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*	Milli-pedes	Mole rats	Nema-todes	
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

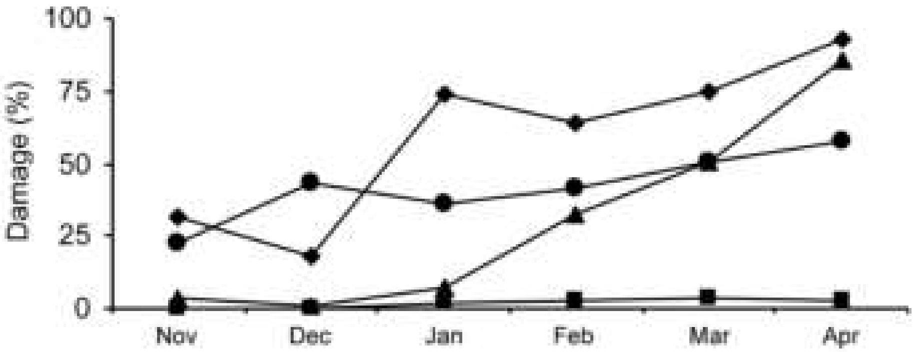

Figure 1. Development of damage by weevils (*Cylas* spp.) (◆), rough weevils (*Blosyrus* spp.) (●), millipedes (▲) and rats (■) in sweet potato tubers stored 'in-ground on plants' during the dry season 2001/2002 (November–April) at Arapai College, Soroti District, north-eastern Uganda.

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-m² 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.

Environment[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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