

Simulated Soil Moisture and Planting Material Health on the Behaviour of *Cosmopolites sordidus*, Germar (Coleoptera: Curculionidae)

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Abstract

The pest status of *Cosmopolites sordidus* has been related to farm sanitation, environmental conditions and local weevil biotypes. This study was to confirm the inherent fecundity of endemic weevils, soil moisture effect and planting material health status that may contribute to weevil behaviour. Adult banana weevils were confined to plantain rhizomes, which were then subjected to four soil moisture regimens for 65 days. In another experiment to measure potential fecundity, weevils collected from the farmer's field were dissected to determine the internal egg follicles. Planting material with different initial weevil egg infestations on the pseudostem were confined below insect screening net in growing pots. Larva damage and stage populations were determined after 22 weeks. The results showed that weevils confined to plants under moisture stress had higher corm damage than irrigated and vigorously growing plants. A lower number of weevils were associated with plants under moisture stress than vigorously growing plants. The maximum number of mature egg follicles present in the ovaries of female weevils was 17. In general, the mean number of mature egg follicles was 4 per female adult weevil. Infested planting material with initial estimated number of 0.3 eggs per sucker resulted in 2.3 adult emergence and $\approx 34\%$ corm cross section damage after 154 days. The potential egg follicles albeit slow weevil population build-up reiterates the k-selected nature of the banana weevil. The egg follicles in adult female ovaries were high and comparable with weevils in other banana growing regions. The default health status of planting material was confirmed to be a contributing factor to weevil build-up in confinement. Soil moisture increased weevil survival but the improved plant vigour compensated for weevil damage.

Keywords: banana weevil, potential fecundity, soil moisture, planting material health

1. Introduction

Plantain (*Musa* spp. AAB) is a significant staple in much of West and Central Africa including Ghana (Gold *et al.*, 2002; FAOSTAT 2007; Norgrove & Hauser, 2014). In Ghana, nematodes and insects are two key pests that reduce the yield potential of plantain farms. The banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is a serious insect pest of bananas worldwide (Ostmark 1974; Waterhouse & Norris 1987; Gold *et al.* 1999). In East Africa for example, the prevalence of the banana weevil has reduced farm life spans to a maximum of 5 years (Lwandasa 2014). The larva of *C. sordidus* feeds and creates tunnels that can riddle plantain corms in a labyrinth manner, which can kill the plant, prevent the growth of the meristem, or inhibit root proliferation (Vilardebo 1973; Mitchell 1978; Treverrow 1985; Gold and Messiaen 2000; Paull & Duarte 2011).

The cropping history of plantain fields and sources of planting material are key determinant factors in weevil pressure and build up in plantain farms in Ghana (Afreh-Nuamah 1993) and elsewhere (Birkett 2010). The use of planting material from the farmers' old plantain fields and land previously cropped to plantain of less than three years fallow are reported to be a major source of infestation (Afreh-Nuamah 1993; Godonou *et al.*; 2000 Sintim *et*

al. 2016). Environmental changes such as fluctuations in light, temperature (Erima et al, 2017) and soil moisture and nutrients can also influence the weevil activity (Franzmann 1972; Prestes *et al.* 2006). There are inconsistent reports about the response of the banana weevil with respect to seasonal moisture conditions. Bakyalire & Ogenga-Latigo (1994) for example reported that *C. sordidus* is hydrophilic whilst Bendicho-Lopez & Gonzalez-Ramos (1986) reported that larvae and pupae populations increased during the dry season. In Brazil, the population peaks of *C. sordidus* adults occur in June and July, which have mild temperatures and low precipitation (Prestes *et al.*, 2006). In Ghana, research showed that, the adult weevil population increased during the rainy seasons (Afreh-Nuamah 1993; Braimah and van Emden 2002; Sintim *et al.* 2016). Other environmental variables such as soil moisture also influences host plant vigour, which subsequently improves plant health (Rukazambuga *et al.* 2002).

The adult weevil is ground dwelling hence soil moisture influences its habitat selection. The effect of soil moisture stress can also lead to the movement of the adult weevil deep into the soil or into the corm to avoid desiccation (Bruce *et al.* 2005). Planting material health is a contributing factor to the initial infestation and build-up of weevils in newly established plantain fields since the banana weevil is generally sedentary and rarely flies (Ragama *et al.* 2012). Farmers obtain planting materials from already weevil infested banana plantations (Bareky *et al.*, 2005) which acts as the initial source of infestation (Gold *et al.* 1998).

Data on the severity of damage as a function of initial infestation is however not available. However, different levels of infestation are inevitable since there are vast variations in population densities and distribution in farms (Rukazambuga 2002). The population of the larva, the destructive stage of the weevil, can be a consequent of the number of eggs produced, laid, or hatched but this can sometimes be unpredictable. At extremely high weevil population densities, there have been instances where egg-laying activity declined (Koppenhöfer 1993). In the field, it is very difficult to detect the number of eggs laid because they are normally embedded in the corm and covered with congealed sap. Under controlled field conditions set up by Koppenhöfer (1993), 0.7 eggs/week were recorded in banana suckers and 1.3 eggs/week occurred in stumps of harvested suckers. Occasionally, eggs are laid in the roots (Abera *et al.* 1997) or in the soil. Koppenhöfer (1993) reported that female banana weevil could lay an average of 2.7 eggs/week under laboratory conditions.

The fecundity of the banana weevil biotypes in Ghana is unknown. Damage by the weevil recorded in Ghana is not as severe as that reported in East Africa, and the Pacific or Caribbean regions where similar adult population densities have been observed in banana fields. This is the reason why the field conditions and weevil reproductive potential leading to reported populations and damage severity must be clarified as a basis to compare local weevil dynamics with other areas and the anticipated pest management tactics. We setup this experiment to determine the activity of endemic banana weevils under four soil moisture conditions and to confirm the consequences of using the default farmers planting material in new farms.

2. Materials and Methods

2.1 Weevil Bioassays

Weevils required for experiments were collected from farmers' fields either with cut pseudostem traps or by macerating rotten pseudostems or stumps. A laboratory culture of weevils that were collected from the farmer's field were maintained on pseudostem diets after separating them into males and females. The ages of the weevils were unknown but was suitable for the objectives of these experiments because the weevil has a *k-selected* lifestyle.

2.2 Effect of Soil Moisture on the Banana Weevil

The seasonal rainfall pattern in Ghana was simulated as a basis of the treatments selected. Data available at the Forest and Horticultural Crops Research Centre, Kade recorded between 1976 and 1997 indicated that on the average there were twenty rain-days/month between May and July, twelve rain-days/month between September and November, seven rain-days/months in March and April and four rain-days/month between December and February and in August. This moisture-controlled experiment (Figure 1) had four treatments with four replications in a completely randomised design. The treatments imposed were watering regimes, which represented the rainfall patterns as experienced during the four seasons in Ghana. This included: watering three times a week (to represent the daily rainfall between May and July when the soil is always at field capacity); watering once a week (to depict the rainfall pattern between September and November during the minor rainy season); watering once a month (to depict the beginning of the major raining season in March and April, when rainfall is scanty and falls at 2 - 4 weeks interval and a control that simulated a drought condition as happens in August or between December and February when the harmattan season with a long dry spell is experienced.

The experiment was conducted in wooden boxes (micro-plots), measuring 90 cm by 180 cm and 60 cm deep (Figure 1). The boxes were initially filled with fresh topsoil. Each box contained a tonne of soil. This filled the

box leaving a space of 20 cm above. The boxes were perforated underneath to allow for leaching. The volume of water needed to wet a unit of soil was determined using Hillel (1980) as adopted by Schwab & Frevert (1985). Sixty litres of water was required to wet the soil in each box to field capacity. This was an extrapolation from preliminary experiments using 100kg samples. This was the volume of water used when the irrigated treatments were applied.



Figure 1. A Moisture-Controlled Set-Up to Determine the Effect of Soil Moisture on Weevil Dynamics (plants before treatments were imposed)

Insect free plants were grown for 28 days in the controlled boxes before the moisture regimens were imposed

Plantain suckers of *apentupa* cultivar (and referred to as suckers) obtained from a split corm plantain nursery were pared and hot water treated at a temperature of 55°C for 20 minutes to eliminate eggs of weevils and nematodes (Colbran 1967; Gold *et al.* 1998)

Cleaned suckers with the circumference at the pseudostem/rhizome interface measuring 28 and 33 cm were selected for the trial. In all twenty plants were subjected to each irrigation frequency treatment Initially all the plants were equally watered after planting for four weeks after which 10 randomly selected each of male and female weevils from the laboratory culture were released at the base of each plant. The high weevil released was to ensure that there was adequate oviposition effect as well as to increase the chances of mating. Cut pseudostems and dried plantain leaves were kept in the boxes as a mulch material or food for the adult weevils. An insect proof mesh was used to secure the weevils to each plant. An emergence hole was made for the growing plant in the mesh. The rim of the emergence hole was fastened with an elastic band to hold the stem of growing plant. The plants were exposed to the irrigation treatments for 65 days when a generation of the weevil would have been completed (Franzmann 1972). The following agronomic data were taken at weekly intervals: plant height, plant girth at the mesh surface and number of fully opened functional leaves.

Underground rhizome size and damage were assessed as determined by the procedures of Gold *et al.* (1994). The number of larvae and pupae were counted after the 65-day irrigation treatments. For adult counting, split pseudostem traps were used to trap the weevils from the micro-plots. The adult weevils were trapped for 21 days which was the termination point (El-Sayed *et al.* 2006) when traps showed no catches for five consecutive

inspections in a 90 x 180cm area. Plants were uprooted for corm damage assessment using Percentage Coefficient of infestation (PCI) (Viladebo 1973) and throughout the experiment, and for juvenile weevil count.

2.3 Potential Weevil Fecundity

The potential number of eggs embedded in gravid females was determined. Three commercial plantain-growing areas in the Eastern Region of Ghana (Akanteng, Dwenase and Pramkese) which are within 30km radius of the University of Ghana' Forest and Horticultural Research station (6.0938° N, 0.8342° W) were selected for the study. Farm sizes were less than a hectare and were mixed cultivars of *apentupa* and *apem* (typical of plantain farms in Ghana) for all locations. There were three treatments (location) and was replicated over twelve months. For each sampling month one hundred adult female weevils randomly selected from trapped weevils in backyard gardens in each of the three locations was used for the study. At fortnight intervals, ten female weevils from each of the three locations were dissected along the lateral abdomen to expose the eggs. In all 240 females from each location were assessed during the 12-month study. The number of mature egg follicles present in their ovaries were extracted and with the aid of a compound microscope Leica DM 2500 were counted. The unused weevils (which was a security measure to take care or deaths and improve randomness) were discarded at the end of each month before new field samples were collected.

2.4 Effect of Planting Material Hygiene on Weevil Dynamics

A preliminary experiment with 15 replications indicated that the number of larvae increased on planting material when more adult weevils were available. Based on results from the preliminary experiment hot water treated suckers were each exposed to two or four weevils in 25-litre plastic containers lined at the bottom with moist soil at ambient conditions. These set ups were covered and kept at 25°C for 7 days to allow oviposition. The weevils were then detached from the suckers. These and a third treatment consisting of default suckers from farmers' field formed the three initial infestation treatments under study. The infested suckers were planted in 25-litre plastic pots filled with topsoil (Figure 2).

It was mulched and covered with 5 mm nylon mesh and fastened with a rubber band at the rim of the container. The potted plants were managed for 22 weeks when eggs would have reached adults. Plants were carefully uprooted for damage assessment using Gold *et al.* (1994). Adult weevil density within each pot was estimated by split pseudostem traps from the four weeks after planting until the 30th week when trap catches were zero for two consecutive weeks, which was considered adequate for trapping effect per container used. The number of larvae and pupae embedded in the plantain corms were also counted after the destructive sampling.



Figure 2. A Controlled Set-Up to Determine Effect of Initial Egg Infestations of Planting Material

2.5 Data Collected and Statistical Analyses

ANOVA was performed on all data using GENSTAT procedures to analyse the effects of: pre-planting material infestation levels and irrigating frequencies on weevil population and damage. The corm cross section damage was angular transformed prior to subjecting the data to ANOVA. Data involving independent counts were transformed using the square root (f) scale. Means were separated using the Least Significant Difference test GENSTAT® (2012)

3. Results

3.1 Effect of Soil Moisture or Plant Vigour on Weevil Behaviour

The effect of soil moisture on weevil due to watering frequencies leading to varying plant vigour indicated that the mean corm diameter from the irrigation frequency regimens: daily (9.76 cm) or weekly (9.08 cm) were significantly ($p < 0.01$) higher than the monthly watering (6.94cm) or the drought condition (7.05 cm) (Figure 3).

The effects of the irrigation treatments on plant height followed a similar response to irrigation frequency like that of the corm diameter (Table 1). The plant heights due to either daily watering (95.7 cm) or weekly watering (86.2 cm) were significantly ($p < 0.001$) higher than those from either the monthly watering (37.5 cm) or the drought (28.4 cm) treatment. There were significant ($p < 0.01$) differences in plant girth between either the daily watering (24.07 cm) or weekly watering (23.42 cm) and the monthly watering (14.20 cm) or drought (12.56 cm) condition. The mean number of leaves per plant increased in response to a higher irrigation frequency.

Table 1. Effect of Watering Regimens on Agronomic Indices of Nursery Plantain

Plant index	Watering frequency				Mean
	Daily	Weekly	Monthly	Drought	
Corm diameter (cm)	9.76a	9.08a	6.94b	7.05b	8.21
Plant height (cm)	95.7a	86.2a	37.5b	28.4b	61.6
Stem girth (cm)	24.07a	23.42a	14.20b	12.56b	18.56
Number of leaves	9.96a	9.57a	5.55b	5.08b	7.54
Number of suckers	1.7a	0.5b	0.3b	0.0c	0.63

Ten each of male and female weevils were confined at the base of each 28-day old nursery plants in micro-plots and were exposed to watering frequency treatments for 65 days.

Means followed by the same letter(s) in a row are not significantly different at 5% level (LSD test, GENSTAT)



Figure 3. Corm Sizes at 95 Days after Planting of Plants Exposed to Different Watering Frequency Regimens

The average number of leaves for the daily watering (9.96) or weekly watering (9.57) were significantly ($p < 0.05$) higher than that of either the monthly watering (5.55) or the drought condition (5.08). At the end of the watering regimens, the mean number of peeper suckers that sprouted (Table 1) from the daily watering treatment (1.7) was significantly ($p < 0.05$) higher compared to the other treatments namely: weekly (0.5), monthly (0.3) or no suckers from the drought simulated treatment. The drought treatment was also significantly ($p < 0.05$) lower than either the weekly or monthly watering treatments.

Table 2. Effect of Simulated Watering Regimens on Banana Weevil Development

Insect stage	Watering frequency				Mean
	Daily	Weekly	Monthly	Drought	
Larva	0.64	0.65	0.35	0.10	0.43
Pupa	0.20	0.13	0.08	0.05	0.12
Adult	5.1	4.7	3.9	3.1	4.19

Ten each of male and female weevils were confined at the base of each 28-day old nursery plants in micro-plots and were exposed to watering frequency treatments for 65 days after which plants were dissected to locate juvenile stages. Introduced adult weevils that survived experiment duration were trapped with cut pseudostem traps over time

The mean number of larvae extracted in different plants from the daily watering (0.64) and the weekly watering (0.65) were not significant (Table 2). These were however significantly ($p < 0.05$) higher than the mean number of larvae in plants from either the monthly watering (0.35) or the drought (0.10) treatment. There were no significant differences in the mean number of emerged pupae or adults for the treatments. The number of pupae from the treatments was highest (0.20) in the daily watering and least (0.05) in the drought treatment. The number of adult insects trapped in the microplots after plants were uprooted was highest (5.1) in the daily watering and least (3.1) in the drought treatment (Table 2).

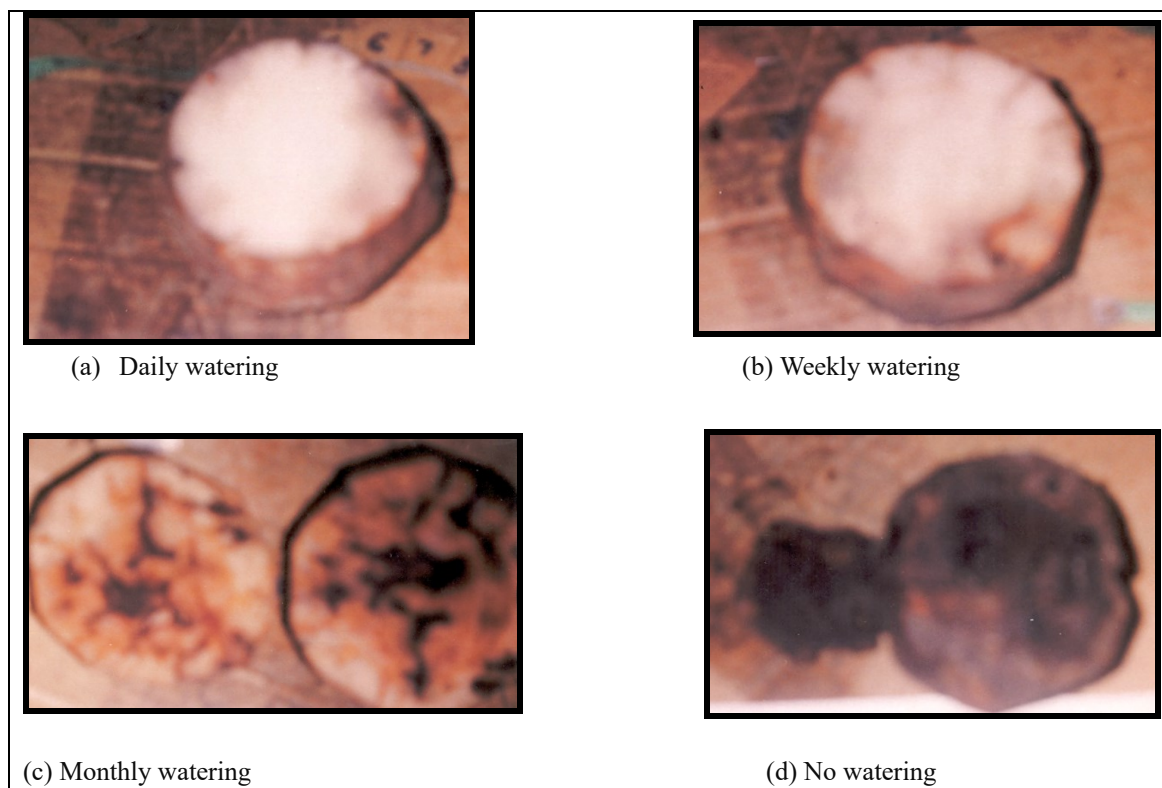


Figure 4. Sample Corm Cross Section Damage from the Watering Treatments

**Dark portions within the circular corm are indicative of level of weevil tunneling*

In the peripheral rhizome assessment, weevil damage on corms due to the daily watering treatment (19.0%) was significantly ($p < 0.05$) lower (Table 3) than either the monthly treatment (42.9%) or the drought treatment (55.6%). Although damage due to the daily (19.0%) and weekly (35.1%) watering frequency treatments were not significantly different, damage due to the weekly watering was higher.

Table 3. Corm Damage Due to Weevil Response to Simulated Watering Regimes

% Damage	Watering frequency				Mean
	Daily	Weekly	Monthly	Drought	
<u>Damage location</u>					
Peripheral	19.0a	35.1ab	42.9b	55.6b	38.2
Inner cross section	18.6a	17.0a	43.0b	53.0b	33.0
Outer cross section	14.2a	15.4a	32.9ab	55.0b	29.4

Ten each of male and female weevils were confined at the base of each 28-day old nursery plants in micro-plots and were exposed to watering frequency treatments for 65 days after which plants were harvested uprooted for corm damage assessment using Percentage Coefficient of infestation (PCI)

Means followed by the same letter(s) in a row are not significantly different at 5% level (LSD test, GENSTAT)

In the outer corm cross section damage, there were no significant differences among the daily (14.2%), weekly (15.4%) and monthly (32.9%) watering treatments. The damage due to the weekly watering was lower than either the monthly or the drought treatments but was not significant. The drought treatment had the highest peripheral rhizome damage. The corm cross section damage analysis showed that damage in plants that received daily (16.4% damage) or weekly (16.2% damage) watering were significantly ($p < 0.01$) lower than those of plants under monthly (38.0% damage) watering and drought (54.1% damage) treatments. However, there was no significant difference between the daily and weekly watering regimens. The damage due to monthly watering was lower than the damage due to the drought situation but was not significant (Table 3).

Damage in the inner corm cross section showed that there was a significantly ($p < 0.01$) lower damage in either the daily (18.6%) or weekly (17.0%) watering treatments than damage in either of the monthly watering (43.0%) or drought (53.0%) treatments. There was however no significant difference between either the daily and weekly treatments or between the monthly and drought treatments (Table 3, Fig 4).

However, the daily and weekly watering treatments resulted in insect damage that were significantly ($p < 0.05$) lower than the drought (55.0%) treatment. The monthly watering treatment had a lower damage than the drought condition, but it was not significant.

3.2 Weevil Fecundity Levels in Ghana

The number of mature egg follicles obtained from the ovaries of female weevils collected from the three locations did not differ significantly ($p > 0.05$). The overall mean number of mature egg follicles extracted from 720 weevils during a 12-month study was 4.03 per female.

Table 4. Insects Emergence from Planting Materials Subjected to Initial Weevil Infestations

insect stage	Initial infestation level/plant			Mean
	Farmer's material	Two weevils per plant	Four weevils per plant	
Larva	0.83a	1.50b	1.78b	1.03
Pupa	0.0	0.0	0.0	0.0
Adult	0.33a	1.73b	2.33b	1.46

Suckers were initially exposed to either two or four weevils and a third treatment of suckers collected directly from the farmer's field were manually inspected and cleaned of adult weevils were planted in 25-litre plastic pots filled with soil. This was managed for 22 weeks after which plants were dissected to locate juvenile stages and introduced adult weevils that survived experiment duration were trapped with cut pseudostem traps over time

Means followed by the same letter(s) in a row are not significantly different at 5% level (LSD test, GENSTAT)

3.3 Pre-planting Infestation on Weevil Dynamics

Results from the effect of initial infestation levels of planting material and subsequent insect emergence indicated that the mean number of larvae found in dissected corms from the farmers source planting material (0.83) was significantly ($p < 0.05$) lower than that from treatments which were initially either cultured with four weevils (1.78) or two weevils (1.50). In all the treatments, no pupa was found associated with the corms (Table 4).

Table 5. Corm Damage from Planting Materials Subjected to Initial Weevil Infestations

% Damage	Initial infestation level/plant			Mean
	Farmer's material	2 weevils per plant	4 weevils per plant	
<u>Damage location</u>				
Corm periphery	3.3a	12.5b	14.4b	10.07
Inner cross section	13.2a	34.5b	35.5b	27.7
Outer cross section	4.0a	25.7b	28.7b	19.5

Suckers were initially exposed to either two or four weevils and a third treatment of suckers collected directly from the farmer's field were manually inspected and cleaned of adult weevils were planted in 25-litre plastic pots filled with soil. This was managed for 22 weeks. after which plants were uprooted for corm damage assessment using Percentage Coefficient of infestation (PCI)

Means followed by the same letter(s) in a row are not significantly different at 5% level (LSD test, GENSTAT)

The mean number of adults trapped per plant was significantly ($p > 0.05$) higher in both the treatments initially cultured with either two weevils (1.73) or four weevils (2.33) than that of the farmer's default planting material (0.33). Although the treatment which was initially cultured with four weevils resulted in higher number of larvae than that with two weevils, it was not significant ($p > 0.05$).

The extent of peripheral corm damage due to the initial infestation treatments indicates that the treatment cultured with two weevils (12.5%) and the treatment cultured with 4 weevils (14.4%) were significantly ($p < 0.01$) higher than that of the farmer's default planting material (3.3%). The corm cross section damage of the treatments cultured with either two weevils (30.1%) or with four weevils (33.6%) were significantly ($p < 0.01$) higher than that of the farmers material (8.6 %) (Table 5).

The experimental plants, which were at the sucker growth stage, had an overall mean outer damage of 19.5% and an inner damage 27.7% (Table 5). The inner corm damage of the treatment cultured with two weevils (34.5%), or the treatment cultured with four weevils (35.5%) was significantly ($p < 0.01$) higher than that of the farmer's default planting material (13.2%). The treatment cultured with two weevils and that with four weevils were however not significantly different ($p = 0.5$). The outer corm damage of the treatment cultured with two weevils (25.7%), or the treatment cultured with four weevils (28.7%) was significantly ($p < 0.01$) higher than that of the farmer's default planting material (4.0%). The treatment cultured with four weevils had a higher damage than the treatment cultured with two weevils, but it was not significant ($p = 0.5$).

4. Discussion

The population of *C. sordidus* fluctuates in response to environmental conditions and cropping systems. Reported population dynamics from literature indicate that the adult weevil behaved differently as reported by Ittyeipe (1986), Bakyalire & Ogenga-Latigo (1994), Rukazambuga *et al.* (2002), and Sintim *et al.* (2016) although these authors worked under similar field conditions and were expected to arrive at the same conclusions.

The plantain weevil is well known to be positively hydrotactic (Ittyeipe 1986; Carval *et al.* 2015.) but there have been reports that suggest that some experiments conducted during the dry season had higher oviposition rates (Masanza 2003). It is well documented that wet plantain mats with obviously high moisture increased trap catches (Bakyalire & Ogenga-Latigo 1994), and soils high in moisture also increases plant vigour. The data obtained in this experiment suggests that increasing the frequency of watering to attain soil moisture capacity, led to an increase in both plant vigour and increased number of adult weevils attracted to the plantain mat. Plants growing vigorously and with broader leaves in response to irrigation, leads to improved shading at the base of the plant. Shading subsequently leads to negative phototaxis which has been reported to be the overriding factor influencing weevil activity in the field (Bakyalire & Ogenga-Latigo 1994; Carval *et al.* 2015).

Our results obtained indicate that increased plant vigour resulted in bigger corms, taller and larger stems, more functional leaves and produced more suckers. This observation confirms earlier results by other workers on the effects of cultural practices which are touted to be the first line of defence (Okolle 2020). Soil amendments including the use of manure and mulches were employed to reduce plant stress by desiccation as reported by Rukazambuga *et al.* 2002. The treatments in this experiment that led to vigorous growing plants improved plant mat conditions, which were conducive for weevil attraction as it is ground dwelling (Carval *et al.* 2015). The bigger corms from these treatments supported a higher number of larvae and pupae which confirms earlier reports by Sintim *et al.* (2016) that bigger corms could compensate for weevil damage. In situations where high number of larvae has been recorded in bigger corms, bigger corm size, which improves space availability to each larva, was also considered to be contributory factor since cannibalism in smaller plants was reported to be due to crowding (Kagezi *et al.* 2004). The mean number of larvae, 0.64, found in the ideal irrigated treatment which was at constant field moisture capacity was higher than the 0.10 mean number of larva reported in the treatment that simulated drought condition.

These results demonstrate the effect of moisture as an attractant to ovipositing sites for female weevils. In Sintim *et al.* (2016) for example, weevil population fluctuation was in synchrony with the number of rain days in a period. However, moisture effect leading to gains in plant growth outweighed the deleterious effects of insect attraction and consequent damage. The vigorously growing plants in this experiment had relatively larger corm sizes, which could have compensated for the damage caused by the larvae in relation to moisture attraction for oviposition. In Rukazambuga *et al.* (2002) manure and mulches were used to enhance plant growth in a similar moisture-damage study. The moisture and manure created a humid condition at the base of the plant like the conditions simulated in this experiment. The report by Rukazambuga *et al.* (2002), however, stated that vigorously growing plants were severely attacked than stressed plants by the banana weevil. This is in contrast with results obtained from this rainfall-simulated experiment. It is however similar to the results reported by Sintim *et al.* (2016) where 2nd ratoon plants had lower weevil attack than newer plantations. The contradictions between these reports may be due to the parameter used as damage. Whilst Rukazambuga *et al.* (2002) presented their damage results in absolute terms on area basis (cm²), this experiment and others including Ogenga-Latigo & Bakyalire (1993), Ortiz *et al.* (1995) and Sintim *et al.* (2016) expressed corm damage as a percentage of corm size.

In the current experiment, the stunted growth in the simulated water stressed treatment resulted in increased percentage larva damage. The feeding tunnels created by the larva were large and created a large hollow in the plant mass with damaged meristem a stressed plant leading subsequently to plant death. For example, whilst the mean cross section damage due to the simulated daily watering was 16.4%, it was as high as 54.1% in the drought simulated treatment. These results confirm earlier reports that the plantain weevil aggravates the problem of plants under moisture stress (Summerville 1944; Jones 1986). The larvae will always consume a constant corm area if available and irrespective of the plant size or continue to riddle upwards into the pseudostem (Franzmann 1972). Plants with larger corms will thus have a relatively smaller absolute percentage of plant material consumed than a stressed plant with a smaller corm (Sintim *et al.* 2016). The percentage corm damage caused by the plantain weevil is thus inversely proportional to corm diameter (Sintim *et al.* 2016). Moisture stressed plants when exposed to scorching or desiccation influences the weevil to seek shelter deep inside the corms. In such situations, larva feeding tunnels can easily consume the whole plant tissue mass (Tinzaara 2005; Osorio-Osorio *et al.* 2006). In other studies where cover crops were introduced as soil amendments, it reduced the abundance of the banana weevil but did not reduce corm damage (Carval *et al.* 2016).

The fecundity studies revealed that female weevils had an inherent fecundity of about five mature egg follicles. Franzmann (1972) reported that the number of eggs produced by weevils were inversely proportional to adult age considering that weevils are k-selected and can live for two or more years. Abera *et al.* (1997) however gave a definite amount of up to 22 mature egg follicles from a single female adult in Uganda, which compares well with the limit potential fecundity of weevils reported in Ghana, which was a maximum of 17 mature egg follicles per female. These variations in inherent fecundity could be evidence of the existence of endemic banana weevil biotypes as reported by Magaña *et al.* (2007) and Twesigye *et al.* (2018).

The data obtained from the pre-planting infestation treatments showed that there is a positive relationship between the level of initial infestation and subsequent damage. There are reports, which indicated that weevil population and damage increased towards older crop cycles (Sintim *et al.* 2016). Therefore, planting material collected from a third cycle crop (2nd ratoon) is more likely to harbour more weevil eggs than a planting material from a plant crop (first year plants). In this trial, the mean number of adult weevils that emerged was 0.33 per plant in the farmers' default material to a high of 2.33 in the treatment that had an initial rhizome infestation of four weevils. Rhizome damage also followed the same trend where the highest infested treatment recorded as much as 33.6%

cross section damage within 22 weeks. Such plants may not be able to reach the reproductive stage. Again, in the highest initial infested treatment, there was 48% plant mortality within the experimental period.

The use of highly infested suckers as planting material will lead to an early start of weevil build up during the growth of the plant, which will subsequently accumulate. The general observation was that although plants from plots with adequate soil moisture had a high number of weevil incidences similar to reports of weevil population builds up with the rains (Uzakah & Olorunfemi 2019) such plants had a relatively smaller percentage of corm tissue damaged. It was observed that though soil moisture resulted in increased weevil attraction in confined situations, the frequency of precipitation was itself not a contributing factor to trap catches as reported by Sintim *et al.* (2016). The micro ecology created at the plant base or mat of a vigorously growing plant was rather responsible for high weevil damage (Abagale 2018). Such inconsistencies have been also reported in French West Indies where *C. sordidus* abundance was positively related to mean temperatures and negatively related to mean rainfall but was not related to soil type (Duyck 2012).

Moisture in our controlled experiments improved plant vigour, which subsequently reduced the proportionate size of absolute corm tissue consumed by the weevil. In an experiment by McIntyre *et al.* (2003), although weevil damage was higher in mulched treatments, water conservation under mulch increased fruit yield, which subsequently outweighed the detrimental effects of the weevil damage. When there is no choice for corm size the weevil will normally completely devour smaller sized corms, which are under moisture stress, but it tends to select and feed on larger corms as a preference. Several authors have recommended the use of maiden suckers, which are bigger, when replanting in already infested plantations or those at risk (Gold *et al.* 2001; Tinzaara *et al.* 2003; Rhino *et al.* 2010, Lwandasa *et al.* 2014; Carval *et al.* 2016). In the development of an integrated pest management strategy for the banana weevil, the key factors that should be considered include, plant nutrition, sources of moisture or its conservation such as through manures and mulches, use of clean and healthy planting material and the possibility of using kairomones such as cut pseudostems which are wet and attractive to the weevil. In other situations where there are sources of irrigation water, sprinklers could be used to wet the entire field. A uniformly wet field will improve crop growth and increase the searching time or reduce the searching efficiency of adult weevils towards plant mats.

5. Conclusion

Plantains and bananas are cultivated in Africa at both the subsistence and commercial farm scales. Commercial growers use clean planting material from tissue culture or split corm sprouts, irrigate fields and adopt other good agronomic practices. The subsistence farmer who is under resourced however relies on cultural practices to remain in business. As we explore alternatives to synthetic pesticides for the management of the banana weevil the situation of the subsistence farmer will remain extremely difficult and expensive if the weevil population is not managed at the onset of farm initiation. The weevil management should be done consciously among community farms since the weevil although sedentary and rarely flies, is able to move across fields. Due to the cryptic behaviour of the weevil (Carval *et al.* 2015), control tactics should be directed at clean planting material. The level of initial infestation should be minimised, and plant nutrition should be boosted to attain vigorous growth. Weevils in Ghana have an equal potential to reproduce similarly to those found in East Africa if plantain stands are sustained are kept ratooned. In the field, the weevils' distribution is uneven, and it displays varying population and damage levels under conditions such as size of the test plants, season of the year, health status or vigour of the plant and the variations in the fecundity of the adult weevil. Control of the banana weevil is still difficult. Recently Tresson *et al.* (2021) have confirmed the challenges with the use of biological control in weevil control. Others have also employed modern technologies such as the use of cameras and concluded that vertebrates such as the Asian shrew, house mouse, oriental garden lizard and the guttural toad were promising predators of the weevil (Tresson *et al.*, 2022). The farmer stage accessible agronomic practices adopted in this experiment influences weevil behaviour, hence amendments that improves soil moisture should be recommended. These results on the use of soil moisture leading to improved plant vigour, add up to the spectrum of tools that can be selected for benign management strategies for the banana weevil including the use of healthy planting material, removal of crop residues, mass trapping and as well as host plant hardiness or tolerance and plant nutrition.

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Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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