

Dysmicoccus brevipes (Cockerell) occurrence and infestation behaviour as influenced by farm type, cropping systems and soil management practices



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ARTICLE INFO

Article history:

Received 23 March 2015
Received in revised form 16 January 2016
Accepted 25 January 2016
Available online 12 February 2016

Keywords:

Coffee husks
Conventional system
Earthing-up
Following
Foliar fertilizers
Organic system
Pineapple–banana intercrop

ABSTRACT

Occurrence of pineapple mealybug (*Dysmicoccus brevipes*) has been increasing at an alarming rate on pineapple in Uganda. The cause of the epidemic is unknown. This study was set out to establish whether prevailing cropping systems, production and management practices could provide an insight into the trend. A biological monitoring study that covered 150 pineapple farms was conducted in 2012 and 2013. Farms were categorised under organic and conventional systems. Mealybug population densities (mealybugs/plant) were recorded in relation to seed bed types, cropping system and soil management practices used on each farm. Mealybug population densities were lower in pineapple–banana intercrop system (27.8) than in a sole pineapple crop (81.8) across seasons. Earthed-up seed beds registered higher mealybug densities (84.1) than flat seed beds (31). Earthed-up seed beds created more favourable environment for mealybug multiplication than flat beds. Use of coffee husks as a soil fertility amendment promoted mealybug population build up (83.8) whereas following had a reducing effect (22.7). More in-depth studies on the role of soil moisture and soil cover in mealybug population build-up in pineapples are recommended.

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1. Introduction

Pineapple mealybugs, *Dysmicoccus* spp. (Homoptera: Pseudococcidae) are very important pests of pineapples nearly everywhere the crop is grown (Beardsley, 1993). Pineapple mealybugs are quarantine pests (Beardsley, 1993) and apart from direct damage caused by feeding, they are responsible for transmission of a virus which causes mealybug wilt disease that devastates pineapples (Sether et al., 1998). Being a virus vector, economic threshold does not exist, only one mealybug/plant can transmit the disease (Jahn et al., 2003) although Carter and Schmidt (1935) reported 5 mealybugs/plant as economic threshold. In addition, mealybugs produce honeydew on which sooty moulds grow that reduce photosynthesis, quality and marketability of pineapple fruits (Qin et al., 2011). There are two reported species of *Dysmicoccus* on pineapples; *Dysmicoccus brevipes* (Cockerell), which is reported everywhere pineapple is grown and *D. neobrevipes* (Beardsley), which is less widespread and has not yet been reported in Africa (Jahn et al., 2003). *D. brevipes* infests

pineapple roots, leaves, fruits, blossom cups and crown while *Dysmicoccus neobrevipes* only infest leaves, fruits and crowns (González-hernández et al., 1999)

Pineapple mealybugs are polyphagous pests of crops of economic importance. Whereas *D. brevipes* commonly infests perennial grasses as alternative hosts including sugarcane, *D. neobrevipes* has never been reported on grasses (Beardsley et al., 1982; Qin et al., 2011). Beardsley et al. (1982) reported both *D. brevipes* and *D. neobrevipes* infesting bananas in Hawaii. *D. brevipes* was also found infesting banana in Uganda (Kubiriba et al., 2001). Kubiriba et al. (2001) also established that abundance of *D. brevipes* was positively and significantly correlated with Banana Streak Virus (BSV) incidence.

The two species of *Dysmicoccus* differ in their ability to cause (or transmit) mealybug wilt disease. *D. neobrevipes* was found to be more important than *D. brevipes* in causing fruit infestation and mealybug wilt in Hawaii (Beardsley, 1993). Though *D. neobrevipes* has not yet been reported in Africa, there has been a severe outbreak of pineapple mealybug wilt disease in Central Uganda (Anonymous, 2009). Incidences of pineapple mealybug wilt disease ranging from 15% to 100% have been reported from farmers' fields in Uganda (Bua et al., 2013). *D. brevipes* and *D. neobrevipes* are primary vectors of pineapple mealybug wilt

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associated virus (Sether et al., 2005) This study aimed at identifying what species of pineapple mealybugs occur in Uganda and establishing whether farmers' practices could explain the increasing trend in mealybug infestation and hence incidence of wilt in Central Uganda.

2. Materials and methods

2.1. Study sites

The study was conducted from November 2012 to July 2013 in the districts of Kayunga (0° 27'N and 32° 51'E) and Luwero (0° 45'N and 32° 38'E) in Central Uganda where the main economic activity is pineapple production. Altitude for Luwero ranges from 1200 to 1500 m above sea level (m.a.s.l.) and Kayunga is 1000–1200 m.a.s.l. The soil type in both districts is ferrallitic soil with red as dominating colour, not differentiated and mainly with sandy clay loams. These areas receive average rainfall of 1200 mm per annum and experience bimodal type of rainfall with peaks in months of April, and September–October for first and second rainy seasons, respectively. The two districts experience average day and night temperatures of 28 °C and 16 °C, respectively.

On farm biological monitoring studies were conducted in organic and conventional farms in sub counties of Busana and Kangulumira in Kayunga District; and in Kikyusa and Luwero sub-counties in Luwero District. Average farm area under pineapple in Kayunga and Luwero Districts were 0.404 and 0.809 hectares, respectively (Anonymous, 2009). The farmers variably grow pineapple in organic and conventional systems with the former intended for export. Pineapples constitute 70% of fresh and dried fruit organic exports from Uganda (Namuwoza and Tushemerirwe, 2011). In organic systems, organic soil fertility amendments such as coffee husks and straw mulches are used; weeding if necessary is done manually. In conventional systems, a variety of fertilizers (DAP, NPK granular and NPK foliar) is used to boost plant nutrition; and herbicides, mainly glyphosate is used to control weeds before planting and Ametryn is used to control weeds in a pineapple crop. Other crops grown in the area include maize, bananas, beans, sweet potatoes, and cassava mainly for food; and coffee, tomatoes, cabbages, pawpaw and mangoes for cash (Bua et al., 2013).

2.2. Selection of farmers for the study

A total of 150 pineapple farmers were selected from the two districts. Of these farmers, 84 farmers were organic pineapple farmers and 66 farmers were conventional. In Luwero District,

58 organic farmers and 42 conventional farmers were selected while in Kayunga District, there were 26 organic and 24 conventional farmers selected. Farmers were selected with assistance of District Agriculture Officers (DAO) and National Organic Agriculture Movement of Uganda (NOGAMU). Organic farms were randomly selected from a list of organic farmers in Luwero and Kayunga using random numbers function (RAND) in Microsoft Excel and sorted in ascending order. Conventional farms were purposively selected from neighbourhoods of organic farms. Organic and conventional farms were comparable of size ranging from 0.40 to 1.62 hectares.

2.3. Sampling and data collection

2.3.1. Farming practices

On each selected pineapple farm, data was recorded on variety of pineapple planted, cropping systems (sole vs. intercrops/mixed), soil and water management practices, and inputs usage.

2.3.2. Pineapple mealybug infestation in farmers' fields

Mealybug infestation was assessed during rainy (April–July) and dry seasons (December–March). On all pineapple farms, destructive sampling (uprooting) of 10 plants was systematically done once during dry and rainy season along a diagonal line of the field according to a modified method described by González-hernández et al. (1999). A diagonal sampling of a plant for every 5th and 10th double rows was carried out in small (1–2 acres) and large fields (>2 acres), respectively. Mealybugs present on each of the ten pineapple plants uprooted from each field were thoroughly counted with aid of a hand lens to see small crawlers. Counts of mealybugs on roots and stems below ground level; stems above ground level and on leaf bases; and finally on leaves, fruits and crowns were taken separately.

2.3.3. Collection and identification of mealybug

A fine bristle paint brush was used to collect mealybug samples from plants into well labelled glass vials. Labels on glass vials indicated a farm's code, date of sampling, sub-county, and district codes. In each vial, 70% ethyl alcohol was added to kill and preserve the specimens before they were transported to the laboratory. A total of 450 specimens comprising of 150 samples collected from each of the three categorized parts of pineapple plant i.e. roots and underground stem; stems and leaf bases; and leaves, fruits and crown were collected. In the laboratory, mealybugs were mounted on slides for identification under a microscope, and identified following the guidelines of Williams and Granara de Willink

Table 1
Proportion of organic and conventional farmers using different soil management practices and cropping systems.

| Management practices/systems | Organic farmers | | Conventional farmers | | Pearson chi-square value (χ^2) | P-value |
|---|-----------------|------------|----------------------|------------|---------------------------------------|---------|
| | Freq. | Percentage | Freq. | Percentage | | |
| Seed bed type | | | | | | |
| Earthed-up | 26 | 31.0 | 24 | 63.6 | 0.487 | 0.485 |
| Flat seed bed | 58 | 69.0 | 42 | 36.4 | | |
| Soil fertility management practices | | | | | | |
| Coffee husks | 26 | 31.0 | 24 | 36.4 | 99.351 | <0.001 |
| Foliar fertilizers | NE | NE | 19 | 28.8 | | |
| Following (<10 years) + Foliar fertilizers | NE | NE | 23 | 34.8 | | |
| Following (\geq 10 years) + No amendment | 58 | 69.0 | NE | NE | | |
| Cropping systems | | | | | | |
| Pineapple–banana intercrop | 50 | 59.5 | 35 | 53.0 | 0.662 | 0.718 |
| Pineapple–bean–banana intercrop | 6 | 7.1 | 5 | 7.6 | | |
| Pineapple sole crop | 28 | 33.4 | 26 | 39.4 | | |

NE = Not evaluated.

(1992). The mealybugs and mealybug-like families key was used (Scale Insects, 2014 idtools.org/id/scales/key.php?key=mealybugs). Identification was carried out at National Research Laboratories (NaRL), Kawanda, Uganda. Reference specimens are kept at National Research Laboratories (NaRL), Kawanda, Uganda.

2.4. Data analysis

Data on mealybug counts were transformed to achieve homogeneity of variance, using square-root transformation $(X+0.5)^{1/2}$. Data was analysed using the statistical package for social scientists (SPSS) version 16.0, for Microsoft windows. Cross tabulations were used to analyse data for establishing proportions of farmers carrying out different cropping systems, soil fertility management and seed bed type in the two districts. A Chi-square test was used to find out whether there were significant differences between organic farmers and conventional farmers as per the different farm aspects in the two districts. An analysis of variance (ANOVA, GLM) was used to assess influence of farm type, seed bed type, cropping systems, and soil management practices on mealybug infestation and distribution pattern on the plant during rainy and dry seasons.

3. Results

3.1. Pineapple farming practices in Central Uganda

Results showed that farmers were planting pineapples in double rows (twin lines) using a spacing of 90 cm between twin lines and 30 cm within a row. Smooth Cayenne was the most grown pineapple variety. However, in Luwero District, organic farmers planted MD2 pineapple variety since exporting companies require small fruits (≈ 1 kg). Luwero is one of the pilot districts in Uganda where MD2 variety was introduced by Government of Uganda in collaboration with SNV Netherlands Development Organisation.

Farmers maintained pineapple either on earthed-up beds or flat beds. Earthing-up is usually implemented from 5 to 6 months after planting. Earthing-up creates a furrow in between the twin crop rows. The proportion of farmers using either earthed up or flat seed bed was not significantly different between organic and conventional pineapple farmers ($\chi^2=0.487$; $df=1$; $P>0.05$) (Table 1). However, the proportion of pineapple farmers using either earthed-up or flat seed bed were significantly different between the two districts ($\chi^2=0.00302$; $df=1$; $P>0.001$) (Table 2). All farmers (100%) in Kayunga District earthed up their pineapple plants whereas in Luwero District, no pineapple farmers (100%) earthed-up their pineapple plants.

Farmers used different soil fertility management practices depending on farm type (organic or conventional) ($\chi^2=99.351$; $df=3$; $P>0.001$) and district of production ($\chi^2=0.0055002$; $df=3$; $P>0.001$). Farmers were using coffee husks, NPK foliar fertilizers, a combination of land fallowing for a short time (<10 years) +NPK foliar fertilizers, or land fallowing for a long time (≥ 10 years). Farmers reported applying 15.6 tons per hectare of coffee husks and NPK foliar fertilizers at a rate of 3 L per hectare. Sixty nine percent of organic pineapple farmers were using land that fallowed for a long time (≥ 10 years) whereas the remaining 31% used coffee husks as their soil fertility management practice (Table 1). Of the conventional pineapple farmers, none used land that fallowed for a long time, 36.4% used coffee husks, 34.8% used a combination of short time fallowed land + foliar fertilizers, and 28.8% used foliar fertilizers as means of managing soil fertility for pineapple production (Table 1). In Kayunga district, all pineapple farmers (100%) used coffee husks as soil fertility amendment (Table 2). In Luwero district, farmers prefer letting land fallow (58% for long fallows; 23% for short fallows) and using foliar fertilizers (19%) to using coffee husks as a soil management strategy in pineapple production (Table 2).

Farmers in the two districts practice pineapple–banana intercrop, pineapple–bean–banana intercrop, and pineapple sole crop as their cropping systems. Choice of cropping system was not significantly affected by farming type ($\chi^2=0.662$; $df=2$; $p>0.05$) but varied significantly with district ($\chi^2=0.0013332$; $df=2$; $p>0.001$). All farmers (100%) in Kayunga planted pineapples as sole crop while in Luwero district, 85% intercropped pineapples with bananas, 11% intercropped pineapples with beans and bananas, and 4% grew pineapples as a sole crop (Table 2).

3.2. Mealybug infestation and distribution on pineapple plants in organic vs. conventional pineapple farms

Mealybugs infestation levels on pineapple plants were significantly different between organic and conventional farms only during rainy season ($F=67.069$; $df=1$; $P<0.001$) (Table 3). Average number of mealybugs per plant was significantly lower on pineapple plants in an organic farm (11.5) than in a conventional farm (56.2). This trend held for infestation on roots and stems in the soil, stem above the soil and leaf bases, leaves and fruits, and the total (on entire plant) (Table 3). The trend of distribution was that the highest mealybug populations were on roots and underground stems, followed by stem and leaf bases, and least on leaves and fruits during rainy season; this trend held true during dry season (Table 3). There was an unexpectedly higher mealybug

Table 2
Proportion of farmers in Kayunga and Luwero Districts using different seedbed types, soil fertility amendments, and cropping systems.

| Practices | Kayunga district | | Luwero district | | Pearson chi-square value (χ^2) | P-value |
|---|------------------|-----------------------|-----------------|-----------------------|---------------------------------------|---------|
| | No. of farmers | Percentage of farmers | No. of farmers | Percentage of farmers | | |
| Seed bed type | | | | | | |
| Earthed-up | 50 | 100 | 0 | 0 | 0.00302 | <0.001 |
| Flat seed bed | 0 | 0 | 100 | 100 | | |
| Soil fertility management practices | | | | | | |
| Coffee husks | 50 | 100 | 0 | 0 | 0.005002 | <0.001 |
| Foliar fertilizers | 0 | 0 | 19 | 19 | | |
| Fallowing (<10 years) + Foliar fertilizers | 0 | 0 | 23 | 23 | | |
| Fallowing (≥ 10 years) + No amendment | 0 | 0 | 58 | 58 | | |
| Cropping system | | | | | | |
| Pineapple–banana intercrop | 0 | 0 | 85 | 85 | 0.0013332 | 0.001 |
| Pineapple–bean–banana intercrop | 0 | 0 | 11 | 11 | | |
| Pineapple sole crop | 50 | 100 | 4 | 4 | | |

Table 3Occurrence and distribution of mealybug infestation (mean counts/plant \pm se.) on pineapple plant in organic and conventional farm.

| Type of farm | Rainy season | | | | Dry season | | | |
|--------------|---------------------------|-------------------|-----------------|-----------------|---------------------------|--------------------|-----------------|----------------|
| | Roots & underground stems | Stem & leaf bases | Leaves & fruits | Total | Roots & underground stems | Stems & leaf bases | Leaves & fruits | Total |
| Organic | 11.5 \pm 1.4 | 4.3 \pm 1.3 | 1.1 \pm 0.3 | 16.9 \pm 2.3 | 24.0 \pm 4.5 | 14.1 \pm 2.4 | 3.1 \pm 0.9 | 41.2 \pm 6.4 |
| Conventional | 56.2 \pm 8.1 | 21.9 \pm 4.9 | 17.4 \pm 13.6 | 95.6 \pm 18.8 | 29.2 \pm 5.2 | 20.3 \pm 4.9 | 2.5 \pm 1.0 | 52.1 \pm 8.3 |
| Mean | 31.2 \pm 4.1 | 12.1 \pm 2.4 | 8.3 \pm 6.0 | 51.5 \pm 8.9 | 26.3 \pm 3.4 | 16.8 \pm 2.6 | 2.8 \pm 0.7 | 46.0 \pm 5.1 |
| P-value | <0.001 | <0.001 | 0.016 | <0.001 | 0.294 | 0.248 | 0.647 | 0.217 |

density on pineapple during rainy season than in dry season (Table 3).

3.3. Mealybug infestation and distribution on pineapple plants in earthed-up vs. flat seed beds

Type of seed bed used for pineapple production significantly influenced mealybug infestation during rainy season ($F=26.889$; $df=1$; $P\leq 0.001$) and dry season ($F=13.429$; $df=1$; $P\leq 0.001$) (Table 4). A significantly higher mealybug infestation was recorded in earthed-up pineapple seed beds (100.6 mealybugs per plant) than flat ones (26.9 mealybugs per plant) in rainy season. This trend held true for different parts of a plant with the highest mealybug populations found on roots and underground stems, followed by stem and leaf bases, and least on leaves and fruits during rainy season. Similarly, there was a significantly higher mealybug infestation in earthed-up fields (67.6) than in flat ones (35.1) in dry season (Table 4); however, it was only on stems and leaf bases where differences were significant (Table 4).

3.4. Influence of cropping systems on pineapple mealybug infestation

Cropping systems used in pineapple growing significantly influenced mealybug populations on pineapple plants during rainy season ($F=5.851$; $df=2$; $P<0.01$) (Fig. 1). The highest number of mealybugs per plant (95.1) was recorded on sole pineapple crop and the least number (24.7) on pineapple–banana intercrop. Cropping systems also significantly influenced number of mealybugs per plant recorded in dry season ($F=8.703$; $df=2$; $P<0.001$) (Fig. 1). The highest number of mealybugs per plant (68.5) recorded on pineapple sole crop and the least on pineapple–banana intercrop (30.9).

3.5. Influence of soil management practices on pineapple mealybug infestation

Soil fertility management practices significantly influenced mealybug infestations on pineapple plants during rainy season ($F=18.467$; $df=3$; $P<0.001$). Generally, the highest number of mealybugs per plant (100.6) was recorded on pineapple plants under coffee husks soil amendment and the least infestation (10.6) on plants from fields where land had been fallowed for at least 10 years without any additional soil amendment (Fig. 2). Number

of mealybugs per plant recorded on pineapple plants from fields where coffee husks had been applied was significantly different from those where foliar fertilizers, fallowed land for less than 10 years with foliar fertilizers, and land followed for at least 10 years without any additional soil management amendment were used (Fig. 2). Similarly, soil management practices significantly influenced number of mealybugs per plant recorded in the dry season ($F=4.542$; $df=3$; $P<0.01$). The highest number of mealybugs per plant (67.6) was recorded on pineapple plants from fields where coffee husks had been used and the least infestation was found on pineapple plants treated with foliar fertilizers (34.2). Only pineapples from fields amended with coffee husks recorded a significantly higher number of mealybugs per plant than those from fields amended with any of the other three soil management practices during dry season (Fig. 2).

3.6. Species of pineapple mealybug in Central Uganda

From all the 150 pineapple farms sampled in Kayunga and Luwero Districts, the species of pineapple mealybugs identified in the samples collected was the pink pineapple mealybug, *D. brevipes* (Cockerell). Some of the features used for identification were: number of antennal segments, cerarii on head and/or prothorax, multilocular pores on venter, spiracular pores, legs, oral collar tubular ducts in cluster between front coxa and body margin, discoidal pores on derm surrounding hind coxa, translucent pores on hind leg, denticle on claw, shape and length of dorsal setae, setae on dorsum of segment viii longer than on segment vii and vi, and abdominal cerarii. For confirmation of *D. brevipes* species features used were: shape and length of dorsal setae, setae on dorsum of segment viii longer than on segment vii and vi, and abdominal cerarii. It was found infesting roots and underground stems, stem and leaf bases, leaves and fruits in the two districts.

4. Discussion

Only one mealybug species *D. brevipes* was found infesting pineapples in Uganda. This confirms reports by Jahn et al. (2003) that the *D. brevipes* is the pineapple mealybug species in Africa.

The study showed that pineapple farmers in the two districts were using different types of water management (earthed-up vs. flat beds) and soil fertility management practices and that the practices were influenced by farm type. The majority of the organic

Table 4Occurrence and distribution of mealybug infestation (mean counts/plant \pm se.) on pineapple plant in the flat and raised seed beds during the rainy and dry seasons.

| Type of seed bed | Rainy season | | | | Dry season | | | |
|---------------------|---------------------------|--------------------|-----------------|------------------|---------------------------|--------------------|-----------------|-----------------|
| | Roots & underground stems | Stems & leaf bases | Leaves & fruits | Total | Roots & underground stems | Stems & leaf bases | Leaves & fruits | Total |
| Flat seed bed | 21.0 \pm 2.8 | 4.9 \pm 0.8 | 1.0 \pm 0.3 | 26.9 \pm 3.1 | 24.0 \pm 4.1 | 8.7 \pm 1.4 | 2.4 \pm 0.7 | 35.1 \pm 5.2 |
| Earthed-up seed bed | 51.5 \pm 10.3 | 26.4 \pm 6.6 | 22.7 \pm 17.9 | 100.6 \pm 24.8 | 31.0 \pm 6.1 | 33.0 \pm 6.6 | 3.6 \pm 1.4 | 67.6 \pm 10.8 |
| Mean | 31.2 \pm 4.1 | 12.1 \pm 2.4 | 8.3 \pm 6.0 | 51.5 \pm 8.9 | 26.3 \pm 3.4 | 16.8 \pm 2.6 | 2.8 \pm 0.7 | 46.0 \pm 5.1 |
| P-value | 0.001 | <0.001 | 0.001 | <0.001 | 0.245 | <0.001 | 0.281 | <0.001 |

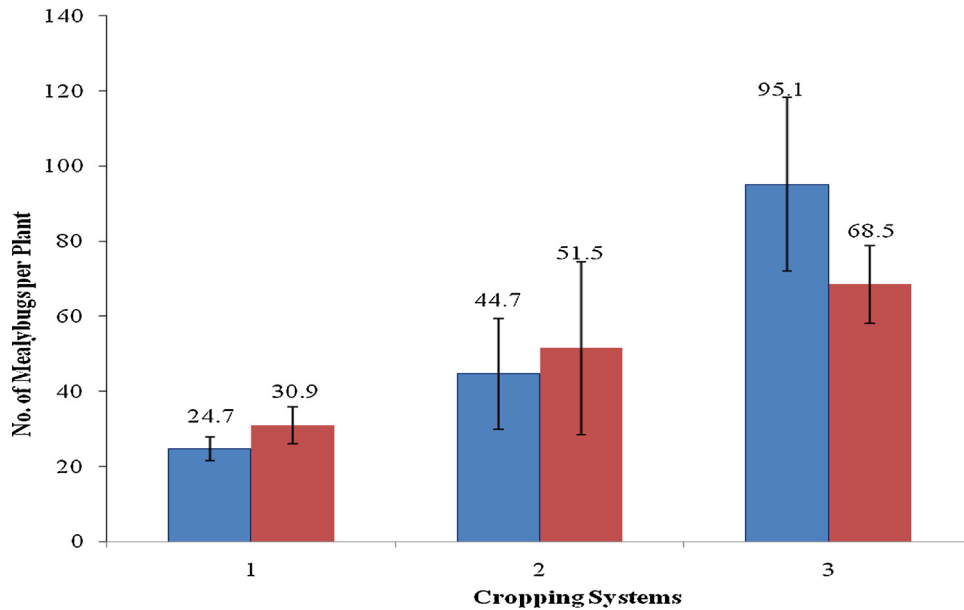


Fig. 1. Mealybug infestation levels from different pineapple cropping systems: (1) pineapple–banana intercrop; (2) pineapple–bean–banana intercrops; (3) pineapple sole crop during rainy and dry seasons. Blue bars—mealybug densities in rainy season; red bars—mealybug densities in dry season. Error bars—standard error of the mean. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

farmers in Kayunga District used coffee husks for plant nutrition, and earthed-up seed beds for soil moisture conservation. The organic farmers in Luwero district opted for long fallows as a soil fertility management strategy. These practices by organic farmers were mainly on the recommendation of National Organic Agriculture Movement in Uganda (NOGAMU) that promotes and coordinates organic agriculture in the country.

Earthing-up as a soil moisture management practice favoured mealybug population build up compared to leaving the bed flat. This could be attributed to high moisture conditions as shown by the high numbers in the rainy season. Bua et al. (2013) also reported more farmers (71%) citing high occurrence of the pineapple mealybug in the rainy season. The fact that *D. brevipes* prefers underground plant parts may also discourage earthing-up as a soil management practice in areas where the pest is a problem.

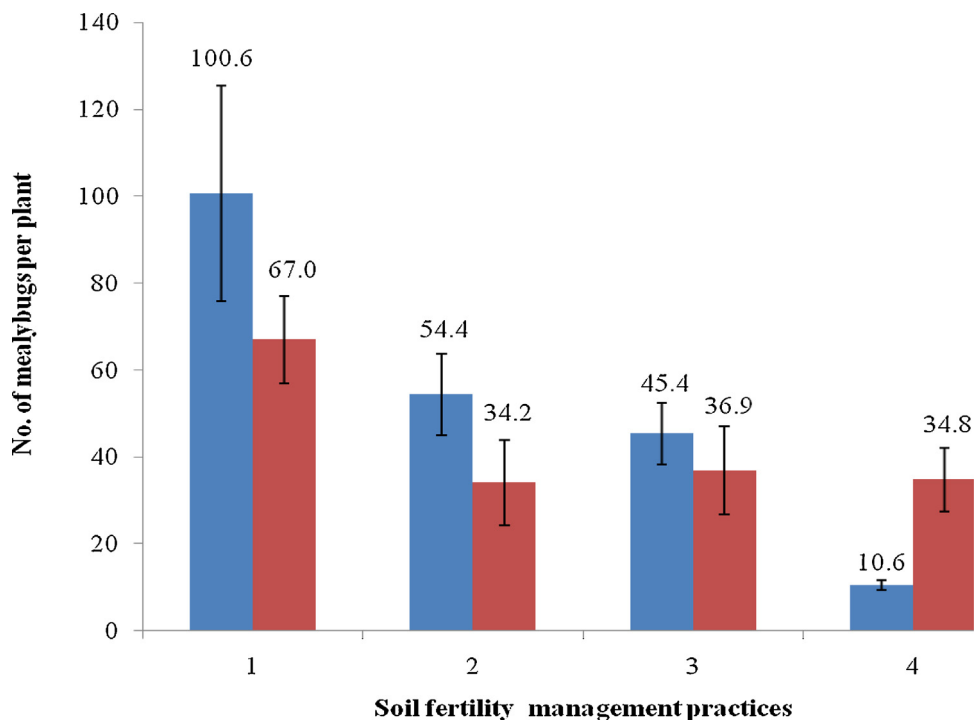


Fig. 2. Mealybug infestation levels during rainy and dry seasons from different soil fertility management practices: (1) coffee husks application; (2) foliar fertilizer application; (3) land fallowed for <10 years + foliar fertilizer application; (4) land fallowed for over 10 years. Blue bars—mealybug densities in rainy season; red bars—mealybug densities in dry season. Error bars—standard error of the mean. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fallowing showed potential in mealybug management as compared to the other soil management practices. The low mealybug levels in fallowed system could be due to increased abundance and diversity of predators as result of reduced land utilization intensity (Lundgren et al., 2006). Another explanation could be that natural enemy communities behaved differently in the different intensity systems with varying insectivory rates and daily predation patterns (Lundgren et al., 2006). It could also be due to higher densities of entomopathogenic fungi present in fallowed land than in agricultural land (Meyling and Eilenberg, 2006). Fallowing may have broken the cycle of *D. brevipipes*. Earlier work by Pandey and Johnson (2006) indicated that apart from *Chloris gayana* and *Eleusine indica*, the mealybug did not use most associated weed species as hosts. As such, using fallowing as rotation method may have merit, both as protection and soil rejuvenation practice.

Coffee husks amendments favoured mealybug population build up in the study, even relative to foliar fertilizers. This may imply that it may not have been the chemical nutrient aspect at play, but rather the microclimate provided by the coffee husks amendment, especially the ability to retain soil moisture, an attribute also reported by Kasongo et al. (2011) and Muwanika (2014). Microclimate provided by coffee husk might also have influenced ants colonising pineapple fields hence protecting mealybugs from natural enemies and facilitating their dispersal (Petty and Tustin, 1993).

With regard to cropping systems, 100% of the pineapple farmers in Kayunga District were found to plant pineapples as a sole crop. This is contrary to recommendations for sustainable organic systems where crop diversity is encouraged and advocated for, as a diverse cropping system promotes more stability (Sastawa et al., 2004). On the other hand, the predominant cropping system in Luwero district was pineapple–banana intercrop system. This system is good for pineapple as dry banana fibres and leaves can be used to mulch the pineapples. However, Beardsley et al. (1982) and Kubiriba et al. (2001) reported that *D. brevipipes* infest both bananas and pineapples and therefore the two may be suboptimal companions where the pest is a problem on pineapple, unless the preference is for bananas. The higher mealybug populations in a sole pineapple crop compared to the mixed systems is not an isolated finding for sap sucking insects. Sastawa et al. (2004) reported higher populations of another sap sucking insect, pod sucking bugs of the order Hemiptera in mono cropped systems compared to intercropped/mixed systems (Smith and McSorley 2000; Hooks and Johnson 2003). Insect mortality and dispersal, barrier from physical environment and response to visual and aromatic stimuli were given as the possible cause of the low numbers of pests in mixed systems. Polycultures are also known to favour activity of natural enemy activity, and thereby reducing pest infestation (Landis et al., 2000).

Mealybug populations were much lower on pineapple plants in organic system compared to conventional counterparts especially in the rainy season. This is in agreement with findings in others studies that widely reported lower pest levels in organic farming systems (Altieri et al., 2003; Karungi et al., 2006; Sigsgaard et al., 2014). They attributed the discrepancy to plant-insect resistance as influenced by biochemical and mineral-nutrient differences in crops under organic and conventional farming systems and fewer disturbances of organic fields. In addition, organic agriculture promotes evenness of natural enemies which results into increased natural pest control (Crowder et al., 2010; Sigsgaard et al., 2014).

There were significantly higher numbers of mealybugs on roots and underground stems and the population decreased towards the top of the pineapple plant. This is in line with the reports of Beardsley (1993) who showed that *D. brevipipes* occupies the roots

and other parts of the plant in the soil and near the ground. The fact that some infestation was found on aerial parts may be due to the high infestation levels on farms in the study.

5. Conclusion

The mealybug infestation levels reported on pineapple farms in the main growing areas are very high and necessitate swift interventions. With this particular pest, allowing land to fallow before planting the crop and intercropping with banana reduced mealybug infestation on pineapple. On the other hand, monocropping, earthing-up pineapple plants, and use of coffee husks consistently provided a favourable environment for *D. brevipipes*. As such, in areas where the pest is a big problem, usage of these three practices should be limited.

Acknowledgements

The research was funded by DANIDA through the Productivity and Growth in Organic Value-chains (ProGrOV) Project. We are grateful to the National Organic Agriculture Movement in Uganda (NOGAMU), National Research Laboratories (NaRL), Kawanda (Uganda), pineapple farmers, and local leaders in Luwero and Kayunga District for their co-operation.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.agee.2016.01.040>.

References

- Altieri, M. a., Nicholls, C.I., 2003. Soil fertility management and insect pests: harmonizing soil and plant health in agroecosystems. *Soil Tillage Res.* 72, 203–211. doi:[http://dx.doi.org/10.1016/S0167-1987\(03\)00089-8](http://dx.doi.org/10.1016/S0167-1987(03)00089-8).
- Anonymous, 2009. First Report of Pineapple Mealybug Wilt Disease in Mukono, Annual Report, Ministry of Agriculture, Animal Industry and Fisheries, Entebbe, Uganda.
- Beardsley, J.W., 1993. The pineapple mealybug complex; taxonomy, distribution, and host relationships. *Acta Hortic.* 334, 383–386.
- Beardsley, J.W., Su, T.H., McEwen, F.L., Gerling, D., 1982. Field investigations on the interrelationships of the big-headed ant, the gray pineapple mealybug, and pineapple mealybug wilt disease in Hawaii. *Proc. Hawaiian Entomomol. Soc.* 24, 51–67.
- Bua, B., Karungi, J., Kawube, G., 2013. Occurrence and effects of pineapple mealybug wilt disease in Central Uganda. *J. Agric. Sci. Technol.* A 3, 410–416.
- Carter, W., Schmidt, C.T., 1935. Mass action phenomena in mealybug wilt. *Anal. Entomol. Soc. Am* 28, 396–403.
- Crowder, D.W., Northfield, T.D., Strand, M.R., Snyder, W.E., 2010. Organic agriculture promotes evenness and natural pest control. *Nature* 466, 109–123.
- González-hernández, H., Reimer, N.J., Johnson, M.W., 1999. Survey of the natural enemies of *Dysmicoccus* mealybugs on pineapple in Hawaii. *BioControl* 44, 47–58.
- Hooks, C.R.R., Johnson, M.W., 2003. Impact of agricultural diversification on the insect community of cruciferous crops. *Crop Prot.* 22 (2), 223–238.
- Jahn, G.C., Beardsley, J.W., González-hernández, H., 2003. A Review of the Association of Ants with Mealybug Wilt Disease of Pineapple, Proceedings of Hawaiian Entomological Society, pp. 9–28.
- Karungi, J., Ekobom, B., Kyamanywa, S., 2006. Effects of organic versus conventional fertilizers on insect pests, natural enemies and yield of *Phaseolus vulgaris*. *Agric. Ecosyst. Environ.* 115, 51–55. doi:<http://dx.doi.org/10.1016/j.agee.2005.12.008>.
- Kasongo, R.K., Verdoodt, A., Kanyankagote, P., Baert, G., Ranst, E.V., 2011. Coffee waste as an alternative fertilizer with soil improving properties for sandy soils in humid tropical environments. *Soil Use Manage.* 27 (1), 94–102.
- Kubiriba, J., Legg, J.P., Tushemereirwe, W., Adipala, E., 2001. Vector transmission of banana streak virus in the greenhouse in Uganda. *Ann. Appl. Biol.* 139, 37–43. doi:<http://dx.doi.org/10.1111/j.1744-7348.2001.tb00128.x>.
- Landis, D.A., Wratten, S.D., Gurr, G.M., 2000. Habitat management to conserve natural enemies of arthropod pests. *Annu. Rev. Entomol.* 45, 175–201.
- Lundgren, J.G., Shaw, J.T., Zaborski, E.R., Eastman, C.E., 2006. The influence of organic transition systems on beneficial ground-dwelling arthropods and predation of insects and weed seeds. *Renew. Agric. Food Syst.* 21, 227–237. doi:<http://dx.doi.org/10.1079/RAF2006152>.
- Meyling, N.V., Eilenberg, J., 2006. Occurrence and distribution of soil borne entomopathogenic fungi within a single organic agroecosystem. *Agric. Ecosyst. Environ.* 113, 336–341. doi:<http://dx.doi.org/10.1016/j.agee.2005.10.011>.

- Muwanika, C.T., 2014. Effect of soil amendments and mulching on occurrence of tomato viral diseases and their vectors in Uganda. Makerere University MSc. thesis. 132 pp .
- Namuwoza, C., Tushemerirwe, H., 2011. Uganda: country report 1. In: Willer, H., Kilcher, L. (Eds.), *The World of Organic Agriculture, Statistics and Emerging Trends 2011*. 2011th ed. IFOAM, Bonn & FiBL, Frick, pp. 117–120.
- Pandey, R.R., Johnson, M.W., 2006. Weeds adjacent to Hawaiian pineapple plantings harboring pink pineapple mealybugs. *Environ. Entomol.* 35 (1), 68–74.
- Petty, G.J., Tustin, H., 1993. Ant (*Pheidole megacephala* F.)–mealybug (*Dysmicoccus brevipes* Ckll.) relationships in pineapples in South Africa. *Acta Horti.* 334, 387–395.
- Qin, Z., Wu, J., Qiu, B., Ren, S., Ali, S., 2011. Effects of host plant on the development, survivorship and reproduction of *Dysmicoccus neobrevipes* Beardsley (Hemiptera: Pseudococcidae). *Crop Prot.* 30, 1124–1128. doi:http://dx.doi.org/10.1016/j.cropro.2011.01.008.
- Sastawa, B.M., Lawan, M., Maina, Y.T., 2004. Management of insect pests of soybean: effects of sowing date and intercropping on damage and grain yield in the Nigerian Sudan savanna. *Crop Prot.* 23, 155–161. doi:http://dx.doi.org/10.1016/j.cropro.2003.07.007.
- Scale Insects. (2014). Mealybugs and mealybug-like families key. Idtools.org/id/scales/key.php?key=mealybugs.
- Sether, D.M., Melzer, M.J., Busto, J., Zee, F., Hu, J.S., 2005. Diversity and mealybug transmissibility of ampeloviruses in pineapple. *Plant Dis.* doi:http://dx.doi.org/10.1094/PD-89-0450.
- Sether, D.M., Ullman, D.E., Hu, J.S., 1998. Transmission of pineapple mealybug wilt-associated virus by two species of mealybug (*Dysmicoccus* spp.). *Phytopathology* 88, 1224–1230. doi:http://dx.doi.org/10.1094/PHYTO.1998.88.11.1224.
- Sigsgaard, L., Naulin, C., Haukeland, S., Kristensen, K., Jensen, N.L., Eilenberg, J., 2014. The effects of strawberry cropping practices on the strawberry tortricid (Lepidoptera: Tortricidae), its natural enemies, and the presence of nematodes. *J. Insect Sci. Sci.* 14, 1–18.
- Smith, H.A., McSorley, R., 2000. Intercropping and pest management: a review of concepts. *Am. Entomol.* 46 (3), 154–161.
- Williams, D.J., Granara de Willink, M.C., 1992. Mealybugs of Central and South America. CAB International Institute of Entomology, London.