers for being grown after sweet potato, especially in the Northern Moist Farmlands. Across the three agro-ecological zones, groundnut and to a lesser extent cassava, are the most important ones that together with beans (kidney bean or other grain legumes) are host plants of millipedes and other pests.

Table 10 shows that 20% of the reactions (n = 206) reflected a ban on groundnut after sweet potato. The main reasons for this were the damaging effects of millipedes on the germinating seeds and young pods (44% and 32% of the reactions, respectively) (Table 11). Also for southern and western Africa millipedes have been reported to damage groundnut (Wightman & Wightman, 1994; Umeh *et al.*, 1999).

Farmers preferred millet after sweet potato above groundnut. They claimed that millipedes caused damage in both groundnut and sweet potato but not in millet. So farmers wanted to discontinue the population build-up of millipedes. Furthermore, the sweet potato crop can suppress weed development because of its excellent soil cover.

In the Northern Moist Farmlands 24% of the respondents grew sorghum after millet in the rotation after sweet potato. After harvesting, the farmers often leave the crop residues of sorghum in the field. Sorghum has been reported to contain cyanogenic glycosides and large amounts of silicates (Van Genderen *et al.*, 1997), which may deter soil pests. Indirectly, this cultivation practice could play a role in controlling the millipede population.

The army ant is another important culprit, although not mentioned by respondents of Lira District (Table 11). For example, in Katakwi District, the incidence of damage by millipedes and army ants in groundnut and sweet potato was high and for that reason only few respondents of this district grew groundnut after sweet potato or sweet potato after groundnut.

Indifference of choice of groundnut after sweet potato

Out of the 106 reactions concerning millipedes in groundnut, 48% (altogether 59 respondents) stated that they would grow groundnut after sweet potato in spite of their awareness and concern about the damaging effect of millipedes on groundnut (Table 12).

Table 10. Crops not favoured after sweet potato in north-eastern Uganda (by agro-ecological zone (AEZ) and district). n = number of reactions.

Agro-ecological zone	n	Indifferent	Crop									
			Groundnut	Millet	Cassava	Maize	Cowpea	Bambara groundnut	Sesame	Sorghum	Beans[2]	Other
AEZ I												
Soroti		14	4	0	1	1	1	0	0	0	0	0
Kaberamaido		18	6	1	1	0	0	1	0	0	1	1[3]
Lira		28	3	5	8	1	0	0	5	3	4	0
Total AEZ I	107	60	13	6	10	2	1	1	5	3	5	1
AEZ II												
Soroti		22	6	0	1	0	1	0	0	0	0	1[4]
Katakwi		11	17	0	0	0	0	0	0	1	0	0
Total AEZ II	60	33	23	0	1	0	1	0	0	1	0	1
AEZ III												
Kumi	39	29	6	0	3	0	1	0	0	0	0	0
Total AEZ I–III	206[5]	122	42	6	14	2	3	1	5	4	5	2

[1] See Table 6.
[2] Mixture of kidney bean and other grain legumes.
[3] Pigeon pea.
[4] Tomato.
[5] Total of 206 reactions given by the 148 farmers.

Table 11. Reasons (absolute numbers; percentages in parentheses) for excluding groundnut after sweet potato in 3 agro-ecological zones (AEZ) in north-eastern Uganda. n = number of respondents.

Agro-ecological zone[1]	n	Reason					No damage
		Millipedes during:		Army ants	Volunteers	Vegetative growth	
		Germination	Pod set				
AEZ I	13	11	6	3	2	1	1
AEZ II	23	18	14	7	0	0	0
AEZ III	6	2	3	2	1	0	0
Total	42[2]	31(44)	23(32)	12(17)	3(4)	1(1)	1(1)

[1] See Table 6.
[2] A total of 71 reactions were given by the 42 respondents.

Table 12. Indifference in choice of growing groundnut after sweet potato in 3 agro-ecological zones (AEZ) in north-eastern Uganda. n = number of reactions.

Agro-ecological zone[1]	n	Awareness of millipede damage, but farmer still grows groundnut	No awareness of millipede damage in groundnut	No damage in groundnut by millipedes	Awareness of damage by army ants
AEZ I	60	34	6	17	3
AEZ II	33	19	4	6	4
AEZ III	29	6	13	1	9
Total	122	59	23	24	16
%	100	48	19	20	13

[1] See Table 6.

Why cassava and other crops are not favoured after sweet potato

Reasons mentioned by the farmers for not planting cassava after sweet potato were its lush vegetative growth, poor germination and low yield, whereas some reactions pointed out millipedes as the reason (Table 13). The respondents claimed that millipedes affect the sprouting planting material, especially when planted at the beginning of the early rains, with poor growth or vigour of young plants as a result. They also reported that if cassava is harvested late, for example after 2 years, millipedes affect its

Table 13. Reasons given by farmers in north-eastern Uganda for excluding cassava, sesame, millet, beans, cowpea, sorghum and maize as crops following sweet potato. n = number of reactions.

Reason	n	Crops following sweet potato						
		Cassava	Sesame	Millet	Beans[1]	Cowpea	Sorghum	Maize
Lush vegetative growth	12	2	3	1	2	2	2	
Poor germination	6	3	1	2				
Low yield	7	3		3				1
Volunteers	2					2		
Heavy feeder	1						1	
Spear grass	1	1						
Striga	1							1
Millipedes	7	3	1		3			
Other pests	1				1			
Total	38	12	5	6	6	4	3	2

[1] Mixture of kidney bean and other grain legumes.

roots. Millipede damage in cassava has also been reported in India (Alagesan & Ganga, 1989), South Africa (Govender *et al.*, 1996) and Colombia (E.E. Carey, personal communication).

Table 13 shows that millipedes damaged germinating beans (kidney bean and other grain legumes). This was especially the case in Lira District, again at the start of the first rains. It was also reported that finger millet did not germinate well after sweet potato. The farmers believed that this was caused by the poor soil structure after harvesting the storage roots. However, another cause might have contributed to the poor germination. For instance, Peterson *et al.* (1999) found that sweet potato has an allelopathic effect, inhibiting the germination of proso millet.

The interval between two subsequent sweet potato crops

Generally, the interval between two subsequent sweet potato crops in the cropping systems across the three agro-ecological zones varied from 1 to 7 years. As sweet potato becomes increasingly important, only few farmers maintained a long interval. Millipede incidence did not differ statistically between the agro-ecological zones ($P = 0.396$). However, a highly significant statistical difference was noted for the millipede incidence across the crop rotations. The same was true for the weevil incidence (Table 14).

Figure 2 shows the relationship between scores for relevance of weevil and millipede infestation and the interval between two subsequent sweet potato crops. Millipede incidence was significantly correlated ($R^2 = 0.4225$; n = 65) with weevil incidence.

Table 14. Average scores[1] by farmers of millipede and weevil incidence in sweet potato cropping systems in north-eastern Uganda, by agro-ecological zone[2] (AEZ). n = number of respondents.

Length of rotation[3] (years)	AEZ I (n = 68)		AEZ II (n = 49)		AEZ III (n = 28)		Across AEZ's	
	Millipedes	Weevils	Millipedes	Weevils	Millipedes	Weevils	Millipedes	Weevils
2	1.0	3.0	1.0	2.0	3.0	3.0	1.7	2.7
3	1.5	2.8	1.6	2.9	2.1	2.3	1.7	2.7
4	1.5	2.2	1.7	2.6	1.4	2.4	1.5	2.4
5	1.0	2.4	1.5	2.9	1.0	2.4	1.3	2.8
6	0.9	2.4	1.8	3.0	1.5	3.0	1.2	2.8
7	1.5	2.5	1.0	3.0	0	0	0.8	1.8
8	1.5	3.0	2.0	2.0	0	0	1.2	1.7
Mean[4]	1.3	2.6	1.5	2.6	1.3	2.0		

[1] Scores on a scale of 1–4 (1 = not relevant, 4 = highly relevant).
[2] See Table 6.
[3] Number of years in a complete sequence of crops in a rotation with sweet potato.
[4] The differences between means across crop rotations are statistically highly significant ($P < 0.001$); P-value (Kruskal-Wallis test) is 0.396 for millipedes and 0.897 for weevils.
The means for millipedes and for weevils across AEZ's are not statistically different.

In the Southern and Eastern Lake Kyoga Basin the patterns of weevil and millipede incidences were slightly different, but this was not the case in the other two agro-ecological zones. In the former zone, weevil incidence showed a stable fluctuation up to an interval of 6 years, after which it decreased. However, in the case of millipedes, the incidence decreased with increasing interval. In the other two agro-ecological zones (Northern Central Farm-Bush Lands with sandy soils and Northern Moist Farmlands) the incidences remained more or less constant.

According to the farmers interviewed, the root damage caused by millipedes followed on the damage caused by weevils. This suggests that these pests could enhance each other's entry and damage. During the dry season, when roots are kept 'in-ground on the plants', weevils are most active in the storage roots, and consequently can inflict a lot of damage. With the onset of the first rains, millipedes – attracted by the damaged storage roots – leave their hiding places. This mutual effect could also imply that control measures applied to one group of pests would affect the other one as well.

Concluding remarks

This inventory showed sweet potato to be important in the cropping systems in north-eastern Uganda. Most farmers regarded millipedes as pests of sweet potato and other

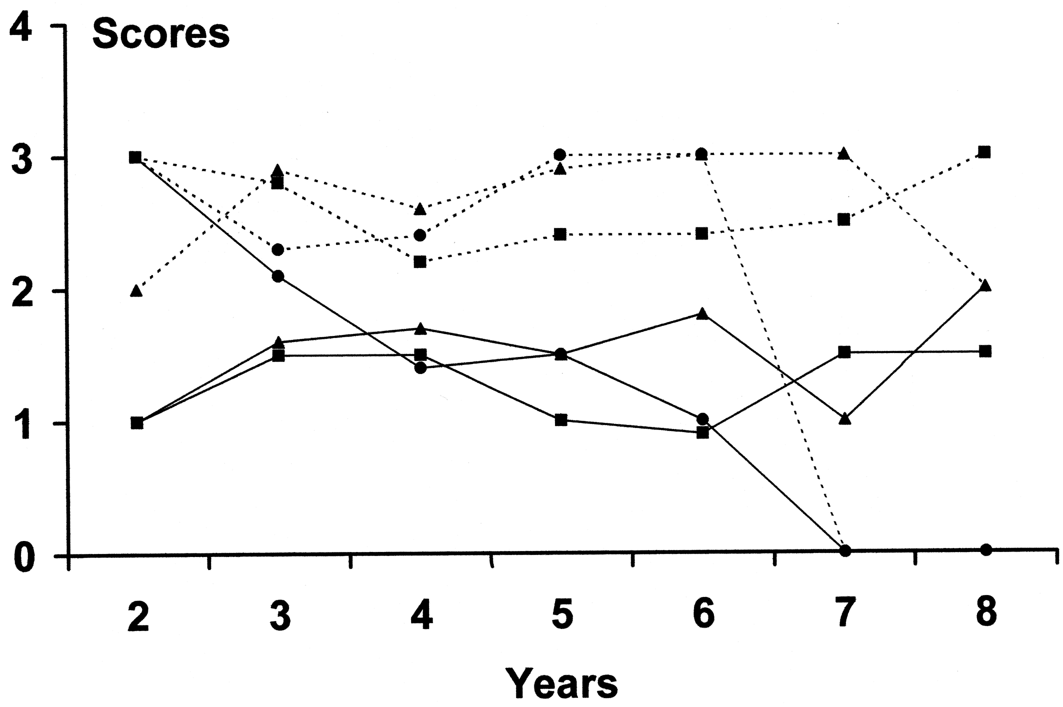

Figure 2. Relationship between scores for relevance of weevil (interrupted lines) and millipede (solid lines) infestation and interval between subsequent sweet potato crops. ● = AEZ I; ▲ = AEZ II; ■ = AEZ III. For explanation see Figure 1.

major food and cash crops. Effects of millipedes were often confounded and confused with those of other soil pests, like the sweet potato weevils. While some farmers had ideas of how to reduce pest damage in their crops, such as separating the fields, others lacked that knowledge. Methods to manage millipedes should be designed that are based on the local cropping system.

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CHAPTER 4

Farmers' information on sweet potato production and millipede infestation in north-eastern Uganda.
II. Pest incidence and indigenous control strategies

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Farmers' information on sweet potato production and millipede infestation in north-eastern Uganda. II. Pest incidence and indigenous control strategies.

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Abstract

Sweet potato (*Ipomoea batatas* (L.) Lamk) is an important staple food for the people of north-eastern Uganda. Crop yields per unit area are low partly because of biological constraints, including pests like millipedes. The objective of this study was to generate information on pest incidence and control strategies of millipedes by interviewing farmers in different districts. The respondents associated the dying of planting material with drought. However, millipedes also damaged planting material planted early in the rainy season. The sweet potato butterfly (*Acraea acerata*, Lepidoptera: Nymphalidae) was present, but considered by farmers to be insignificant. Measures to control sweet potato pests, like sanitation, were hardly implemented and insecticides were not used at all. Most respondents performed piecemeal harvesting. Whenever farmers delayed the harvest, they risked severe damage of their sweet potato crops by weevils (*Cylas* spp., Coleoptera: Curculionidae) and millipedes (Diplopoda). Millipedes pierce and tunnel the storage roots, especially when harvesting is delayed. The farmers did not mention specific natural control agents for millipedes. Knowledge about pests was generally limited, so control strategies were poorly developed, understood and applied.

Additional keywords: biological control measures, botanical pesticides, damage symptoms, Diplopoda, *Ipomoea batatas*, piecemeal harvesting, tolerant varieties

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Introduction

In Uganda, sweet potato (*Ipomoea batatas* (L.) Lamk) is grown as a subsistence crop for food security and as a cash crop (Ewell & Mutuura, 1994; Scott *et al.*, 1999; Abidin, 2004).

Cropping systems in north-eastern Uganda are diverse. The agro-ecological growing conditions and sweet potato cropping systems have been discussed recently (Abidin, 2004). In sweet potato production, cassava is often the crop preceding sweet potato, while millet, groundnut, and maize are usually the after-crop (Ebregt *et al.*, 2004).

Sweet potato storage roots are mainly grown for home consumption (Smit, 1997a; Abidin, 2004). For that reason, and because of low quality demands, a high level of tolerance of farmers to pests can be expected. Because the storage roots can only be stored for a short time, farmers practise 'in-ground storage on the plant'. As a result sweet potato crops can be found in the field throughout the year (Smit, 1997b).

The yield per unit area in Uganda is low (Anon., 2002) due to several biological, physical and socio-economic constraints. In order for the potential of sweet potato to be fully realized, these constraints must be removed. Insect pests were identified by farmers to be the most important biological constraint (Bashaasha *et al.*, 1995). For Uganda, crop losses due to sweet potato weevils (*Cylas brunneus* and *C. puncticollis,* Coleoptera: Curculionidae) of up to 73% have been reported (Smit, 1997a). Second in importance are the caterpillars of the sweet potato butterfly (*Acraea acerata*, Lepidoptera: Nymphalidae) (Bashaasha *et al.*, 1995; Smit, 1997a). Recently, the damage in sweet potato by millipedes was brought to attention (Abidin, 2004). Millipedes also attack crops like cassava, maize, groundnut and beans (kidney bean or other grain legumes), which all are part of the sweet potato cropping systems in north-eastern Uganda, and often grown in direct succession (Ebregt *et al.*, 2004). The level of damage caused by millipedes in these crops is not known, but farmers intimate that the impact is serious, especially in groundnut. Separation of plots over time and in space is often neglected and might be another factor contributing to the occurrence of millipedes (Ebregt *et al.*, 2004).

In a companion paper Ebregt *et al.* (2004) reported that millipede incidences were not statistically different for the three agro-ecological zones in the research area. It was also noted that the patterns of weevil and millipede incidences in the sweet potato cropping systems were interrelated and associated with the frequency of sweet potato. It was suggested that weevils enhance millipede attacks.

The subsistence farmers of north-eastern Uganda, and eastern Africa as a whole, cannot afford pesticides for a low-value crop like sweet potato. So control strategies based on cultivation practices are presently the most promising component of an integrated pest management strategy against many pests for small-scale sweet potato farmers (Smit, 1997a).

This paper presents the results of farmers' interviews about the relevance of pests occurring in the crop, and about pest management and its constraints. The paper focuses on the millipede problem.

Materials and methods

Interview area and methodology of collecting farmers' information on sweet potato production and millipede infestation have been described in a companion paper (Ebregt *et al.*, 2004).

Questionnaire

A standard, partly structured and partly open questionnaire for individual interviews and focused on the millipede problem was designed and administered. The following issues were targeted: (1) harvest practices, (2) pest management and its constraints, (3) ranking (incidence of) pests and damage symptoms caused by millipedes, and (4) state of planting material of sweet potato two weeks after planting.

Data collection and processing

Farmers were asked which pest caused a decline in yield or quality of their sweet potato and the rate of severity of damage they experienced by that pest. From here, the ranking of severity and the ranking of the incidence of each pest could be established by giving them a score, using a 4-nominal rating scale. For ranking the severity of the pest (incidence), scores were made as follows: score 4 = severe/serious, score 3 = moderate, score 2 = slight, and score 1 = no damage/no pest. Next, for each district, the relative ranking for each variable was calculated by using the formula $(\Sigma\, n_i s_i) / n_t$; where n_i is the number of farmers who gave ranking 1 to 4, s_i is the score 1 to 4 and n_t is the total number of farmers interviewed.

Genstat (Anon., 1997) was used for general analysis of variance to determine the ranking of pest (millipedes, weevils, rats and sweet potato butterfly) occurrence in sweet potato.

Results and discussion

Harvesting practices

Piecemeal versus one-time harvesting

When a farmer expects part of his crop to be ready, he may start to uproot the mature storage roots. A crack in the mound indicates the place where he can expect a storage root, ready to be eaten. This part by part removing the roots from plants without uprooting the plant itself is called piecemeal harvesting. Table 1 shows that piecemeal harvesting, which extends the availability of food, starts in May for those who planted early, with most of the farmers digging for their meals from June/July up to November. The majority of the respondents practised both piecemeal and one-time harvesting, confirming earlier findings by Bashaasha *et al.* (1995), Smit (1997a) and Abidin (2004).

Table 1. Number of farmers in north-eastern Uganda (by agro-ecological zone – AEZ) indicating month for piecemeal harvesting of sweet potato. n = number of respondents.

Agro-ecological zone[1]	n	Month of harvesting											No. of piecemeal harvests	Piecemeal only	Whole harvest only	Both types of harvesting
		May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March				
AEZ I	61	4	6	15	11	7	9	7	5	2	2	3	71	3	18	40
AEZ II	38	0	5	8	8	7	7	3	3	0	1	0	42	0	9	29
AEZ III	26	0	8	3	6	11	3	4	2	1	0	0	38	0	3	23
Total	125	4	19	26	25	25	19	14	10	3	3	3	151	3	30	92

[1] AEZ I = Northern Moist Farmlands; AEZ II = North Central Farm-Bush Lands with sandy soils; AEZ III = Southern Lake Kyoga Basin.

According to Smit (1997b), the practice of piecemeal harvesting has a positive effect on the control of weevil infestation. On the other hand, millipedes hardly damage the storage roots until 5 months after planting (Abidin, 2004), i.e., the storage roots are not damaged by millipedes whether farmers practise piecemeal or one-time harvesting. So the piecemeal practice cannot be considered a control strategy.

Period of harvesting and possible delays

According to the respondents in all agro-ecological zones, the final harvest was generally done in two steps, namely during July/August and December/January. There was a tendency to delay harvesting. Reason for this delay was that many respondents waited for a better market price or hoped that some more rain would come so that the storage roots would increase in size. Another reason is that during this period the rains normally have disappeared and everybody in the village is busy slicing storage roots for sun-drying in order to prepare chips (amukeke) for storage or for immediate consumption.

Respondents who planted after August often left the storage roots during the dry season in the soil, in order to harvest when food supply runs short. Weevils, however, will have heavily worked on the storage roots by now, as they are very active during dry periods (Bashaasha *et al.*, 1995; Smit, 1997a). Some farmers interviewed even left the storage roots 'in-ground on the plants' up to May/June. In this way, so the respondents claimed, there was a risk of millipede damage, especially when the rains returned and these hungry creatures returned to the topsoil from lower depths and humus-rich hiding places.

Pest management and its constraints

Susceptible and tolerant varieties

Asked about the tolerance of their varieties to weevils farmers indicated that Osukut is more or less susceptible to this pest, but that Araka Red and Araka White (whole research area) and Tedo Oloo Keren (Lira District) have some tolerance. Six respondents, five from Kamuda Sub-county (Soroti District) and one from nearby Kalaki (Kaberamaido District), reported that also Opaku (syn. Esegu), a less important variety, has some tolerance to weevils (Table 2). Research on varieties susceptible to weevils has also been described by Abidin (2004).

Additionally, farmers also mentioned 11 varieties that, according to their perception, were 'tolerant' to millipedes. These were the common varieties Araka White, Tedo Oloo Keren, Latest and Lira Lira and the less common ones Odupa, Ajara, Bibi, Chapananca, Odyong Bar, Josi-Josi and Acan-Kome-Tek. All of them were mentioned only once.

Pest control measures

As can be seen from Table 3, 85% of the respondents reported to implement a form of pest control management in their crops. The use of insecticides, especially in Kumi District, was the main pest control option, namely 55%. This is a high figure for resource-poor farmers. During the turmoil in the period 1980 – early 1990, when

Table 2. Number of farmers in north-eastern Uganda (by agro-ecological zone (AEZ) and district) who considered a sweet potato variety tolerant to sweet potato weevil (*Cylas* spp.). n = number of respondents.

Agro-ecological zone[1] / District	n	Variety										Times a tolerant variety was identified
		Araka Red	Araka White	Esegu[2]	Ateseke	Keren[3]	Osapat	Ibiolot	Osukut	Lira Lira	Okuja[4]	
AEZ I												
Soroti	18	5	2	0	1	0	0	0	1	0	0	9
Kaberamaido	23	2	1	1	1	0	0	0	0	0	1	6
Lira	30	1	1	0	0	4	0	0	0	4	2	12
Total AEZ I	71	8	4	1	2	4	0	0	1	4	3	27
AEZ II												
Soroti	25	5	3	5	2	0	0	0	1	0	0	16
Katakwi	24	1	1	0	2	0	1	3	0	0	0	8
Total AEZ II	49	6	4	5	4	0	1	3	1	0	0	24
AEZ III												
Kumi	28	4	2	0	0	0	4	0	2	0	0	12
Total AEZ I–III	148	18	10	6	6	4	5	3	4	4	3	63

[1] See Table 1.
[2] Esegu is synonym for Opaku.
[3] Keren = Tedo Oloo Keren.
[4] Okuja is synonym for Namuhenge.

many people lost their lives and properties, important traditional information and working knowledge on agricultural technologies declined. In that situation, pesticide agents, often through extension officers, easily obtained a foothold to promote and sell their products, which were mostly Ambush (a.i. permethrin) and Fenkill (a.i. fenvalerate). Both are mainly used against aphids in legumes. The re-introduction of cotton, with its extraordinarily high use of subsidized insecticides, consolidated the idea under many smallholders that these chemicals were the only control measures against pests. So other pest control strategies were neglected.

Mechanical control, which followed the use of insecticides in importance, was mostly done by means of uprooting (mainly cassava with Cassava Mosaic Virus) and killing pests by hand. The use of insecticides in sweet potato was not reported, which is in contrast to other districts in Uganda (Bashaasha *et al.*, 1995). The use of an extract of the neem tree (*Azadirachta indica*) leaves was only mentioned once.

Table 3. Number of farmers practising pest control measures in north-eastern Uganda (by agro-ecological zone (AEZ) and district). n = number of respondents.

Agro-ecological zone[1] / District	n	Control measures								
		In general					In sweet potato			
		Yes	Insecticides		Hand-picking	Use of botanicals	Destruction of debris		Resistant varieties	Other
			Yes	No			Vines	Roots		
AEZ I										
Soroti	18	13	10	8	10	0	3	2	10	4
Kaberamaido	23	19	7	16	15	10	8	2	7	3
Lira	30	28	16	14	14	3	10	5	16	1
Total AEZ I	71	60	33	38	39	13	21	9	33	8
%	100	84	46	54	55	18	30	13	46	11
AEZ II										
Soroti	25	20	15	10	11	4	9	4	11	1
Katakwi	24	19	11	13	18	11	2	1	13	0
Total AEZ II	49	39	26	23	29	15	11	5	24	1
%	100	80	53	47	59	31	22	10	49	2
AEZ III										
Kumi	28	27	23	5	13	2	1	1	13	1
%	100	96	82	18	46	7	4	4	46	4
Total AEZ I–III	148	126	82	66	81	30	33	15	70	10
%	100	85	55	45	55	20	22	10	47	7

[1] See Table 1.

According to the respondents, leaving most of the crop residues including the small or badly affected storage roots in the field immediately after harvesting, is common practice in sweet potato production especially in Kumi District. Crop residues are left for cattle to feed on and for vine regeneration. Often the small roots were buried to stimulate the development of volunteer plants. So weevils and millipedes could survive in the storage roots during the dry season. At the beginning of the next growing season, the excess of volunteers and affected storage roots is usually piled in heaps outside the field, from where millipedes can easily affect after-crops like groundnut, beans (kidney bean or other grain legumes), cassava and maize, besides sweet potato. Sometimes, the infested tubers are taken home, after which the bad parts are cut off and thrown away. The weevils and millipedes will still survive in them. Only eight respondents reported destroying millipedes manually or by burning them.

Use of botanical pesticides

Botanical insecticides were hardly used, with the exception of ash (Table 4). One farmer used a mixture of extracts of leaves from the neem tree, tobacco and chillies. Other plants used were a pine tree called 'ajerabos' and the Lira tree (*Melia azedarach*), which is a member of the same family (Meliaceae) as the neem tree. Striking during the discussions was that one or two generations back the use of botanicals was quite normal, but they have been 'forgotten' in spite of the fact that the technique of preparing botanical pesticides is based on a simple technology (Stoll, 1992).

Table 4. Number of farmers in north-eastern Uganda (by agro-ecological zone (AEZ) and district) using botanical pesticides. n = number of respondents.

Agro-ecological zone[1] / District	n	Botanical pesticide				
		Neem	Tobacco	Chillies	Ash	Other
AEZ I						
Soroti	18	0	0	0	0	0
Kaberamaido	23	0	0	0	10	0
Lira	30	0	0	0	3	0
AEZ II						
Soroti	25	0	0	0	0	0
Katakwi	24	3	1	1	8	3[2]
AEZ III						
Kumi	28	1	0	0	2	1[3]
Total	148	4	1	1	23	4

[1] See Table 1.
[2] Ajerabos, Lira tree and pine trees.
[3] Ajerabos.

Exceptional control measures

Exceptional control methods were prompt harvesting and avoiding harvesting in March/April. One respondent reported the use of a trap plant, amalakwang (*Hibiscus sabdariffa*), a common wild vegetable in the area, for attracting weevils and sweet potato butterflies, after which he killed them.

Natural control agents

Many respondents mentioned that farm animals like chickens, ducks, turkeys and pigs feed on millipedes. It was not clear whether these animals really eat millipedes as part of their diet, or whether it was out of hunger. As it so happens, the influx of millipedes coincides with the beginning of the first rains (Ebregt *et al.*, 2004), when livestock is lacking feed.

Four respondents observed true crickets (Gryllidae) feeding on millipedes. At least in a number of cases the remains of a millipede were found near the entrance of a cricket's underground burrow. Three other farmers informed us about army ants, while two others saw scorpions predating on millipedes, as had also been observed before by Lawrence (1984) and Herbert (2000). However, in Murchison Falls National Park, Uganda, it has also been noticed that millipedes in turn fed on dead scorpions (E. Ebregt, personal observations). Furthermore, farmers saw a crow, an owl and an Abdim's stork (*Ciconia abdimii*) feeding on millipedes, although no literature could be found to confirm this. Probably due to the lack of knowledge about birds, no other birds were mentioned. Maclean (1993), however, lists a number of bird predators of millipedes in South Africa, and singles out Hadeda ibis (*Bostrychia hagedash*), Grey heron (*Ardea cinerea*), Helmeted guinea fowl (*Numida meleagris*), Crested guinea fowl (*Guttera pucherani*), Woodland kingfisher (*Halcyon senegalensis*), Rufous-naped lark (*Mirafra africana*), Fawn-coloured lark (*Mirafra africanoides*), Schalow's wheatear (*Oenanthe oenanthe*) and the Spectacled weaver (*Ploceus ocularis*). All of these birds are also a part of the natural ecosystem, permanently or during migration, of north-eastern Uganda (Williams & Arlott, 1995). However, none of them is known to make a habit of destroying millipedes by choice or of making them the main item of their diet (Lawrence, 1984). Small burrowing animals might also feed on them (Lawrence, 1984) and numerous eggs must also form the meals of soil scavengers (Hopkin & Read, 1992), but according to the latter authors there is little quantitative information on the number of millipedes that fall victim to predators.

Unfamiliarity with pests and their life cycles

During the exercise of identifying sweet potato weevils, rough sweet potato weevils, tortoise beetles and small (Odontopygidae) and big (Spirostreptidae) millipedes, the respondents in most cases were familiar with both kinds of millipedes. In 87% of the interviews (92 respondents; n = 106), the small millipede was identified as the culprit, piercing the storage roots of sweet potato. During this exercise it generally appeared that the respondents had a poor working knowledge of other pests and of general control measures, the importance of which was not completely understood. Smit (1997a) suggested that life cycles and behaviour of the major pests should be explained to the farmers, so that they better understand the insects' mode of dispersal.

Unintentional control measures

Many control strategies, such as shallow ploughing, were implemented without the full awareness of their importance. Even hand-picking and roguing were probably done on a larger scale. A number of control methods based on cultivation practices are difficult to implement, especially in sweet potato. For instance, planting early in the growing season is rarely done. Mainly the commercial farmers do this as they try to fetch the best price for their produce. Respondents claimed that early-planted vine cuttings risk to be attacked by millipedes and many farmers also preferred first to plant millet and groundnut in the relatively weed-free field previously used for growing sweet potato. Simultaneous planting and legislation on not growing sweet potato in a certain period of the year are not feasible in Uganda. And harvesting without delay is often not an option, as many respondents still want to await some more rain and target the best market for their produce, and so wait till the price suits them. Farmers also preferred to leave some of the crop in the field to supplement their scarce diet during the dry season. In this period the sweet potato weevil will cause a lot of damage in the storage roots.

Damage symptoms caused by millipedes

Importance of millipedes in sweet potato

In all districts, the respondents indicated weevils as the most important pest (Table 5), confirming earlier studies by Bashaasha *et al.* (1995) and Smit (1997a). Millipedes and rats follow as second, the former playing a less significant role in Soroti District, according to farmers' information. This is in contrast to earlier reports by Lawrence (1984) stating that millipedes are not pests of primary importance. The caterpillars of the sweet potato butterfly are largely considered of less importance, which contrasts with findings in other parts of Uganda (Bashaasha *et al.*, 1995) and in Rwanda (Hitimana, 2001). However, according to farmers' information this pest can occasionally become a nuisance, entirely defoliating sweet potato fields, especially during dry spells. Literature shows outbreaks to be seasonal, and usually to occur at the beginning of the dry season (Skoglund & Smit, 1995; Ames *et al.*, 1997). Lugojja (1996) and Smit (1997a) suggested that one complete defoliation does not have much effect on yield. The latter author even hinted that farmers might overrate the nuisance.

It is generally assumed that millipedes merely aggravate the damage initiated by some other agents (Lawrence, 1984; Blower, 1985; Hopkin & Read, 1992). Weevils often affect storage roots, especially during dry spells. If storage roots are kept too long in the soil, weevil injuries can attract millipedes (Ebregt *et al.*, 2004). Results from our study show that 78% of the respondents experienced that the weevils attack storage roots before the millipedes.

In the case of planting material, the millipedes might be attracted by newly planted vine cuttings because of the injury and because of the easily available digestible material. A number of respondents were reasoning in this way.

Millipede damage in sweet potato

Out of the 148 farmers interviewed, 126 respondents experienced damage in sweet potato caused by millipedes. Farmers in all districts reported that the onset of the damage could start, although very slightly, when the storage roots were 2 months old. Most farmers experienced the start of the impact on storage roots when these were 5 months old. After this, millipede activity tended to slow down. Based on our farm-walk observations and the daily experience of our farmers in the field, the periods of

Table 5. Mean scores[1] of ranking pests and their incidence in sweet potato, in 5 districts of north-eastern Uganda. n = number of respondents.

Pest	District									
	Soroti (n = 43)		Kumi (n = 28)		Katakwi (n = 24)		Kaberamaido (n = 23)		Lira (n = 30)	
	Ranking	Incidence	Ranking	Incidence	Ranking	Incidence	Ranking	Incidence	Ranking	Incidence
Millipedes	2.4c[2]	2.4b	2.5b	2.8b	2.8b	2.7b	2.4b	2.3bc	2.8b	2.5b
Weevils	3.6a	3.5a	3.7a	3.5a	3.7a	3.7a	3.6a	3.5a	3.6a	3.7a
Sweet potato butterfly	1.0d	1.5c	1.2c	2.1c	1.0d	1.8c	1.6c	1.9c	1.2d	1.7c
Rats	2.8b	2.7b	2.3b	2.5b	2.4c	2.4b	2.6b	2.6b	2.2c	2.4b
Other vertebrates[3]	1.4d	1.4c	1.3c	1.4d	1.2d	1.4d	1.2c	1.3d	1.0d	1.0d
F-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
LSD[4] ($P = 0.05$)	0.4	0.3	0.4	0.4	0.4	0.4	0.6	0.5	0.4	0.4

[1] Importance and incidence were scored on a scale of 1–4 (1 = unimportant and low, respectively; 4 = very important and high, respectively).

[2] Mean scores in the same column, followed by a common letter are not statistically different ($P > 0.05$).

[3] Goats, pigs, cows, baboons and velvet monkeys.

[4] LSD = least significant difference.

low millipede activity and re-activation correspond with the dry season and the onset of the rains, respectively. In contrast, the respondents of Lira District experienced another pattern. Here the less active period started early, when the crops were at least 2 months old.

Most farmers complained about pierced and burrowed storage roots, and often found millipedes inside them. Tunnels are filled with the insects' excrements and with trash, causing the roots to rot. This damage may heal if it takes place in a very early stage of root development.

Millipede damage in groundnut

Seventy percent of the respondents indicated to have problems with millipedes in groundnut. According to the farmers, damage can occur in the seedling stage and/or during pod development and pod filling. The cotyledons of the seedlings are partly pierced or completely eaten, often only leaving behind the testa, and/or the radicle may be consumed so that germination will fail. During pod development and pod filling millipedes pierce the young pegs and destroy the young seeds, which will leave the plant with empty pods. Ebregt *et al.* (2004) showed that 20% of the respondents did not grow groundnut after sweet potato for these reasons. Many other farmers are aware of the problem, but still grow groundnut after sweet potato. One farmer in Kaberamaido District even indicated that it was not an economically worrying problem for her, although she was aware of the fact that the millipede incidence in her sweet potato was severe and that germination and pod filling of her groundnut crop were affected. An intensive survey of soil insects in approximately 100 groundnut fields in Malawi, Zambia, Zimbabwe, Tanzania and Botswana showed that millipedes were generally present, but rarely in sufficient numbers to warrant concern (Wightman & Wightman, 1994). In the cropping season of 1996 in Mali, Burkina-Faso, Niger and Nigeria, it was found that 9.3% of the surveyed groundnut fields were attacked by millipedes (Umeh *et al.*, 1999). However, in Uganda, following an outcry from farmers in Gweri Sub-county (Soroti District) in 1999 about millipedes attacking sweet potato, groundnut and other crops, a follow-up survey did not show that millipedes contributed to the death of plants. This problem of the millipede being an economic pest in groundnut has been studied further (Ebregt *et al.,* submitted).

Millipede damage in other crops

A relatively long list of crops not favoured to be planted after sweet potato has been published by Ebregt *et al.* (2004). According to farmers' information, over-mature cassava roots can be burrowed and millipedes can eat the young sprouts of cassava cuttings, especially in the period March–May. Millipedes are also attracted by injuries created on cassava roots due to weeding or foraging rats. Germinating maize, beans, soya bean, bambara groundnut and green gram are also hosts, especially at the onset of the early rains. The respondents also reported millipedes burrowing banana pseudo-stems and cabbage. Even germinating cotton and sunflower seeds were mentioned.
In all situations moisture content of the soil or the host plant, like in the case of the pseudo-stem of banana, should be high enough.

State of planting material of sweet potato two weeks after planting

The need for infilling after two weeks

Farmers claimed that not all vine cuttings will have established within two weeks after planting. For that reason infilling, if vines were available, was often done after 2 weeks. Especially in Kumi and Katakwi Districts, and to a lesser extent in Soroti, planting material does not establish well. The survival of vine cuttings was more or less related to the conditions in the agro-ecological zones, with an exception of Soroti District (Table 6).

Table 6. Number of farmers in north-eastern Uganda (by agro-ecological zone (AEZ) and district) who had suffered non-establishment of sweet potato vine cuttings 2 weeks after planting. n = number of farmers.

Respondents	Agro-ecological zone[1] and district						Total
	AEZ I			AEZ II		AEZ III	
	Soroti (n = 18)	Kaberamaido (n = 23)	Lira (n = 30)	Soroti (n = 15)	Katakwi (n = 24)	Kumi (n =28)	(n = 138)
Number	0	16	13	4	0	0	33
%	0	70	43	27	0	0	24

[1] See Table 1.

Causes of vine cuttings failing to establish

The respondents mentioned drought as the most common cause for planting material failing to take off, confirming earlier reports by Bashaasha *et al.* (1995) and Smit (1997a). The farmers stated that the most important biological constraints are millipedes, weevils, rats and other (unknown) pests. Unhealthy planting material, wrong planting methods and roaming farm animals are other causes (Table 7). Table 8 shows that only 30% of the farmers interviewed 'inspect' the inside of the mounds, enabling soil pests like millipedes to hide unnoticed. On top of that, many respondents pull the remains of the planting material out of the mound, without thoroughly inspecting the vines. During our own inspections, the mound was opened carefully around the remains of the planting material. In this way we often found the millipede coiled around the remains or in the vicinity of it. For this reason it may be expected that the actual incidence of millipedes could have been much higher had farmers used this method of inspection. Sweet potato weevils were hardly reported by our respondents. But due to the fact that most farmers are not familiar with the insect's life cycle, weevils may have been overlooked. In this study, rats were mentioned as a minor problem. Rats have a marked habit of collecting vine cuttings as nesting material. Smit (1997a) warned for the possibility that farmers overrate rat damage, as it looks more dramatic than weevil damage.

Table 7. Causes of failure of sweet potato vine cuttings to establish, in 5 districts in north-eastern Uganda. n = number of respondents[1].

Cause of failure	District					Total
	Soroti (n = 39)	Kumi (n = 28)	Katakwi (n = 24)	Kaberamaido (n = 16)	Lira (n = 13)	(n = 120)
Drought	24	24	15	15	11	89
Millipedes	11	2	3	1	2	19
Weevils	1	2	2	0	2	7
Rats	5	0	0	0	0	5
Farm animals	3	0	0	0	0	3
Unknown pest	3	5	4	3	3	18
Poor planting material	2	2	2	1	0	7
Wrong planting method	2	2	2	0	0	6
Other	1	0	0	0	1	2
Unknown	2	3	5	0	1	11

[1] Only respondents with crop establishment problems are considered; more than one reaction per farmer is possible.

Table 8. Farmers' methods of checking sweet potato vine cuttings for pests, in 5 districts of north-eastern Uganda. n = total number of farmers inspecting.

District	n	Farmers pulling up plants		Farmers inspecting inside of mound	
		Number	%	Number	%
Soroti	36	23	64	13	36
Kumi	31	24	77	7	23
Katakwi	24	17	71	7	29
Kaberamaido	19	14	74	5	26
Lira	15	10	67	5	33
Total	125	88	70	37	30

Damage symptoms of 2 weeks old dying planting material

According to the respondents, the aboveground parts of non-established planting material often showed symptoms of desiccation, though in many cases the cuttings tried to take off. Frequently the underground parts of dying vine cuttings were rotten or dried up. However, 12 out of the 120 respondents who inspected their vine cuttings reported that the planted material started to develop roots, but that 'something'

Table 9. Number of farmers in north-eastern Uganda (by district) rating millipedes, weevils and drought as stress factors for establishing sweet potato vine cuttings, and period when millipedes were considered a problem. n = total number of farmers.

District	n	Stress factor			Period most important for millipedes		
		Millipedes	Weevils	Drought	1st planting	2nd planting	Both plantings
Soroti	43	10	2	2	10	0	0
Kumi	28	2	1	2	0	1	1
Katakwi	24	3	2	2	1	2	0
Kaberamaido	23	1	0	1	1	0	0
Lira	30	2	1	1	2	0	0
Total	148	18	6	8	14	3	1

chewed away the new developing roots. In this way water uptake was blocked, resulting in wilting and finally rotting of the planted cutting. Six of these farmers inspected the inside of the mound and 3 of them pointed out the millipede as the culprit.

Eighteen respondents reported millipedes to be responsible for the destruction of planting material, often in combination with drought (Table 9). Moreover, more than 75% of the respondents appeared to have experienced this impact of millipedes on sweet potato planting material during the early rains of the first rainy season. This tallies with earlier reports from farmers (Abidin, 2004).

We will soon report in detail on the identification of the millipede species involved (Ebregt *et al.*, submitted).

Concluding remarks

Farmers take the presence of millipedes in sweet potato for granted. Certain control strategies based on cultivation practices and implemented by the farmers in north-eastern Uganda actually enhance the incidence of millipedes in the sweet potato cropping system. Furthermore, farmers' knowledge on this issue is limited, and so is their understanding of the life cycles of the most common sweet potato pests. Attention has to be paid to these issues if sweet potato production is to be increased.

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CHAPTER 5

Pest damage in sweet potato, groundnut and maize in north-eastern Uganda with special reference to damage by millipedes (Diplopoda)

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Pest damage in sweet potato, groundnut and maize in north-eastern Uganda with special reference to damage by millipedes (Diplopoda)

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Abstract

Field experiments were conducted in Soroti District, north-eastern Uganda, an area with two rainy seasons per calendar year, the first one with long, reliable rains and a second one with short, less reliable rain. The trials were with sweet potato (*Ipomoea batatas* (L.) Lamk), groundnut (*Arachis hypogaea* L.) and maize (*Zea mays* L.) and aimed at collecting information on the incidence of millipede damage. Failure of sweet potato cuttings to establish caused by biotic stress varied from 4 to 33%. A significant but variable proportion of that biotic stress was caused by millipedes. Millipedes of the species *Omopyge sudanica* were responsible for the loss of up to 84% of the sweet potato cuttings if the crop was planted early in the first rainy season. During bulking hardly any damage was inflicted on the storage roots. When the tubers were stored 'in-ground on plants' during the dry season, millipedes in combination with other insect pests affected up to 86% of the tubers at the onset of the rains of the following growing season. Data on groundnut and maize were taken on plots where in the previous season sweet potato had been grown. Early in the first rainy season, *O. sudanica* also caused damage in germinating groundnut, causing plant losses of 12–29%. Maturing groundnut seeds were affected for 39%. Millipede damage in germinating maize seeds in the first and second rainy seasons amounted to 34% and 29%, respectively. The species *O. sudanica*, *Spirostreptus ibanda* and *Tibiomus* spp. cfr. *ambitus* were found in the vicinity of the maize seeds but were only found feeding on them during the second rainy season. More research is needed to quantitatively assess economic damage to crop production caused by millipedes.

Additional keywords: *Arachis hypogaea*, crop establishment, cropping system, *Ipomoea batatas*, *Omopyge sudanica*, *Spirostreptus ibanda*, *Tibiomus* spp. cfr. *ambitus*, *Zea mays*

Introduction

In Uganda, sweet potato (*Ipomoea batatas* (L.) Lamk), groundnut (*Arachis hypogaea* L.) and maize (*Zea mays* L.) are important food and cash crops. Sweet potato is mostly grown as a subsistence crop by resource-poor farmers in a non-seed carbohydrate staple food system (Smit, 1997), in which banana, cassava and Irish potato are the other components (Ewell & Mutuura, 1994; Smit 1997). Sweet potato is rich in carbohydrates and vitamin A (Anon., 1998) and can be stored during the dry season 'in-ground on plants' (Smit, 1997). After the common bean, groundnut is the second most widely grown legume in Uganda. Groundnut provides the farmer with a source rich in protein and fat. It also plays an important role as a nitrogen-fixing crop. Maize is becoming increasingly important in Uganda since the introduction of drought-tolerant varieties, such as Uganda Hybrid B. Especially in the Lira District it is an important source of food.

The rainfall pattern of north-eastern Uganda is bi-modal (Bakema *et al.*, 1994), characterized by a season with long rains from March to June, in which all major crops can be grown. A season with shorter, less reliable rains follows from July to November. So crop failure is common in this period.

Many farmers plant sweet potato at the onset of the first rains of the season with the long rains so as to secure the families' food supply and to sell their produce at the highest price when the market is not yet flooded with sweet potato (Smit, 1997; Abidin, 2004; Ebregt *et al.*, 2004a, b). However, most farmers prefer to plant groundnut first, because seed of that crop is available early and in case of late sweet potato harvesting, the land is reasonably weed-free. Lack of sweet potato planting material in the beginning of the growing season (Smit, 1997; Abidin, 2004; Ebregt *et al.*, 2004a) and the risk of millipedes affecting early planted material (Abidin, 2004; Ebregt *et al.*, 2004b) are other reasons to plant sweet potato late.

The final harvest of sweet potato in the second growing season usually takes place at the beginning of the dry season, i.e., December and January. During this period the dry weather will be suitable for sun-drying the storage roots (Abidin, 2004; Ebregt *et al.*, 2004b). Some farmers store the tubers 'in-ground on plants' in order to have fresh storage roots to supplement the scanty diet during the dry season. However, during the dry season, weevils affect the storage roots seriously (Smit, 1997) and from the onset of the first rains after the dry season millipedes also cause damage (Ebregt *et al.*, 2004a, b).

After the sweet potato harvest, the plant debris is left behind and non-consumable roots are buried intentionally to stimulate the regeneration of volunteer plants (Smit, 1997; Ebregt *et al.*, 2004a). This material provides millipedes and weevils with food, and breeding and hiding places.

The sweet potato crop has a good canopy cover. So the harvesting of sweet potato leaves the fields free from weeds and easy to prepare for planting subsequent crops. At the onset of the rains in March, many of these fields are planted with groundnut or maize. Millipedes are normally regarded as saprophytes, eating dead plant material. But millipedes can also eat living plant parts, especially the soft and easily digestible material. This may include germinating seeds, seedlings, fine roots, groundnut pods or sweet potato cuttings. Millipedes lay eggs in a nest of earth. After hatching, the larvae take more than a year to reach full size. They moult frequently and are very vulnerable during moulting, seeking refuge in specially constructed cells. Millipedes moving from the sweet potato host may cause considerable damage in germinating groundnut and possibly maize, when these crops are planted at the start of the first rains. So many farmers hesitate to plant groundnut as an 'after-crop' of sweet potato (Ebregt *et al.*, 2004a).

The extent of damage caused by millipedes in sweet potato, groundnut and maize in north-eastern Uganda is not well known. Concern is warranted, because farmers also acknowledged cassava, the predominant crop preceding sweet potato in north-eastern Uganda, as a host crop to millipedes. Moreover, farmers also reported millipede damage in kidney bean, cowpea, green gram and soya bean, all crops included in the cropping system of north-eastern Uganda (Ebregt *et al.*, 2004a, b).

This paper reports on observational experimentation on the extent of damage and damage symptoms caused by pests, millipedes in particular, in sweet potato, groundnut and maize. Millipede species found in fields with several host crops in the Soroti District of north-eastern Uganda will be identified. Genetic variation in sweet potato in millipede damage, suggested by Abidin (2004) and Ebregt *et al.* (2004b) will also be analysed.

Materials and methods

Site characteristics and trial set-up

Sweet potato trials

Variety trials with sweet potato were conducted on sandy loam and on clay loam at the stations Arapai and Serere, and on sandy loam on-farm at Dokolo and Abalang, all in Soroti District, north-eastern Uganda. The trials were set up at the beginning of the season with the short rains of the year 2000 (July/August) and at the start of the season with the long rains of 2001 (March/April).

The four trials in Arapai and Serere were of the same design: a randomized complete block with 16 varieties, replicated 3 times. A plot consisted of two rows, each with 10 mounds and 3 vine cuttings per mound. So the number of vine cuttings planted per variety and per trial was 180 and 2880, respectively.

The trials at Dokolo and Abalang were also of the randomized complete block design and were replicated 3 times, but only 6 varieties were compared. A total of 1080 vine cuttings were planted at each location.

Besides the Ugandan cultivars NASPOT 1 (in Serere), NASPOT 6 (in Abalang) and NASPOT 5 (in Dokolo), five farmer varieties were included that had been selected by the farmers: Ejumula, Ekampala, Etelepat, Osapat and Opong Bur B (Abidin, 2004).

Moreover, a sweet potato production field was set up at Arapai on sandy soil. The area had been fallow for more than 10 years and no trees were present in its surrounding because of frequent bush fires. The crop was established in April 2001. The storage roots remained 'in-ground on plants' during the following dry season (December

2001 – April 2002). During this period observations were taken on the incidence of storage root pests.

In addition, a trial of the International Potato Center (CIP, Lima) on clay loam at Serere station was used for data collection on pest infestation (with emphasis on millipedes). This trial, which was conducted during the first rainy season of 2001, was also of a randomized complete block design with 3 replicates, but now 20 varieties were compared. Each plot consisted of one row with 20 mounds, 3 vine cuttings per mound. A total of 3600 vines were planted.

Groundnut trials

At Arapai (sandy loam soils), two groundnut trials were planted at the beginning of the first rainy season of the years 2001 and 2002, with the varieties Igola-1 (local name India) and Serut-3 (local name Rudu-Rudu), respectively. Sweet potato was the preceding crop in both trials. On the site of the 2002 trial sweet potato had been grown previously for two successive years. In both trials, the sweet potato storage roots had been harvested in January–February. The groundnut trial of 2001 was planted on fertile soil in a surrounding without shrubs or trees, whereas the one of 2002 was planted on less fertile soil. Nearby there were some bark-cloth figs (*Ficus natalensis*) with a dense canopy and an undergrowth of shrubs.

The groundnut trials consisted of 6 plots, 5 m apart, each with six 1.35-m rows, 40 cm apart. Per row, 10 seeds were planted one by one, 5 cm deep, at a distance of 15 cm in the row. The locations of the seeds were marked with thin metal pegs.

Maize trials

Two trials with the maize variety Uganda Hybrid-B were planted in 2002, one at the beginning of the first rainy season and one during the second rainy season. The preceding crop in both trials was sweet potato. A bark-cloth fig, with an undergrowth of shrubs was near the second rainy season trial.

The trial in the first rainy season consisted of 4 plots, each with 5 rows of 3.75 m. The second trial consisted of 4 plots; each plot had 2 replicates. Each replicate had 5 rows of 7.5 m. The four plots had different environments. We therefore prefer to indicate them from hereon as Environment 1, 2, 3 and 4.

Planting depth in both trials was 3 cm, 2 seeds per planting hole and a spacing of 30 cm × 75 cm. Also in these trials the locations of the seeds were marked with metal pegs.

Data collection and processing

Millipede identification and behaviour

Dr C.A.W. Jeekel identified the millipedes and provided useful information on the life cycle and behaviour of the different millipede species.

Other pests were not taxonomically identified or sampled, but records were made about their presence.

Sweet potato trials
Fourteen days after planting (14 DAP), the trials were inspected for crop establishment. The not established cuttings were counted. Damage symptoms were recorded by pulling out the cutting and possible causal agents were identified. Observations below soil surface to reveal soil pests from mounds with not established cuttings were done too.

At harvesting, the total number of storage roots (marketable and non-marketable) of each genotype, total number of storage roots damaged by pests and number of storage roots infested by a specific pest (sweet potato weevils (*Cylas brunneus* and *C. puncticollis*), rough sweet potato weevils (*Blosyrus* spp.), nematodes and/or millipedes) were counted. Harvesting was carried out 4 months after planting for the on-station trials and 5 months after planting for the on-farm trials.

The numbers of storage roots of the 2001 first rainy season sweet potato trials conducted in Arapai, Serere, Dokolo and Abalang were transformed into percentages by using the formula $x = s_i/n_t \times 100$, where n_t is the total number of storage roots of a specific genotype harvested (marketable and non-marketable) and s_t is the total number of storage roots of that genotype damaged by a specific pest.

Sweet potato tubers stored 'in-ground on plants'
Depending on the occurrence of occasional showers, at least once a month, a sub-plot with 100 mounds (300 plants) was selected at random. Each mound was inspected to determine the number of tubers damaged by sweet potato weevils, rough sweet potato weevils, millipedes, nematodes or rats. The average percentages of tubers damaged by these agents were recorded for each month in the period November 2001 – April 2002.

Groundnut trials
Ten to 15 days after planting (10–15 DAP), the number of germinated seeds were counted. Per plot, the not germinated seeds were carefully removed, counted and the causes of failure and the damage recorded. The seeds affected by millipedes were counted separately and the data transformed into percentages. For the trial carried out in 2002 also the number of pods per plot was counted. Pods damaged by millipedes were counted separately.

Maize trials
Ten days after planting (10 DAP), data on germination and pest damage were collected. For the trial of the first rainy season simple calculations were used to determine the percentage millipede damage in germinating seed.

For the second rainy season trial, the number of missing seeds and the seeds damaged by millipedes per row were counted and transformed into percentages. Next, the average numbers of missing seeds and seeds damaged per replicate were calculated.

Statistical analysis
The arcsine (in degrees) of the percentages not established sweet potato plants, plants

Table 1. Causes of sweet potato cuttings failing to establish. Data recorded in the first rainy season of 2001, 14 days after planting at 5 locations in Soroti District, north-eastern Uganda.

Location	Soil texture	Number of cuttings	Number of not established cuttings	Number of cuttings not established due to:		
				Millipedes	Other[1]	Not known
Arapai	Sandy loam	2880	108	91	6	11
	Clay loam	2880	514	46	58	410
Serere	Sandy loam	2880	565	182	0	383
	Clay loam	2880	165	2	71	92
Dokolo	Sandy loam	1080	66	66	0	0
Abalang	Sandy loam	1080	359	359	0	0
Serere – CIP	Clay loam	3600	154	126	12	16

[1] Includes termites, weevils, farm animals, larvae of unknown beetle, vervet monkey, wrong planting method and mole rats (depending on location).

damaged by millipedes, storage roots damaged by *Cylas* spp., *Blosyrus* spp. and millipedes of the trials at Arapai and Serere on sandy loam and clay loam were calculated and subsequently statistically analysed, using ANOVA or the χ^2-test of Kruskal-Wallis (Anon., 1997). For ease of interpretation these data were back-transformed.

The χ^2-test of Kruskal-Wallis was also used to analyse the percentages not germinated maize seeds, not retrieved seeds and seeds affected by millipedes and other pests in the four types of environments of the 2002 second rainy season trial at Arapai.

Results

Sweet potato

Pest damage during crop establishment

During the second rainy season of 2000, the number of not established sweet potato vine cuttings in the four trials at Arapai and Serere on sandy loam and clay loam was 306 (11%), 377 (13%), 245 (9%) and 305 (11%), respectively. In Dokolo and Abalang more than 50% of the vine cuttings had not established, the main cause being drought. No vine cuttings had been affected by millipedes and no millipedes were observed 14 DAP.

During the first rainy season of 2001, the proportion of not established vine cuttings in the Arapai trials on sandy loam was 4% and on clay loam 19%. Out of these not established cuttings, 84% and 9%, respectively, were due to millipede activity (Table 1). In the trial on clay loam, termites (Isoptera: Termidae) and pigs were the other main causes of non-establishment. The numbers of millipedes encountered in the affected mounds were 35 and 30 on sandy loam and clay loam, respectively. Table

Table 2. Millipede species found in sweet potato at crop establishment and harvesting. Results from 5 locations in Soroti District, north-eastern Uganda[10].

Millipede genus/ species	Location and soil texture						
	Arapai		Serere		Serere-CIP	Dokolo	Abalang
	Sandy loam	Clay loam	Sandy loam	Clay loam	Clay loam	Sandy loam	Sandy loam
Omopyge sudanica Kraus	> 45[5]	19[6]	> 20[1]	7[1]		> 50[1]	> 50[1]
Spirostreptus ibanda Silvestri	> 20	75	156[1]	525[2]	170[1] > 450[3]	536[3]	
Tibiozus robustus Attems	2[1]	9[4]				1[3]	
Prionopetalum spp. (cfr. *xerophilum*) Carl	1[6]	6[7]					
P. xerophilum Carl		4					
Rhamphidarpe spp. (cfr. *dorsosulcata*)		15[1]					
Rhamphidarpe spp.[8]		6[6]			1[3]	24[3]	
Xanthodesmus vagans Carl		5[9]					
Aulodesmus spp.[8]					7[9]		

1 Found in mounds with non-established cuttings.
2 14 found in mounds with non-established cuttings (no thorough inspection); the rest found at harvesting.
3 Found at harvesting.
4 5 found in mounds with non-established cuttings; 4 found at harvesting.
5 Found during general trial inspection (n > 25) and at harvesting (n > 20).
6 Found during general trial inspection.
7 Found in mounds with non-established cuttings and at harvesting. During general trial inspection the same species were found (n = 4).
8 Identification not final.
9 Only sample taken.
10 The species *Syndesmogenus laticollis* Carl, *Tibiomus* spp. cfr. *ambitus* Attems and *Haplothysanus emini* Carl were found incidentally at Arapai. One individual of *Hadrodesmus* spp. was identified at Serere – CIP.

2 shows that the majority of them were identified as *Omopyge sudanica* Kraus (family: Odontopygidae) and *Spirostreptus ibanda* Silvestri (family: Spirostreptidae).

At Serere, the proportions of not established cuttings in the trials on sandy loam and clay loam were 21% and 6%, respectively. On the sandy loam, millipedes were responsible for 32% and on the clay loam for only 1% of the failures (Table 1). On top of the mounds in both trials, more than 200 fresh entrance holes of millipedes were found, which amounts to an average of more than 0.2 per mound. During a thorough inspection of the mounds in the sandy loam trial 156 millipedes (on average 0.16 per

Table 3. Percentage of non-established cuttings, cuttings damaged by millipedes, and storage roots affected by *Cylas* spp., *Blosyrus* spp. or millipedes in 11 farmer varieties and 5 Ugandan cultivars of sweet potato. Data from 4 locations (sandy loam and clay loam at both Arapai and Serere) during the first rain season of 2001 in north-eastern Uganda (n = 180).

Genotype	Non-established cuttings		Storage roots affected by:		
	Total	Damaged by millipedes	*Cylas*	*Blosyrus*	Millipedes
	(%)				
Farmer varieties					
Araka Red	9.9	1.1	4.9	9.8	0.1
Bale Acol	8.4	2.8	4.7	15.2	0.9
Ejumala	9.8	1.9	7.5	10.8	0.5
Ekampala	8.0	1.5	6.6	19.1	0.1
Etelepat	6.7	1.5	3.6	11.1	2.3
Muyambi	5.3	1.6	5.9	40.3	0.7
Opong Bur B	4.4	0.5	3.8	5.5	0.0
Osapat 016	7.8	2.7	3.4	15.8	0.3
Osapat 041	9.3	1.7	5.8	12.3	0.2
Osukut	6.2	0.4	5.7	15.5	1.1
Purple	9.9	2.3	3.6	14.6	0.4
Ugandan cultivars[1]					
No. 93/29	3.4	0.4	3.4	9.3	0.3
NASPOT 1	60.5	18.4	4.2	12.6	0.0
NASPOT 2	17.0	3.9	6.7	11.3	0.1
NASPOT 5	11.6	2.8	0.0	2.8	0.0
NASPOT 6	6.9	1.1	8.3	44.8	0.6
P-value[2]	< 0.001	0.087	0.110	0.001	0.001

[1] Developed by Namulonge Agricultural and Animal Research Institute (NAARI) under the mandate of the National Agricultural Research Organisation (NARO) of Uganda.

[2] Based on Analysis of Variance test after arcsin transformation.

mound), about 90% *O. sudanica*, were found coiled around or in the vicinity of the not established cuttings. No thorough inspection of the mounds on the clay loam was conducted. Sweet potato weevils (*Cylas brunneus* and *C. puncticollis*) and vervet monkeys (*Cercopithecus* spp.) were the other pests in the Serere trials. Mole rats (*Spalax* spp.), as the local farmers call them, were present but damage appeared negligible.

At Dokolo and Abalang farms, 6% and 33% plants, respectively, had failed to establish (Table 1). This was due to millipede activity only. During a field walk inspection at Abalang in the period of plant establishment we mostly encountered young individuals of the species *O. sudanica*. This was also the case in Dokolo (Table 2).

In the Serere-CIP trial, 154 (4%) cuttings had not established, of which 82% were affected by millipedes and only 3% by weevils (Table 1). Each mound with not established cuttings was inspected and a total of 170 millipedes, mainly of the species *S. ibanda*, were encountered (Table 2). On top of the mounds altogether 197 fresh entrance holes of millipedes (average almost 0.2 per mound) were identified. On opening the holes, in about 95% of the cases the species *S. ibanda* was encountered.

Table 3 shows that a highly statistically significant difference in non-establishment was found among the genotypes investigated at Arapai and Serere. The percentage not established cuttings was highest (61%) for the Ugandan cultivar NASPOT 1, whereas only a few cuttings (3%) of the Ugandan cultivar No. 93/29 had not established. NASPOT 1 was damaged most by millipedes (18%), but the differences among the cultivars were only weakly statistically significant ($P < 0.10$; Table 3). In Dokolo and Abalang there were no statistical differences among the varieties.

Pest damage during bulking

At harvesting, very few storage roots appeared to have been affected by millipedes in the second rainy season trials of 2000 at Arapai, Serere, Dokolo and Abalang: on average 0.1% at each site. For the first rainy season trials of 2001 the figures for Arapai and Serere (both sandy loam and clay loam) were slightly higher: Arapai sandy loam 6 (0.2%), Arapai clay loam 19 (0.6%), Serere sandy loam 22 (0.7%) and Serere clay loam 36 (0.9%). Also on the sandy loam soils of Dokolo and Abalang the numbers of storage roots affected by millipedes were low: 10 (0.4%) and 1 (0.1%), respectively (Table 4).

O. sudanica and *S. ibanda* were commonly found in the mounds at Arapai, Serere and Dokolo. *O. sudanica* was also encountered in Abalang, whereas the identification of *S. ibanda* (all larvae) was not final. *Tibiozus robustus*, *Prionopetalum* spp. and individuals of probably the genus *Ramphidarpe* were occasionally present. In the CIP and the Serere trials on clay loam *S. ibanda* outnumbered *O. sudanica*. In Abalang many Odontopygidae larvae were found belonging to the genus *Rhamphidarpe*, but also their identification was not very clear (Table 2).

In all first rainy season trials also sweet potato weevils (*Cylas* spp.) and rough sweet potato weevils (*Blosyrus* spp.) were recorded. The symptoms of nematode damage on storage roots were present in Abalang, Dokolo, Serere and Arapai, but at the last two locations nematode damage was insignificant. Mole rats had affected sweet potato in the trial at Serere on clay loam and in the CIP-Serere trials (Table 4).

The sweet potato weevil was mostly active at Arapai on sandy loam. Also at Serere the storage roots were more frequently damaged on the sandy loam than on the clay loam. At none of the experimental sites did we observe a difference in infestation by the sweet potato weevil for any of the 5 Ugandan cultivars or 11 farmer varieties (Table 3). The rough sweet potato weevil mainly damaged storage roots at the Arapai clay loam site ($P < 0.001$) and at the sandy loam sites of Dokolo and Abalang ($P < 0.001$). This weevil preferred the Ugandan cultivar NASPOT 6 and the farmer variety Muyam-

Table 4. Proportion (%) of sweet potato storage roots affected by storage root feeders and number of millipedes encountered per trial 4–5 months after planting. Averages over 6 trials planted in the first rainy season of 2001 at 5 locations in Soroti District, north-eastern Uganda.

Location/ soil texture	No. of roots	Storage root feeder (%)					No. of millipedes encountered
		Cylas	*Blosyrus*	Millipedes	Mole rats	Nematodes	
Arapai							
Sandy loam	3203	13.6	13.5	0.2	0	n.d.[1]	n.d.
Clay loam	3469	2.0	23.4	0.5	0	n.d.	59
Serere							
Sandy loam	3325	4.8	14.3	0.7	0	n.d.	153
Clay loam	3961	0.4	12.2	0.9	4.0	n.d.	521
Serere – CIP							
Clay loam	9377	2.4	6.3	1.5	2.0	2.0	449
Dokolo							
Sandy loam	1591	0.5	14.5	0.6	0	6.3	551
Abalang							
Sandy loam	1531	1.6	20.2	0.1	0.7	13.2	88

[1] n.d. = no data available.

bi ($P < 0.001$) (Table 3), but no statistical difference in infestation between the five selected farmer varieties was observed at the sites of Dokolo and Abalang (data not shown).

Although millipedes affected only few storage roots during bulking, they were particularly active at the sites in Serere. At Serere and Arapai, the farmer variety Etelepat had the highest percentage damaged plants (2.3%), followed by Osukut ($P < 0.001$) (Table 3). At Dokolo and Abalang, however, where Etelepat was one of the five selected farmer varieties, no statistical difference between genotypes was found.

In the CIP-Serere trial, 141 (1.5%) storage roots (total n = 9377) were affected by millipedes. At harvesting, the millipede species *S. ibanda* was observed, mainly as sub-adults and larvae. Also one individual of the genus *Rhamphidarpe* was identified, although the identification was not final.

Pest damage during 'in-ground on plants' storage

During the whole period of 'in-ground on plants' storage (the dry season) mole rats usually caused little damage: normally below 3% (Figure 1). On two inspection dates (21 March and 26 March 2002), however, the damage measured was around 7.5%. The percentage storage roots affected by the *rough sweet potato weevil* gradually increased from 21% in November to 58% in April, when the rains had returned. However, the

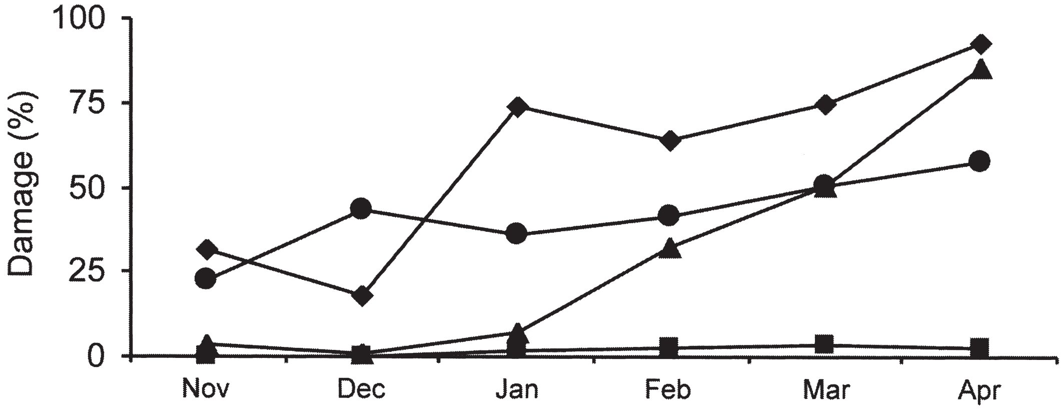

Figure 1. Development of damage by weevils (*Cylas* spp.) (◆), rough weevils (*Blosyrus* spp.) (●), millipedes (▲) and rats (■) in sweet potato tubers stored 'in-ground on plants' during the dry season 2001/2002 (November–April) at Arapai College, Soroti District, north-eastern Uganda.

level of damage was never serious, because it was always superficial. The percentage storage roots affected by *sweet potato weevils* increased from 25 in November to approximately 98 in April of the next growing season. The level of damage in April was severe, resulting in only 13% marketable roots, whereas in the third week of November this was about 80%. Figure 1 also shows that until January the percentage roots infested by millipedes was below 1%, gradually increasing thereafter until April when on average 86% of the tubers was infested. In April, most roots were affected by a combination of pests, weevil damage being the most serious as it renders the roots unfit for marketing and/or eating.

O. sudanica was most frequently detected in the sweet potato field where pest damage during in-ground storage was investigated. We also came across *Syndesmogenus laticollis*. A not yet described small slender species, *Tibiomus* spp. cfr. *ambitus* was also identified.

Groundnut

Pest damage in germinating and podding groundnut

The results from the trials at Arapai show that millipedes caused damage in both germinating and in podding groundnut planted at the beginning of the first rainy seasons of 2001 and 2002 (Tables 5 and 6).

The percentage germinated seeds (59%) in the 2001 trial was low because a slowly germinating variety was used. Millipedes were responsible for a seed loss of 12% (Table 5). Table 6 shows that by damaging (germinating) seeds millipedes were responsible for a reduction in plant density of 29% in the 2002 trial. Table 6 also shows that millipedes affected 32% (79 out of 254) of the remaining plants in their podding stage. Thirty-nine per cent (144 out of 366) of the pods had been damaged in a young stage when they were still tender and easily penetrable.

Juvenile individuals of the species *O. sudanica* were found scavenging on the

Table 5. Groundnut seeds damaged by millipedes and other soil pests, recorded 10 days after planting. Data from six 2.7-m^2 plots (6 × 60 = 360 seeds planted) in a field trial planted in the first rainy season of 2001 at Arapai, Soroti District, north-eastern Uganda.

Plot	Number of seeds not germinated	Number of seeds damaged by:		Number of millipedes found
		Millipedes	Other soil pests	
1	23	9	0	6
2	22	6	2 (rats)	8
3	22	10	0	3
4	24	6	0	4
5	29	7	3 (rats)	2
6	26	5	0	8
Total	146	43	5	31
%	41	12	1	

Table 6. Millipede damage in groundnut 14 days after planting (DAP) and at harvesting. Data from six 2.7-m^2 plots (6 × 60 = 360 plants) of a trial planted in the first rainy season of 2002 at Arapati, Soroti Distrct, north-eastern Uganda.

Plot	Damage 14 DAP		Damage at harvesting					
	Germinated seeds	Damaged seeds (%)	Plants			Pods		
			Millipede damage[1] (%)	Other damage	Without pods[2] (%)	Total number[3]	Millipede damage	
							Number	%
1	42	30	40	0	48	56	32	57
2	43	28	58	0	30	76	28	37
3	40	33	33	2[4]	33	61	17	28
4	50	17	34	0	25	59	14	24
5	46	23	65	0	20	71	33	47
6	33	45	61	0	30	43	20	47
Total	254			2[4]		366	144	
%		29	32		31			39

[1] Plants with pierced pods.

[2] Based on number of germinated seeds.

[3] Pods per plot.

[4] Damage caused by rats.

Table 7. Damage by millipedes to germinating maize seeds, recorded 10 days after planting. Data from four 3.6-m^2 plots (4 × 5 = 20 seeds planted) in a field trial planted in the first rainy season of 2002 at Arapi, Soroti District, north-eastern Uganda.

Plot	Germinated seeds	Seeds damaged by millipedes	Type of damage	
			Cotyledon	Radicle/plumule
	(%)			
1	62	38	74	26
2	52	48	88	12
3	72	28	57	43
4	78	22	64	36
Mean	66 ± 5.7	34 ± 5.7	71 ± 6.7	29 ± 6.7

cotyledons, the emerging radicle or on the cortex of the hypocotyl, or were present near the seeds. The cotyledons were often pierced or completely eaten, only leaving behind some remainders of the testa. In 2002, during harvesting, juveniles of the same species were also found on the roots (3 cases) and inside the pods, foraging on the kernels (11 cases). There was no evidence that millipedes had affected the roots. *Tibiomus* spp. cfr. *ambitus*, *Prionopetalum xerophilum*, *Haplothysanus emini* and two unknown species of the Odontopygidae family were also encountered, but not found feeding on seeds in the pods. Mole rats, termites (Isoptera) and white grubs (Coleoptera: Scarabaeidae) were occasionally present, but damage was absent or negligible.

Maize

Millipede damage in germinating maize (first rainy season)
Millipedes had affected 34% (n = 200) of the germinating maize seeds planted at the beginning of the first rainy season (Table 7). Cotyledons were preferred most and as a result germination often failed. When radicles/plumules were damaged, germination was seriously impaired. Few termites, wireworms (Coleoptera: Elateridae) and larvae of chavers were found in the proximity of seeds, but these potential soil pests had not affected the seeds. We came across four millipede species near the (germinating) seeds: *S. ibanda, O. sudanica, Tibiomus* spp. cfr. *ambitus* and one unknown species of the Odontopygidae family. Although the seeds were damaged, no millipedes were found feeding on them.

Millipede damage in germinating maize (second rainy season)
When maize was planted during the second rainy season, millipede damage led to no germination at all or to badly impaired germination in 64% of the total of 800 seeds. Twenty-three per cent of the seeds were not retrieved at all (Table 8), suggesting that

Table 8. Germination of maize seeds, germinating maize seeds affected by millipedes and other pests and maize seedling parts damaged. Observations 10 days after planting in 4 types of environment[1] during the second rainy season of 2001 in Arapai, Soroti District, north-eastern Uganda.

Environ-ment[1]	No germination	Not retrieved	Causal organisms		Seedling parts damaged			
			Millipedes	Other[2]	Cotyledon	Plumule	Radicle	Whole seed
	– – – – – – – – – – – – (%) – – – – – – – – – – – –							
1	28	10	15	3	13	3	0	0
2	85	25	57	3	50	2	2	4
3	62	27	34	1	25	2	1	8
4	79	31	48	0	32	0	0	15
Total (%)					120 (76)	7 (5)	3 (2)	27 (17)
P-value[3]	< 0.001	< 0.001	< 0.001	0.192				

[1] Environment 1 = soil with average organic matter content; 10 m northwards from tall tree and dense bush;
Environment 2 = soil organic matter content as above; 5 m from tall tree and dense bush;
Environment 3 = soil organic matter content as above; 10 m southwards from tree and dense bush;
Environment 4 = low soil organic matter content; 20 m southwards from tree and dense bush.

[2] Mole rats, termites and army or red ants.

[3] Based on Analysis of Variance test; $P < 0.001$ = differences highly significant; 0.192 = not statistically different.

they had been eaten entirely by millipedes. However, it cannot be completely ruled out that rats had eaten the seeds shortly after planting. Millipedes affected on average 38.5% of the seeds and consequently the seeds had a defective germination or were not able to germinate at all. Like during the first rainy season millipedes mostly affected the cotyledons (Table 8). This time plumules and radicles were little affected. Some of the cotyledons retrieved were completely destroyed. Often the central part of the cotyledon was pierced or only little bits of the cotyledon were unfolded. Unlike in the first rainy season trial, juveniles of *S. ibanda*, *O. sudanica* and *Tibiomus* spp. cfr. *ambitus* were found feeding on the (germinating) seeds.

Furthermore, statistical analysis showed that the numbers of not germinated seeds, seeds not retrieved and seeds damaged by millipedes were highly significantly different among the four environments. Soil insect pests such as termites, army ants, wireworms and larvae of chavers, and mole rats were encountered but their presence was not significant. Table 8 presents detailed information about percentages not germinated seeds, seeds not retrieved, causal organisms and components of seeds damaged in each environment.

Discussion

Sweet potato

Earlier studies in Uganda showed that farmers consider arthropod pests as the most important biological constraint on sweet potato production (Bashaasha *et al.*, 1995; Smit, 1997; Abidin, 2004; Ebregt *et al.*, 2004a). Sweet potato farmers from north-eastern Uganda considered millipedes the second most important arthropod pest after sweet potato weevils (Abidin, 2004; Ebregt *et al.*, 2004b). This study shows that millipedes only inflict damage on planting material and on storage roots after 4–5 months if planted at the beginning of the first rainy season. These findings support earlier reports received from farmers (Abidin, 2004; Ebregt *et al.*, 2004a, b).

Several authors (Demange, 1975; Masses, 1981; Dangerfield & Telford, 1992; Umeh *et al.*, 1999) reported the large-scale disappearance of millipedes during the course of the rainy season, starting with the smaller species and the larval stages, which dig to deeper soil layers with a stable humidity (Demange, 1975; Masses, 1981). Because of their higher desiccation tolerance, bigger/thicker species (Appel, 1988) can survive in places where the humidity is less stable, such as humus-rich topsoils and abandoned termite hills or in self-made chambers (Masses, 1981). In our research area the same phenomena were observed. As the rainfall in the second growing season is less reliable, it is evident that this behaviour makes the sweet potato crop (and other crops) less affected by millipedes during this period.

Besides factors such as time, amount of rainfall and species present, the occurrence of millipedes on/near the soil surface depends on abiotic features of the soil (texture, organic matter, calcium content, etc.) (Demange, 1975). Smit (1997), Umeh *et al.* (2001) and Ebregt *et al.* (2004b) also mentioned crop residues as an important factor for the occurrence of soil pests. The sandy loams at Arapai and Serere had a low organic matter content despite the crop residues from the sweet potato crop, so that there was little food for the millipedes when they emerged from their quiescence. The fresh planting material could have been very attractive to them. Moreover, the millipede population was known to be high due to the fact that the area is intensively used for sweet potato production and in addition crop residues had not been properly removed after harvest. According to Smit (1997) and Ebregt *et al.* (2004b) this practice of leaving crop residues is common in the region. In this way millipedes from adjacent fields might have invaded the trial plot and contributed to the damage.

The high soil organic matter content, the intensive production of sweet potato and the lack of field hygiene may also have contributed to a bigger millipede population in Abalang than in Dokolo. Moreover, sweet potato was often grown in short rotation with groundnut and maize, both of which are hosts to millipedes according to the farmers in the region (Ebregt *et al.*, 2004a, b). Unlike at Abalang, the field in Dokolo had been under fallow for a long time and the number of millipedes encountered during planting time was low, resulting in fewer sweet potato plants being affected. On the other hand, results from field visits showed that the higher level of precipitation at Abalang also stimulated millipedes to emerge from their quiescence, which then attacked the recently planted sweet potato cuttings.

In some trials the cause of failure of many not established cuttings could not be identified. For example in the sandy loam trial at Serere, many plants (14%) had rotted and the cause of failure was recorded as 'not known' (Table 1). It is most likely that millipedes had affected the young plants shortly after planting, which is reflected by the high number of millipedes (156) present in the mounds, often coiled around the remains of the dead stem, and by the many fresh entry holes (> 200) found in the mounds. Other possible causes of failure could be drought or poor planting material. The majority of millipedes found in the sweet potato fields at the beginning of the first rainy season were *Spirosteptus ibanda* (Spirostreptidae) and *Omopyge sudanica* (Omopygidae) (Table 2), the latter of which was also linked to damage in groundnut (Masses, 1981; Wightman & Wightman 1994, Umeh *et al.*, 1999). During our inspections we noted that mainly *O. sudanica* was found curled around the not established cuttings. So it is likely that they affected the planting material. This conclusion agrees with findings of Mwabvu (1991), who observed in laboratory experiments that after encountering a high-quality food type, some millipedes dropped searching behaviour and coiled next to the food source. He argued that this behaviour is also likely to develop in a heterogeneous environment, such as a sweet potato field.

In both Serere trials, 14 DAP, many millipedes were already encountered in the mounds with not established cuttings (Table 1). During the further establishment of the sweet potato crop, more millipedes may have been attracted to the easily penetrable loose humid mounds. However, the number of storage roots affected by millipedes 4–5 months after planting was low. It appeared that there was no correlation between the number of millipedes present in the mounds and the extent of damage in the storage roots. Sweet potato is a sturdy crop and it is possible that the other vines in a mound (partly) make up for the potential yield loss caused by a millipede-damaged not established cutting (cf. compensation after defoliation by sweet potato butterfly, Smith *et al.*, 1997). The ability to compensate for loss of plants or loss of vigour of some plants deserves further attention in research.

By the end of the dry season the sweet potato tubers stored 'in-ground on plants' had been in the field for more than 10 months. Besides the sweet potato weevils and sweet potato rough weevils, also millipedes of the Odontopygidae (mainly *O. sudanica*) had affected the storage roots. These results confirm reports from farmers that millipedes affect storage roots that stayed in the field (Ebregt *et al.*, 2004a, b). Their damage may be facilitated by the damage caused by weevils. The habitat being unsuitable, *S. ibanda* was not encountered.

Groundnut

The stand losses and pod damage in groundnut caused by millipedes (Odontopygidae) during the first rainy seasons of 2001 and 2002 confirm earlier findings (Ebregt *et al.*, 2004a, b). However, Busolo-Bulafu & Obong (2001) stated that in Uganda there are no serious pests causing direct damage to groundnut, although millipedes occasionally gnaw at the hypocotyls of seedlings during emergence. Moreover, the Groundnut Manual for Uganda (Page *et al.*, 2002) does not mention millipede as a pest in this crop.

Wightman & Wightman (1994) reported millipedes being active as pod borers in

Zambia, Zimbabwe, Botswana, Malawi and Tanzania. But in their survey, millipedes, which were not identified, were rarely present in sufficient quantities to warrant concern. They contributed the unevenness of stands primarily to root damage by white grubs, which were hardly present in our study. On the other hand, Mercer (1978) thought that besides beetle larvae and even mice, millipedes were responsible for the poor stands in Malawi.

In West Africa several researchers mentioned millipedes (Odontopygidae) as a nuisance in groundnut (Demange, 1975; Johnson *et al.*, 1981; Masses, 1981; Lynch *et al.*, 1985; Umeh *et al.*, 1999; Youm *et al.*, 2000). In Senegal, for example, millipedes were responsible for up to 20% reduction in plant density, reducing the yields by 30–40% (Masses, 1981). Like in our experiment, Masses (1981) also observed that millipedes consumed cotyledons and frequently the cortical part of the hypocotyl. Johnson *et al.* (1981) occasionally observed adult millipedes of the genus *Peridontopyge* (Odontopygidae) attacking the main stem of very young plants at ground level. This feeding behaviour was also mentioned by local farmers in north-eastern Uganda. The farmers indicated that the injury was always slight and that the plants did not perish.

At harvest time, pods in our experiment appeared to be pierced by small slender millipedes and their larvae were even found inside them, feeding on the kernel(s). It is thought that they penetrated the immature pods. Also Masses (1981) found small millipedes in the young pods, feeding on the ovules and the pericarp. He reported that 15–30% of the pods were damaged or showed lesions caused by millipedes during pod formation. Johnson *et al.* (1981) likewise showed that attack by millipedes (*Peridontopyge* spp.) was largely restricted to immature pods, of which some could be lost before harvesting. The observation by Demange (1975) that millipedes constantly seek a source of moisture, led Wightman *et al.* (1989) to the conclusion that millipedes are attracted by the soft pods. According to the latter authors, groundnut pods provide water as well as a nutrient-rich diet.

As an indirect effect, pods and kernels can become infected by *Aspergillus* spp., which can result in seeds contaminated with carcinogenic aflatoxins (Roisson, 1976; Mercer, 1978; Masses, 1981; Johnson & Gumel, 1981; Lynch *et al.*, 1985; Wightman & Wightman, 1994). The poor drying techniques used in north-eastern Uganda can enhance this contamination, imposing a health risk to the people.

The gaps in a groundnut field caused by not germinated seeds and poor germination can cause a serious indirect impact on the health of the crop. In Uganda, groundnut rosette disease is prevalent (Busolo-Bulafu & Obong, 2001; Page *et al.*, 2002). If a susceptible variety is used, the groundnut aphid (*Aphis craccivova*) can easily infect the crop with the groundnut rosette virus due to gaps in the stand, enabling the aphids to land, and more damage is inevitable.

Damage to the testa, as could be the case with mechanically shelled seeds, can affect seed germination due to fungal infection (Carter, 1973). As our seeds were hand-shelled, the effect of fungal infection should have been limited.

The stand loss in the 2002 trial was serious. During two successive years the trial field had been used for sweet potato and was then gradually abandoned. These frequently occurring poor sanitary field conditions, and the fact that groundnut and maize (also a host crop to millipedes) were often grown in short rotations with sweet potato, helped the millipede population to build up. So these conditions probably have contributed to the excessive damage.

Many groundnut plants in our trial did not produce pods (Table 6). A probable cause could have been that in June, when the gynophores were formed, the soil was dry and crusted due to little rainfall, making it difficult for the gynophores to penetrate the soil. Poor pod development and low yields could have been the result.

In India a millipede was found feeding on the inflorescences of green gram (*Vigna* spp.) and cowpea (*V. unguiculata*) (Siddadappaji *et al.*, 1979), whereas from Senegal it was reported that millipedes gnawed at petals and flower buds (Masses, 1981). The same author also found millipedes cutting gynophores before these penetrated the soil, thus affecting pod development in the soil. Although never reported by Ugandan farmers, millipedes may also affect inflorescences, fructification and pod setting. In this way millipedes can be partly responsible for the countries' low groundnut yields. The fact that the same group of millipedes is active in Uganda suggests that further research on this problem is needed.

Maize

Millipedes caused serious damage to maize seeds before and during germination (Tables 7 and 8), confirming the concerns expressed by farmers during earlier interviews (Ebregt *et al.*, 2004a, b). No literature was found on millipede damage in germinating maize seed. According to farmers' experience, damage could be expected especially during the onset of the first rains. However, the results of our second rainy season trial (Table 8) showed that millipedes were also active during this period. Often the cotyledon was damaged. The seed's endosperm makes up the bulk of the starch with which the cotyledon is packed, whereas the aleuron layer of the endosperm contains much of the protein. The embryo is rich in fats, proteins and minerals (Purseglove, 1988). It is suggested that when the seed has absorbed water, these constituents attract the millipedes, which – according to our observations – start to feed on the embryo. We also observed that while the seed tried to germinate, the millipede could affect the (impaired) radicle/plumule. It is striking that millipedes significantly affected the radicle/plumule more during the first rainy season than during the second rainy season. So we think that millipedes emerging from their quiescence (first rainy season), were in need of minerals dissolved in water, which were present in parts of the germinating seeds. On the other hand, the millipedes preparing themselves to go into quiescence (second rainy season) were probably more in need of starch, fats and proteins. This explains why during the second rainy season millipedes preferred endosperm and embryos.

In the second maize trial little damage was recorded in Environment 1. It is possible that the millipedes had an alternative source of food in the surrounding area, i.e., a previously poorly harvested sweet potato field. Environment 2, which was nearest to the refuges (fig tree litter and shrubs) of the millipedes, had a high percentage of not germinated seeds because millipedes from the tree litter probably had easy access to the maize. Moreover, the millipedes in this field could longer benefit from the morning shade and humidity. As a result the millipedes in the topsoil may have longer remained active in this environment than in the adjacent ones. The percentage germination was slightly higher for the adjacent Environment 3 than for the one nearest to the tree probably due to the fact that millipedes continued moving to the farthest plot. For Environment 4 the percentage of not germinated seeds was as high as for Environment 2. The natural boundary of Environment 4 was free from vegetation and direct sunshine desiccated the topsoil. This condition contributed to limited food resources available for millipedes outside the plot. So we speculated that millipedes were confined to Environment 4 and could therefore cause a lot of damage.

Termites, army ants and other soil pests were hardly present in the four environments, but in the fig tree litter large-sized millipede species such as *S. ibanda* were found most frequently. We suspect that these species must have been able to consume the whole seed. In this way the large number of not retrieved seeds (Table 8) can be accounted for. Another (unlikely) explanation could be mammals.

Identification of millipedes

Little is known about the millipede species of north-eastern Uganda (C.A.W. Jeekel, personal communication). Due to lack of males and the fact that many larvae of different developmental stages were often living along with sub-adults and adults of different species, it was difficult to identify all the millipedes collected. Species of the Odontopygidae, such as the *O. sudanica*, are pests of sweet potato, groundnut and maize, and possibly other crops. *S. ibanda*, encountered in some fields and characteristic for shaded litter-rich gardens, did not have a clear host range. With the return of the first rains at the beginning of the next growing season, *S. ibanda* together with *Prionopetalum xerophilum* was often seen first on the soil surface, indicating that their hiding places were not far from the surface area.

Field observations showed that millipedes preferred sweet potato mounds with good soil, rich in organic matter, especially when host crops had been used as preceding crops. Millipedes like an environment that can hold water and that can easily be burrowed.

Concluding remarks

The results of our research show that millipedes are an important pest of sweet potato, especially during crop establishment. Thereafter they cause no serious damage provided harvesting is done timely. If the crop is kept in the field during the dry season, millipedes will become active on the storage roots when the rains return. As long as no adequate measures are developed for the control of weevils and millipedes, storing sweet potato ‘in-ground on plants’ during the dry season remains risky.

Maize is affected if planted in the vicinity of millipede refuges. In north-eastern Uganda, millipede damage in groundnut is quite serious if the crop is planted early in the first rainy season. Farmers most commonly grow millet after sweet potato: avoiding millipede damage on maize and groundnut could be one of the reasons for this practice.

More research is needed to quantify the economic damage caused by millipedes.

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CHAPTER 6

Feeding activity of the East African millipede *Omopyge sudanica* Kraus on different crop products in laboratory experiments

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Feeding activity of the East African millipede *Omopyge sudanica* Kraus on different crop products in laboratory experiments

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Abstract

Millipedes can cause considerable damage in the production of sweet potato and some other crops in East Africa. Quantitative information on intake of crop diets by and body weight gain of millipedes was collected in short-term no-choice feeding activity laboratory experiments conducted in north-eastern Uganda using female millipedes of the species *Omopyge sudanica*. Diets consisted of sweet potato and cassava storage root material, groundnut seeds, or maize grains. Differences in intake and body weight gain between diets were not statistically different. The consumption index, i.e., the ratio between intake and body weight gain, was significantly higher for sweet potato than for most other diets. The efficiency of conversion of ingested food, i.e., 100 × the ratio between body weight gain and intake, was significantly lower for the root crops – especially sweet potato – than for the grain crops. The research showed how difficult it is to obtain reliable, quantitative data on the feeding habits of millipedes, but also illustrated that *O. sudanica* can cause harm to crops in north-eastern Uganda and elsewhere in East Africa.

Additional keywords: no-choice feeding activity, food intake, body weight gain, consumption index, efficiency of conversion of ingested food

Introduction

In north-eastern Uganda, sweet potato (*Ipomoea batatas* (L.) Lamk), cassava (*Manihot esculenta* Crantz), maize (*Zea mays* L.) and groundnut (*Arachis hypogaea* L.) are important food and cash crops. Subsistence farmers have to grow their crops on the little land they have available (Kisamba-Mugerwa, 2001). Crop rotation is often not practised, which may result in high frequencies of pest-prone crops and in a high incidence of certain soil-borne pests (Ebregt *et al.*, 2004a). Moreover, field hygiene is commonly lacking and farmers cannot afford to buy pesticides (Bashaasha *et al.*, 1995;

Smit, 1997; Abidin, 2004; Ebregt *et al.*, 2004b). So the best strategy is an integrated approach in pest management based on non-chemical control (Smit, 1997).

In north-eastern Uganda, sweet potato, besides cassava and banana, is a major starchy staple in the diet (Smit, 1997). Its storage roots, high in vitamin A (Anon., 1998), are mainly grown as a subsistence crop for home consumption (Smit, 1997; Abidin, 2004), but in some areas are also produced for the market in Kampala (Abidin, 2004; Ebregt *et al.*, 2004a). In the sweet potato production systems, cassava is often the crop preceding sweet potato, whereas millet, groundnut and maize are usually the after-crops (Ebregt *et al.*, 2004a).

Insect pests, such as the sweet potato weevils *Cylas brunneus* and *C. puncticollis*, were identified by farmers to be the most important biological constraint on sweet potato production (Smit, 1997; Abidin, 2004; Ebregt *et al.*, 2004b). Farm visits and field experiments have shown that many crop species are hosts of harmful arthropods, including millipedes. But millipedes mostly affect sweet potato (early planted vines and roots stored in-ground), maize (germinating seeds) and groundnut (germinating seeds and young pods). Interviewed farmers also named cassava as host. The main culprits were *Omopyge sudanica* Kraus (family: Odontopygidae) and *Spirotreptus ibanda* Silvestra (family: Spirostreptidae) (Ebregt *et al.*, 2004a, b; 2005).

Little is known about the preference of millipedes for host crop diets and about intake, digestibility and efficiency of conversion of these crop diets. Quantitative studies about the consumption and utilization by millipedes can provide valuable information on their potential damage in cultivated crops (Band *et al.*, 1976; Somasundaram & Chockalingam, 1981).

This paper presents the results of attempts to quantify in short-term laboratory runs the no-choice feeding activity of the millipede *O. sudanica* when offered different host crop diets. The choice of crops was determined by their presence in the cropping system dominated by sweet potato. Parameters assessed included: (1) intake, (2) body weight gain, (3) consumption index (CI), i.e., the ratio between intake and body weight gain, and (4) the efficiency of conversion of ingested food (ECI) into body substance. The millipedes' feeding activity on the different crop diets and the consequences for pest management will be discussed.

Materials and methods

General methodology, crops, diets and millipedes

The experiment consisted of three batches, each with the same six diets, either exposed to millipedes for 24 hours or not exposed, in four replicates. The experiment was carried out to assess no-choice feeding laboratory activity of five millipedes of the same species. Batches of five immature female millipedes of the species *Omopyge sudanica* were offered diets consisting of different fresh crop materials. For each batch and replicate, each combination of diet and millipedes was kept in a separate plastic jar. The experiment was carried out at Arapai, Soroti District, north-eastern Uganda, at the onset (March/April) of the long rainy season when millipedes are available in large numbers.

The experiment included six diets based on four crop species: sweet potato (cv. Osukut/ Tanzania), groundnut (cvs. RPM 12 and Rudu-Rudu), maize (cv. Longe I), and cassava (cv. Nigeria). The first three crop species are generally known to host millipedes (Ebregt *et al.*, 2004a, b; 2005). Cassava was included as interviewed farmers suggested that it is a potential host crop too (Ebregt *et al.*, 2004a, b). The storage roots of sweet potato and cassava were cut into pieces of about 1 cm^3. Groundnut seeds and maize grains were soaked in water for 24 (groundnut and maize) or 48 hours (maize) at room temperature (24 ± 3 °C), making the seeds and grains more palatable for millipedes. Shortly before initiating the experiment the seeds and grains were blotted with a dry cloth.

The six diets included: sweet potato storage root, cassava storage root, groundnut seed from cv. RPM 12, groundnut seed from cv. Rudu-Rudu, maize grain soaked for 24 hours, and maize grain soaked for 48 hours.

Immature female millipedes of the species *O. sudanica* were hand-collected from the field and kept in the dark, without food, at room temperature (24 ± 3 °C) for 10 days. This preparation period served to clear their gut and make or keep them hungry. During this preparation period, faeces were removed every other day to prevent coprophagy (i.e., to prevent the millipedes from eating faeces), and water was sprayed to prevent desiccation. The amount of faeces removed during the preparation period was not assessed as during the experiment the millipedes fed a certain diet were always compared with a group of millipedes without any feed. Although the spraying of water may have been a source of uncontrolled variation among the millipedes, it is believed that it actually reduced the variation as the extent of desiccation would certainly have been more variable. After the preparation period of 10 days, the millipedes were allowed to feed on the different diets for 24 hours.

Set-up of the experiments

Wide plastic jars (15 × 12 cm) with well fitting, non-perforated lids (Ø 10 cm) were used for this experiment. Jars were large enough to contain the amount of air needed for five millipedes to breathe normally during a 24-h period.

The experiment consisted of a series of tests comparing a particular crop diet exposed to millipedes with the same diet not exposed to millipedes in quadruplicate. These tests were organized in three batches, which were run at different times. Per batch, 6 tests were carried out, one for each diet. Each individual test consisted of 8 jars, four jars containing 50 g of the crop diet studied plus five millipedes, and four jars containing 50 g of the same diet, but without millipedes. In total the experiment comprised 3 batches × 6 diets × 2 treatments (with and without millipedes) × 4 replications = 144 experimental units. For the treatments with millipedes, each jar had five millipedes. During the 24 hours of the test, the millipedes, after their 10 days of starvation, did not produce faeces, despite their food intake.

Data collection and processing

Data collected at the start of a test

Before starting a test, the weights of four empty jars were scaled down to zero on an electrical digital balance at room temperature. Exactly 50 g of the diet studied was then placed in each jar and jar + diet were weighed for accurate records. These four jars served as controls. This procedure was repeated, but now five millipedes were added to each jar and the weight of jar + diet + millipedes was determined. From these data the initial weights of the five millipedes of each batch × diet × replication were calculated.

Data collected at the end of the tests

The tests lasted 24 hours. At first the 'final' weights (t = 24) of the four control jars were determined. The average weight loss per jar due to water evaporation and respiration of the crop material in the four control jars was then calculated.

Next the weights of the four jars with millipedes (jar + diet + millipedes) of each replicate were determined. Then the millipedes were carefully removed from each jar, using tweezers. In order to prevent additional weight loss due to evapotranspiration, the jars were closed at once, and the 'weights' of the five millipedes collected and of the jar + remaining diet were recorded immediately.

Based on these data we calculated the corrected food intake and the final weight of the five millipedes separately for each replicate. The millipede weight calculated in this way might differ slightly from the directly determined weight. During removal and weighing of the millipedes, some imperfections such as defensive body secretions on the tweezers and water condensation on the tweezers' fingers may have occurred. The average difference between the directly determined and the calculated weight of five millipedes was used to correct the directly measured weight gain.

In order to calculate the consumption index (CI) the formula of Waldbauer (1968) was slightly modified:

$$CI = \text{intake}/ [(\text{initial weight} + \text{final weight})/2] \qquad (1)$$

The efficiency of conversion of ingested food (ECI; %) into body substance of the five millipedes of each jar was calculated using Equation 2 (Waldbauer, 1968; Chaudhury, 1994):

$$ECI = 100\ [\text{weight gain (in g)} / \text{intake (in g)}] \qquad (2)$$

Data analysis

Initial body weight per five millipedes (at t = 0), their weight after 24 hours (at t = 24), food intake, body weight gain, and CI and ECI were calculated for each of the crop diets. Analysis of variance was used for the statistical analysis. Relations between the parameters were quantified using a correlation matrix. Correlation coefficients (R^2) ≥ 0.25 were considered statistically significant ($P \leq 0.05$). Student's t-test was used to separate the means of CI and ECI of the root crops (cassava and sweet potato) and the grain crops (groundnut cvs. RPM 12 and Rudu-Rudu, and maize soaked for 24 or 48 hours). The computer programme Genstat Release 8 (Anon., 2005) was used for the statistical analyses.

Table 1. Mean scores of ingested crop product (intake), initial and final millipede weights, and body weight gain. Data from laboratory experiments carried out at the start of the first rainy season of 2002 at Arapai station, Seroti District, north-eastern Uganda.

Crop product	Intake	Body weight		
		Initial	Final [1]	Gain
		----------	(g)	----------
Sweet potato storage roots	0.53	6.89	7.26	0.37
Cassava storage roots	0.41	7.20	7.57	0.37
Groundnut (cv. RPM 12) seeds	0.38	7.13	7.47	0.34
Groundnut (cv. Rudu-Rudu) seeds	0.48	7.22	7.66	0.43
Maize grains soaked for 24 hours	0.45	7.51	7.92	0.41
Maize grains soaked for 48 hours	0.36	7.48	7.81	0.33
Mean	0.43	7.24	7.61	0.37
P-value [2]	ns	ns	ns	ns
Coefficient of variation (%)	40.3	13.5	13.5	46.2

[1] After correction for difference between directly measured and calculated weight; see Materials and methods.

[2] ns = statistically non-significant differences within column.

Results

Intake and body weight gain of the millipedes

At the end of the feeding experiments (t = 24) the weights of all diets offered to the millipedes had decreased, suggesting millipede feeding activity. The average decrease in weight of sweet potato, cassava, groundnut and maize varied from 0.36 (maize soaked for 48 hours) to 0.53 g (sweet potato), but the differences among crops were not statistically significant (Table 1). The mean body weight gain of the millipedes after terminating the experiment varied among diets from 0.33 for maize soaked for 48 hours to 0.43 g for groundnut cv. Rudu-Rudu. Here the differences were not statistically different either (see tests and coefficients of variation in Table 1).

The body weight of five millipedes related to the intake and weight gain

For the crop diets cassava and maize grains soaked for 48 hours a statistically significant, positive correlation was found between initial body weight per five millipedes and intake and body weight gain (data not shown). The R^2 values for intake were 0.27 for

Table 2. Mean scores for consumption index (CI) and efficiency of conversion index (ECI) of cop products offered to millipedes. Results from laboratory experiments carried out at the start of the first rainy season of 2002 at Arapai station, Soroti District, north-eastern Uganda.

Crop product	CI (g/g)	ECI (%)
Sweet potato storage roots	0.081 a [1]	70.6 (b) [2]
Cassava storage roots	0.053 b	83.7 (a)
Groundnut (cv. RPM 12) seeds	0.052 b	90.4 (a)
Groundnut (cv. Rudu-Rudu) seeds	0.064 ab	89.8 (a)
Maize grains soaked for 24 hours	0.061 ab	88.9 (a)
Maize grains soaked for 48 hours	0.046 b	89.7 (a)
Overall mean	0.059	85.5
P-value [3]	*	(*)
Coefficient of variation (%)	42.9	21.3
LSD [4]	0.021	12.39
Mean		
Root crops (n = 24)	0.067	77.2
Grain cops (n = 48)	0.056	89.7
P-value of contrast between root and grain crops [5]	ns	*

[1] Means in this column, followed by a common letter are not statistically different ($P < 0.05$).

[2] Means in this column, followed by a common letter in brackets are not statistically different ($P < 0.10$).

[3] * = $P < 0.05$; (*) = $P < 0.10$.

[4] Least significant difference at $P < 0.05$ for CI and at $P < 0.10$ for ECI.

[5] ns = contrast not statistically significant; * = contrast statistically significant at $P < 0.05$.

cassava and 0.25 for maize soaked for 48 hours; for body weight gain R^2 was 0.25 for both diets. The initial body weight per five millipedes and the intake for groundnut cv. Rudu-Rudu were significantly and positively correlated too ($R^2 = 0.25$; data not shown).

A negative correlation was found between initial body weight and intake and body weight gain for the crop diets sweet potato and maize soaked for 24 hours (data not shown). Correlations between the initial body weight and intake with groundnut cv. RPM 12 and between the initial body weight and the weight gain with groundnut cvs RPM 12 and Rudu-Rudu were not significantly correlated (data not shown). As the correlations were relatively weak and inconsistent in sign and significance across diets, these relationships were not used for additional co-variance analysis.

Consumption index

A statistically significant ($P < 0.05$) difference in consumption index (CI) was found between the sweet potato diet and the diets cassava, groundnut cv. RPM 12 and maize soaked for 48 hours (Table 2). The differences in CI between the sweet potato diet and the diets groundnut cv. Rudu-Rudu and maize soaked for 24 hours were not statistically significant (Table 2). Similarly, no statistically significant differences were found among the diets groundnut cv. Rudu-Rudu, groundnut cv. RPM 12 and maize soaked for 48 hours. The difference in CI between the means for root crops and grain crops was not statistically significant either (Table 2).

Efficiency of the conversion of ingested food

The efficiency of the conversion of ingested food (ECI) of the crop diets varied from 70.6% for sweet potato to 90.4% for groundnut cv. RPM 12 (Table 2). ECI was lower for sweet potato than for the other crops ($P < 0.10$) (Table 2). A statistically significant difference in ECI was found between the means for root crops and grain crops (Table 2).

Discussion

General

At the start of the growing season (March/April) hungry millipedes emerge from their quiescence at the soil surface and attack the recently planted crops (Ebregt *et al.*, 2005). Millipedes have a large spectrum of food diets (Dangerfield & Telford, 1993). However, in a study with *Alloporus uncinatus* (Mwabvu, 1998a, b) the feeding behaviour of this millipede was 'non-random': the immature female millipedes showed clearer selective feeding than the adult females and the adult males also showed clearer selective feeding than the adult females (Mwabvu, 1998a, b). The species *Omopyge sudanica* was selected for our experiments because it has a well defined host range and is a pest of sweet potato, maize and groundnut (Ebregt *et al.*, 2005).

In our feeding experiments equally sized immature females of *O. sudanica* were used, as the larvae of different development stages are hard to distinguish from other species (C.A.W. Jeekel, personal communication). Moreover, as observed in earlier studies, at this time of the year few male individuals of this species are encountered (Ebregt *et al.*, 2005). Although they were not fully mature, the individuals could be sexed with adequate accuracy.

Intake and weight gain of the millipedes

The weights of all crop diets had decreased due to feeding activity of the millipedes, but no statistical differences among the diets were found. This indicates that the crops investigated fitted within the range of host crops of *O. sudanica*. That farmers experienced millipede damage in these crops was mentioned in previous publications

(Ebregt *et al.*, 2004a, b; 2005), and in an earlier experiment the groundnut cultivar Rudu-Rudu appeared a potential host crop (Ebregt *et al.*, 2005). The statistically non-significant difference between the two groundnut diets showed that the cultivar RPM 12 could equally well serve as a potential host crop.

It should be noted that the lack of statistically significant differences could also have been caused by the short period of our feeding trials. However, extending the experiment would have undoubtedly introduced other inaccuracies and sources of variation. Precision could also have been improved by increasing the number of replicates or the number of batches to obtain even more than the 24 experimental units per diet (12 with and 12 without millipedes) obtained in this experiment.

We assumed that millipedes find it difficult to gnaw at freshly planted maize grains. So the maize grains were soaked before being used in the experiment. Imbibition might induce changes in chemical composition of the dry matter, for example by inducing activity of various enzymes, thus changing intake or weight gain. Heimsch (2003) and Villela *et al.* (2003), however, showed that the water uptake by maize grains during soaking does not affect their quality in terms of dry matter composition and that after 48 hours of soaking, the process of water uptake in the endosperm is not yet completed. In our experiments there was no statistically significant difference in intake by the millipedes between 24 h and 48 h of soaking (Table 1). This may suggest that millipedes can start to gnaw and ingest the seed shortly after planting, even within 24 hours, thanks to their 'strong jaws' (Lawrence, 1984; Hopkin & Read, 1992).

Consumption index

The statistically significant difference in consumption index (CI) was due to the differences between the sweet potato diet and the diets cassava, groundnut cv. RPM 12 and maize soaked for 48 hours. We assume that peeled and cut sweet potato storage root material does not differ from storage roots stored 'in-ground on plants' at the end of the dry season. In an earlier study (Ebregt *et al.*, 2005) it was suggested that sweet potato weevils cause damage during the dry season and consequently provide the millipedes with easy access to the storage roots.

Efficiency of the conversion of ingested food

The data on the efficiency of the conversion of ingested food (ECI) suggest that *O. sudanica* efficiently utilized the grain crop diets groundnut and maize for its growth. With regard to this feeding behaviour, this millipede species is less 'interested' in the 'clean' root crops cassava and sweet potato (Ebregt *et al.*, 2005), but rather prefers to feed on groundnut and maize. The hungry millipedes usually appear from their quiescence at the end of the dry season. Hungry as they are, they will devour anything eatable. They are in need of energy-rich diets, and consequently are often found in neglected fields with in-ground on-plants stored sweet potato. After being satisfied with the energy-rich food, the then planted groundnut seeds will supply the millipedes with the necessary proteins needed for their growth.

Practical implications

The damage to planting material of groundnut and maize can be economically serious. Earlier observations showed that millipedes pierced or completely consumed the cotyledons of germinating groundnut seeds, only leaving behind some remains of the testa. The cotyledon of maize was preferred most and as a result germination failed. Radicles and plumules were also damaged, seriously impairing emergence (Ebregt *et al.*, 2005).

As part of their traditional practices farmers in Zimbabwe prime the maize seeds by soaking them in water overnight before sowing (Clark *et al.*, 2001). Clark *et al.* (2001) argued that this method enhances emergence, ensures an adequate plant stand when planting is done into residual moisture and may assist in catching up with the other plants when soaked seed is used for gap filling. Given the long time required to complete endosperm imbibition (Heimsch, 2003), this traditional practice may not be very advantageous. However, it could make the maize grains a more attractive food for millipedes of the species *O. sudanica*. Priming is not commonly practised in north-eastern Uganda.

Ebregt *et al.* (2005) stated that millipedes are not interested in sweet potato storage roots in crops that have been growing for 5 months after planting. Careless weeding and loosening and earthing up the mounds, resulting in damaged storage roots can nevertheless attract millipedes and provide access to these roots. The damage to the storage roots by millipedes will influence the quality of the roots as a source of human food.

With respect to planting material, sweet potato farmers in north-eastern Uganda usually do not depend on storage roots, but mostly use the vines. Even partly damaged storage roots, often left behind in previous sweet potato fields, are able to produce volunteer plants. These volunteer plants are habitually used as planting material to establish new sweet potato plantings (Bashaasha *et al.*, 1995; Smit 1997; Abidin, 2004; Ebregt *et al.*, 2004a).

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This research was part of a PhD study on integrated management of millipede pests of sweet potato in north-eastern Uganda. The authors wish to thank the Principal of Arapai Agricultural College in Soroti District for providing logistic support and Jonathan Aisu and David Okulimo for being supportive research assistants in the laboratory. The authors are grateful to the Director of Namulonge Agricultural and Animal Production Research Institute (NAARI) for supporting the study within the national mandate of the National Agricultural Research Organisation (NARO) of Uganda.

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CHAPTER 7

Piecemeal versus one-time harvesting of sweet potato in north-eastern Uganda with special reference to pest damage*

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Abstract

In north-eastern Uganda, the sweet potato crop of small subsistence farmers is severely affected by many pests, including (rough) sweet potato weevils, nematodes and millipedes. Field experiments with sweet potato (*Ipomoea batatas* (L.) Lam.) were conducted at Arapai Station in Soroti District, north-eastern Uganda in three consecutive seasons to study the differences between the indigenous practice of harvesting piecemeal in combination with storage 'in-ground on plants' and one-time harvesting after crop senescence, with special reference to damage caused by sweet potato weevils (*Cylas* spp.), rough sweet potato weevils (*Blosyrus* spp.), millipedes (Diplopoda) and nematodes. The area has two rainy seasons per calendar year, the first one with long, reliable rains and the second one with short, unreliable rains. Severe sweet potato weevil damage in the vines was responsible for the mortality of 46% of the plants in Experiment 1, which was carried out during the first rainy season. Starting 3 months after planting (MAP), sizable storage roots could be harvested, although their number and weight declined after 4 MAP with piecemeal harvesting. The highest storage-root yield (17.8 Mg ha^{-1}) was found in Experiment 2 (second rainy season) at the final harvest. The yield of storage roots stored 'in-ground on plants' during the prolonged dry season (Experiment 3) was very low compared with the yields of Experiment 1 (first rainy season) and Experiment 2 (second rainy season). Sweet potato weevil damage of the storage roots was significantly less with piecemeal harvesting than with one-time harvesting and piecemeal harvesting also increased the quality of the storage roots for human consumption and commercial purposes. However, with piecemeal harvesting the rough sweet potato weevil (*Blosyrus* spp.) caused more storage root damage than with one-time harvesting. No statistically significant differences between the two types of harvesting were found for damage caused by nematodes or millipedes. It was concluded that piecemeal harvesting of sweet potato storage roots contributes to the control of sweet potato weevil in both vines and storage roots and hence improves the quality of the harvested roots. As rainfall distribution affects the population dynamics of this weevil this method can only be used during a limited period of the year.

Keywords: *Cylas* spp., *Ipomoea batatas*, millipedes, nematodes, rough sweet potato weevil, storage root damage, sweet potato weevil, vine damage

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Introduction

In north-eastern Uganda, sweet potato (*Ipomoea batatas* (L.) Lam.) is grown year-round by resource-poor farmers, mostly as a subsistence crop for food security (Smit, 1997a; Abidin, 2004), but is also grown as a cash crop for the markets in the rural areas and the Kampala markets (Abidin, 2004; Ebregt *et al*., 2004a). Sweet potato storage roots are rich in carbohydrates and vitamin A and are crucial for people during the harsh dry period (December–March) when people depend on the crop to combat hunger (Anon., 1998).

The climate in the area is characterized by a bimodal rainfall pattern (Bakema *et al*., 1994). A long first rainy season is experienced from March to June, defined as the first growing season, during which all major crops can be grown. After a short dry season, during which crops such as groundnut and sorghum are harvested, there is a second rainy season from August to November, defined as the second growing season but this is less reliable and crop failure is quite common in this period (Bakema *et al*., 1994; Rabwoogo, 1997). Amongst other crops, farmers grow sweet potato during this second rainy season.

Many farmers plant sweet potato at the onset of the first rainy season to secure the families' food supply. However, most farmers often plant groundnut first (Ebregt *et al*., 2004a), because seed of that crop is available early, while lack of sweet potato planting material is eminent at the beginning of the first rainy season (Smit, 1997a; Abidin, 2004; Ebregt *et al*., 2004a). The risk of millipedes affecting early planted material (Abidin, 2004; Ebregt *et al*., 2004b) is another reason to delay planting sweet potato in this rainy season. The final one-time harvest of sweet potato planted either late in the first rainy season or early in the second rainy season usually takes place at the beginning of the second dry (and hot) season, i.e., during December and January. Storage roots have a short shelf life and deteriorate rapidly in the 'store room' (Smit, 1997a). For that reason, farmers who plant in the second growing season often store the roots 'in-ground on plants' during the dry season (Smit & Matengo, 1995; Smit, 1997a; Ebregt *et al*., 2004b).

Because sweet potato is mainly grown for home consumption and consequently a low quality is acceptable, a high level of tolerance of resource-poor farmers to pests can be expected (Smit, 1997a, b). Sweet potato weevils (*Cylas brunneus* and *C. puncticollis*) (Smit, 1997a, b; Ebregt *et al*., 2004b; Ebregt *et al*., 2005) and millipedes (Diplopoda) of the species *Omopyge sudanica* (Omopygidae) (Ebregt *et al*., 2004a, b; Ebregt *et al*., 2005; Ebregt *et al*., 2007) are known to affect the crop. Throughout the year, sweet potato plants and crop residues are accessible to the sweet potato weevil. Vines are susceptible to sweet potato weevils from planting onwards (Sutherland, 1986a). Under favourable conditions sweet potato weevils can produce 13 generations a year, can live 3–4 months and can produce up to an average of 100 eggs per female during its lifetime (Smit, 1997a). Therefore, population densities build up in the course of the growing season. Mwanga *et al*. (2001) stated that the weevils are more abundant and injurious during the dry season than during the rainy season. Dry and hot conditions promote fast development of the weevil and induce the soil to crack, thus exposing the storage roots to the weevils. The larvae tunnel through the storage root, depositing frass, which results in major damage and economic yield loss (Sutherland, 1986b; Chalfant *et al*., 1990). As a result of weevil damage, the crop produces bitter-tasting and toxic terpenes, which reduce the quality of the infested root part for human consumption (Akazawa *et al*., 1960; Uritani *et al*., 1975; Sato *et al*., 1981). It has been suggested that storage root damage inflicted by millipedes may be facilitated by the damage caused by the sweet potato weevil (Ebregt *et al*., 2004a, 2005, 2007).

Pest control is commonly lacking in the area (Smit, 1997a; Ebregt *et al*., 2004b) as farmers cannot afford to buy pesticides (Bashaasha *et al*., 1995; Smit, 1997a; Abidin, 2004; Ebregt *et al*., 2004b). In addition, crop rotation and spatial arrangements avoiding neighbouring crops of the same species are often not practised, resulting in high frequencies and abundances of the pest-prone sweet potato and thus in high pest incidence (Ebregt *et al*., 2004a). Cultural control measures are the best strategy for small-scale sweet potato growers (Smit & Matengo, 1995; Smit 1997a).

In north-eastern Uganda most farmers practise storage ‘in-ground on plants’ combined with piecemeal harvesting (Bashaasha *et al*., 1995; Smit, 1997a, b; Abidin, 2004; Ebregt *et al*., 2004b). This means that from 3 months after planting (MAP), several times during the growing period, farmers remove harvestable, large storage roots from the plant without uprooting the plant itself. Smit (1997b) observed that this harvesting practice reduces sweet potato weevil infestation.

In summary, sweet potato growers in north-eastern Uganda tolerate pest occurrence to a considerable extent but suffer greatly by the detrimental effect of sweet potato weevil on the quality of the storage roots, an effect that can be enhanced by millipede attack but reduced by piecemeal harvesting. This chapter therefore compares the indigenous practice of in-ground storage in combination with piecemeal harvesting with one-time harvesting after crop senescence, with special reference to effects on damage caused by the sweet potato weevil, the rough sweet potato weevil (*Blosyrus* spp. (Coleoptera; Curculionidae)), millipedes and nematodes.

Materials and methods

Site characteristics

Three field experiments with sweet potato, each consisting of piecemeal harvesting plots and one-time harvesting plots, were set up in the Northern Central Farm-bush lands (Wortmann & Eledu, 1999), at an altitude of 1100 m above sea level. The experiments, covering three different seasons, were conducted on sandy loam at the station Arapai in Soroti District, north-eastern Uganda, in 2002 and 2003. Prior to planting, the experimental fields had been under grass fallow for over 10 years, and because of regular bush fires during the dry seasons no trees or shrubs were present in their surroundings.

Experiment 1 was started in May 2002 shortly after the start of the first growing season and lasted 5 months. The experimental field was far away from the intensively cropped fields. Experiment 2 was started in August 2002 at the beginning of the second growing season and also lasted 5 months. Sweet potato and groundnut were grown near the experimental field. Experiment 3 started two weeks after Experiment 2. It differed from the previous two in that the storage roots remained ‘in-ground on plants’ during the subsequent dry season (December 2002 – March 2003). The final harvest was in June 2003 so that Experiment 3 experienced two rainfall periods. Different crops used to be grown at 70 m from the experimental field, but during the course of the experiment that area was under fallow. A dust road cut through the experimental field and through the cropping area.

Rainfall distribution
Rainfall data were obtained from the daily weather recordings at Arapai Station. Figure 1 depicts the average monthly rainfall distribution in Soroti District over the period 1943−1993 and the monthly rainfall during the three experiments. Averaged over the two years, the distribution did not deviate much from the regular rainfall pattern (Bakema *et al*., 1994), except for the rainfall in January and February 2003, which was much higher than normal.

Experimental layout
The three experiments were of the randomized complete block design with one variety (Osukut/Tanzania) and four replications. A block (replication) consisted of 16 plots, 8 plots to be harvested piecemeal and 8 plots to be harvested all at once. A plot comprised 10 mounds, each planted with 3 vine cuttings. So the number of vine cuttings planted per block was 480 and each experiment contained 1920 cuttings. Based on farmers’ practice the mound arrangement was 60 cm × 60 cm. The size of a plot was 3.6 m^2, and that of an experiment 230.4 m^2.

The moment the first crack appeared in a mound, indicating the presence of a harvestable storage root, the treatment *piecemeal harvesting* was assigned to that particular plot. From that moment onwards the remaining plots of an experiment were

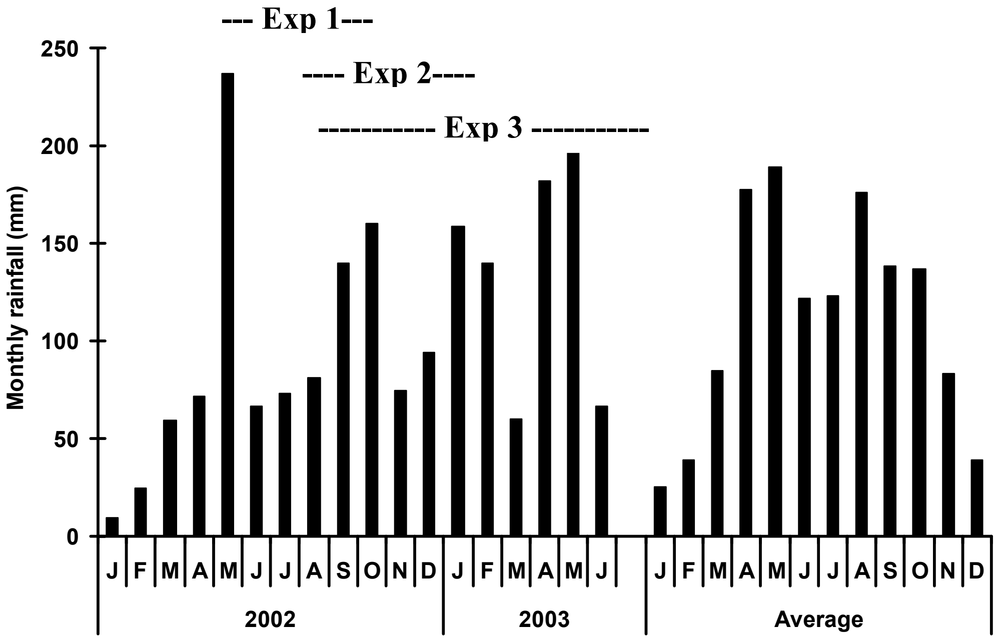

Figure 1. Average monthly rainfall distribution at Soroti station (1943–1993) and monthly rainfall distribution in 2002 and 2003 during Experiments 1, 2 and 3 at Arapai Station, Soroti District, north-eastern Uganda.

checked weekly for the presence of harvestable roots, which continued until 8 plots had been identified for the treatment *piecemeal harvesting*. A consequence of this procedure is that the piecemeal harvesting plots were on average slightly earlier than the plots for one-time harvesting, but this difference did not affect the results presented in this paper.

Final harvesting, consisting of piecemeal harvesting and one-time harvesting, took place on 1 October 2002 (Experiment 1), 3 January 2003 (Experiment 2), and 19 June 2003 (Experiment 3).

Data collection

Fourteen days after planting (14 DAP), each plot was inspected for crop establishment. The cuttings that had not taken root were counted and pulled out. Damage symptoms were recorded and possible causal agents identified. Observations included the above-ground incidence of sweet potato weevil (*Cylas brunneus* and *C. puncticollis*) damage. Mounds with not established cuttings were inspected below soil surface for the presence of millipedes.

With piecemeal harvesting we inspected the soil of each mound for cracks and if encountered the storage root concerned was harvested. In Experiment 2, with piecemeal harvesting, the number of cracks, and the number of mounds containing harvestable storage roots were counted and the storage roots were collected. The roots were separated into harvestable and non-harvestable storage roots and their numbers and weights determined. These data were not collected in Experiments 1 and 3.

At the final harvest of all experiments the following data were recorded or calculated based on adding the results of all harvests: (1) total number and weight of harvestable and non-harvestable storage roots, (2) total number of piecemeal harvested and total number of one-time harvesting roots, (3) number of plants established, (4) the number of vines damaged by sweet potato weevil, and the number of storage roots damaged by sweet potato weevil, rough sweet potato weevil, millipedes and nematodes (only in Experiments 1 and 2), and (5) assessments of damage on vines and storage roots by the sweet potato weevil (Experiments 1, 2 and 3).

The severity of sweet potato weevil damage (incidence) on the storage roots was determined by using a 4-nominal rating scale for the level of damage. To this end, the surface area of the storage root was divided into three sections: top, middle and base. Insignificant damage was scored as 1. If one third of the surface of the storage root was damaged, we scored the damage as 2. When two thirds of the surface area was affected, the score was 3. A score of 4 was given if the storage root's entire surface was affected.

Statistical analysis

For the piecemeal harvesting treatment in Experiment 2, the number of cracks, the number of mounds with a harvestable storage root and the total number of storage roots (harvestable and non-harvestable) were recorded for each plot and block and averaged at each piecemeal harvest. Also the average weights of harvestable and non-harvestable roots were determined. For the one-time harvesting treatment in Experiment 2, the numbers and weights of harvestable and non-harvestable fractions were determined at final harvest. Data are expressed per block, per plot or per hectare. Data were analysed using standard analysis of variance or regression analysis.

For Experiments 1 and 3, only the overall yield level in the experiment was assessed by pooling piecemeal and one-time harvesting treatments. Final yields were converted into Mg per ha.

At the final harvest of Experiments 1 and 2 the number of plants that had established was counted per plot for both types of harvesting, assuming that a missing plant was associated with a not established cutting. However, we could not record the number of vines for Experiment 3 (experiment with 'in-ground storage on plants') as the vines had died and disappeared before harvesting the storage roots. The number of storage roots per plot was counted for both types of harvesting in Experiments 1, 2, and 3. The data were analysed using standard analysis of variance.

The number of vines damaged by sweet potato weevil, and the storage roots damaged by sweet potato weevil, rough sweet potato weevil, nematodes or millipedes were counted per plot in Experiments 1 and 2 and then transferred into percentages. A standard analysis of variance was used to analyse these data.

For Experiments 1 and 2, the relative frequencies of severity scores for the storage roots damaged by sweet potato weevil were calculated by using $\Sigma n_i/n_t$, in which n_i is the number of storage roots of a specific score (i) and n_t is the total number of storage roots. A standard analysis of variance was used to analyse each score.

For Experiments 1, 2 and 3 we used a non-parametric measure to analyse the level of damage by sweet potato weevils in vines and storage roots assessed at final harvesting. The vines and storage roots were divided into two classes: damaged (score 1) and undamaged (score 0). If the base of a vine was clearly swollen and cracked it was classified as damaged. A storage root was classified as damaged if at least two thirds of its surface was damaged. Kruskal-Wallis one-way analysis was used to analyse the effects of type of harvesting on the values of these scores.

All statistical analyses were done using Genstat Release 8.1 (Anon., 2005). The usual arcsine$\sqrt{x}$ transformation of percentages did not improve the normality of the residuals and was therefore not applied. Data were not only analysed per separate experiment but where possible also after combining data sets of different experiments.

Results

Crop establishment

The percentage not established sweet potato vine cuttings in Experiments 1 and 3 two weeks after planting (14 DAP) was less than 1, whereas in Experiment 2 it was 4 (data not shown). In all three experiments millipedes had not affected the vine cuttings and no millipedes (or fresh entrance holes) were observed. The not established vines were replaced by new cuttings.

The vines in Experiment 1 faced a period of drought after 14 DAP. As a result, at the final harvest (5 MAP) the average percentages plants established in the piecemeal harvesting and the one-time harvesting plots were only 48 and 59, respectively (data not shown). The plants in Experiments 2 and 3 established well with negligible or no visible damage to the above ground parts up to 4 MAP. No gap filling was done after 14 DAP in any of the three experiments. In Experiment 3, with the storage roots stored 'in-ground on plants' up to 9 months, the plants wilted and perished at 7 MAP; volunteer plants appeared with the onset of the first rainy season of 2003.

Piecemeal harvesting – Experiment 2

The successive ('progressive') harvests of the piecemeal harvesting treatment of Experiments 1 and 2 were done 91 (3 MAP), 98, 105, 112, 119, 126 (4 MAP), 133, 140 and 147 (5 MAP) days from planting. In Experiment 3, piecemeal harvesting took place beyond 5 MAP, at longer and less regular intervals.

The average number of cracks, the number of mounds with harvestable storage roots, the number of harvestable and non-harvestable storage roots, and the weight of harvestable and non-harvestable storage roots per block tended to decline with time (Figures 2a, 2b and 2c).

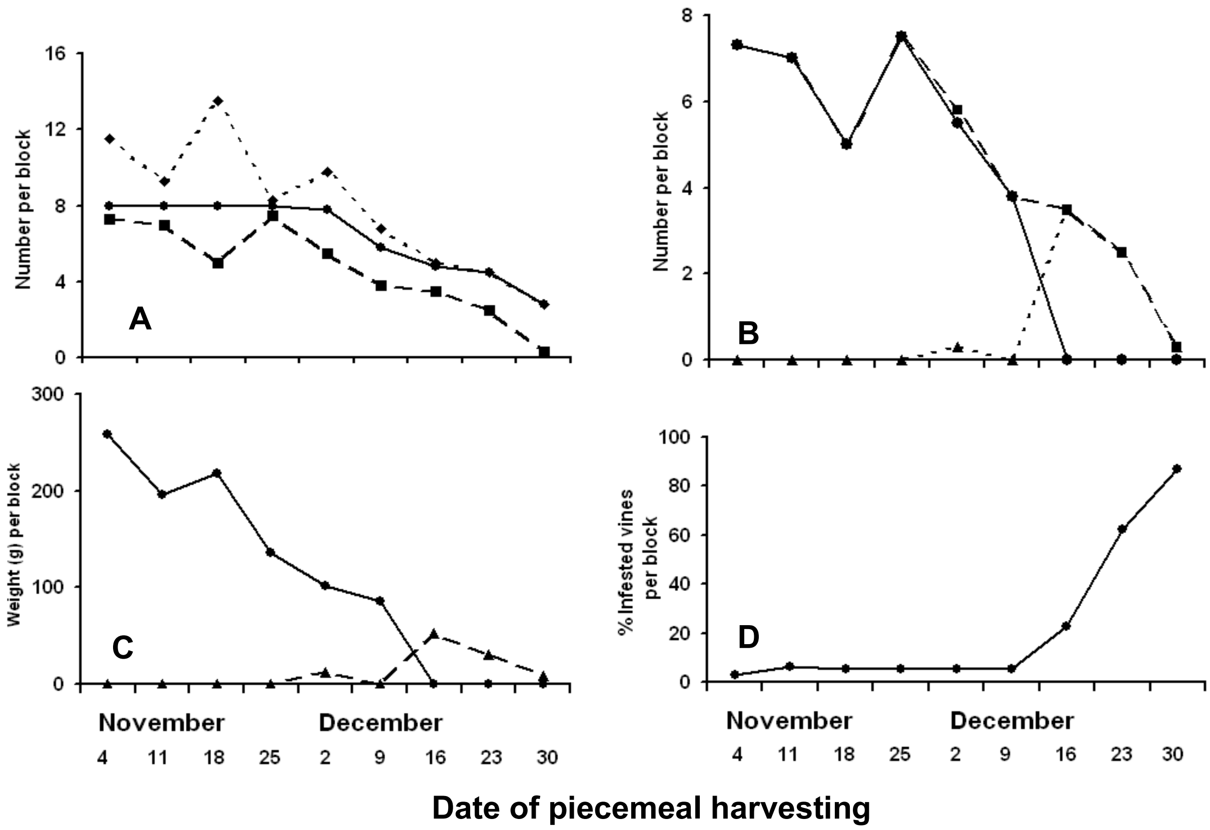

Figure 2. Changes in (A) average number of cracks (●), number of mounds containing harvestable storage roots (♦) and number of storage roots (■) per block; (B) average number of harvestable storage roots (●), average number of non-harvestable storage roots (▲) and total number of storage roots (■) per block; (C) average weight of harvestable (●) and non-harvestable storage roots (▲) per block, and (D) % infested vines per block during the period 4 November – 30 December 2002, as affected by piecemeal harvesting. Results from Experiment 2 (planted in August 2002; see text) at Arapai Station, Soroti District, north-eastern Uganda. Note that each block contained 80 mounds.

The average number of vines affected by sweet potato weevils was low up to the sixth piecemeal harvest (4 MAP), but sharply increased from 4.5 MAP onwards (Figure 2d).

Figures 2b and 2c show that the average number and weight per block of harvestable storage roots sharply decreased with time, whereas the average number and weight per block of non-harvestable storage roots remained low until 9 December (the sixth piecemeal harvest). However, their average number and weight per block had increased at the next harvest but decreased again thereafter.

Number of vines and number, weight and yield of storage roots

In Experiment 1, significantly more vines had established in the one-time harvesting plots than in the piecemeal harvesting ones, but the average number of established vines per plot was similar for the two harvesting practices in Experiment 2 (Table 1).

Highly significant differences in number of storage roots were found between the three experiments (data not shown), with Experiment 1 yielding the highest number and Experiment 3 the lowest. One-time harvesting resulted in more storage roots in Experiment 1, whereas in Experiment 2 piecemeal harvesting yielded more storage roots; in Experiment 3 the difference was not statistically significant (Table 1). Averaged over the three experiments, the difference in total number of storage roots between harvesting practices was not statistically significant.

Table 1. Sweet potato. Number of vines and number of storage roots per plot at the final harvest of the piecemeal and one-time harvesting plots, as recorded in three experiments at Arapai Station in Soroti District, north-eastern Uganda.

Harvesting	Exp. 1		Exp. 2		Exp. 3		Average	
practice	Vines	Roots	Vines	Roots	Vines	Roots	Vines	Roots
Piecemeal harvesting	14.5	20.2	29.3	54.1	– [1]	11.0	21.9	28.4
One-time harvesting	17.7	28.5	29.5	50.6	–	10.8	23.6	30.0
P-value [2]	**	**	ns	(*)	–	ns	**	ns
LSD [3]	1.9	4.3	–	(3.5)	–	–	1.0	–

[1] Not determined.

[2] ns = not statistically significant; (*) = $P < 0.10$; ** = $P < 0.01$.

[3] LSD = least significant difference; values not in brackets at $P = 0.05$; value in brackets at $P = 0.10$.

Highly significant differences were found among the three experiments in the number and weight of harvestable and non-harvestable storage roots. The total yields of harvestable plus non-harvestable roots in Experiments 1, 2, and 3 were 8.4, 17.8, and 1.1 Mg ha^{-1}, respectively ($P < 0.001$; LSD = 4.48; data not shown).

A positive linear relationship ($P < 0.001$) was found between the number of vines and the number of storage roots for each of the two types of harvesting across Experiments 1 and 2 (Figure 3).

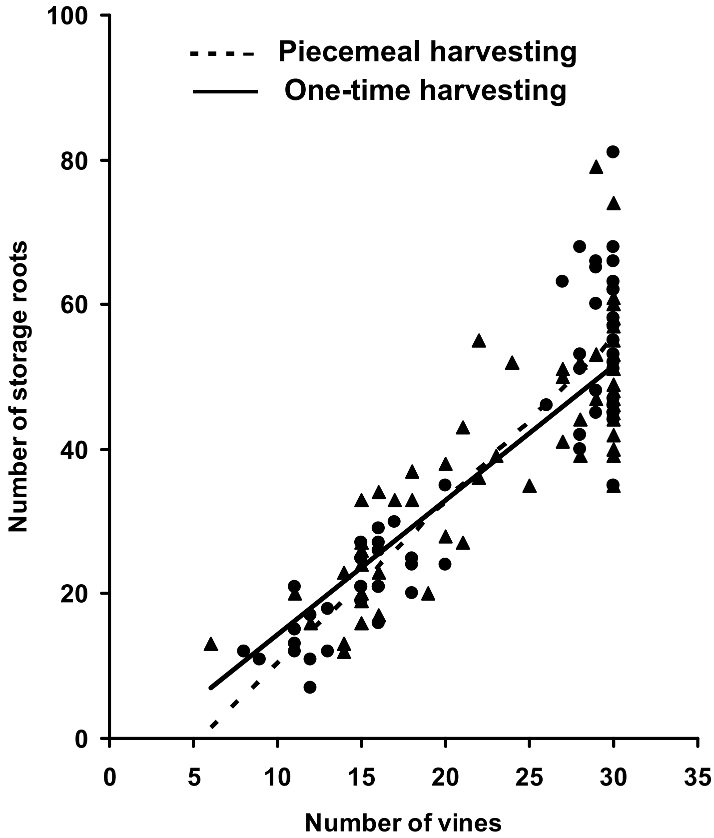

Figure 3. Fitted and observed relationships between average number of storage roots and vines per plot for one-time harvesting (▲) and piecemeal harvesting (●) across two experiments conducted at Arapai Station, Soroti District, north-eastern Uganda. Regression equation for piecemeal harvesting: $y = -11.88 + 2.24\ x$ ($R^2 = 0.829$; n = 64); for one-time harvesting: $y = -4.01 + 1.85\ x$ ($R^2 = 0.689$; n = 64). The interaction between the effect of the number of vines and the type of harvesting is statistically significant at $P < 0.10$.

Vine and storage root damage by sweet potato pests

Vine damage by sweet potato weevil was more severe in Experiment 1 than in Experiment 2 ($P < 0.001$; data not shown). As for the storage roots, no statistically significant differences were found in sweet potato weevil, millipede or nematode damage between the experiments. But a highly significant difference was found in root damage for the rough sweet potato weevil ($P < 0.001$; data not shown).

The harvesting practice affected vine damage by sweet potato weevil significantly ($P < 0.001$) only in Experiment 2, and affected storage root damage in Experiment 1 ($P < 0.001$) and weakly so in Experiment 2 ($P < 0.10$) (Table 2). The damage to vines and storage roots was significantly more with one-time harvesting than with piecemeal harvesting. With regard to the rough sweet potato weevil, the effect of harvesting practice was only statistically significant in Experiment 2 ($P < 0.01$): the piecemeal harvesting resulted in more damage to the storage roots than the one-time harvesting. The effects of harvesting practice were not statistically significant for the damage to storage roots by millipedes or nematodes.

A statistically weakly significant difference ($P < 0.10$) in vine damage by sweet potato weevil between piecemeal and one-time harvesting was observed when the results were analysed across experiments, but a highly significant difference ($P < 0.001$) was found for storage root damage. The storage root damage by the rough sweet potato weevil was significantly different ($P < 0.05$), whereas no statistically significant differences in storage root damage between piecemeal and one-time harvesting were found for millipede and nematode damage (Table 2).

Scores of sweet potato weevil damage on storage roots

In Experiment 1, statistically significant differences were found in the frequencies of scores 1, 3 and 4 between the two types of harvesting practice, but the differences in the frequencies of score 2 were not statistically different (Table 3). In Experiment 2, none of the scores differed significantly. When analysing the results across the three experiments a statistically significant difference ($P < 0.01$) in frequencies of score 1, weakly significant differences ($P < 0.10$) in scores 3 and 4, and a non-significant difference in score 2 were found between piecemeal and one-time harvesting. Highly significant differences were found between Experiments 1 and 2 for scores 2, 3 and 4 ($P < 0.001$); a non-significance was found for score 1 (data not shown).

Field assessment of vine and storage root damage in Experiments 1, 2, and 3

A highly significant difference in vine damage was found among Experiments 1, 2 and 3 ($P < 0.001$; data not shown). The vines in Experiments 1 and 3 were severely damaged, whereas the damage in Experiment 2 was negligible (data not shown). No

Table 2. Sweet potato. Percentages of vines damaged by sweet potato weevil (*Cylas* spp.), percentages of storage roots damaged by sweet potato weevil, rough sweet potato weevil (*Blosyrus* spp.), millipedes and nematodes at the final harvest of piecemeal and one-time harvesting plots, as recorded in two experiments at Arapai Station in Soroti District, north-eastern Uganda.

Experiment/	Vines damaged	Storage roots damaged by			
Harvesting practice	by *Cylas* spp.	*Cylas* spp.	*Blosyrus* spp.	Millipedes	Nematodes
	←		%		→
Experiment 1					
Piecemeal harvesting	96.0	22.4	2.1	0.3	4.7
One-time harvesting	95.0	35.7	1.9	0.6	5.8
P-value [1]	ns	**	ns	ns	ns
LSD [2]	–	7.5	–	–	–
Experiment 2					
Piecemeal harvesting	10.5	22.9	32.0	0.6	4.4
One-time harvesting	18.9	27.6	26.5	0.7	5.1
P-value	**	(*)	**	ns	ns
LSD	5.6	(4.6)	4.3	–	–
Averaged over both experiments					
Piecemeal harvesting	53.3	22.7	17.0	0.4	4.6
One-time harvesting	57.0	31.6	14.2	0.6	5.4
P-value	(*)	**	*	ns	ns
LSD	(3.4)	4.6	2.4	–	–

[1] ns = not statistically significant; (*) = $P < 0.10$; * = $P < 0.05$; ** = $P < 0.01$.

[2] LSD = least significant difference; values not in brackets at $P = 0.05$; values in brackets at $P = 0.10$.

statistically significant differences were found in sweet potato weevil damage of the vines between piecemeal and one-time harvesting.

Highly significant differences in storage root damage were observed among the three experiments ($P < 0.001$; data not shown). In Experiments 1 and 3 the storage roots were severely damaged, whereas in Experiment 2 the damage level was low and unimportant (data not shown). The number of storage roots damaged by the sweet potato weevil as determined over the three experiments was significantly lower ($P < 0.10$) with piecemeal than with one-time harvesting.

Table 3. Sweet potato. Relative frequencies of severity scores of damage to storage roots caused by sweet potato weevil (*Cylas* spp.) at the final harvest of the piecemeal and one-time harvesting plots, as observed in two experiments at Arapai Station in Soroti District, north-eastern Uganda.

Experiment/	Score[1]			
Harvesting practice	1	2	3	4
Experiment 1				
Piecemeal harvesting	0.78	0.02	0.12	0.08
One-time harvesting	0.64	0.02	0.19	0.15
P-value [2]	**	ns	*	*
LSD [3]	0.08	–	0.07	0.07
Experiment 2				
Piecemeal harvesting	0.76	0.19	0.04	0.02
One-time harvesting	0.72	0.21	0.04	0.03
P-value	ns	ns	ns	ns
LSD	–	–	–	–
Averaged over both experiments				
Piecemeal harvesting	0.77	0.11	0.08	0.05
One-time harvesting	0.68	0.11	0.12	0.09
P-value	**	ns	*	*
LSD	0.05	–	0.04	0.04

[1] Scores on a scale of 1–4 (1 = negligible damage; 4 = severe damage).

[2] ns = not statistically significant; * $P < 0.05$; ** = $P < 0.01$.

[3] LSD = least significant difference ($P = 0.05$).

Discussion

This rationale of this chapter was to compare the indigenous practice of in-ground storage in combination with piecemeal harvesting with one-time harvesting after crop senescence, with special reference to effects on damage caused by the sweet potato weevil, the rough sweet potato weevil, millipedes and nematodes.

Crop establishment

No millipede damage was observed in any of the three experiments 14 DAP. This was not expected, especially not in Experiment 1, as earlier research on sandy loam at

Arapai Station has shown that failure of vine establishment is often due to millipede activity (Abidin, 2004; Ebregt *et al*., 2005). In our experiments vine cuttings had been planted approximately 6 weeks after the onset of the first rains so that by then millipedes may have been distracted by other food sources. Moreover, the absence of millipedes or fresh entrance holes in the mounds suggests that the millipede population must have been low as the area had been under fallow for a long time and had frequently been invaded by bush fires.

Experiment 1 experienced a severely dry period (Figure 1) two weeks after planting, resulting in the death of many vines. Populations of sweet potato weevil build up in dry conditions (Smit, 1997a) so that it is not surprising that at 4 MAP this pest was already active in the crop, starting on the vines. In contrast, in Experiments 2 and 3, good rains prevented sweet potato weevil from building up their populations: damage symptoms were present at 4 MAP, but were very low.

Piecemeal harvesting – Experiment 2

Lately farmers tend to also grow sweet potato in the second rainy season, which is characterized by unreliable rains (Abidin, 2004; Ebregt *et al*., 2004a). For that reason the explicit impact of piecemeal harvesting on weevil and millipede infestation was studied in Experiment 2.

With piecemeal harvesting, subsistence farmers look for cracks in the mounds to detect the location where a harvestable storage root (> 75 g) can be expected. This usually starts at 3 MAP (Bashaasha *et al*., 1995; Smit 1997a). So this practice was also followed in our experiments. However, the number of cracks became smaller from 9 December onwards (6th piecemeal harvest or 4.5 MAP) (Figure 2a). This drop corresponded with the onset of the dry season (Figure 1). In this period the weevil started to invade the crop above soil surface and the proportion of vines damaged increased with time (Figure 2d). Based on the results in Figure 2a, it is advisable not to uproot the storage roots later than 4.5 MAP, since the number of storage roots is declining. From this moment farmers should check their crop for weevil infestation. As a weevil control strategy infested plants should be uprooted and destroyed. This would prevent the field from becoming a breeding site for weevils. It would also prevent the vines from this field becoming a source of infested planting material.

Sutherland (1986a) observed an increase in the number of damaged vines, beginning 25 days from planting, a number that increased logarithmically with time. In our experiment a comparable trend was noticed (Figure 2d). However, the initial trend of the graph shows a delayed increase, which may have been due to gap filling followed by adequate rainfall, making conditions unfavourable for the increase of the sweet potato weevil population.

Sherman (1951) presumed that vines act as a source of weevil infestation for storage roots. As the crop develops, the breeding place of the weevil moves from the base of the vine to the root. In addition, Jayaramaiah (1975) and Ames *et al*. (1987) mention that the root is the preferred oviposition site. Sutherland (1986a) suggests that the change in breeding site would cause a decline in the rate of increase in the number of damaged vines but would increase the percentage of damaged storage roots, starting 12 weeks after planting.

Sizable storage roots could still be removed after 4 MAP, although their number and weight declined (Figures 2b and 2c). However, as by then cracks may have been caused by drought, we could easily have been confused not knowing whether the crack contained a sizable root or not. It was noted that at that time the number and weight of non-sizable roots increased (Figures 2b and 2c). At the same time weevils infested the crop (Figure 2d), causing a reduction in quality of some storage roots and rendering them non-marketable (Figure 2b). Another reason of a decline in storage root quality might be the effect of resorption and sprouting, enhanced by the high soil temperatures and the low level of residual soil moisture, which will be discussed later. Nonetheless, a few weeks later the average number and weight of the roots started to drop, a trend that continued until the final harvest. It is possible that meanwhile non-harvestable roots grew out into harvestable storage roots (Figure 2b).

Number of vines at final harvest and number, weight and yield of storage roots

Only the data of Experiments 1 and 2 could be analysed for an effect of number of vines on storage roots at the final harvest (Table 1). In Experiment 3 the storage roots stayed 'in-ground on plants' and the vines wilted and perished. Following the prolonged drought period prior to the onset of the second rainy season volunteer plants appeared in the field, which was caused by sprout growth from storage roots and resulted in resorption of these roots.

As for the number of vines at the final harvest, an effect of the two types of harvesting practice was only observed in Experiment 1. We suspect that some vines were easily mechanically damaged especially with piecemeal harvesting during dry spells (Figure 1). Drought stress may make sweet potato stems brittle.

The numbers of storage roots harvested from the two types of harvesting practices in the three experiments, which were conducted in three different seasons, varied largely (Table 1). This result is in line with earlier research by Janssens (1984) and Abidin *et al*. (2005), in which it was shown that the performance of sweet potato in terms of number and yield of storage roots is very sensitive to environmental conditions, such as climate.

The average number of storage roots in Experiment 3 was very low because most roots had rotted due to infestation by sweet potato weevil and other pests, or had shrunk due to resorption and disappeared following the production of volunteers. This is reflected by the data in Figures 2b, 2c and 2d.

In Experiment 2 the vines were seriously damaged by the sweet potato weevil (Table 2) and by drought (Figure 1). This finding is in accordance with results obtained by Smit (1997). However, Mullen (1982) singled out the mortality of plants caused by weevil infestation. Talekar (1982) found no correlation between numbers of sweet potato weevils in 'crowns' (vines) and numbers in the roots, and the weevil infestation did not reduce root yield. On the other hand, Ames *et al*. (1987) found that the sweet potato weevil feeds inside the vine, causing malformation, thickening and cracking of the affected vine. Heavy infestation of vines with high damage levels in vines (i.e., vine base) could affect the storage roots and consequently a reduction in total yield and root size (Sherman, 1951; Mullen, 1982; Sutherland, 1986a; Smit, 1997a, b). A statistically significant relationship was found between number of vines and number of storage roots (Figure 3). Consequently, this could imply that there is also a strong relationship between weevil damaged vines and weevil damaged storage roots.

Most harvestable storage roots affected by weevils are not accepted on the market. Hence they were regarded as non-marketable. Rose (1979) called the non-marketable storage roots 'pig' roots. In north-eastern Uganda, however, the edible parts of infested marketable roots are used for human consumption together with the non-marketable sized roots, e.g. for preparing *inginyo* by drying crushed sweet potato pieces (Abidin, 2004).

Piecemeal versus one-time harvesting

Piecemeal harvesting led to less weevil damage to vines only in Experiment 2 (Table 2). In Experiment 1, where conditions for weevils were optimal, the damage level to the vines was extremely high. In such situations piecemeal harvesting cannot reduce weevil infestation. Piecemeal harvesting only works when there is enough rainfall to slow down the rate of population growth of the weevils.

In the sweet potato agro-ecological zones of north-eastern Uganda the sweet potato weevil is considered a potentially serious pest (Bashaasha et al., 1995; Smit, 1997a; Hakiza *et al*., 2000; Ebregt *et al*., 2004a). In Experiments 1 and 2, carried out in the first and second rainy season, the level of infestation of the storage roots was similar (Table 2). Compared with one-time harvesting, piecemeal harvesting reduced the storage root damage, suggesting that this harvesting method could also be used as a cultural practice for controlling below-ground weevil infestation to reduce storage root damage, as earlier suggested by Smit (1997a, b). Crack filling could be another method. However, O'Hair (1991) found that weevil pressure is a continuum in piecemeal harvesting areas, during which plants are often allowed to remain in the field for prolonged periods. Moreover, the sweet potato weevil can facilitate millipede damage (Ebregt *et al*., 2004a, 2005, 2007), especially if storage roots are stored 'in-ground on plant' up to the end of the dry season (Abidin, 2004; Ebregt *et al*., 2004a, b; 2005).

In north-eastern Uganda, sweet potato is the major staple food and an increasingly important cash crop at subsistence level (Scott *et al*., 1999; Abidin, 2004). In addition, the use of several by-products of the sweet potato is on the increase (Abidin, 2004). Farmers should improve the quality of their sweet potato harvest. Therefore, determining the quality by using scores of the level of damaged storage roots is an important assessment. However, a farmer can only wish to get enough rain. The dry spells during the first rainy season of 2002, when Experiment 1 was conducted, created optimal conditions for the sweet potato weevil to build up its population. In this experiment severe damage (score 4) occurred most frequently with the one-time harvesting practice (Table 3). In order to maintain the quality of the produce under these circumstances, piecemeal harvesting is advised.

At the final harvest of 'in-ground on-plants' of Experiment 3, most plants had wilted and perished due to a combination of drought and sweet potato weevil infestation. When the rains returned, volunteer plants emerged from the storage roots. Most volunteer plants and the remaining storage roots were severely damaged by sweet potato weevils. As a result, the effect of harvesting practice was not significant.

The rough sweet potato weevil can cause serious problems in some areas in Eastern Africa (Ames *et al*., 1997; Smit, 1997a). Nonetheless, in north-eastern Uganda, farmers never indicated this weevil as a serious pest in sweet potato (Ebregt *et al*., 2005). The larva of this weevil can cause greater damage than the adult weevil. While feeding under the soil surface, the larvae gouge shallow channels on enlarging storage roots, resulting in reduced marketability (Ames *et al*., 1997; Smit, 1997a). Results of our experiments (Table 2) show that this pest caused significantly more storage root damage with piecemeal than with one-time harvesting. However, this finding only applied to Experiment 2. Consequently, we suggest that piecemeal harvesting should not be considered a cultural control measure to reduce rough weevil populations and their associated damage.

Nematode and millipede damages in the storage roots were slight (Table 2). In north-eastern Uganda, however, nematode and millipede populations can easily grow in size due to the customarily negligence of basic pest control practices such as sanitation, proper crop rotation, timely planting and spatial arrangements avoiding neighbouring crops of the same species.

Conclusions

The results of our research show that piecemeal harvesting of sweet potato contributes to the control of sweet potato weevil in both vines and storage roots and as a result increases the quality of the storage roots, but that it can only be practised during a limited period of the year.

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CHAPTER 8

General discussion

The approach that was taken in the research described in this thesis included the following steps and methodologies:

- A literature study to gain a working knowledge on millipedes.
- Collection of information from farmers through individual interviews using a participatory rural appraisal.
- Field assessments of pest damage in sweet potato and other major crops.
- Laboratory experiments on feeding activity of the East African millipede *Omopyge sudanica* Kraus.
- Field trials aimed at comparing the indigenous cultural practices piecemeal harvesting and storage 'in-ground on plants' with one-time harvesting at maturity.

The highlights of the thesis are:

With regard to the sweet potato in the cropping system and farmers' awareness of pests and diseases:

1. Sweet potato is an important crop in the cropping system of north-eastern Uganda and its spatial and temporal patterning has an impact on the level of pest infestation.
2. Millipede infestations are associated with general agricultural practices but farmers are not always able to recognize the damage caused by millipedes or by other soil pests in their crops.
3. Farmers' working knowledge about pests and their understanding of the life cycles of the most common sweet potato pests is generally limited. This is also true for their knowledge on control strategies.

With regard to the damage by millipedes:

1. Millipedes inflict damage on planting material in the beginning of the first rainy season. Millipede damage in germinating groundnut and maize is quite serious if the crop is planted early in the first rainy season.
2. At harvest 5 months after planting, millipedes hardly inflict damage on storage roots of sweet potato. The percentage storage roots infested by millipedes gradually increases when stored 'in-ground on plants' during the dry season, with a high incidence when rains return.
3. Quantitative data on feeding habits of millipedes are difficult to obtain.

4. The millipede *O. sudanica* can cause harm to crops in north-eastern Uganda. This species efficiently utilizes the grain crop diets groundnut and maize for its growth.

With regard to damage by sweet potato weevils:
1. Although indigenous piecemeal harvesting can only be done during a limited period of time, it is advantageous for the control of the sweet potato weevils (*Cylas* spp.) and can therefore be used to maintain the quality of storage roots.
2. When storage roots are severely infested by sweet potato weevils, then there is no difference between one-time and piecemeal harvesting in maintaining quality.

In this general discussion, I want (i) to highlight some of the aspects that are relevant to the different approaches,and (ii) to generate some ideas on possible Integrated Crop Production and Pest Management Strategies using the information generated from farmers and the results from laboratory and field experiments.

The farmers' interviews

Participatory rural appraisal methodology was used to interview 148 farmers from 32 sub-counties during a year. Each interview took about 1 hour and 45 minutes. The farms were located in the Northern Moist Farmlands, North-Central Farm-Bush Lands, and Southern and Eastern Lake Kyoga Basin agro-ecological zones (AEZs) in north-eastern Uganda (Chapters 3 and 4). In the three agro-ecological zones a number of broad valley bottoms occur with grassland communities consisting of *Echinochloa* and *Sorghastrum*, which are seasonally water-logged (Aluma, 2001).

From the interviews it was concluded that sweet potato is an important crop in the cropping system (Ebregt *et al*., 2004a, b) which can be found in the field year round (Smit, 1997a; Abidin, 2004; Ebregt *et al*., 2004a, b). Sweet potato weevils were considered the most important pests, followed by rats and millipedes (Ebregt *et al*., 2004b). This in contrast with earlier reports by Lawrence (1984) stating that millipedes are not pests of primary importance. Farmers intimated that the impact of millipedes was also serious in other major food and cash crops, such as cassava, groundnut, maize and beans (kidney bean or other grain legumes) (Ebregt *et al*., 2004a). Other crops affected by millipedes were bambara groundnut, soya bean, cabbage, cotton, sunflower and banana (Ebregt *et al*., 2004b).

Farmers often neglected the desirable separation of plots in space and over time. Not implementing a spatial distance might be a factor contributing to the introduction of millipedes from neighbouring fields (Ebregt *et al*., 2004a). Furthermore, the sweet potato crop rotation systems varied among the agro-ecological zones and even within households. In a generalized rotation system for the area, sweet potato was often followed by finger millet or groundnut. In the Northern Moist Farmlands, maize was also grown after sweet potato. Moreover, sunflower, soya bean, kidney bean or other legumes, sesame and cassava were grown after sweet potato. Occasionally sweet potato was followed by a fallow period (Ebregt *et al*., 2004a). The most common crop preceding sweet potato was cassava. Sorghum, millet, maize, bean, sesame and groundnut were often cropped before sweet potato. In the Northern Central Farm-Bush Lands, the preceding crops were cassava, groundnut, sorghum, millet and sesame. In the Southern and Eastern Lake Kyoga Basin the preceding crops were cassava, groundnut, millet or sorghum, and sometimes cowpea or green gram (Ebregt *et al*., 2004a). It appeared that millipede incidences depended on the frequency of millipede hosts. Especially groundnut planted after sweet potato had high levels of millipede attack (Ebregt *et al*., 2004a, 2005). Despite the farmers' awareness and concern about the damaging effect of millipedes on groundnut, many of them stated that they would still grow groundnut after sweet potato (Ebregt *et al*., 2004a).

Home nurseries have a function to secure planting material in the homegarden. It also supplements the families' scanty diet during the dry season (Ebregt *et al*., 2004a). However, these home nurseries harboured relatively high populations of millipedes (Ebregt *et al*., 2004a).

Farmers were eager to plant in March-April for reasons of food security (Abidin, 2004). However, this increased the risk of losing plant material due to millipede activity. In contrast, millipedes generally did not affect the storage roots until 5 months after planting (Abidin, 2004; Ebregt *et al*., 2004a, b).

During weeding the mound is carefully loosened and earthed up with surrounding soil to allow water to penetrate. Although this cultivation practice could prevent sweet potato weevil from having easy access to the storage roots (Smit, 1997a), millipedes now find a suitable environment to live in (Ebregt *et al*., 2004a). It is generally assumed that millipedes merely aggravate the damage initiated by some other agents, like farming equipment (Lawrence, 1984; Blower, 1985; Hopkin & Read, 1992). Weeding close to the stem basis can disturb the root development. Therefore a second weeding was not really recommended by farmers (Abidin, 2004; Ebregt *et al*., 2004a).

Immediately after harvest it is common practice to leave behind the sweet potato crop residues including the small or badly affected storage roots in the field. Often the small roots are buried to stimulate the development of volunteer plants. So weevils and millipedes can survive in the storage roots during the dry season (Ebregt *et al*., 2004b). During the dry season, farmers often practise storage 'in-ground on plants'. In this way farmers secured volunteer plants (Ebregt *et al*., 2004b). Cleaning the field at the beginning of the first rainy season provided the millipedes suitable hiding places under the piles of excess of volunteers and infected storage roots, from where they could easily affect after-crops, like groundnut, maize and cassava, besides sweet potato (Ebregt *et al*., 2004b).

The interviews indicated that the root damage caused by millipedes follows on the damage caused by sweet potato weevils. This suggests that sweet potato weevils enhance the entrance and damage by millipedes. This is especially important at the end of the dry season with the onset of the first rains, when the sweet potato weevils have inflicted a lot of damage on the storage roots stored 'in-ground on plants'. Millipedes emerge from their quiescence and are attracted by the damaged storage roots (Ebregt *et al*., 2004a).

Most farmers pull the remains of the dying planting material out of the mound, without thoroughly inspecting them, enabling soil pests like millipedes to hide unnoticed. Because the leftovers of the planting material often show symptoms of desiccation, they often blame drought as the most common cause for failing to take off (Ebregt *et al*., 2004b), confirming earlier reports by Bashaasha *et al*. (1995) and Smit (1997a). Only 30% of the farmers interviewed 'inspected' the inside of the mounds, and sometimes the failure was contributed to millipedes, but other farmers also reported that 'something' chewed away the new developing roots. As a result, it may be expected that the actual incidence of millipedes reported can be much higher when farmers use this method of inspection (Ebregt *et al*., 2004b). Most farmers were able to recognize the damage by millipedes in storage roots, as the roots are clearly pierced and burrowed and millipedes are often found in them (Ebregt *et al*., 2004b).

Many farmers indicated that they had problems with millipedes in groundnut, especially when the groundnut was sown after sweet potato at the first rains of the new growing season (Ebregt *et al*., 2004a, b). They were able to identify the damage symptoms (Ebregt *et al*., 2004b). Also from the interviews it appeared that a large group of farmers was not aware of millipede damage in groundnut (Ebregt *et al*., 2004a).

In the Northern Moist Farmlands, maize is an after-crop of sweet potato (Ebregt *et al*., 2004a). During the interviews only very few farmers indicated maize as a host plant of millipedes (Ebregt *et al*., 2004a, b). It could not be established whether farmers were aware of the damage symptoms in this crop. Very few farmers mentioned that millipedes affected the sprouting material of cassava, especially planted at the beginning of the early rains of the new growing season (Ebregt *et al*., 2004a).

Millipedes could be easily identified by most of the interviewed farmers. On showing two species, the *O. sudanica* and the bigger species *Spirostreptus ibanda*, often the *O. sudanica* was identified as the culprit. Although the sweet potato weevil (*Cylas brunneus* and *C. puncticollis*) is the most important biological constraint of sweet potato cultivation, many farmers think that the larval stage, often indicated by them as 'worms', is another pest (Ebregt *et al*., 2004b). The farmers' knowledge on the understanding of the life cycles of other sweet potato pests, such as the rough sweet potato weevil (*Blosyrus* spp.) and the sweet potato butterfly (*Acraca acerata*) is generally limited (Ebregt *et al*., 2004b).

During the turmoil in the period 1980 – early 1990, many people lost their lives and properties and so important traditional information and working knowledge on control strategies declined. Due to this situation and the reintroduction of cotton, pesticide agents easily obtained a foothold to promote their subsidized chemicals. Hence during the interviews of 2001/2002 farmers showed, besides the little working knowledge of pests, that indigenous control strategies were poorly developed, understood and applied (Ebregt *et al*., 2004b). However, the use of insecticides in sweet potato was not reported (Abidin, 2004; Ebregt *et al*., 2004b), which is in contrast to other districts in Uganda (Bashaasha *et al*., 1995). Very occasionally, farmers implemented the killing of millipedes manually, and the use of the extracts of the neem tree (*Azadirachta indica*) or the Lira tree (*Melia azedarach*). More often ash was used (Ebregt *et al*., 2004b). Some farmers perceived the use of 'tolerant' varieties (Ebregt *et al*., 2004b). Planting approximately 6 weeks after the onset of the first rains (Abidin, 2004; Ebregt *et al*., 2004a), prompt harvesting and avoiding harvesting in March/April were cultural control measures to avoid infestation by millipedes (Ebregt *et al*., 2004b).

Field assessments of millipede damage in sweet potato and other major crops

Field experiments showed that millipedes inflict damage on planting material planted early in the first rainy season (Abidin, 2004; Ebregt *et al*., 2005). Millipedes of the species *O. sudanica* were often present in the affected mounds, mostly in the vicinity of the non-established vine cuttings. Often fresh entrance holes of millipedes were present (Ebregt *et al*., 2005). Some farmers preferred to establish their sweet potato field in the beginning of the second rainy season (Ebregt *et al*., 2004a). In this period millipedes did not affect planting material during its establishment (Ebregt *et al*., 2005).

At harvest at 5 months after planting, millipedes affected only few storage roots, although these figures were a bit higher when planted during the first rainy season. During storage 'in-ground on plants' at the time of the dry season, the number of affected storage roots increased gradually until the first rains of the first rainy season. By then most of the storage roots were badly affected, often in combination with sweet potato weevils (Ebregt *et al*., 2005).

At the beginning of the first rainy season, millipedes also inflicted damage in both germinating and in podding groundnut (cv. Rudu-Rudu), causing plant losses of 12–

29%. Millipede damage in maize occurred in both rainy seasons. The damage inflicted on the seed during the second rainy season was probably brought forth by millipedes coming from hiding places. They were frequently present in the vicinity of the field. In all cases the preceding crop was sweet potato (Ebregt *et al*., 2005).

Feeding activity of the East African millipede *Omopyge sudanica* Kraus

Farm visits and field experiments showed that many crop species are hosts of millipedes. But millipedes mostly affect sweet potato, maize (germinating seeds) and groundnut (germinating seeds and young pods). Interviewed farmers also mentioned cassava as host. *O. sudanica* is one of the main culprits (Ebregt *et al*., 2004a, b; 2005). A no-choice feeding activity experiment with this species showed that the weight of all diets (sweet potato, cassava, groundnut and maize) offered to the millipedes, decreased. However, the correlation between initial body weight and intake and body weight gain was relatively weak and inconsistent in sign and significance across diets. The research revealed how difficult it is to obtain reliable, quantitative data on the feeding habits of millipedes (Ebregt *et al*., 2007a). This is supported by early studies. Mwabvu, (1998a, b) showed that the feeding behaviour of the millipede *Alloporus uncinatus* was 'non-random': immature female millipedes and adult males showed clearer selective feeding than the adult females.

A statistically significant difference in consumption index (CI) was found between the sweet potato diet and the diets cassava, groundnut cv. RPM 12 and maize soaked 48 hours. This was due to the differences between the diets. The difference in CI between the means for root crop and grain crops was not statistically significant. However, the peeled and cut sweet potato storage roots in the experiments reflected the condition of storage roots stored 'in-ground on plants' during the dry season and the condition made it easy for millipedes to access these roots (Ebregt *et al*., 2007a). In an early study (Ebregt *et al*., 2005) it was suggested that sweet potato weevils cause damage during the dry season and provide the millipede with the conditions described above. Nevertheless, *O. sudanica* utilized the grain crop diets groundnut and maize for its growth more efficiently than the root crops sweet potato and cassava. This difference in 'interest' may play a role when the hungry millipedes appear from their quiescence at the end of the dry season. They will devour anything eatable. Consequently they are often found in neglected fields with stored 'in-ground on plants' energy-rich sweet potato. With the onset of the new growing season, the then planted groundnut seeds, often as an after-crop of sweet potato, will supply the millipedes with proteins needed for their growth (Ebregt *et al*., 2007a).

The comparison of the indigenous cultural practices piecemeal harvesting and storage 'in-ground on plants' with one-time harvesting after crop senescence

The risk of millipedes affecting early planted sweet potato material is one of the reasons to delay planting sweet potato in the first rainy season (Abidin, 2004; Ebregt *et al*., 2004b). The final one-time harvest usually takes place at the beginning of the dry season, i.e. December and/or January. Farmers also practise storage 'in-ground on plants' during the prolonged dry season, after which the final harvest will be done at the onset of the first rainy season (Smit & Matengo, 1995; Smit, 1997a; Abidin, 2004; Ebregt *et al*., 2004b).

In Chapter 7, field experiments on piecemeal harvesting revealed that this indigenous practice was only useful during a limited period of time. Piecemeal harvesting started at 3 months after planting (MAP). The sizable storage roots could be removed up to 4 MAP, after which numbers and weight declined. This reduction corresponded with having less rain at the onset of the dry season. This condition was optimal for the sweet potato weevil to invade the crop above soil (Ebregt *et al*., 2007b).

Concerning damage in vines and storage roots by sweet potato weevils, there was less damage in piecemeal harvesting compared to one-time harvesting (Ebregt *et al*., 2007b). The above finding confirmed an earlier study on the positive affect of piecemeal harvesting on the reduction of damage on storage roots of sweet potato (Smit, 1997a, b). In addition, Ebregt *et al*. (2007b) suggested that the standard of quality of storage roots for consumption and commercial purposes could also be improved by practising piecemeal harvesting.

The population dynamics of the sweet potato weevils should be taken into account. When the conditions were optimal for the population build-up of the sweet potato weevil, such as dry conditions, this pest invaded the crop, no matter whether the farmer practised piecemeal or one-time harvesting (Ebregt *et al*., 2007b). It has been stated before that the sweet potato weevil can facilitate millipede damage (Ebregt *et al*., 2004a, 2005, 2007a). This is especially true when storage roots are stored 'in-ground on plants' during the dry season up to the onset of the first rains of the new growing season (Abidin, 2004; Ebregt *et al*., 2004a, b, 2005). This issue will be discussed further in the section Integrated Crop Production and Pest Management Strategy.

During the prolonged dry season most plants wilted and perished due to a combination of drought and sweet potato weevil infestation. With the returning of the rains, volunteer plants and the remaining storage roots were severely infested by this pest. Ebregt *et al*. (2007b) suggested that any harvesting practice could not make a difference in combating the infestation and damage.

Integrated Crop Production and Pest Management Strategy

Based on the information collected in this thesis a strategy for integrated crop production and pest management can be drafted.

Developing local knowledge and farming technologies

The subsistence farmers of north-eastern Uganda, and of eastern Africa for that matter, cannot afford pesticides for a low-value crop like sweet potato (Smit, 1997a; Abidin, 2004; Ebregt *et al*., 2004b). Hence control strategies based on the local cultivation practices are presently the most promising component of an integrated crop production and pest management strategy to control the numerous pests affecting the sweet potato (Smit, 1997a; Ebregt *et al*., 2004b). Concerning sweet potato weevils and millipedes, biological information about the life cycle, behaviour and the host range is essential to understand the incidence of these pests, and for developing the best management strategy (Ebregt *et al*., 2004a). Farmers attending Farmer Field Schools should discuss ways of managing the problem under local conditions, instead of the top-down approach of the traditional extension service (Van de Fliert & Braun, 1999).

Aggravation of the damage by millipedes initiated by other agents

Concerning possible control measures, it is important to realize that it is generally assumed that millipedes merely aggravate the damage initiated by some other agents (Lawrence, 1984; Blower, 1985; Hopkin & Read, 1992). Ebregt *et al*. (2005) suggested that, based on the results of a field experiment with sweet potato stored 'in-ground on plants' during the dry season, the damage inflicted by millipedes in the storage roots of sweet potato was facilitated by the damage caused by sweet potato weevils. For that reason, any control strategy concerning millipedes is inevitable interrelated with sweet potato weevil control programmes.

Spatial and temporal crop diversity

Besides being a problem in sweet potato production, millipedes are a serious pest in the major crops cassava, groundnut and maize (Ebregt *et al*., 2004a, b, 2005, 2007a, b). Beans (kidney bean or other grain legumes), bambara groundnut, soya bean, cabbage, cotton, sunflower and banana are also affected (Ebregt *et al*., 2004b). All these crops play an important role in the cropping system of north-eastern Uganda. At least the major crops should be separated in space and time. Many farmers experienced limited availability of land to implement such a strategy. More research should be done on the interval between subsequent major host crops above-mentioned. Millet and sorghum, for example, will discontinue the population build-up of the sweet potato weevil as they are not host crops of millipedes (Ebregt *et al*., 2004a).

Hygiene
Farmers often obtain their planting material from volunteer plants from sites where sweet potato was previously grown (Abidin, 2004; Ebregt *et al*., 2004a). The disadvantage is that at the beginning of the first rainy season, these sites can harbour large populations of sweet potato weevils and millipedes. On top of that, crop residues can function as refugees for millipedes. So, if farmers do not separate these plots from (new) plots with potential host crops over time and space, infestation by sweet potato weevils and millipedes from previous or adjacent fields will likely occur. It is also suggested to clean abandoned fields as soon the volunteer plants are collected. The use of planting material obtained from volunteer plants can also be regarded as an accidental advantage. A farmer can only plant when enough volunteer plants have established, which is about 6 weeks after the start of the first rains. By then the incidence of millipedes with the possible damage in planting material is expected to be relatively low.

Hiding places
With the onset of the first rains of the new growing season, farmers clear the sweet potato fields with storage roots stored 'in-ground on plants'. Crop residues are often left behind in piled heaps (Smit, 1997a; Ebregt *et al*., 2004b, 2005), thus creating optimal hiding places for millipedes. During farm walks in this period, millipedes were usually found in large numbers under the heaps of removed sweet potato vines or grass. Therefore farmers are advised to remove the millipedes by hand-picking and to bring them to places where they do less harm.

During daytime millipedes also hide in refuges, such as moist soil litter under shady mango trees (*Mangifera indica*) and bark-cloth figs (*Ficus natalensis*) with undergrowth of shrubs (Ebregt *et al*., 2004a, b, 2005). Soil litter under mango trees can be easily sieved and millipedes, mainly *O. sudanica* and *S. ibanda*, can be simply removed. Shrubs, especially under trees, should be cleared. Millipedes also often hide in abandoned termite hills (Masses, 1981). Removing the whole mound will be too labour-intensive, but closing the openings with clay soil might be an option.

Home nurseries, which also function to supplement the families' scanty diet during the dry season, harbour relatively large populations of millipedes. These nurseries are often kept in shady environments (for example under a mango tree) and have a relatively long lifetime (often more than 2 years) (Ebregt *et al*., 2004a). Such nurseries can function as a natural 'trap'.

Timely planting
Mostly planting of sweet potato started about 2 months after the start of the growing season, because by then planting material was available and the risk of millipede

damaging planting material was limited. Nonetheless, many farmers, especially those who liked to catch a good price for their storage roots, planted early with the onset of the first rains and so these farmers took the risk of losing plant material due to millipede activity (Abidin, 2004; Ebregt *et al*., 2004a, b, 2005). Also groundnut, maize and cassava were often planted with the onset of the first rainy season (Ebregt *et al*., 2004a, 2005) and they were often damaged by millipedes (Ebregt *et al*., 2004a, b, 2005, 2007a, b). In order to prevent millipedes from invading a sensitive crop, neighbouring plots with host crops should be avoided.

Weeding

During the process of weeding, the mound is carefully loosened and earthed up. Although this cultivation process could prevent sweet potato weevils from having easy access to the storage roots (Smit, 1997a), millipedes now find a suitable environment to live in. It is therefore recommended to maintain the indigenous cultural practice of one-time weeding in crops, such as sweet potato and cassava.

Tolerant varieties

Many farmers liked to plant a mixture of sweet potato farmer varieties, mostly based on yield performance, maturity, culinary traits and tolerance to pests. Araka Red and Araka White (both whole research area), and the less common varieties Tedo Oloo Keren (Lira District), Odupu (Katakwi District) and Opaku (syn. Esugu) (Kamunda Sub-county – Soroti District; Kalakwi – Kaberamaido District) were said to be ‘tolerant’ to sweet potato weevils (Abidin, 2004; Ebregt *et al*., 2004a, b).

Farmers also mentioned 11 varieties that, according to their perception, were ‘tolerant’ to millipedes. Araka White, Tedo Oloo Keren, Latest and Lira Lira were some of them (Ebregt *et al*., 2004b).

Further investigation should be done on this ‘tolerance’ to sweet potato weevils and millipedes.

Piecemeal versus one-time harvesting

Farmers looked for cracks in mounds to identify the location where a sizable storage root could be expected. This piecemeal harvesting practice was continued over a prolonged period. Soil cracks can generally still be found until the final harvest. However, dry and hot conditions also induce the soil to crack, thus exposing the roots to weevils (Mwanga *et al*., 2001). Our research revealed that the optimal number of storage roots occurred only in the fourth piecemeal harvesting, i.e. at 112 days after planting. After that the total number of storage roots declined as well as the number of harvestable ones.

Applying this indigenous practice is not always giving advantage on production management and weevil control.

Storage 'in-ground on plants'

During the prolonged dry season, sweet potato storage roots were stored 'in-ground on plants' for food security reasons. As stated before any control strategy concerning millipedes should be inevitably interrelated with sweet potato weevil control programmes. Smit (1997a) initially reported about sweet potato weevil control based on an integrated pest management strategy. More research on this primary pest is underway. A proper integrated crop production and pest management strategy should be developed. The reduction of the sweet potato weevil population may automatically reduce the impact of millipedes on the sweet potato, hence securing food for the people.

Conditions under which millipedes are likely to occur abundantly

The occurrence of millipedes on/near the soil surface depends on abiotic features of the soil (texture, organic matter content, calcium content, etc.), besides factors such as amount of rainfall, period of soil surface activity and millipede species present (Demange, 1975). In north-eastern Uganda but most likely also in the rest of eastern Africa, the impact of these features on the millipede population should be investigated, in addition to the already mentioned impact of intensive production of sweet potato grown in short rotation with other host crops.

Challenges and opportunities

Below some recommendations for further research, for control of millipedes and for increasing farmers' knowledge on millipedes are given.

Basic research on millipedes

Little is known about the millipede species in north-eastern Uganda and in other parts of eastern Africa. The results of this research showed that many crops are host plants and that the damage on them is evident. A few species have been identified, but still many are unknown in Uganda and in other parts of eastern Africa. A follow-up research should identify the most important species and collect information about their occurrence and distribution, biology, ecology and possible host crops.

Research on sweet potato weevils

Any control strategy concerning millipedes is inevitably interrelated with sweet potato weevil control programmes. Research concerning sweet potato weevil management should be given high priority.

Choice feeding activity laboratory experiments on millipedes

Experimental equipment has been designed, in which millipedes can choose between different promising baits. The objective of such experiments is to determine which bait is most attractive or repellent. However, a preliminary try-out showed a number of weaknesses of the equipment, which can easily be adjusted. The results of such experiments will be very useful in determining the baits for pitfall traps. A proper repellent can also be used in control programmes.

Handpicking of millipedes

During early morning hours and cloudy/rainy days in the beginning of the first rainy season (for example in north-eastern Uganda in March/April), millipedes can be seen moving around in abundant numbers. By then they can be easily collected by means of handpicking.

Trapping millipedes

Millipedes are generally active during the night. During daytime, they hide themselves in refuges. Preliminary research has been done, catching millipedes with baited pitfall traps, and with the help of piles of heaped grass/sweet potato vines or roof tiles.

<u>Baited pitfall traps</u> – In a preliminary experiment by the author, baited traps were planted in a sweet potato field. 'Extracts' of groundnut, sweet potato, cassava, and maize as well as molasses were used as baits. However, the baits and their constitution should be improved and other promising suitable baits should be tried out as well. The timing of installing the traps appeared to be crucial. Follow-up field experiments with baited pitfall traps in sweet potato, groundnut, maize and cassava fields should be done.

<u>Grass heaps as 'traps'</u> – In another preliminary experiment, it appeared that piled grass in heaps, originating from a cleared sweet potato field, functioned as biological 'traps'. The advantage was that local, low-cost material could be used. Heaped piles of sweet potato vines also did well. Field experiments should be designed and carried out.

<u>Roof tiles as 'traps'</u> – In another preliminary field experiment, roof tiles appeared to be hiding places for millipedes during daytime. However, during hot sunny days millipedes dug themselves in the soil and were difficult to retrieve. Another disadvantage was that roof tiles were rare in the village. The efficiency of roof tiles or other possible devices, which function as a trap', should be tried out in the field.

Use of botanicals to control millipedes

Despite the fact that the technique of preparing botanical pesticides is based on a simple technology (Stoll, 1992), these cheap control options have been 'forgotten' (Ebregt *et al*., 2004b). Preliminary research in north-eastern Uganda, in which extracts of the neem tree (*Azadirachta indica*), goat weed (*Ageratum conyzoides*), African marigold (*Tagetes* spp.), tobacco (*Nicotiana tabacum*) and chilies (*Capsicum* spp.), and ash and goat droppings soaked in urine were used, showed poor results due to logistic problems and dry weather conditions. Laboratory and field trials, in which the repellant and insecticidal effects of extracts of local plants on sweet potato weevils and millipedes will be determined, are crucial, as such trials can assess the relevance of control options, which fit in an integrated crop production and pest management approach in sweet potato, groundnut, maize and cassava.

Development of Farmer Field School Curriculum

In Kenya, Tanzania and Uganda, many farmers are organized in Farmer Field Schools. A field guide and technical manual 'Farmer Field School Integrated Crop Management of Sweet Potato' (Van de Fliert & Braun, 1999) for Indonesia has been prepared. No information about millipedes appears in this guide. A manual concerning integrated crop production and pest management with emphasis on millipedes and sweet potato weevils should be developed for Farmer Field Schools in eastern Africa.

Summarizing conclusions

The research activities presented in this thesis have led to four recommendations for improving the sweet potato, groundnut, maize and cassava production, serving the needs of resource-poor farmers in low-input agricultural systems in north-eastern Uganda and other parts of eastern Africa:

- Collecting and identification of millipedes, especially those which are expected to inflict damage on major crops, and gaining information about their occurrence and distribution, biology, ecology and possible control options.
- Intensification of research on sweet potato weevils, with emphasis on integrated crop production and pest management strategies related to millipedes.
- Setting up further research concerning controlling millipede populations in order to develop proper integrated crop and millipede management strategies.
- Preparing a curriculum for the Farmer Field Schools concerning integrated management of millipedes in major crops in low-input agricultural systems.

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Summary

Currently, Uganda is the largest producer of sweet potato in Africa. However, compared to neighbouring countries the sweet potato yield in Uganda is still relatively low. This is due to production constraints. Farmers in north-eastern Uganda consider insect pests the most important constraint in sweet potato. They believe sweet potato weevils (*Cylas brunneus* and *C. puncticollis*), the caterpillar of the sweet potato butterfly (*Acraea accerata*), rats (*Spalax* spp.) and millipedes (Diplopoda) are the main culprits. At present, there is inadequate information about the identity, biology, ecology, behaviour, damage and possible control strategies of millipedes in Uganda and Eastern Africa as a whole.

This thesis provides information on the role millipedes play in the production of sweet potato and other crops as perceived by farmers and as proven by laboratory and field experimentation. It also provides information on other important sweet potato pests.

A literature study was carried out to gain knowledge on millipedes. This study provided information on the taxonomy of millipedes, their anatomy, reproduction, life cycle, feeding and digestion, pest status, natural enemies, and their seasonal activity and dispersal. The role of the millipede in decomposition processes was also included.

An extensive field survey was carried out to collect information from farmers about general agronomic practices of sweet potato, the position of sweet potato in crop rotation, relevance of pests with emphasis on the millipede problem occurring in crops, and the indigenous pest management and its constraints.

Through field experimentation, the extent of damage and damage symptoms caused by pests, millipedes in particular, in sweet potato, groundnut and maize were determined.

In laboratory experiments, the no-choice feeding activity of the East African millipede *Omopyge sudanica* Kraus on different crop products (sweet potato, cassava, groundnut and maize) was observed.

A comparison was made in the field between the indigenous cultural practices of in-ground storage roots and piecemeal harvesting with one-time harvesting with special reference to effects on damage done by the sweet potato weevil, the rough sweet potato weevil (*Blosyrus* spp.) and millipedes.

On the basis of the literature study, the survey, the results of the field and laboratory studies, a strategy was recommended for integrated production and pest management in sweet potato, groundnut, maize and cassava, serving the needs of resource-poor farmers in low-input agricultural systems in north-eastern Uganda and East Africa.

The field survey
We interviewed 148 sweet potato growers from 32 sub-counties during a year. The farms were located in Northern Moist Farmlands, North-Central Farm-Bush Lands, and Southern and Eastern Lake Kyoga Basin agro-ecological zones in north-eastern Uganda. These sweet potato growers considered sweet potato weevils the most important pests, followed by rats and millipedes. The impact of millipedes was also serious in other major food and cash crops, such as cassava, groundnut, maize, beans (kidney bean or other grain legumes), bambara groundnut, soya bean, cabbage, cotton, sunflower and banana.

Separation of plots in space and over time was often neglected. Not implementing a spatial distance might be a factor contributing to the introduction of millipedes from neighbouring fields. The sweet potato rotation systems varied among the agro-ecological zones and even within households. It appeared that millipede incidences depended on the frequency of millipede hosts; especially groundnut planted after sweet potato had a high level of millipede attack. Despite the farmers' awareness and concern about the damaging effect of millipedes on groundnut, many of them stated that they would still grow groundnut after sweet potato.

Farmers often left behind the sweet potato crop residues in the field immediately after harvest. The small storage roots were even buried to stimulate the development of volunteer plants. Farmers also practised storage 'in-ground on plants'. In this way sweet potato weevils can survive in the storage roots during the dry season and millipedes have suitable hiding places under the piles of excess of volunteers and infected storage roots.

During the interviews farmers showed that they had little working knowledge on pests. Indigenous control strategies were poorly developed, understood and applied. The use of chemical insecticides was not reported. Very occasionally, farmers killed millipedes manually or used extracts of the neem tree (*Azadirachta indica*) or the Lira tree (*Melia azedarach*) for control. More often ash was used. Some farmers claim to use 'tolerant' varieties. Planting approximately 6 weeks after the onset of the first rains, prompt harvesting and avoiding harvesting in March/April are cultural control measures to avoid infestation by millipedes.

Field assessment of pests in sweet potato and other major crops
Field experiments revealed that, early in the first rainy season, millipedes of the species *O. sudanica* inflict damage on planting material of sweet potato and on germinating and podding groundnut. Damage in maize occurred in both rainy seasons. However, millipedes did not affect the sweet potato planting material in the beginning of the second rainy season.

Storage roots of sweet potato were hardly affected by millipedes at harvest 5 months after planting. However, if storage roots were stored 'in-ground on plants' during the prolonged dry season, at the end of this season most of the storage roots were badly affected by millipedes, often in combination with damage by sweet potato weevils. In other words, sweet potato weevils can facilitate the millipede damage.

Feeding activity of the East African millipede *O. sudanica*

No-choice feeding activity laboratory experiments showed that *O. sudanica* efficiently utilized the grain crop diets groundnut and maize, but they also ate storage roots of sweet potato. This finding is relevant when the hungry millipedes appear from the quiescence at the end of the dry season. They will devour anything eatable. Hence, they are often found in neglected sweet potato fields.

Comparison of indigenous cultural practices piecemeal harvesting and storage 'in-ground on plants' with one-time harvesting after crop senescence

In north-eastern Uganda, most sweet potato farmers practise storage 'in-ground on plants' combined with piecemeal harvesting. This means that 3 months after planting, several times during the growing period, farmers remove harvestable large storage roots from the plant without uprooting the plant itself. Most varieties senesce at 5 months after planting.

The results of our field experiments on piecemeal harvesting revealed that this indigenous practice was only useful in a limited period of time. After the fourth piecemeal harvesting (112 days after planting) number and weight of storage roots declined. This reduction corresponded with having less rain with the onset of the dry season. This condition is optimal for the sweet potato weevil to invade the crop above soil.

The population dynamics of sweet potato weevils should be taken into account. When the conditions are optimal for the weevil to build up its population, such as dry conditions, this pest will invade the crop in large numbers. Consequently, volunteer plants and/or the remaining storage roots 'in-ground on plants' will be severely infested by this pest. In this situation piecemeal harvesting cannot be used as control measure in reducing the infestation of the sweet potato weevil.

Importance of millipedes for sweet potato production in East Africa

From the results presented in this thesis a number of important issues have arisen, which can be implemented pest control programmes in the sweet potato crop.

Developing local knowledge and farming technologies – The knowledge of life cycle, behaviour and the host range of millipedes is essential in the local cultivation practices in order to understand more about the millipede incidence.

Aggravation of the damage by millipedes initiated by other agents – We assume that millipedes merely aggravate the damage initiated by some other agents, i.e., sweet potato weevils. Any control strategy concerning millipedes is inevitable interrelated with the weevil control programmes.

Spatial and temporal crop diversity – Farmers experienced limited availability of land to implement a strategy on spatial and temporal crop diversity. More research should be done on the associations concerning the interval between the two subsequent millipede major host- and non-host crops. Millet and sorghum are suggested to breaking up the life cycle of millipedes.

Hygiene – Volunteer plants from previous sweet potato gardens, crop residues, soil litter under shady mango trees (*Mangifera indica*), bark-cloth figs (*Ficus natalensis*) with undergrowth of shrubs, abandoned termite hills, and neglected home nurseries can harbour large populations of millipedes. Therefore, these hiding places should be cleared.

Timely planting – Planting sweet potato is ideally at two months after the start of the growing season to avoid millipedes damaging planting material. However, farmers can also plant sweet potato at the onset of the first rainy season as long as its neighbouring and preceding crops are not hosts.

Weeding – During the process of weeding the mound is carefully loosened and earthed up. This cultivation process could prevent sweet potato weevils from having access to the storage roots, but it provides millipedes a suitable environment to live in. It is therefore recommended to maintain the indigenous cultural practice of one-time weeding in sweet potato.

Tolerant varieties – A number of sweet potato varieties, which are recognised by farmers to be ‘tolerant’ to sweet potato weevil and millipedes, should be planted. Further research on this ‘tolerance’ should be done.

Piecemeal versus one-time harvesting – It is considered that piecemeal harvesting is not always giving advantage on production management and weevil control. Furthermore, it was revealed that the optimal number of harvestable storage roots occurred only up to the fourth weekly piecemeal harvesting.

Storage roots stored 'in-ground on plants' – During the prolonged dry season sweet potato storage roots are stored 'in-ground on plants' for food security reasons. Efforts in reducing the sweet potato weevil population may automatically reduce the impact of millipede infestation.

Conditions under which millipedes likely occur – The occurrence of millipedes on/near the soil surface depends on abiotic features of the soil. The impact of these features on the millipede population is not fully understood. Thus further investigation should be done.

Challenges and further research in identification of millipede species, handpicking, laboratory experiments on choice feeding activity, the use of botanicals such as repellants and insecticides, and the use of baited pitfall traps, grass heaps and roof tiles as 'traps' have also been met in this thesis. Furthermore, a manual concerning integrated crop production and pest management with emphasis on millipedes and sweet potato weevils should be developed for Farmer Field Schools in East Africa.

The research activities presented in this thesis have led to four concluding recommendations for improving integrated sweet potato production and pest management aimed at the needs of resource-poor farmers in low-input agricultural systems of East Africa. The recommendations are:

- Collection and identification of millipedes in north-eastern Uganda and/or East Africa, and gaining information about their occurrence, distribution, biology, ecology, and possible control options.
- Intensification of research on sweet potato weevils related to their interaction with millipedes.
- Setting up of further research concerning controlling millipede populations.
- Preparing a curriculum for the Farmer Field Schools concerning integrated management of millipedes in major crops in low-input agricultural systems.

Samenvatting

Momenteel is Oeganda de grootste bataat (zoete aardappel) producent van Afrika. Vergeleken bij de omringende landen, is de opbrengst van de bataat nog steeds relatief laag. Dit wordt veroorzaakt door productiebeperkingen. De boeren in het noord-oosten van Oeganda beschouwen insectenplagen als het belangrijkste probleem. Zij geloven dat de Cylas snuitkevers (*Cylas puncticolllis* en *C. brunneus*), de rups van de Acraea vlinder (*Acraea accerata*), ratten (*Spalax spp.*) en miljoenpoten (Diplopoda) de hoofdschuldigen zijn. Op het ogenblik is er in Oeganda en in heel oostelijk Afrika onvoldoende informatie over de soorten miljoenpoten, hun biologie, ecologie, gedrag, de schade die ze veroorzaken en mogelijke strategiën om deze dieren te bestrijden. Dit proefschrift geeft informatie over de invloed die miljoenpoten hebben op de productie van de bataat en andere gewassen, zoals blijkt uit de informatie van boeren, en laboratorium- en veldexperimenten. Dit proefschrift voorziet ook in informatie over andere schadelijke dieren in de bataatproductie.

Een literatuurstudie van miljoenpoten zorgde er voor dat er een goed beeld ontstond van deze dieren: de taxonomie, de anatomie, de voortplanting, de levenscyclus, de voeding en vertering, de plaagstatus, de omvang van de veroorzaakte schade, de natuurlijke vijanden, de activiteit gedurende de verschillende seizoenen en de verspreiding. De rol van de miljoenpoot in de afbraakprocessen van organisch plantmateriaaal in de bodem werd ook bestudeerd.

Een veelomvattend veldonderzoek werd uitgevoerd om uiteindelijk van de boeren informatie in te winnen over de teelttechniek van de bataat, de plaats die de bataat in de gewasrotatie inneemt, en de plagen van betekenis, met nadruk op de problemen die miljoenpoten geven in de gewassen, alsmede de traditionele plaagbestrijdings-programma's en hun beperkingen.

Met behulp van veldexperimenten kon de omvang van de schade en de schadesymptomen, met name veroorzaakt door miljoenpoten, in de bataat, pinda en maïs bepaald worden.

De voedingsactiviteit van de Oost Afrikaanse miljoenpoot *Omopyge sudanica* Kraus werd in het laboratorium onderzocht waarbij het dier slechts het dieet van één gewas (bataat, cassave, pinda en maïs) tot zijn beschikking had.

De inheemse traditionele teeltmaatregel 'opslag-in-de-grond', gecombineerd met 'stapsgewijs' oogsten, al naar gelang de behoefte, werd vergeleken met éénmalig oogsten. De nadruk werd hierbij gelegd op de schade die veroorzaakt werd door de Cylas snuitkever, de Blosyrus snuitkever (*Blosyrus* spp.) en miljoenpoten.

Gebaseerd op literatuurstudie, interviews met de boeren, resultaten van de veldonderzoeken en de laboratoriumexperimenten, werd een geïntegreerde productie en plaagbestrijdingsteeltmaatregelen geadviseerd voor de bataat, pinda, maïs en cassave. Een dergelijke programma zal ten goede komen aan de kleine boeren van noord-oost Oeganda.

Interviews met boeren

Gedurende een jaar hebben wij 148 boeren in 32 regio's geïnterviewd. De 32 regio's lagen in de 'Northern Moist Farmlands', 'North-Central Farm-Bush Lands, en 'Southern en Eastern Lake Kyoga Basin', agro-ecologische zones in noord-oost Oeganda. Deze bataattelers beschouwen de Cylas snuitkevers als de meest schadelijke plaag, gevolgd door plagen van ratten en miljoenpoten. De schade, veroorzaakt door miljoenpoten was ook ernstig in andere gewassen, zoals cassave, pinda, bambara pinda, maïs, sojaboon, kool, katoen, zonnebloem en banaan.

Het scheiden van de percelen, waarop de gewassen verbouwd worden, in ruimtelijke zin en in de tijd, wordt veelal niet toegepast. Het niet scheiden van percelen met potentiële waardplanten, kan er toe leiden dat miljoenpoten geïntroduceerd worden vanuit aangrenzende percelen. Het rotatiesysteem waarin de bataat is opgenomen, varieert per agro-ecologische zone en zelfs binnen een huishouden. De aanwezigheid van miljoenpoten bleek te worden bepaald door de frequentie van de waardplanten. Vooral percelen met pinda's, die na de bataat ingezaaid waren, hadden een hoge plaagdichtheid. Ondanks het feit dat de boeren zich bewust zijn van en zich zorgen maken over de gevolgen van miljoenpoten, planten velen nog steeds pinda na de bataat.

Boeren laten vaak na de oogst het afval van de bataat achter op het land. Bovendien worden kleine wortels onder de grond gestopt voor de ontwikkeling van nieuwe scheuten. Boeren laten de wortels vaak ook gewoon in de grond. Op deze manier kunnen tijdens de droge tijd de Cylas snuitkevers gemakkelijk overleven in de wortels. Bovendien kunnen de hopen plantafval en overtollige wortels dienen als schuilplaatsen voor miljoenpoten.

Uit de interviews bleek dat de boeren weinig praktische kennis van plagen hadden. Inheemse plaagbestrijdingsmethoden waren slecht ontwikkeld, werden niet begrepen en slecht toegepast. Er werd geen gebruik gemaakt van chemische middelen in de bataatteelt. Af en toe werd er een miljoenpoot met de hand of voet gedood of werden er extracten van de neemboom (*Azadirachta indica*) of de liraboom (*Melia azedarach*) gebruikt als botanische insecticide. Veel vaker werd er as gestrooid. Een aantal boeren beweerde dat zij 'waardplantresistentie' toepasten. Veel boeren wachten met het planten van het plantmateriaal tot ongeveer 6 weken na de eerste regen. Op tijd oogsten en het voorkomen van oogsten aan het einde van het lange droge seizoen zijn ook traditionele teelttechnieken ter voorkoming van miljoenpoten in het gewas.

Beoordeling in het veld van plagen in de bataat en andere belangrijke gewassen

Veldexperimenten hebben aangetoond dat, vroeg in het eerste regenseizoen, de miljoenpoot *O. sudanica* schade teweeg brengt aan plantmateriaal van de bataat, en aan de ontkiemende en peulzettende pinda. Schade aan maïs vond in beide regenseizoenen plaats. Er werd echter geen schade gevonden in het plantmateriaal aan het begin van het tweede regenseizoen.

De wortels van de bataat waren nauwelijks aangetast door de miljoenpoot wanneer er 5 maanden na het planten geoogst werd. Als echter tijdens het lange droge seizoen de techniek 'wortels opgeslagen-in-de-grond' werd toegepast, waren de wortels aan het einde van dit seizoen ernstig aangetast door miljoenpoten, vaak in samenspel met de schade veroorzaakt door de Cylas snuitkever. Anders gezegd, de Cylas snuitkever kan de schade van de miljoenpoot op gang brengen.

De voedingaktiviteit van de Oost Afrikaanse miljoenpoot *O. sudanica*

Als de *O. sudanica* in een laboratorium experiment de beschikking kreeg over het dieet van slechts één soort gewas, bleek dat de miljoenpoot op een efficiënte manier de pinda en maïs diëten kan benutten. Deze miljoenpoot nam ook het dieet van de wortel van de bataat tot zich.

Een vergelijkingsstudie van inheemse traditionele 'stapsgewijs' oogsten in combinatie met de 'opslag-in-de-grond' teeltmaatregel met éénmalige oogsten op het moment dat de wortels oogstklaar zijn

In het noord-oosten van Oeganda telen de bataattelers volgens het principe van 'opslag-in-de-grond', in combinatie met 'stapsgewijs' oogsten. Dit houdt in dat 3 maanden na het planten, verschillende keren gedurende het groeiseizoen, grote wortels van de plant verwijderd worden, zonder de plant uit de grond te trekken. De meeste variëteiten zijn 5 maanden na het planten oogstklaar.

De resultaten van ons veldonderzoek van het 'stapsgewijs' oogsten toonden aan dat deze inheemse praktijk alleen gedurende een beperkte periode zinvol was. Na de vierde keer 'stapsgewijs' oogsten (112 dagen na het planten) werd het aantal en het gewicht van de wortels minder. Deze vermindering kwam overeen met de verminderde regenval aan het begin van het lange droge seizoen. Deze omstandigheid is optimaal voor de Cylas snuitkever om het gewas bovengronds aan te tasten.

Er zal rekening gehouden moeten worden met de populatiedynamiek van de Cylas snuitkever. Als de voorwaarden voor de snuitkever optimaal zijn om in aantal toe te nemen, zoals gedurende droge perioden, zal deze plaag het gewas in grote aantallen binnendringen. Als gevolg hiervan zullen de vanzelf opgekomen planten en/of de restanten van wortels, die bewaard zijn als 'opslag-in-de-grond', ernstig aangetast worden door deze plaag. Onder deze omstandigheden kan ‘stapsgewijs’ oogsten als een bestrijdingsmethode niet toegepast worden om de aantasting door de Cylas snuitkever te verminderen.

Het belang van de bataatproductie in Oost Afrika

Uit de resultaten, die in dit proefschrift weergegeven worden, komt een aantal zaken naar voren, die een aanvulling kunnen zijn voor de plaagbestrijdingsprogramma’s in de bataatteelt.

Het ontwikkelen van kennis over plaatselijke landbouwtechnologieën – De kennis over de levenscyclus, gedrag en het waardplantenassortiment van de miljoenpoot is van essentieel belang voor de plaatselijke teeltechnieken. Hierdoor kan men uiteindelijk de aanwezigheid van de miljoenpoot beter verklaren

Verergering van miljoenpotenschade, ingeleid door andere plagen – Wij veronderstellen dat miljoenpoten enkel de schade verergeren die door andere plagen, zoals die van de batatensnuitkever, ingeleid zijn. Elk plaagbestrijdingsprogramma dat te maken heeft met miljoenpoten, is onvermijdelijk verbonden met het bestrijdingsprogramma van de Cylas snuitkever.

Het scheiden van de verscheidenheid aan gewassen in ruimtelijke zin en tijd – Boeren ondervinden dat ze een te beperkte oppervlakte aan land hebben om de verschillende gewassen te kunnen scheiden in ruimtelijke zin en tijd. Er zou meer onderzoek gedaan moeten worden naar de effecten van het interval tussen twee opeenvolgende belangrijke waardplanten en niet-waardplanten van de miljoenpoten. Van gierst en sorghum wordt gesuggereerd dat zij de levenscyclus van de miljoenpoot onderbreken.

Hygiëne – Vanzelf opgekomen scheuten op percelen waar voorheen de bataat verbouwd werd, oogstafval, bladafval onder schaduwrijke mangobomen (*Mangiferia indica*), ficussen (*Ficus natalensis*) met ondergroei van struiken, verlaten termietenheuvels, en verwaarloosde bataatkwekerijen kunnen grote populaties miljoenpoten herbergen. Deze schuilplaatsen moeten daarom opgeruimd worden.

Op tijd planten – Wil men miljoenpotenschade voorkomen dan is het verstandig om 2 maanden na het begin van het groeiseizoen de bataat te planten. Boeren kunnen echter dit gewas ook aan het begin van het groeiseizoen planten, mits naburige en voorgaande gewassen geen waardplanten voor miljoenpoten zijn.

Onkruidwieden – Tijdens het onkruidwieden wordt de grond van het plantheuveltje voorzichtig los gemaakt en weer opgehoogd. Deze teeltmaatregel leidt er toe dat de snuitkever geen toegang heeft tot de wortel. Aan de andere kant verschaft het de miljoenpoot een gunstig leefklimaat. Er wordt daarom geadviseerd niet van de inheemse traditionele praktijk af te wijken en daarom vast te houden aan slechts één keer wieden.

Tolerante variëteiten – Een aantal bataatvariëteiten, die volgens de boeren 'tolerant' zijn jegens Cylas snuitkevers en miljoenpoten, zouden geplant moeten worden. Meer onderzoek naar deze 'tolerantie' zou moeten plaats vinden.

'Stapsgewijs' vs éénmalig oogsten – 'Stapsgewijs' oogsten wordt niet altijd als voordelig beschouwd wat betreft teeltmaatregel en snuitkeverbestrijding. Het is bovendien aangetoond dat het grootst mogelijke aantal grote wortels alleen geoogst konden worden tot het vierde wekelijkse 'stapsgewijs' oogsten.

Wortels bewaard als 'opslag-in-de grond' – Tijdens het lange droge seizoen werden de bataatwortels in de grond gehouden als 'opslag-in-de-grond' ten einde garant te staan voor een constante voorraad aan verse wortels. Pogingen om de Cylas snuitkeverpopulatie te verminderen zullen automatisch leiden tot het terugbrengen van de miljoenpootaantasting.

Mogelijke voorwaarden voor de aanwezigheid van miljoenpoten – De aanwezigheid van de miljoenpoten aan/bij het grondoppervlak hangt af van de abiotisch kenmerken van de bodem. De uitwerking van deze kenmerken op de miljoenpotenpopulatie is nog niet volledig duidelijk. Onderzoek naar de samenhang van abiotische bodem kenmerken en de aanwezigheid van miljoenpoten is belangrijk.

Verder onderzoek naar de determinatie van miljoenpotensoorten, handmatig verzamelen, eetgedrag-experimenten waarbij het dier kan kiezen uit verschillende diëten, het gebruik van botanische extracten als afweermiddel of insecticide, en het gebruik van 'valkuilen' van 'aas' voorzien, grashopen en dakpannen als 'vallen' zijn ook besproken in dit proefschrift. Er moet bovendien een handboek samengesteld worden voor de 'Farmer Field Schools' in Oost Afrika over geïntegreerde bataatproductie en plaagcontrole met de nadruk op miljoenpoten en Cylas snuitkevers.

De onderzoeksactiviteiten, die beschreven zijn in dit proefschrift hebben ten slotte vier aanbevelingen opgeleverd voor het verbeteren van geïntegreerde bataatproductie en plaagbestrijding, gericht op de behoeften van kleine boeren van Oost Afrika, die zich geen kunstmest of bestrijdingsmiddelen kunnen veroorloven. De aanbevelingen zijn:

- Verzamelen en determineren van miljoenpoten in noord-oost Oeganda en/of Oost Afrika, en het verwerven van informatie over hun aanwezigheid, verspreiding, biologie, ecologie, en mogelijke bestrijdingsopties.
- Meer nadruk leggen op het onderzoek naar de Cylas snuitkever met betrekking tot hun wisselwerking met miljoenpoten.
- Uitvoeren van verder onderzoek naar het beheersen van miljoenpotenpopulaties.
- Samenstellen van een curriculum voor de ‘Farmer Field School’, betreffende geïntegreerde beheer van miljoenpoten in de voornaamste gewassen in de ‘low-input’ landbouwsystemen.

Curriculum vitae

Ernst Ebregt was born in Arnhem, The Netherlands on 19th March 1953. In June 1972, he finished his Higher General Advanced Education (HAVO) in Arnhem. In July 1976, he completed the Agricultural College in Groningen. In June 1977, he got a certificate of competence to teach Biology and Agricultural Sciences at the Agricultural College in Den Bosch. From 1978 to 1984, he began his career as a teacher in Biology and Agricultural Sciences at the Agricultural Vocational School in Gorinchem. From 1984 to 1988, he worked at Chironga High School, in Mount Darwin, Zimbabwe. He was director, and also teaching in courses on Agricultural Sciences and General Science. In 1989, he travelled by car from Zimbabwe to The Netherlands. During this trip, he worked in the Kibale Rain Forest National Park in Western Uganda for four months. In 1990, he joined the Master of Science Programme at the Wageningen Agricultural University. In 1991, he did his MSc thesis research on tsetse fly at the Chunga Research Station of the Kafua National Park, Zambia. His research work was focused on the economic benefits in the use of different types of traps (devices with an electric charge) and baits for the eradication of the tsetse fly. In February 1992, he obtained his MSc degree at the Department of Plant Science with specialization in Crop Protection, with orientation in Entomology. From August 1992 to June 1994, he worked in Mozambique at the Agricultural College of Boanne through the Finnish Bilateral Development Cooperation Programme (FINNIDA). He was a lecturer in Tropical Crop Production and Protection. From September 1994 to September 2001, he was a Principal Senior Lecturer at the Arapai Agricultural College in Soroti, under the Ministry of Education of Uganda. Besides his responsibility of planning and implementing lectures in Crop Science, additional responsibilities included: (i) head of the Entomology Department; (ii) mobilizing donors for funding requests; (iii) collaborating scientist with the International Potato Center (CIP) and the Ugandan National Agricultural Organization (1996 to 2003). From 2000 to 2003, he worked on his PhD thesis research in north-eastern Uganda. Part of his research was sponsored by the Crop Physiology chair of Wageningen University, and the Department for International Development (DFID) in Soroti, Uganda. The main part of the study was self- and parents sponsored. From 2002 to 2003, he worked at the Roelof van Echten College in Hoogeveen as a teacher in Biology and Physics. From 2003 until August 2007, he was working at the 'Christelijk Lyceum' in Zeist as a teacher in Biology and Science for Public Understanding. Since 2004 he is working at the 'Christelijke Scholengroep De Hoven' in Sleeuwijk. At this school, he is teaching Biology and Mathematics. From 2003 to 2005, he followed a Master of Education

Programme at the Archimedes Teacher Training Institute of the Faculty of Education at the Academy of Utrecht. He received his Master of Education (Biology) in September 2005. From 2004 to 2007, he completed his PhD-thesis work on millipedes at the Crop and Weed Ecology Group, Wageningen University, The Netherlands. All research papers of his thesis have been published in the NJAS-Wageningen Journal of Life Sciences, or are in press. In the future he wishes to continue working in the field of integrated crop production and pest management in order to lift up the livelihood of resource-poor farmers.

He is married to Dr. Putri Ernawati (Erna) Abidin and they have one daughter.