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

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Received 3 April 2007; accepted 27 June 2007

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.

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

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; 2005) and millipedes (Diplopoda) of the species *Omopyge sudanica* (Omopygidae) (Ebregt *et al.*, 2004a, b; 2005; 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 paper 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.

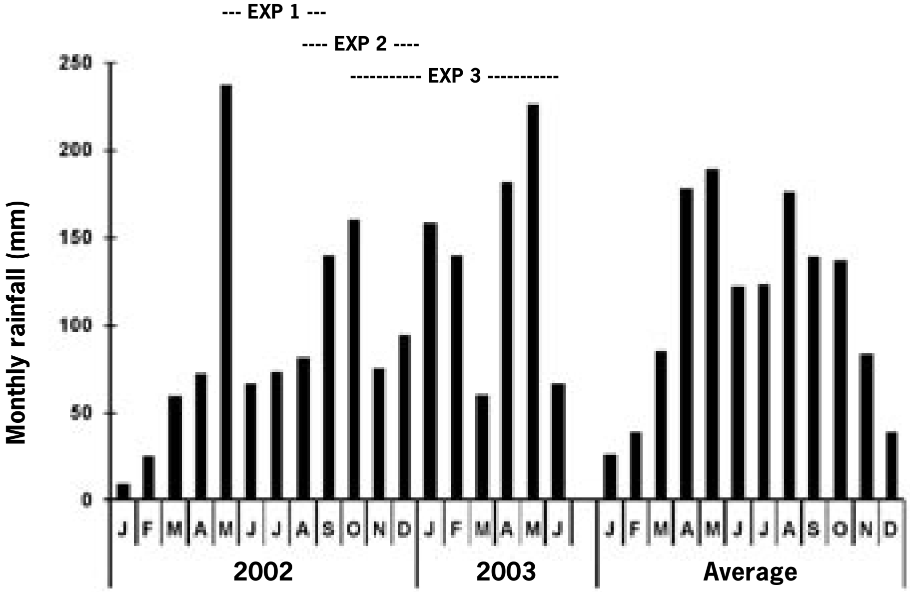

Figure 1. Average monthly rainfall distribution at Soroti station (1943–1993) and monthly rainfall distribution in 2002 and 2003 during Experiments 1, 2 and 3 at Arapai Station, Soroti District, north-eastern Uganda.

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 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

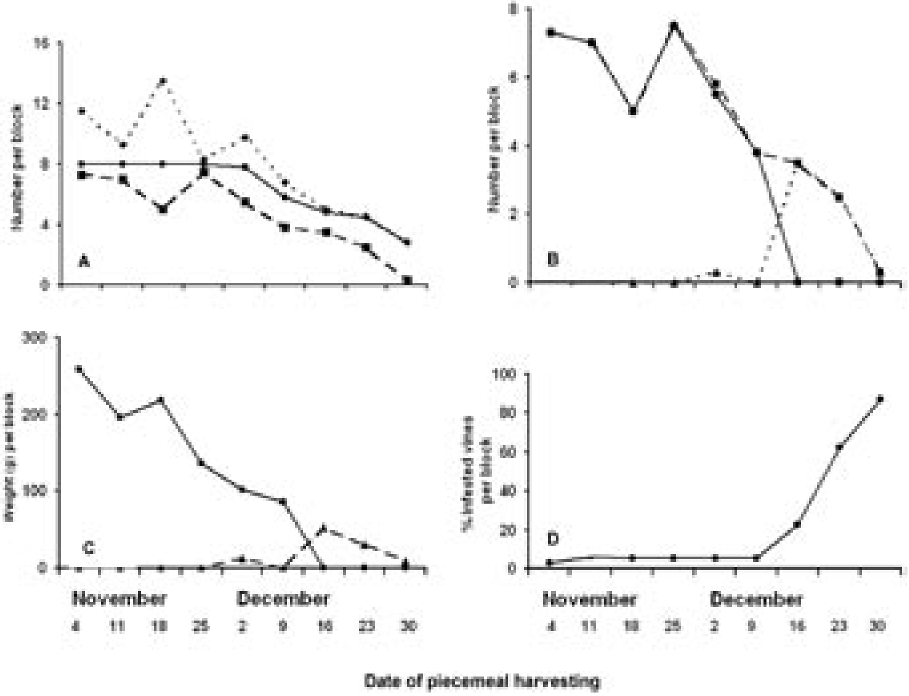

Figure 2. Changes in (A) average number of cracks (●), number of mounds containing harvestable storage roots (◆) and number of storage roots (■) per block; (B) average number of harvestable storage roots (●), average number of non-harvestable storage roots (▲) and total number of storage roots (■) per 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.

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).

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.

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).

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 practice	Exp. 1		Exp. 2		Exp. 3		Averaged over experiments	
	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; (*) = $P < 0.10$; ** = $P < 0.01$.

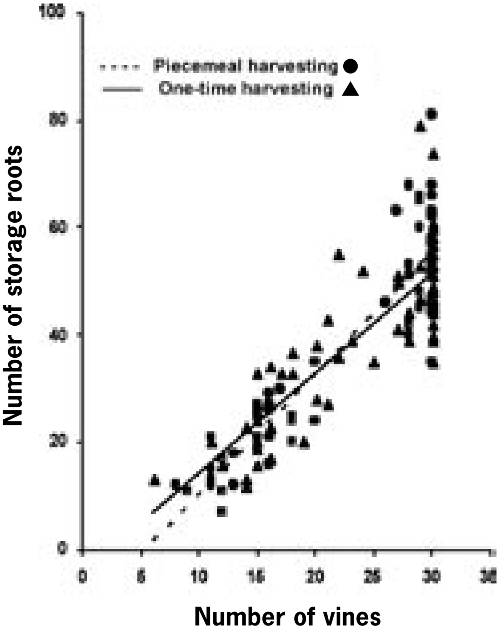

Figure 3. Fitted and observed relationships between average number of storage roots and vines per plot for one-time harvesting (▲) and piecemeal harvesting (●) across two experiments conducted at Arapai Station, Soroti District, north-eastern Uganda. Regression equation for piecemeal harvesting: $y =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

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 or 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/ Harvesting practice	Vines damaged by *Cylas* spp.	Storage roots damaged by:			
		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 $P = 0.10$.

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 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.

Discussion

This rationale of this paper 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.

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 ($P = 0.05$).

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 of 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 plants' 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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