POPULATION DYNAMICS OF THE PLANTAIN STEM BORER (*COSMOPOLITES SORDIDUS* GERMAR) AND FACTORS AFFECTING THE SEVERITY OF DAMAGE TO PLANTAIN (*MUSA SPP.* AAB GROUP) IN GHANA

BY

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ABSTRACT

A study was conducted to determine the behaviour of the banana weevil *Cosmopolites sordidus* Germar and the differential severity of its larval damage on four stages of plantain' (suckers, preflowering, flowered and recently harvested) in three different crop cycles. The results indicate that the population of the adult weevil increased in the ratoon crops, and that 3-day old traps were more attractive than 5-day old traps.

The longevity of weevils decreased with increasing ratooning from 63.8% in the plant crop, 63.6% in a 2nd cycle crop to 42% in a 3rd cycle crop.

Larval damage on the cross section and periphery of the corm indicates that the mean damage on corms in a plant crop was 3.1% and 6.2% respectively and a mean cross section damage of 8.6% and 12.5% peripheral damage in the ratoon crop. It was observed that a higher proportion of damage was located in the outer cortex. However the ratio of the damaged central cylinder to the outer cortex decreased from 1:4 in a plant crop to 1:2 in the ratoon crops. When all the plant growth stages were available, the larval damage was lower in sword suckers of corm diameters<9cm than the bigger mature corms with diameters>19cm. The ratio of cross-section damage in the inner cylinder to outer cortex was 1:1 in sword suckers, 2:3 in preflowering plants, 2:5 in flowered plants and 1:2 in harvested plants. The overall corm cross section damage ranged from 2% in a sword sucker from a 1st cycle crop to 14% in a harvested plant from a 1st ratoon crop.

In a soil moisture or plant vigour trial, the results suggest that, in confined situations where weevils have no choice for corm size, plants under moisture stress had a higher

percentage damage than vigorously growing plants with larger corms. A lower number (3.1) of insects was however associated with plants under stress than vigorously growing plants (5.1) during the 65-day experimental period.

Studies on the potential fecundity of weevils in Ghana revealed that the number of mature egg follicles present in the ovaries of a female was up to 18. Thirty percent of the weevils collected had no eggs. In general the mean number of mature egg follicles was 4.03/female.

A study on the effect of initial infestation of planting material on subsequent adult population build up and damage, indicates that as the level of initial infestation increased subsequent adult weevil population and damage also increased. An initial planting material of 0.2 and 0.3 larva per corm of mean diameter 4.6cm led to 0.3 and 2.3 adults respectively after 22 weeks of plant growth in pots. Damage to these plants ranged from 8.6% to 33.6% respectively in the 0.2 and 0.3 larva initial infestations.

DECLARATION

I hereby declare that, except for references to work of other researchers which have been duly cited, this thesis consists entirely of my original research work and that no part of it has been presented for another degree elsewhere.

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DEDICATED

To

Yaa Dufie and Yaw Ofosuhene

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ARPPIS	African Regional Postgraduate Programme in Insect Science
ARS	Agricultural Research Station
BMZ	Bundesministerium fur Wirtschaftliche Zusammenarbeit und Entwicklung
IITA	International Institute of Tropical Agriculture
KG	Kilogram
LSD	Least significant difference
P	Probability
PCI	Percentage coefficient of infestation
PD	Peripheral damage
PHMD	Plant Health Management Division
SP	Species
UG	University of Ghana
WAPP	West African Plantain Project
X-SECTION	Cross section of the corm

CHAPTER 1

GENERAL INTRODUCTION

Plantains and bananas (*Musa spp.*) are grown mostly in East, West and Central African Countries and form a staple for about 70 million people in sub-Saharan Africa (Swennen, 1990). In West Africa, plantain serves as a cash crop (Masefield, 1944) in addition to its traditional role as a food crop.

The dessert and cooking types of *Musa spp.* are grown at subsistence levels in Ghana as part of mixed cropping systems. The fruit is available fresh throughout the year, thus, making it an important food security crop (INIBAP, 1988). Plant stands can last for 7 years (Schill *et al.*, 1996b) when conditions are favourable. In Ghana, there was a recorded decline in the trend of plantain production from 1.32 million tonnes in 1985 to 0.79 million tonnes in 1990 (PPMED, 1991). The low productivity experienced was attributed to several factors including decreasing soil fertility, scarcity and limited availabity of planting material, competition for land due to population pressure, diseases, nematodes and insect pests (Sikora, 1989; Gold *et al.*, 1991; Akomeah *et al*, 1995). These constraints either lead to the shortening of the life of the crop stands or reduced plant vigour and consequent yield reduction (Udzu, 1998).

Nematodes and insect pests have been implicated as the main cause for the shortening of the life span of crop stands (Udzu, 1998). Nematode damage is mainly on the roots

or corm. The plant parasitic nematodes feed, migrate and reproduce in the roots of plantain and thus reduce root volume, leading to toppling and yield losses.

The plantain weevil *Cosmopolites sordidus* Germar has been identified as one of the major constraints to plantain production in Ghana (Gorenz, 1963; Afreh-Nuamah, 1993a; Schill *et al* 1996b,1997; Udzu, 1998; Nkakwa, 1999; Godonou, 1999). The weevil's damage is caused by its larva, whose feeding activities create tunnels that riddle the corm in a blind-ending manner. The damage caused has two consequences on the plantain corm: Internal damage kills or prevents the growth of the meristem whilst peripheral damage inhibits root proliferation (Mitchell, 1978; Vilardebo, 1973). Either one or a combination of these two lead to growth retardation and subsequent reduction in yield (Udzu, 1998). Effect of damage is higher when suckers are attacked in older fields (Godonou, 1999)

In Ghana a diagnostic survey conducted between 1994 and 1996 on farmers' fields in five plantain growing regions in Ghana showed that an average internal cross sectional damage of up to 5% by the weevil occurred during the first year of plantation establishment (Schill *et al.*, 1996b). Afreh-Nuamah (1993a) had made an earlier observation that the weevil population was negligible during the first year of plantation establishment. The cropping history of the land and sources of planting material to a large extent are determinant factors in weevil pressure and build up in a farm. For example, Afreh-Nuamah (1993a) again observed that planting material from the farmers' old plantain fields and land previously cropped to plantain of less than 3 years fallow were a major source of initial infestation. The study showed that weevil presence in a virgin forest was negligible compared to previously cropped land.

However weevil build up increases after one year of plantation establishment irrespective of planting history. This report was confirmed Godonou, 1999 by that suckers taken from older fields could be a great source of initial infestation for a new field.

The plantain weevil is markedly influenced by environmental changes such as fluctuations in light, temperature, soil moisture and nutrients (Frogatt, 1925; Cuille, 1949; Simmonds, 1966; Franzmann, 1972). These factors may influence the weevil directly or indirectly through effect on the plant vigour. Soil moisture and subsequent plant vigour and its influence on the weevil is discussed in Chapter 4.

Musa cultivars grown in Ghana have a graded susceptibility to the weevil. The dessert banana is more tolerant than plantains. Among the plantain cultivars grown, 'brodewiou is the most susceptible (Nkakwa, 1999), although no appreciable level of resistance in the local varieties was observed. It is thus surprising that recorded damage in Ghana is not as severe as that observed in East Africa. Probably the current short crop cycles (due to nematodes) do not allow weevil population to accumulate or weevils in Ghana have a low fecundity. Also with short crop cycles, planting material may not have any appreciable innoculum of eggs before planting. With the introduction of more effective methods for nematode control, longer crop cycles will have ramifications with respect to weevil population dynamics and control.

The effect of environmental factors on the level of population build up and the severity of damage must be clarified in order to establish consistent sampling

methodologies for weevils in Ghana, and to provide a basis for an Integrated Pest Management (IPM) of the weevil populations. The main objectives were:

i. To determine the effect of crop cycles on trends of weevil population as well as the cumulative damage levels

ii. To establish the extent of weevil damage on plantain growth stages during the different crop cycles,

iii. To determine weevil behaviour under varying soil moisture conditions

iv. To determine fecundity levels of female weevils in Ghana and

v. To determine the level of weevil eggs or larval population on planting material that will mediate adult population build up.

CHAPTER 2

LITERATURE REVIEW

2.1 ORIGIN AND BOTANY OF PLANTAIN

Banana, plantain and the manila hemp plant (abaca) are monocotyledons of the genus *Musa* (family, *Musaceae*). Most cultivated *Musa* are triploids (Purseglove, 1972). Plantains, *Musa sp.* (AAB) originated in southern India (Simmonds, 1966) and were introduced into Africa from Malaysia (Simmonds, 1966).

Although plantain in Africa is an exotic crop, its variation exceeds even that of its centre of origin (Swennen, 1990). Africa has thus become a secondary centre of diversity (Swennen and Vuylsteke, 1990). *Musa spp.* cultivated in Africa include: dessert (AAA), East African Highland bananas (AAA), cooking bananas (ABB) (Gold *et al.*, 1996) and plantain (AAB) (Simmonds, 1966).

Plantain is a large herbaceous plant with an underground stem or rhizome (Simmonds, 1966). It has adventitious roots that may emerge out of the soil (Skinner, 1987). The plant produces suckers within a year after planting. The sucker arises from the rhizome as lateral buds. On average, plantain produces about 35 leaves (Simmonds, 1966). The canopy created by the foliage at various stages of the plants' growth may influence the biotic components of the undergrowth. The suckers may be categorized as a peeper, sword, water or maiden suckers. It is the maiden sucker that replaces the mother plant when it is harvested or toppled.

Plantains produce an inflorescence about 7 months after planting, depending on the variety and cultural practices adopted (Simmonds, 1966). After the first harvest from a stand, the maiden plant flowers within 7 months when conditions are favourable. The fruits of the common edible varieties of plantains and bananas are seedless. They grow to full size from an edible pulp and ripen in the absence of normal processes of fertilization. The time from shooting of the bunch to harvesting is about 90 days.

2.2 PLANTAIN PRODUCTION IN GHANA

Plantains are classified according to the degree of inflorescence degeneration as french, false-horn or true-horn (INIBAP, 1990). In Ghana, Karikari (1971) and Akomeah *et al.*, (1995) classified plantain cultivars grown into french and false-horn. Ahiekpor (1996) later classified the plantains grown in Ghana by distinguishing the horn plantain into true-horn and false-horn cultivars. The cultivars are distinguished by their morphological features. Attributes used as indicators include days to maturity, number of hands, size of hands and the presence or absence of a male inflorescence (Skinner, 1987; Swennen, 1990; Akomeah *et al.*, 1995; Ahiekpor, 1996). The cultivars grown have various local names which vary within the country due to differences in dialect (Karikari, 1971).

Plantain is grown mainly in the southern parts of Ghana, though few backyard gardens are found all over the country. The key regions associated with plantain growing are Eastern, Western, Ashanti, Volta, Central and Brong Ahafo. The preferred annual rainfall for plantain production is about 1500mm with a water deficit below 400mm. These regions also tend to be associated with cocoa production. When plantain is grown with tree crops like cocoa, oil palm or citrus, it serves as a shade

crop and gives way to the tree crop, (Schill *et al.*, 1996b) after at most three years. Plot sizes are small ranging from 0.2 ha to 5 ha and production is basically in mixed cropping systems with root crops, cereals and vegetables (Akomeah *et al.*, 1995). The total land area cropped to plantain in Ghana is about 129,000 hectares with an annual yield of about 7.1 tonnes per hectare (PPMED, 1991).

Africa is estimated to produce 50% of the total world output of plantain. This (estimated production) is an underestimate since most of the production occurs on small-holdings without proper statistical documentation. Plantain provides about 25% of the carbohydrate and 10% of the calorific intake for 70 million Africans (Ortiz and Vuylsteke, 1996). It is extremely rich in vitamin A (INIBAP, 1992). In Ghana it is a highly priced staple which serves as food for over 60% of the population (Akomeah, *et al.*, 1985). Plantains contribute 9% of Agricultural Gross Domestic Product of Ghana with a per capita consumption of 83kg (PPMED, 1991). Industrially, fibres obtained from the crushed and dried pseudostem are used as ropes and doormats (Akomeah *et al.*, 1995). The leaves are used as roofing materials, wrapping for certain local dishes and as an insulator during cocoa bean fermentation. Rejected, immature or ripen fruits as well as the fruit peels are fed to animals.

2.3 CONSTRAINTS TO PLANTAIN PRODUCTION

Plantain like many other field crops, is subjected to certain constraints which have led to a continual decrease in yield as well as the inability of the plant to perpetuate itself. In some parts of West Africa, for example Ghana, plantain grow as an annual crop whereas previously it could ratoon for more than 7 years (Schill *et al.*, 1996b). This short crop cycle has resulted from pests, diseases and the increasing competition for

farmlands and thus treating plantain as a minor crop to fill the rows in tree crop farms (Afreh-Nuamah and Hemeng, 1993).

2.3.1 Soil as a constraint

Decreasing soil fertility is a major constraint to plantain production in Ghana (Afreh-Nuamah and Hemeng, 1993) resulting from short fallow periods due to population pressure on land and repetitive cropping on the same land.

Soil moisture has an effect on both the flora and fauna that depend on the soil. Waterlogging and rapid variations in soil moisture content have an effect on root functioning (Simmonds, 1966). Also the effect of optimal soil moisture influences plant vigour which can offset the effects of pest damage (Summerville, 1944).

2.3.2 Weeds

Weeds are one of the underestimated pests in tropical agriculture (Akobundu, 1987). Weeds compete with crops for soil nutrients, water and light. Weeds can also habour insects and plant pathogens harmful to crop plants (FAO, 1994). The canopy formed by weeds can influence other biotic agents that live beneath. Thus, weeds enhance the density of pest organisms. The weed either feed on the crop or reduces the crop vigour making it susceptible to other pests and diseases. The critical period during which weeds suppress the growth and yield of bananas and plantains is assumed to be during the early establishment of the crop, especially during the first six months (Seeyave and Phillips, 1970)

Weed control is one of the practices that determines the productivity of plantains and bananas (Terry, 1994). Tezenas du Montcel (CTA, 1985) recommends weeding three times a year for plantain farms. Chemical weed control is gradually becoming widespread in developing countries but they are very expensive.

2.3.3 Diseases

The causes of diseases on plantain are either physical or biotic. The physical factors involves attributes such as changes in soil pH , temperature or soil moisture. A low pH for example favours the spread of diseases like Panama wilt (Simmonds, 1966). The biotic agents that cause diseases to plantain include parasitic nematodes and fungi. They cause a deterioration of the plants' health leading to growth retardation and yield loss (Speijer *et al.*, 1992; Sabassigari & Stover, 1988).

2.3.3.1 Black sigatoka

Black sigatoka is a fungal disease caused by the fungus *Mycosphaerella figiensis* Morelet var. deformis. The fungus is widespread in West Africa. In Ghana for example it jeopardized the initial production of dessert banana along the Volta basin in the early 1990's (Asiseh *et al.*, 1996). The fungus is air borne and easily transferred from one field to the other. The fungus causes severe leaf necrosis called leaf spot or black leaf streak which leads to yield reductions between 30% and 50% (Pasberg-Gauhl and Gauhl, 1996). This yield loss results from a decrease in the photosynthetic ability due to reduced leaf area.

The economic aspect of its control is so complex (Sery, 1991) that small-holder farmers cannot afford. It is managed extensively with very toxic and expensive fungicides such as Tilt^{R}, Bavistin^{R}, and Bayfidan^{R}. Resistant varieties are being considered as the most promising strategy that can be incorporated in IPM (Vuylsteke and Swennen, 1991).

2.3.3.2 NEMATODES

Plant parasitic nematodes are associated with plantain. These nematodes include *Meloidogyne sp, Pratylenchus sp., Helicotylenchus multicinctus, Hoplolaimus paraburatus and Radophilus similis* (Bridge, 1996). They cause considerable damage to plantain crops by feeding, multiplication and migration activities in roots (Sarah, 1989; Queneherve, 1991; Bridge, 1991). These activities lead to a reduction in the volume of functional roots of the crop. There is reduced plant anchorage leading to toppling especially in windy situations (INIBAP, 1994) or a decrease in the amount of nutrient absorbtion and necrosis of the corm, which prevents root initiation. Sites that have been damaged serve as entry points for other organisms. Yield losses due to nematodes of up to 65% have been reported by Udzu (1998) in Ghana. When nematodes are in association with plantain weevils they cause 85% yield loss (Udzu, 1998).

Currently, nematodes are managed by cultural practices such as the use of clean planting materials. Some Class I pesticides which are expensive and very toxic (Danneel *et al*, 1996) are also available on the market.

2.3.3.3 BANANA WEEVIL

The Banana weevil has been reported to be the most important insect pest of bananas in the tropics (Bakyalire and Ogenga-Latigo, 1994). It is a ground dwelling bettle and spends all its entire life associated with banana. It feeds and lays into banana tissues thereby causing harm. The attributes of this weevil are discussed more fully in the next section.

2.4 BANANA WEEVIL: *Cosmopolites sordidus* Germar (COLEOPTERA CURCULIONIDAE)

Out of the two hundred insect pests recorded attacking *Musa spp.*, the most important is the plantain weevil *Cosmopolites sordidus* Germar (Purseglove, 1972)

2.4.1 Origin

Cosmopolites sordidus Germar is native to the Indo-Malaysian region (Zimmerman, 1968). This region where Germar's weevil specimen came from is advocated to be a likely centre of origin of the weevil as reported by some explorers investigating likely sources of natural enemies of the weevil. By 1824 when Germar described the banana weevil, there had already been centuries of intercontinental travels by Europeans, through which the weevil could have been brought in to the Indo Malayan region. This has sometimes obscured the origin of the weevil (Pemberton, 1954).

2.4.2 Pest status and damage caused

Cosmopolites. sordidus is probably the most important insect pest of bananas in the tropics (Bakyalire and Ogenga-Latigo, 1994). It is present in most banana growing areas (Haarer, 1964; Wolfenberger, 1964), particularly where cooking bananas

(Sikora *et al.*, 1989) and plantains (Jones, 1986) grow. This weevil attacks banana cultivars, plantain and Manila hemp. There is a record of an attack on sugarcane but this has not been confirmed (Annon, 1982).

There is some debate about the pest status of the banana weevil. Generally opinions range from the most serious pest (Purseglove, 1972; INIBAP, 1988), one of the more important pests in Brazil from economic point of view (Sulplicyfo and Sampaio, 1982) to a troublesome pest of neglected plantations in Fiji (Swaine, 1971). In Australia it was reported as not being a serious pest of normal established plantations and that the weevils economic importance was often exaggerated (Wallace, 1937). However Frogatt (1925) and Braithwaite (1963) put it as a serious pest, especially under poor plantation management

Adult weevils cause relatively little damage as they feed on rotten banana tissues (Frogatt, 1925; Franzmann, 1972; Budenberg and Ndiege, 1991). Perhaps the living rhizome is inaccessible to the adult. This is because in captivity the adult weevil preferentially feeds on fresh corms (Bakyalire *and* Ogenga-Latigo, 1994). It is the larva, which is largely responsible for all the damage caused to the plant (Harris, 1947; Franzmann, 1972). After hatching, the larva tunnels as it feeds on the rhizome, destroying the vascular bundles. This leads to a breakdown in physiological communication between the aerial shoot and the rhizome (Frogatt, 1925; Franzmann, 1972). These large tunnels made by the larva, interfere with the normal flow of nutrients and water, and stem growth (Taylor, 1991). Infested plantains produce bunches which are small with undersized fruits (Franzmann, 1972; Treverrow, 1985). Tunnelling severely weakens the plant; entry points created give access for disease

pathogens to enter. Severely infested plants have the entire corm completely riddled and are more easily blown down by snapping at the ground level before the bunch is ripe (Franzmann, 1972: Budenburg and Ndiege, 1991; Pena *et al.*, 1991). In extreme cases snapping of plants can cause 100% yield loss (Feakin, 1971).

Peripheral damage of the plant rhizome may adversely affect root development as a result of the destruction of the cortical tissue leading to the production of small numbers of roots, which adversely affects anchorage of the plant (Franzmann, 1972; Wright, 1977). In situations of heavy infestation, mature plants may be killed and or fail to flower, while newly planted suckers within infested fields are readily destroyed almost immediately after planting. The larva can riddle the butts and travel a metre up the pseudostem (Frogatt, 1925). Thus, for suckers the larvae can traverse the entire length from the central core of the rhizome to the in-folding leaf (Ostmark, 1924; Frogatt, 1925). Under unfavourable conditions such as soil moisture stress, the plant's vigour is unable to sustain the voracious feeding habit of the larvae. The plant stool then breaks down completely, which would not have happened in a normal vigorous growing plant (Frogatt, 1925; Yaringano and Van der Meer, 1975; Treverrow, 1985). The activities of the banana weevil thus cause a considerable reduction of profits to the farmer (Frogatt, 1925). Crop losses due to this pest range between 30 and 90% in infested areas in Latin America, Florida and the Caribbean region (Pena *et al.*, 1991). Yield losses between 5 and 44% in a plant crop and 4th cycle crops respectively as a result of reduced bunch weight has been attributed to the weevil in East African highland banana (Rukazambuga *et al.*, 1998).

2.4.3 Biology of the Banana weevil

The adult female deposits its eggs in punctures made with the rostrum below the surface of the corm. The eggs are white, sausage-shaped and approximately 0.5mm long. In the field, they are extremely difficult to detect as the oviposition site becomes covered with congealed sap (Franzmann, 1972). Oviposition mainly takes place at night. The most preferred laying site is between the sheath scars on the crown of the plantain corm just above the ground or at the base of the pseudostem (Frogatt, 1925; McNutt, 1974). Egg production is low, with oviposition estimated from 1 to 4 eggs per week (Koppenhofer, 1993; Griesbach and Gold unpubl. data). The female displays a classical "k" selected life cycle (Pianka, 1970) with long life span and low fecundity. The adult female lays egg throughout its life but there exists an inverse oviposition rate with the age of the weevil (Frogatt, 1925).

The length of the reproductive life cycle varies according to the environmental conditions but lasts for an average of two months (Viswanath, 1977). There is a seasonal effect on egg development. Egg incubation shows a wide variation in response to climatic conditions (Frogatt, 1925). Higher temperatures reduce oviposition.

The incubation period varies from 4 days at high temperatures to over 30 days at low temperatures (Franzmann, 1972). The emerged larva feeds for about three weeks to several months, depending on temperature. Afreh-Nuamah (1993b) reported that the larval period lasts 21 days whilst Godonou (1999) gave the larval period as 32 days in Ghana. The fully-grown larva is a stout; soft bodied, legless grub approximately 12.5mm long, creamy white with a reddish-brown head. The pupa is about the same

length as the larva, white in colour and with all the external characters of the adult visible. An average time of about 8 days is spent in the pupal stage, which finally changes to the adult. Newly emerged adults are first reddish-brown and turn black after about 4 days (Frogatt, 1925).

2.4.4 Life history of the weevil

The adult is a black hard-shelled weevil, about 12mm long with a long snout. They are sluggish in nature and feign death if disturbed (Woodruff, 1969; Treverrow, 1985). The weevil has a long life span and a low natural mortality (Koppenhofer, 1993). Adults are free living (not confined to the plantain plant) and have been reported to live for four years (Rukazambuga *et al.*, 1998).

The adult is the only migratory stage outside the plant and it moves about in the plantation, mainly during the night or in darkness. Wings are well developed but flight is very rare and movement is mostly by walking. Adult weevils feed on plant tissue, such as rotten corms and pieces of pseudostem.

All stages of the insect, from egg to adult, are associated with the plantain and are present in varying numbers throughout the year (Treverrow, 1985). The most preferred habitat of the weevil is the stump, together with the pseudostem from the stages of flowering to the emergence of young suckers (Vilardebo, 1984) and also the wet rotten pseudostem (Godonou, 1999).

2.4.5 Factors affecting weevil behaviour and population

There have been reports that since the length of the adult life is very long, about four years (Rukazambuga et al., 1998) and the rate of multiplication is very slow, variations such as population changes cannot be rapid. The weevils' behaviour varies under environmental, edaphic, status of host plant and presence of other biotic organisms.

2.4.5.1 EFFECT OF LIGHT ON THE WEEVIL

Adult weevils show a strong negative phototaxis (Bakyalire and Ogenge-Latigo, 1994). The weevil is nocturnal and can move long distances at night but is generally sedentary (Whalley, 1957). When weevils are exposed to soil during the day, they burrow down rather than crawl away (Frogatt, 1925). The flight activity of the weevil is controversial. It flies during warm muggy nights, shortly after dusk (Frogatt, 1925). Flight is also enhanced during cloudy periods. Since the movement of the weevil is enhanced in the dark, the plant canopy will thus contribute to its behaviour. An optimum plant population density of 1000 stools/ha under good edaphic conditions will create a closed canopy after ten months of plantation establishment. A close crop canopy will thus create darkness and induce flight.

2.4.5.2 EFFECT OF MOISTURE ON THE WEEVIL

The adult weevil is markedly hygrophilous (Viswanath, 1977). Adult weevils could survive when submerged in water for eleven days (Frogatt, 1925). The adult weevil prefers the moist plant trash where it can hide all day and avoid desiccation. In the field the adult is found in the moist stump of the plant or in wet conditions of rotting butts and pseudostems (Godonou, 1999). Nevertheless if the plantain butt is rotten and

wet, weevils do not oviposit (Frogatt, 1925). Again when a larva develop in a harvested stump, they fail to reach adult stage when the stump rots before the pupae emerge since the larvae drown in the excess water produced (Frogatt, 1925). Reports on the effect of moisture due to rainfall on the weevil have been conflicting. For example in Cuba, it was reported that larvae and pupae increase in great numbers during the dry season (Bendicho-Lopez and Gonzalez-Ramos, 1986). In contrast, in Brazil, studies made between September 1985 and September 1996 indicated that trap catches had a population peak in June, a rainy period (Prando *et al.*, 1987). In Ghana the emergence of adult weevils reach a peak during the rainy season from August to September and again in early November. There is however a reduction in population at the peak of the drought between December and March (Afreh-Nuamah, 1993a).

2.4.5.3 EFFECT OF TEMPERATURE ON THE WEEVIL

Most activities of the plantain weevil are markedly affected by temperature. Oviposition has been reported to be greatest during spring and autumn in Australia. Although oviposition does not cease at any time of the year, chilly conditions retard the rate (Frogatt, 1925). The temperature range within which development of the weevil takes place is very wide. Larval development can vary from 21 to 32 days at room temperature in Ghana (Afreh-Nuamah, 1991; Godonou, 1999) to about 100 days during winter in Australia (Frogatt, 1925). The biology and behaviour of the weevil changes with variations in temperature. Various developmental periods and behaviour have been quoted for each time of the year or each cycle of the crop due to temperature changes. In Australia for example, different economic thresholds have been quoted for the same country due to temperature variations from north to south (NSW Agric. & Fisheries, 1990). In Ghana possible factors that can influence

temperature include crop canopy and season of the year. The canopy of plantain farms changes from year to year. The canopy closes up after the first cycle when the number of plants constituting a stand increases. Thereafter the canopy may reduce if soil productivity and pests are not managed.

2.4.5.4 EFFECT OF CHEMICALS ON THE WEEVIL

The banana weevil is attracted to plantain due to volatile chemicals produced by the plant (Budenberg and Ndiege, 1991, 1993; BFG Bulletin, 1995). There are reports that as many as 47 adult weevils were attracted to a single trap due to emission kairomones (Frogatt, 1925). When the cut surfaces of the corm or pseudostem are exposed, weevils are attracted to it. Bakyalire and Ogenga-Latigo (1994) reported that in a choice test with different concentrations of corm extracts, the weevils were attracted to the highest extract concentration. Chemical attraction occurs on the field when suckers are harvested and piled on weevil infested fields. The adult weevil oviposits on piled planting material and serves as the initial inoculum for new farms. Also when a new farm is made near an older one, adult weevils migrate to the new field due to chemicals emitted from the suckers. Adult weevils can move across fields when attractants are present (Godonou, 1999).

It is reported that in a field, when the larva feeds, its galleries may lead from an adult plant to an attached sucker (Frogatt, 1925). It is possible that the different stages of the plant will exhibit different attractants or repellents. The adult weevil prefers the moist rotten pseudostem or stump (Godonou, 1999). Thus weevils may select different stages of the plant for different activities such as ovipisition, larval growth, hiding or resting and feeding.

2.4.5.5 EFFECT OF BIOTIC AGENTS ON THE WEEVIL

The plantain weevil has varying degrees of association with other biotic agents. When weevils and nematodes occur in a plantation, there is a synergistic effect resulting in a combined damage of 85% (Udzu, 1998).

Some nematodes and fungi on the other hand have a detrimental effect on weevils as they act as natural enemies. This has been exploited where the fungus *Beauveria bassiana* has been formulated into an insecticide against adult weevils (Godonou *et al.*, 1998). There are other predators that have been used to manage the weevil in Asia and Latin America.

2.5 CONTROL MEASURES

Like a number of weevil pests, *C sordidus* is spread mainly by human agency through the transport of infested parts of plantain plants.

In countries where banana is grown in large estates such as in the Caribbean, Latin America and Uganda, chemical pesticides have been adopted for the control of the weevil. Poison baiting of cut surfaces of stems with Paris green were once advocated (Weddell, 1934) although they are now considered to be relatively inefficient (Braithwaite, 1958).Other chemicals that have been used, include Carbofuran (Furadan^{R} 10 G), Primicid^{R} (Pirimiphos-ethyl, ICI), Dursban^{R}, Terracur P^{R} (fensulfothion, Bayer), Kepone^{R} (Chordecone, Allied chemicals), Oftanol^{R} (isophenphos, Bayer) (Pullen, 1973; Allard *et al.*, 1991). These chemicals are expensive and farmers abuse their application. This situation poses a danger due to their effect on non-targets such as deposits finding their way in food and the possibility of resistance build up. These problems have recently increased the interest

in non-insecticidal control (Treverrow and Maddock, 1988). Such controls as cultural, physical and biological are now incorporated in Integrated Pest Management programs.

Cultural control involves the use of clean planting stock and rigid sanitation. The planting materials can be cleaned by paring the corm to remove traces of larvae tunnels and potential egg infested sites and hot water treating at 55°C for 20 minutes.

Physical control involves the use of pieces of rhizomes and pseudostem as traps for weevils, (Yaringano and van der Meer, 1975). In East Africa trapping is enhanced, by adding pheromones to the traps. The cutting of the plantain stool down to ground level after harvesting the bunch and chopping the felled pseudostem has also been advocated (Wright 1977).

Biological control of the weevil includes the use of natural enemies. Predaceous ants such as *Tetramorium sp.*, *Pheidole megacephala* Fab, *P. guineense* Fab., *Azteca delpini* Emery, *Ectatomma ruidun* Roger, *Solenopsis geminata* Fab., *Wasmannia auropuntacta* and *P. fallax* Mayr have been used. For example Roche *et* al. (1975) reported that in banana plantations where the ant *Tetramorium bicarinatum* is established either naturally or introduced, *C. sordidus* is under effective control. The ant feeds on the weevil's larvae. The efficacy of entomopathogenic nematodes such as *Steinernema carpocasae* Weiser (Agrios strain), *S. bibionis, S. glaser* and *Heterorhabditis sp.* (HT2-Trinidad strain) (Kermarrec *et al.*, 1991) are under investigation. In Australia *S. carpocasae* has been observed to be potent against the weevil (NSW Agriculture & Fisheries, 1990).

Microbial control with the use of fungi is also promising. The entomopathogenic fungi *Metarrhizium anisopliae* (Metschnikoff) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin have been tested (Pena *et al.*, 1991; Godonou *et al.*, 1998). Delattre and Jean-Bart (1978) succeeded in infecting the weevil with the fungi but there were problems of disease inhibition in the field. Certain histerid beetles such as *Plaesius javanus* and *Hololepta quadridentata* are currently being advocated as future potential natural enemies capable of reducing the pest status of the weevil.

Another control measure is the use of resistant cultivars. Thus cultivars with increased corm hardness reduce larval penetration. Although all plantain cultivars in Ghana are susceptible to the weevil (Nkakwa, 1999), the level of susceptibility is graded. Hence the least susceptible cultivar can be incorporated in an IPM programme.

CHAPTER 3

EFFECT OF PLANTATION AGE AND PLANT DEVELOPMENTAL STAGE ON WEEVIL BEHAVIOUR

3.1 INTRODUCTION

The life span of a well-maintained field was reported by Karikari (1971) to be between 4 and 5 years. However due to pest and soil fertility problems in Ghana, crop cycles are rather short, less than 2 years. There have been earlier reports on the behaviour of the weevil in relation to population build up in a plant crop (Afreh-Nuamah, 1993a), perception of farmers on the pest status of the weevil (Schill *et al.*, 1996a), the severity of damage on harvested or toppled plants in plant crops (Schill *et al.*, 1996b), the effect of nematode association with the weevil on damage (Udzu, 1998), damage on the early stages of the plants growth (Udzu, 1998) and the extent of plant mortality on sword suckers in a farmer's infested field (Godonou, 1999).

It is upon these earlier reports in Ghana that this experiment was set up as a review and to co-ordinate the various data given in Ghana. The population build up which was reported to be negligible in the first year of plantation establishment was also studied in a 2nd and 3rd cycle crop in addition to the plant crop under the farmers' field condition. The duration of trapping was also extended for a year to take care of environmental changes. Damage figures due to weevil were separated according to crop cycle as well as for the four stages of the plants' growth, from a sword sucker stage to a harvested plant. The damage due to the weevil was also sampled over a year during the various seasons

This trial had the following objectives

i) to determine weevil population due to environmental factors in three crop cycles

ii) to assess corm damage on all growth stages of plantain in different crop cycles.

3.2 MATERIALS AND METHODS

3.2.1 Effect of plantation age on weevil dynamics

3.2.1.1 SELECTION OF TRIAL SITE

The plantain growing areas in the Eastern Region of Ghana were identified using information providedby Udzu, (1998) whilst the sources of plantain on the Kade market were identified by information given by traders in Kade. Three towns namely Dwenase, Awaham and Akanteng in the Eastern Region were selected for the preliminary survey.

Akanteng was selected from the 3 towns because it was a major plantain growing community and high weevil populations had previously been reported by (Udzu, 1998 and Godonou, 1999). It is about 80km Northwest of Accra. It lies within an agroecosystem of a semideciduous tropical rainforest (Taylor, 1960). It has an annual rainfall of 1650mm (Obeng, 1959). Plantain is grown in farm sizes of up to a hectare and also in backyards.

Farms selected for the trial were those with; plantain in the first cycle, plantain in the second cycle and plantain in the third cycle. The age of the fields were determined using such attributes as plant population density, type of intercrops, presence of

harvested stools and the number of plants that constituted a stand. All the farms comprised mixed cropping systems of plantain, cassava, cocoyam and young cocoa, indicative of traditional Ghanaian agriculture (Plate 6.1).

The plant crop was easily identified since no plant stand had a harvested plant. There were no plant stumps or rotten stools. In the plant crop, the plant population density was 750 plants per hectare planted at random. Generally each plant stand had a mother plant and peeper suckers only.

In the second cycle field, there were rotten stumps from harvested plants. The rotten stumps represented the harvests of the first cycle crop. The canopy was not as thick as that of the plant crop due to toppled plants. Plant population density was about 625 plants per hectare.

The farm in the third cycle was identified by the fact that a cocoa intercrop was already two years old. The plantain was originally used as a shade crop for the cocoa and was being out-competed by the cocoa. Plant population density was sparse with 300 plants per hectare. Most of the stands had a single plant. Some stands had only a maiden plant that looked thin for its age.

3.2.1.2 MANAGEMENT OF EXPERIMENTAL PLOTS

A field experiment was conducted between September, 1998 and August, 1999. There were 3 crop cycles and data collection was replicated over 12 months. The experimental plots were managed by hand weeding at 3 monthly intervals. Farmers

were advised not to desucker within the experimental period to avoid unnecessary disturbance at the base of the plants.

3 2.1.3 TRAP SETTING AND INSPECTION

The borer population was estimated at monthly intervals by trapping the adults. Graham and Stark (1954) reported that the sampling of a particular insect population must be revolved around the life cycle of the insect involved.

Weevils (required for experiments) were collected from farmers' fields either with traps or through macerating rotten pseudostems or stumps. The traps were made at least 10cm thick and 15cm long cut from spent plantain pseudostems (Ogenga-Latigo and Bakyalire, 1993). A split pseudostem trap was placed at the base of each labelled mother plant with the flat length-wise portions on the soil surface. The thicker basal part of the stem was always used because it had the ability to remain moist for longer periods of time. On each farm, 100 stands were selected at random, pegged and labelled as plant numbers 1 to 100. These plants were used to monitor the adult weevil population during the experimental period. For each month, the middle ten days were used as the sampling period. There was a lapse of 20 days between each sampling period to ensure that weevils collected in each period had a greater proportion from the most current generation. This was also to reduce overlapping of populations and also to ensure that weevils trapped were as a result of treatment effects including rainfall in each crop cycle.

Traps were set and inspected after 3 days and 5 days. New traps were set after 5 days after inspecting the old traps. The sampling pattern described above was such that,

there were four trap inspections every month to ensure that, a greater proportion of the active weevils present was collected. The weevils trapped were later sent to the laboratory to determine the sex (Roth and Willis, 1963). The weevils from each field were kept in the laboratory as separate sexes. At the beginning of each monthly sampling the mortality of the previously caught weevils were determined. The relative age of the weevils sampled from each field was determined from this and was compared to Abera *et al.* (1996) which stated that older weevils have a higher mortality.

3.2.1.4 DATA COLLECTED

i) Number of adult weevils caught by traps

ii) Number of toppled plants

iii) Adult longevity

iv) Rainfall (in relation to weevil population)

v) Trap efficiency

The insects collected were reared in plastic containers lined with soil and kept at 25°C. The amount of rainfall and rain-days were recorded. In each sampling period, the number of pegged mats that had toppled plants was noted.

3.2.1.5 STATISTICAL ANALYSES

ANOVA was performed on all data using GENSTAT procedures in order to analyse the effects of the crop cycle on weevil population and damage. The damage, such as peripheral damage (PD), Corm cross section (x-section) were 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, 1993). Rainfall and raindays were recorded at the experimental site using a rain gauge. The counts of insects or toppled plants and rainfall or raindays within a period were subjected to Linear regression analysis in GENSTAT.

3.2.2 Effect of plant developmental stage on weevil attack

3.2.2.1 TRIAL ESTABLISHMENT

This experiment was conducted at Akanteng in the same fields on which adult weevil population was monitored monthly (Section 3.2.1.1). Sampling was done during the four distinct seasons recognised in the agroecozone (Obeng, 1959):

-September to November (minor rains)

-December to March (major drought)

-April to July (major rains)

-August (minor drought)

Sampling was done at the beginning of each season i.e.: September, 1998; December, 1998; April, 1999 and August, 1999 and the plant phenological stages assessed were:

-Suckers (< 100 cm high/sword sucker)

-Preflowering plants (> 100 cm without bunches)

-Flowered plants and

-Recently harvested plants (within 4 weeks of harvesting)

3.2.2.2 DATA COLLECTION

The test plants were harvested by cutting the top of the plant 30cm above the ground. At each sampling season, 5 plants of each growth stage were uprooted. With the help of a spade the corms were carefully uprooted, the roots carefully removed and the

corm washed to clean off the soil. Corm damage was then assessed based on cross section (Mitchel, 1978) and peripheral (Vilardebo, 1973) damage scores.

The peripheral damage of the corm was assessed, by scoring and also estimating the actual percentage area consumed by weevil galleries. The corm was marked into two cross-sections (Figure 3.1) representing the top 0-5cm and 5-10 cm below the pseudostem/rhizome interface. The scoring was based on a percentage coefficient of infestation (PCI). Half of the surface area of the corm periphery was divided into 10 equal sections of 18° each with the help of a template (Figure 3.2). Each of either the upper or lower cross-section should have a PCI sum of up to 10. The presence of a tunnel was given a score of one and an absence a zero. After scoring for a PCI value, the area covered by weevil tunnels was then assessed as a percentage of the total peripheral surface. Each section from the template was assessed up to 10%

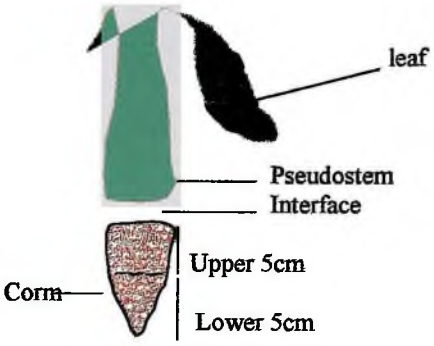

Figure 3.1 A two cross sectional division of a plantain corm into upper and lower sections

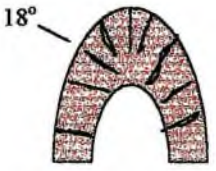

Figure 3.2 Template divided into 10 equal sections of 18°

The cross section damage was assessed, by cutting two transverse cross-sections at the pseudostem/rhizome interface and another 5cm below (Figure 3.3). The diameter of the corms at these levels were measured and the area or portions with weevil galleries were expressed as a percentage of the total area of the corm transverse cross-section assessed (Gold *et al*, 1996). The percentage cross section damage obtained at each level was averaged for each plant (Figure 3.4).

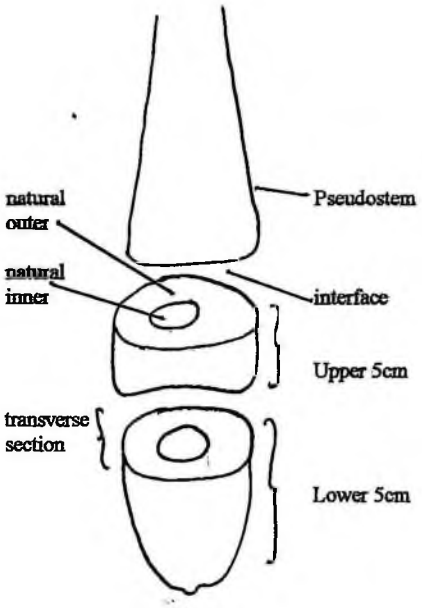

Figure 3.3 A transverse section of the corm at the interface level and 5cm below

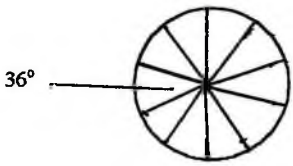

Figure 3.4 Transverse section divided into10 equal sections of 36° each assessed over 10%

After damage assessment, the corm was carefully split into pieces to expose the larvae, which were then counted. The pupae which, are mostly attached to the dead material covering the corm were collected before paring for damage assessment. Pupae were also collected as the corm was split into pieces. Adults that were attached to the corm after uprooting were counted.

3.2.2.3 Statistical analyses

This was done as in Section 3.2.1.5

3.3 RESULTS

3.3.1 Effect of plantation age on weevil population

The results shown in table 3.3.1a indicate that the overall mean number of insects caught by traps after 3 days in all the crop cycles under study were not significantly different P=0.05. However the 2nd crop cycle (0.93/plant) had a higher trap catch after 3 days of trap setting than either the 1st cycle (0.48/plant) or the 3rd cycle (0.84/plant). The mean number of insects caught by 5 day old traps in the 2nd cycle (0.76/plant) was significantly higher compared with that of the 1st cycle (0.34/plant) and the 3rd cycle (0.44/plant) $P < 0.05$. The 3rd cycle in turn was significantly higher than the 1st cycle (Appendices 1 & 1a2 & 2a). The overall mean number of insects caught in a months trapping followed a similar pattern to the 5day old trap catch (Figure 3.5; Appendices 3 & 3a).

It was observed that the trap efficiency of 3 day old traps (0.75 weevil/trap) was significantly higher (P=0.05) than 5 day old traps (0.52 weevil/trap) (Appendix 3b) $t_{35}=5.48$;P=0.05).

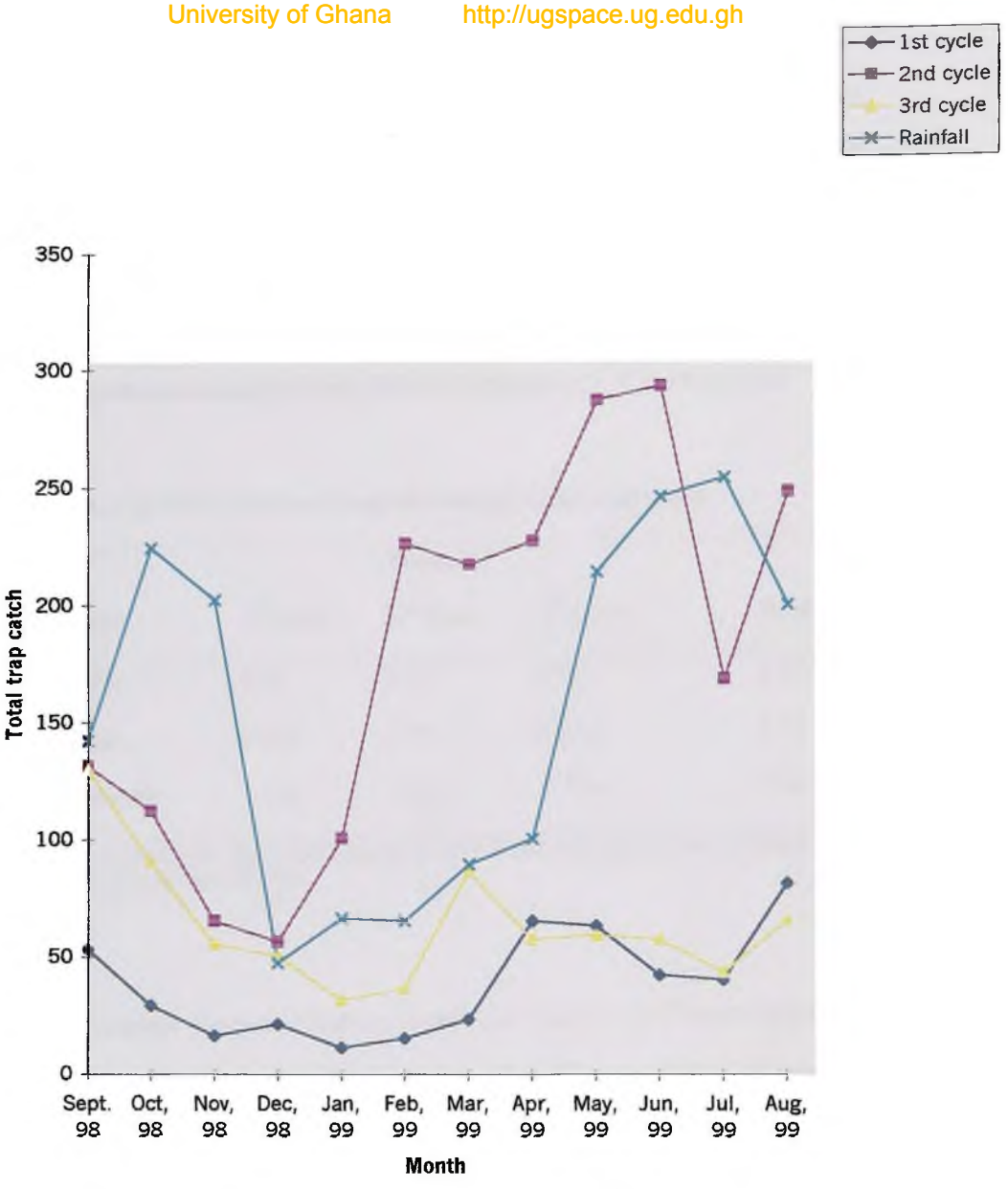

Figure 3.5 Number of weevils trapped in each crop cycle between September 1998 and August 1999 in relation to rainfall

Regression analysis for the overall counts of insects and rainfall or rain-days was not significant $P < 0.05$ (Appendices 4 & 5). However regression analysis for counts of insects and rain-days in the 3rd cycle was significant ($t_{10} = 3.77$; $P<0.01$) There was a positive relationship between rain-days and trap catch in the 3rd cycle (Figure 3.6; Appendix6). In the other crop cycles both rainfall and rain-days as well as rainfall in the 3rd cycle were not significantly different (Appendices 7, 8, 9, 10, and 11).

Table 3.3.1a: Mean number of weevils trapped in the crop cycles

	Treatment			
Trap catch	1st Cycle	2nd Cycle	3rd Cycle	Mean
3-day old	0.48	0.93	0.84	0.75
5-day old	0.34a	0.76 c	0.44 b	0.52
3 + 5 day old	0.59a	1.25 c	0.78 b	0.88

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

The percentage cumulative toppling of plants per month in the 2nd cycle crop (4.6%) was higher than that of either the 1st or 3rd cycle crops (3.3%). However the difference was not significantly different at P=0.05 (Table 3.3.1b; Appendices 12, 13,14, 15, 16, and 17). The overall cumulative toppling was not significant (Appendices 18 & 18a).

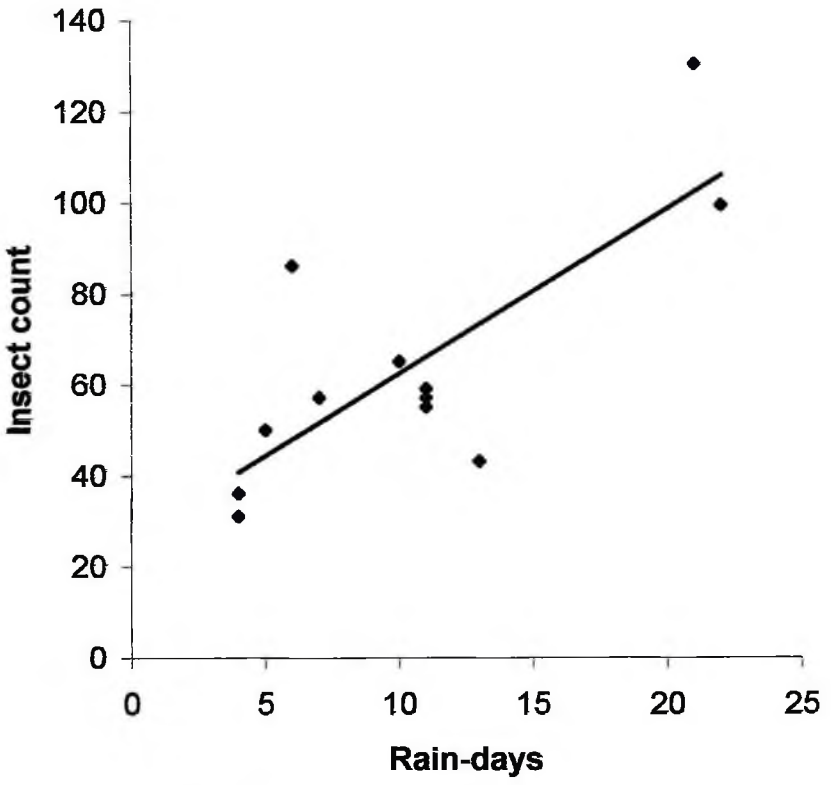

Figure 3.6 Regression fitted line for counts of weevils in a 3rd cycle crop on number of rain-days

Regression analysis for the overall number of toppled plants and rainfall or rain-days was not significantly different (Appendices 19 & 20).

Table 3.3.1b: Percent cumulative plant toppling in the crop cycles

	Treatment			
	1st Cycle	2nd Cycle	3rd Cycle	Mean
Toppling (%)	3.3	4.6	3.3	3.8

n = 1200

Adult weevils collected from the crop cycles and reared in the laboratory showed that there were no significant differences (Appendix 21, 21a, 22 & 22a) in either the overall longevity of insects or longevity of females. The relativelongevity of males from the 1st cycle (77.8%) and 2nd cycle (67.0%) were significantly higher ($P<0.01$) than the longevity of males from the 3rd cycle (38.6%) (Appendix 23 & 23a). However males from the 1st cycle had a higher longevity than males from the 2nd cycle (Table 3.3.1c).

Table 3.3.1c Longevity of adult male and female weevils collected from the crop cycles

	Treatment			
Sex	1st Cycle	2nd Cycle	3rd Cycle	Mean
Male	77.8a	67.0a	38.6b	61.1
Female	38.6	60.2	45.4	48.1
Male/female	63.8	63.6	42.0	56.5

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

3.3.2 Effect of plant growth stage on weevil damage

Results shown in Table 3.3.2a, Appendix 24 and 24a indicate that all the damage parameters; Percentage Coefficient of Infestation (PCI), Peripheral damage (PD) and Internal Cross Sectional Damage showed significant differences ($P<0.05$) between corms damage from the crop cycles.

In the PCI assessment, mean damage on corms from either the 2nd cycle (9. 54) or 3rd cycle (8.31) was significantly ($P<0.05$) higher (Appendices 25 & 25a) than damage on corms from the 1st cycle (5.01). Damage on corms from the 2nd and 3rd cycles were not significantly different. Corm damage in the 2nd cycle however was slightly higher than the corm damage in the 3rd cycle.

The damage parameter PD gave a similar pattern (Appendices 26 & 26a) as that of the PCI with mean damage figures as, 1st cycle (6.15%), 2nd cycle (12.50) and 3rd cycle (11.08%).

Internal cross section damage analysis also gave the same pattern (Appendices 24 & 24a) of damage as either the PD or PCI. The mean damage figures were 1st cycle (3.11%), 2nd cycle (8.58%) and 3rd cycle (6.84%)

Table 3.3.2a: Mean corm damage in the crop cycles

	Treatments			
Damage parameter	1st Cycle	2nd cycle	3rd Cycle	Mean
PCI %	5.01a	9.54b	8.31b	7.62
PD %	6.15a	12.50b	11.08b	9.91
X-SECTION %	3.11a	8.58b	6.84b	6.18
DIAMETER(cm)	17.22a	17.73a	16.00b	16.99

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

The mean diameter of corms from the different cycles indicate that the 2nd ratoon crop had a significantly smaller mean diameter (16cm) than either a corm from a plant crop (17.2cm) or a first ratoon crop (17.7cm)

The location of damage on the transverse cross section of the corms from the crop cycles is presented in Table 3.3.2b and Appendices 27 27a,28 & 28a. It was observed that mean damage to the outer corm was higher than that of the inner corm in all the crop cycles. It was however observed that a significantly ($P<0.001$) higher mean inner corm damage occurred in the 2nd cycle (6.79%) and 3rd cycle (4.52%) than in the 1st cycle (1.54%). The mean outer corm damage followed a similar pattern to the mean inner corm damage with the following mean damage figures, 1st cycle (4.69%), 2nd cycle (10.4%) and 3rd cycle (9.16%). In both the mean inner and outer corm damage, the 2nd cycle was higher than the 3rd cycle although they were not significant.

Table 3.3.2b: Mean corm cross section damage location in the crop cycles

	Treatments			
Damage location	1st Cycle	2nd cycle	3rd Cycle	Mean
Inner %	1.54a	6.79b	4.52b	4.28
Outer %	4.69a	10.40b	9.16b	8.08

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

The insect population extracted from the corms was differentiated into larva, pupa and adult. This was compared among the crop cycles (table 3.3.2c Appendices 29, 29a, 30, 30a, 31 & 31a). There were no significant differences in either the number of larvae or adults attached to corms. However more larvae were in the 2nd cycle (0.31) than either the 1st cycle (0.28) or the 3rd cycle (0.25). However there was a significantly ($P<0.05$) higher number of pupae attached to corms from the 2nd cycle (0.10) than from either the 1st or 3rd cycle. Corms from the 3rd cycle had a higher number of pupae (0.04) than 1st cycle corms (0.01). Although the number of adult weevils associated to corms from the various crop cycles were not significantly different, the 3rd cycle had a higher mean number of adult (0.23) than either the 2nd cycle (0.14) or the 1st cycle (0.01).

Table 3.3.2c: Mean number of insects collected from corms from the cycles

	Treatments			
Insect stage	1st Cycle	2nd cycle	3rd Cycle	Mean
Larva	0.28	0.31	0.25	0.28
Pupa	0.01a	0.10b	0.04a	0.05
Adult	0.01	0.14	0.23	0.13

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

Table 3.3.2d, (Appendices 24, 24a, 25, 25a, 26 & 26a) show a comparison of the extent of corm damage of the various growth stages of the plant. The PCI assessment indicates that there were no significant differences in the damage caused to preflowered plants (8.08), flowered plants (10.12) or harvested plants (8.90). There was however a significantly ($P<0.05$) lower damage in sword suckers compared to any of the other growth stages. When PD was used as the damage parameter, the mean damage to the various growth stages followed a similar trend, as that of the PCI assessment. The peripheral damage (PD) of the sword sucker (4.40%) was significantly ($P<0.05$) lower than the other growth stages, [preflowering (10.52%), flowered (12.90%) and harvested (11.82%)]. Internal cross section damage analysis [sucker (0.12%), preflowering (5.55%), flowered (7.99%) and harvested (9.22%)] also gave a similar pattern of damage on the growth stages as either the PD or PCI. Of all the damage parameters, the PD gave a relatively higher mean damage (9.91%) than either PCI (7.62) or cross section (6.18%). The corm sizes followed a similar trend; with suckers having mean corm diameter of 8.6cm whilst the other growth stages had corm diameters ranging from 19.6cm to 20.2cm

Table 3.3.2d: Mean damage of corms from plant growth stages

	Treatment				
Damage parameter	Sword sucker	Preflowering	Flowered	Harvested	Mean
PCI	3.40a	8.07b	10.12b	8.90b	7.62
PD	4.40a	10.52b	12.90b	11.82b	9.91
X-SECTION	0.12a	5.55b	7.99b	9.22b	6.18
DIAMETER	8.62a	19.56b	19.59b	20.17b	16.99

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

The location of damage on the transverse section of corms of the different growth stages were compared (Table 3.3.2e). The data indicate that damage to the inner section was not significantly different from any of the growth stages (Appendices 27 & 27a) [sucker (1.77%), preflowering (4.17%), flowered (4.56%) and harvested (6.63%)]. However the outer cross section damage of suckers (2.18%) was significantly ($P<0.05$) lower than any of the other growth stages [preflowering (6.93%), flowered (11.42%) and harvested (11.80%)]. The overall mean damage in the inner cross section (4.28%) was lower than in the outer cross section (8.08%).

Table 3.3.2e: Mean corm cross section damage location for the plant growth stages

	Treatment				
Damage location	Sucker	Preflowering	Flowered	Harvested	Mean
Inner	1.77	4.17	4.56	6.63	4.28
Outer	2.18a	6.93b	11.42b	11.80b	8.08

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

The diameter of sword sucker corms (8.62cm) was significantly lower ($P<0.05$) (Appendix 32) than the others [preflowering (19.56cm), flowered (19.59cm) and harvested (20.17cm) The diameter of corms of the other growth stages were not significantly different.

Regression analysis to compare corm diameter and damage using either of PCI, PD, or cross section damage showed that the slopes were significant.

Diameter/PCI	($t_{232} = 4.63$; $P<0.001$) (Figure 3.7, Appendix 33)
Diameter/PD	($t_{232} = 3.96$; $P<0.001$) (Figure 3.8, Appendix 34)
Diameter/cross section	(($t_{232} = 4.06$; $P<0.001$) (Figure 3.9, Appendix 35)

The slopes of the regression fitted lines for any damage parameter used, showed a positive relationship with corm diameter when either PCI or PD was assessed. This indicates that as the corm diameter increases an increasing large area is exposed to weevils.

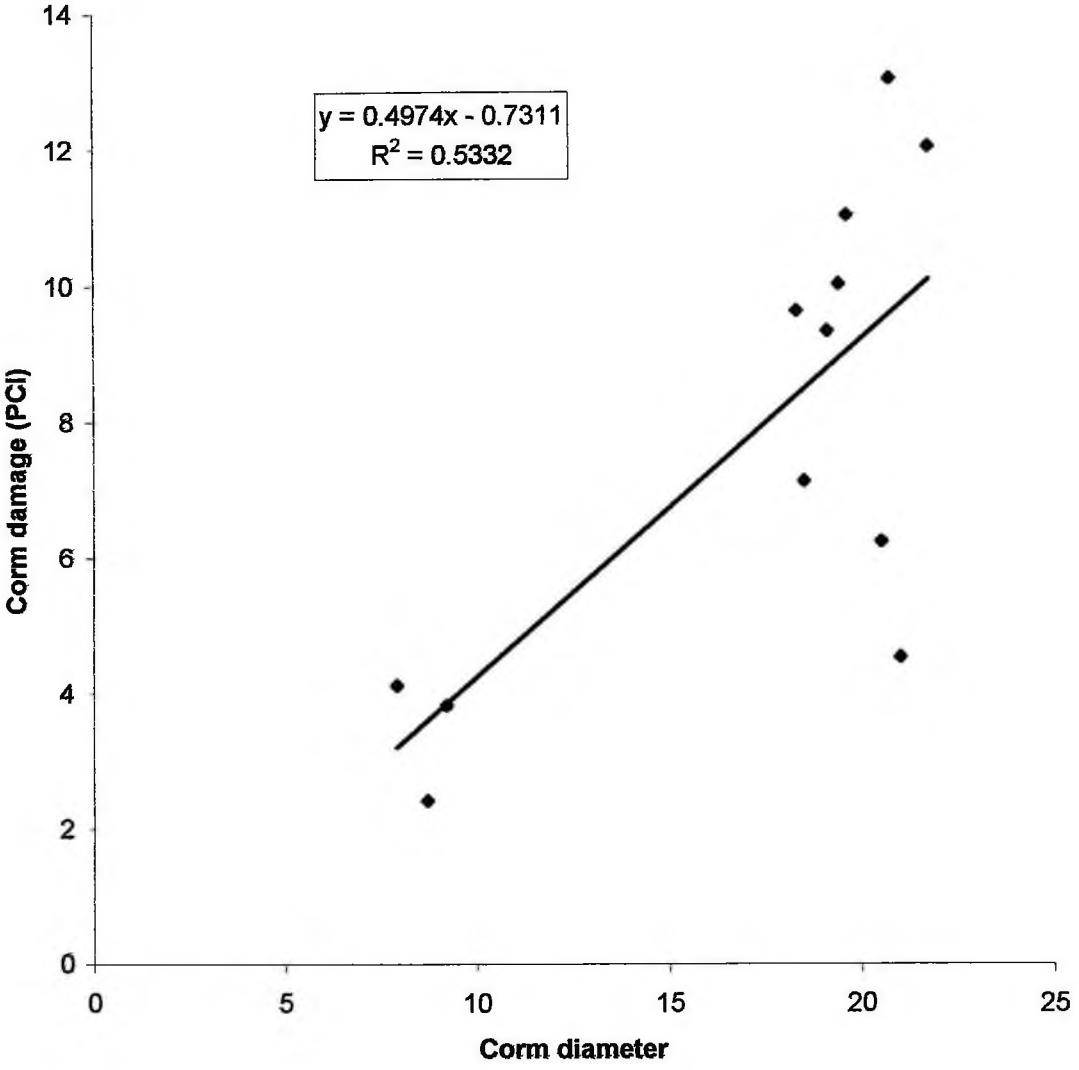

Figure 3.7: Regression fitted line for corm damage (PCI) on corm diameter

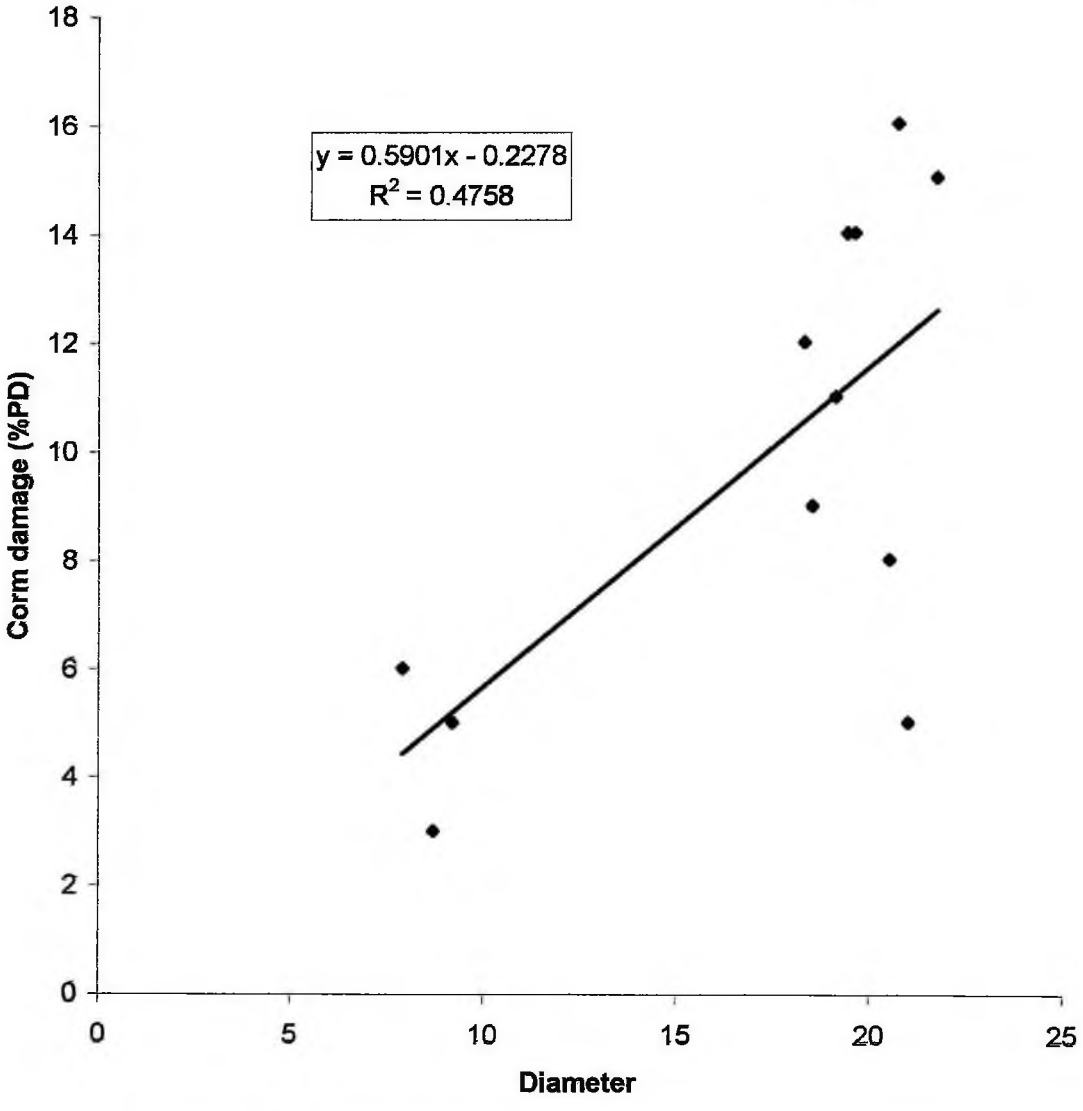

Figure 3.8: Regression fitted line for corm damage (PD) on corm diameter

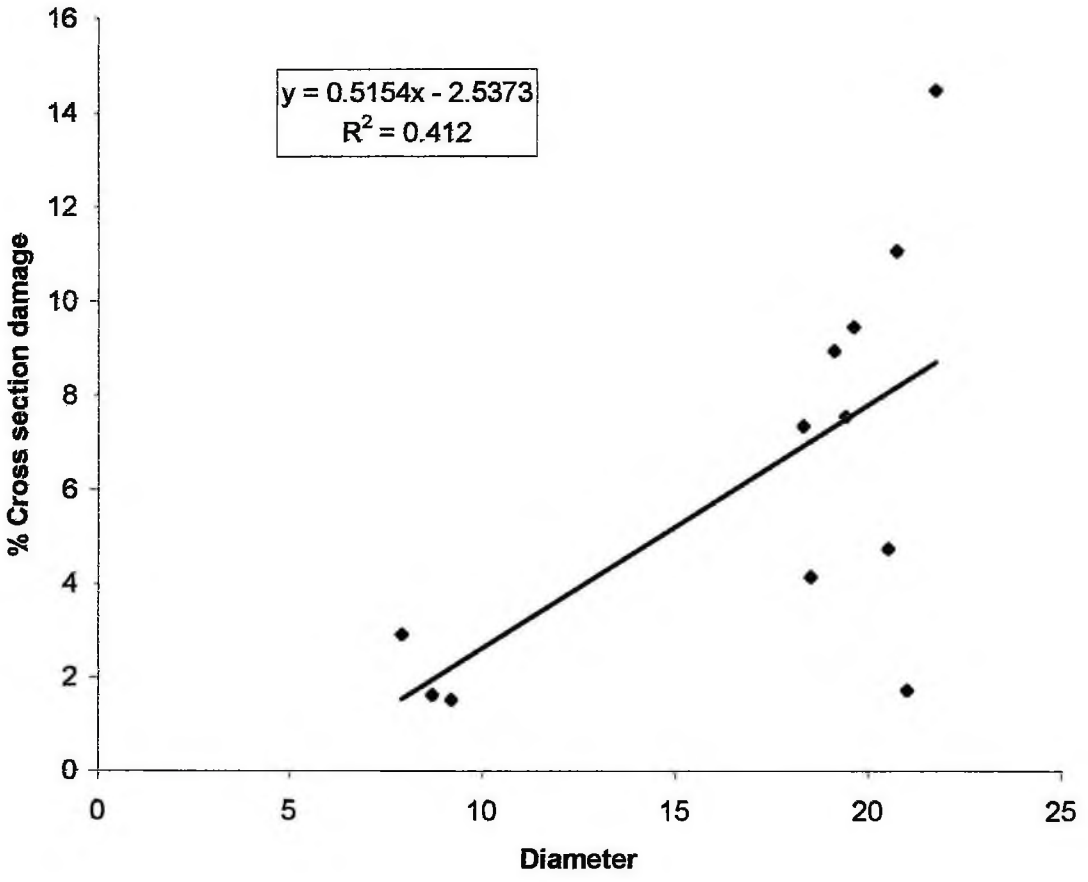

Figure 3.9: Regression fitted line for corm damage (cross section) on corm diameter

Table 3.3.2f represents the mean number of the various insect stages found in each of the growth stages. The mean number of pupae or adults found in any of the growth stages was not significantly different (Appendices 30, 30, 31 & 31a) from any other. The mean number of pupae found in a corm was 0.05. The mean number of adults found in a corm was 0.13. The mean number of larvae found in dissected corms were significantly ($P<0.05$) higher (Appendices 29 & 29a) in the harvested plant (0.62) than in either of sucker (0.02), preflowering (0.20) or flowered plant (0.28). The results show that as the plant grows it supports an increasing number of larvae development. The mean number of larvae found in a corm was 0.28.

Table 3.3.2f: Mean number of insects emerging from corms from plant growth stages

	Treatment				
Insect stage	Sucker	Preflowering	Flowered	Harvested	Mean
Larva	0.02a	0.20a	0.28a	0.62b	0.28
Pupa	0.00	0.05	0.10	0.05	0.05
Adult	0.02	0.83	0.27	0.13	0.13

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

In all the indicators of insect presence or damage, the damage to a growth stage in the crop cycles was not significantly different (Appendices 24, 24a, 25, 25a 26 & 26a). Figures 3.1a, 3.1b & 3.1c show the trend of damage of each of the growth stages in the crop cycles.

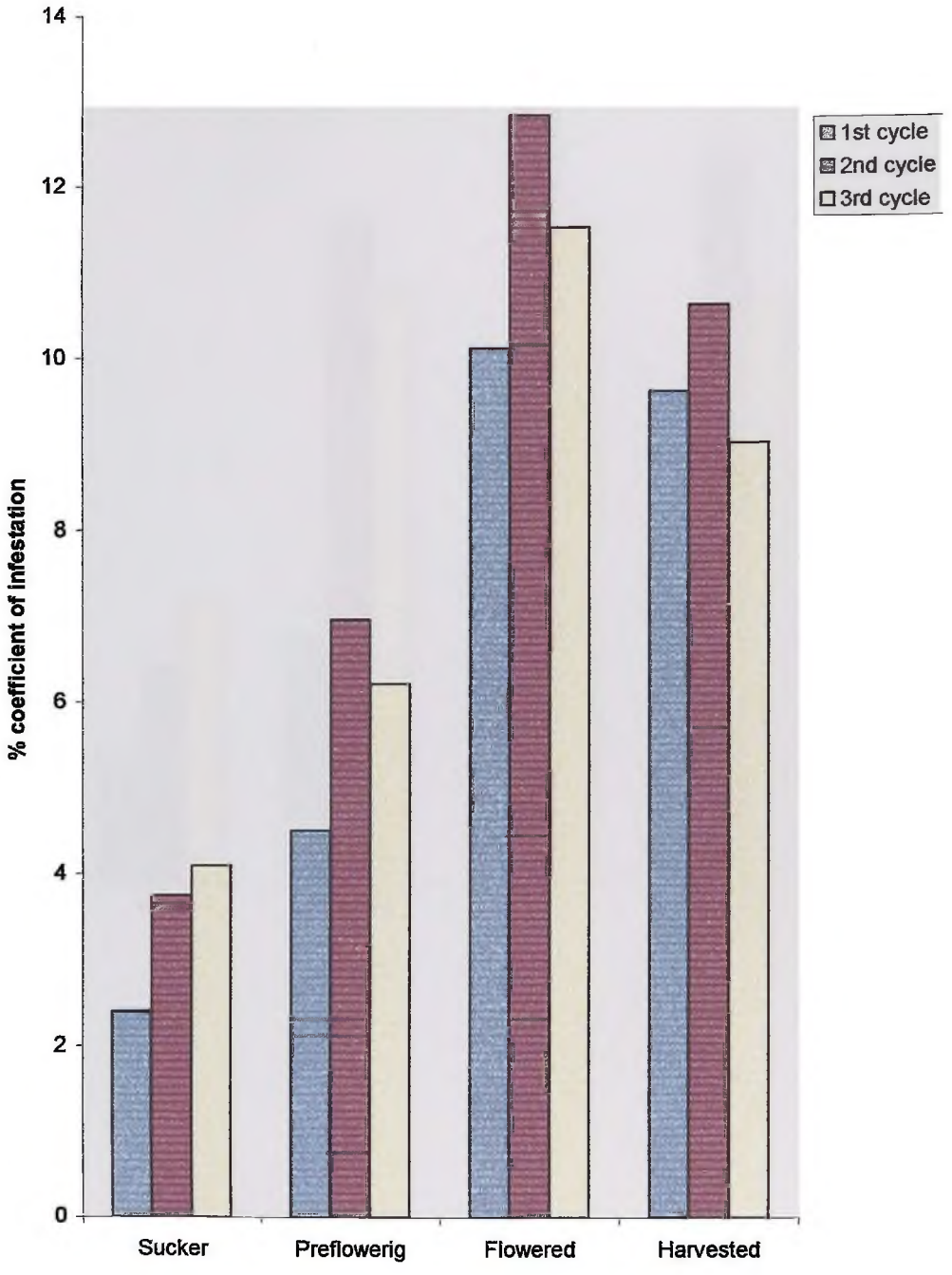

Figure 3.1a: Damage recorded on plant growth stages from different cycles (PCI)

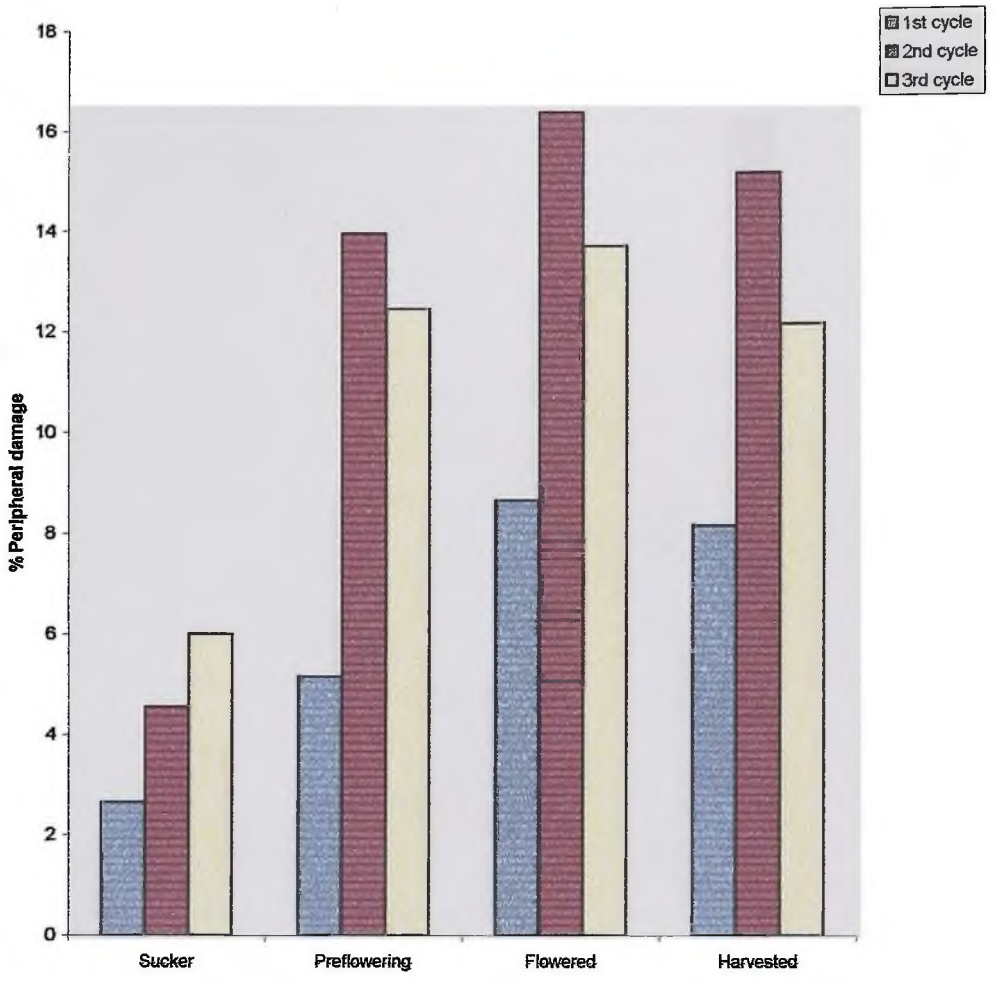

Figure 3.1b: Damage recorded on plant growth stages from different cycles (PD)

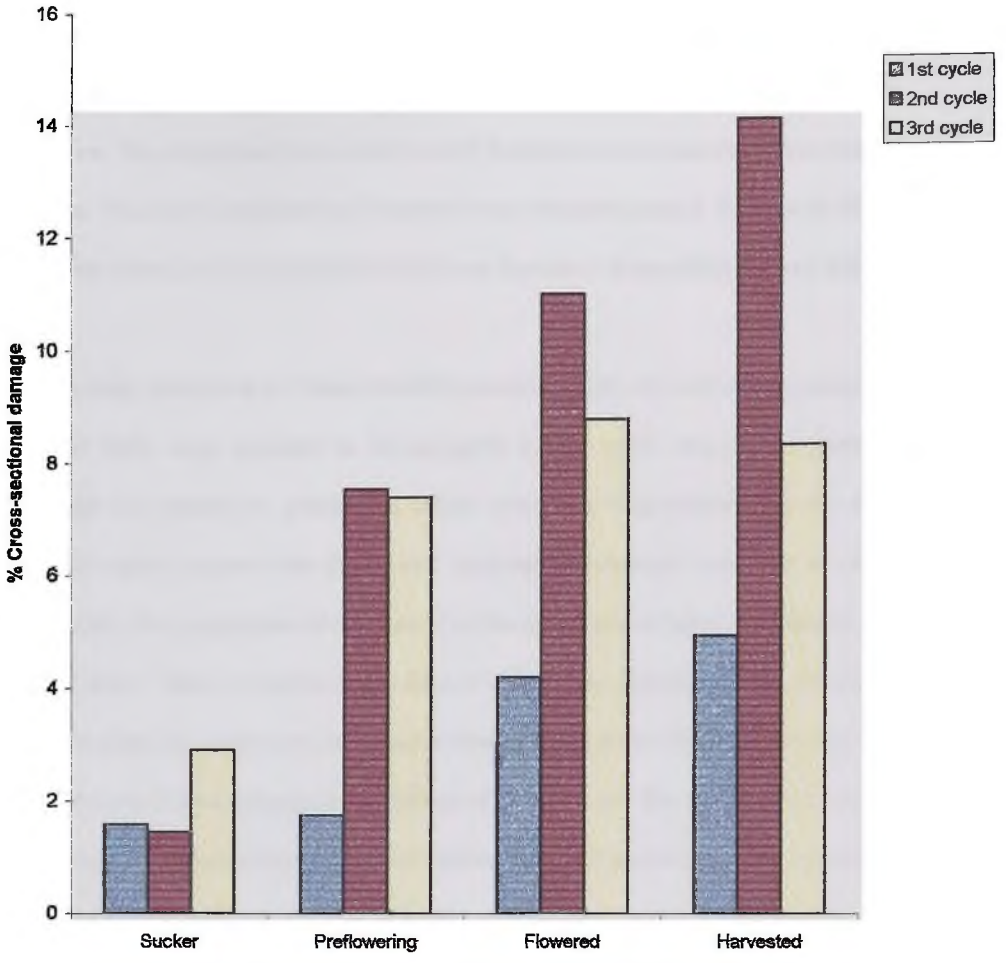

Figure 3.1c: Damage recorded on plant growth stages from different cycles (cross section)

3.4 DISCUSSION

The pest status of *C sordidus* is controversial. Its population varies extensively. The inconsistencies in population can be attributed to environmental and cropping variations. The population of the adult weevil fluctuates in response to environmental changes. The adult is harmless and feeds on rotten plantain material. Perhaps its effect is indirect since it is the population of the larva that has a direct effect on the plant.

In field trials conducted in Ghana (Afreh-Nuamah, 1993a), the weevil population in plantain fields were reported to be negligible in first cycle crops when planting materials are cleaned or planted on fallow land. The data obtained in this trial confirms earlier reports that the weevil becomes increasingly important in older plantations. The population of the weevil in the plant crop is lower than that in the ratoon crops. There is therefore the effect of cumulative population over the years. This indicates that, when a plantain field is managed and plant stands last for long, > 3 years, there will be overlapping populations of adult weevil. The first ratoon however had a higher population than the second ratoon. This inconsistency was due to the fact that, the farms under study, had plantain in intercrops with cocoa, cassava and cocoyam. The plantain was treated as a minor crop to the cocoa. As soil fertility and the effect of other pests increase after the first ratoon, the plantain is neglected since its production at this stage is not economical

Trap catches showed that 3-day old traps were more efficient than 5-day old traps. This suggests that the chemical attraction of newly cut pseudostems fade with time. There are chemical volatiles present in the plant that attract the weevil (Bundenburg and Ndiege, 1991 and BFG Bulletin, 1992), however the presence of weevils in rotten

plantain material (Godonou, 1999) is due less to chemical attraction but humidity. The weevil develops and hides in banana tissues where relative humidity is high and temperatures are moderate and fairly constant (Bakyalie and Ogenga-Latigo, 1994).

The effect of rainfall or number of rain-days had no effect on trap catches. It was realized that although rainfall and increased rain-days had a lower temperature, which was conducive for movement, trap catches did not change significantly. This was due perhaps to the increased availability of moisture. In the third cycle however, the number of rain-days increased trap catch. The third cycle, which had fewer plants, had solar insulation penetrating the crop canopy, which dries the ground. This makes the wettraps more preferred for hiding. The plantain weevil hides under trash and comes out only when temperatures are low, during cloudy conditions or at night.

The data also imply that toppling had no relation with the amount of rainfall or the number of rain-days. Perhaps it is the winds associated with rainfall that topple weakened plants. Toppling was equal in the crop cycles with a mean of 3.8% per month. Toppling in the first cycle may be due to the heavy weight of pseudostems. In the third cycle, toppling would be due to a combination of nematode and weevil damage whilst in the second cycle toppling would be due to a combination of pests and the heavy weight of pseudostems, which increase weevil damage and easily yield to winds associated with rainfall.

When adult weevils collected from the various crop cycles were reared in the laboratory, there were no differences in the fitness (longevity) which was a ratio of dead to total insects collectedin the various crop cycles. Male weevils however lived

longer in the plant crop (78%) than either the second cycle crop (67%) or the third cycle crop (39%). The overall longevity indicates that weevils from the third cycle crop were older and lived for a shorter period than either the first or second cycle crop. This explains the cumulative behaviour of plantain weevils where there is always overlapping populations.

In the current study, the corm damage recorded in the various crop cycles, indicate that the ratoon crops had a higher damage than the plant crop. It was observed that a mean corm damage of 9% occurred in the second cycle crop whilst the plant crop had a corm damage of 3%. These damage figures follow a similar trend to damage figures given in East Africa, where crop cycles extend further and as such damage continues to increase. There is however relatively lower damage in the various crop cycles compared to reports in Uganda (Rukazambuga *et al.*, 1998). The effect of cumulative weevil damage across crop growth within a cycle also indicated, that suckers were least preferred by the weevil. There was however no differences in the severity of damage to the growth stages in each cycle. The mean damage of suckers was 1.6% in a plant crop whilst it was 2.9% in a third cycle crop. In all, damage ranged from 1.5% in a sucker to 14.4% in a harvested plant. This data suggests that the weevil preferred either the larger corms or corm damage is cumulative and builds up during the growth of the plant.

The damage on suckers may be due to an extension of tunnels from the older plants in a mat. Attack of young suckers is an important factor in later plant loss (Rukazambuga *et al.*, 1998) since the plant starts growth in a stunted form. If plants are managed and have bigger corms, damage will be restricted to the older plants

Such mother plants will have enough corm tissue to support the tunnels of the growing larvae. Damage to plants will thus be deferred to a later stage in the plants' growth, which may have some tolerance unlike the feeble sucker.

The location of corm damage in the cross section, either in the outer cortex or inner cylinder have differential implications. In the sword suckers the ratio of the inner and outer damage is lower than that of the other growth stages. This is because the corm diameter of suckers, are small and the tunnels made by the larvae easily reach the inner cylinder. When damage is high in both sections, both root initiation and apical growth are hampered. There is therefore little chance for plants, which are infested at planting of reaching the flowering stage in a third cycle crop. This was shown in the stunted nature of flowered plants in the third cycle crop which supported poor crop yield. From the results it was realised that pupae and adults were not normally associated with the corms. Larvae are rather embedded in the corms. The harvested plant stage had higher larval populations of about 0.62/corm whilst suckers had as low as 0.02/corm. Larvae may not complete their development in a sucker due to small corm diameter and rather tunnel the mother plant. Sometimes the larvae tunnel along the pseudostem.

CHAPTER 4

INFLUENCE OF HOST PLANT VIGOUR DUE TO SOIL MOISTURE ON WEEVIL ATTACK

4.1 INTRODUCTION

The behaviour of the plantain weevil is influenced by several environmental factors including soil moisture (Rukazambuga, 1996). Soil moisture deficiency in addition to plantation age and plant growth stage affects weevil numbers and damage through its effect on plant vigour which in turn affects the plants' susceptibility to or severity of weevil attack (Rukazambuga, 1996)

There have been mixed reports about the response of the plantain weevil with respect to moisture conditions. Bakyalire and Ogenga-Latigo (1994) reported that *C. sordidus* is hydrophilic whilst Bendicho-Lopez and Gonzalez-Ramos (1986) reported in Latin America that larvae and pupae populations increased during the dry season. In Ghana research showed that the adult weevil population increased during the rainy seasons (Afreh-Nuamah, 1993a). When four plantain cultivars were tested in Ghana, weevil population increased with increased rainfall (Schill *et al.*, Unpubl. data). Soil moisture also influence host plant vigour or plant health (Rukazambuga 1996). The adult weevil is ground dwelling so soil moisture may influence 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 dessication.

This experiment was conducted to further investigate the conflicting reports by Bendicho-Lopez and Gonzalez-Ramos (1986); Afreh-Nuamah (1993a); Bakyalire and Ogenga-Latigo (1994); and Rukazambuga (1996) to determine the activity of the

weevil in relation to soil moisture conditions and subsequent plant vigour or stress in Ghana.

4.2 MATERIALS AND METHODS

4.2.1 Experimental design

This experiment was a controlled one in a completely randomised design: the rainfall pattern in Ghana was simulated as a basis of the treatments selected. Data recorded from 1996 to 1998 at the Agricultural Research Station, Kade, indicated that on the average there were 20 rain-days/month between May and July, 12 rain-days/month between November and September, 7 rain-days/month in March and April and 4 rain-days/month between December and February and in August.

There were four treatments with four replications. This was repeated once due to space constraints under the moisture controlled shed (Plate 4.1). The treatments imposed were watering regimes, which represent the rainfall patterns as experienced during the seasons.

The treatments were:

i) Watering 3 times a week (to represent the daily rainfall between May and July when the soil is always at field capacity).

ii) Watering once a week (to depict the rainfall pattern between September and November during the minor rainy season).

iii) Watering once a month (to depict the beginning of the major raining season in March and April, when rainfall is scanty and comes within 2 and 4 weeks intervals).

iv) No watering (this is a drought condition and it is what happens in August and between December and February when the harmattan season is experienced. There is a long dry spell during this period).

4.2.2 Trial establishment

4.2.2.1 EXPERIMENTAL PLOTS

The experiment was conducted in wooden boxes (micro-plots), measuring 90 cm by 180 cm and 60 cm deep (Plate 4.1). The boxes were filled with topsoil. Each box contained a tonne of soil. This filled the box leaving a space of 20 cm above. The boxes had holes underneath to allow for leaching.

4.2.2.2 DETERMINATION OF SOIL MOISTURE CAPACITY

A 25-litre bucket with perforations beneath was filled with a sample of the soil that was used for the experiments. A known volume of water (x) was poured gradually onto the soil until water started to leach out of the bucket into a collecting basin. This set-up was left for 24 hours. The total volume of water that leached out of the bucket (y) was then subtracted from the total volume of water added. The volume of water needed to wet a unit of soil (Q) was then determined by dividing the volume of the water used by the volume of soil (Hillel, 1980; Schwab and Frevert, 1985).

$$\mathbf{Q = x - y \,/25kg}$$

This was the amount of water that was used for watering in treatments 1-3. Thus at each time of watering, the soil was wet to field capacity. Sixty litres of water was required to wet the soil in each box to field capacity.

4.2.2.3 TREATMENT OF EXPERIMENTAL MATERIALS

One hundred suckers of 'apantu-pa' (False horn) cultivar 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; Seshu-Reddy *et al.*, 1991). Eighty treated suckers were selected for the trial based on the circumference at the pseudostem/rhizome interface. The corms selected had circumferences between 28 and 33 cm. Twenty plants were subjected to each treatment of 5 plants per replicate. The boxes were roofed with a transparent plastic sheet, 140 cm high to prevent rainfall and to allow sunlight (Plate4.1). The plants were equally watered for 4 weeks from the date of planting.

Before imposing the treatments, 20 weevils of 10 males and 10 females were released at the base of each plant and mulched with stem cuttings from *Chromolaena odorata*. Twenty weevils of an equal number of males and females introduced in each replication were 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 food for the adult weevils. An insect proof net was used to cover the boxes to ensure that the weevils released were confined to each plant. Holes were however pierced to allow the growing plant to sprout out. The plants were exposed to the treatments for 65 days when a generation of the weevil would have been completed (Franzmann, 1972).

4.2.2.4 DATA COLLECTED

The following agronomic data were taken at weekly intervals due to the vigorous growth expected in some of the treatments.

i) Plant height

Plant height was measured from the net covering the boxes to the intersection between the last two leaves using a tape. Twenty centimetres being the height of the net from the soil surface (section 4.2.2.1) was added

ii) Plant girth

The circumference of the plant at the surface of the net was measured using a flexible tape

iii) Number of leaves

The number of fully opened functional leaves were counted

iv) Rhizome cross section diameter at the end of the experiment

The diameter of the corm cut at the pseudostem/rhizome interface was measured during corm damage assessment

v) The number of larvae, pupae and adults were counted (Section 3.2.2.2)

vi) Corm damage assessment (Section 3.2.2.2)

The adult population was monitored for 21 days, by destroying trap catches until traps showed no catches for 5 consecutive inspections. Pseudostem traps (Section 3.2.1.4) were used to trap the weevils from the micro-plots. These were then replaced after 3 days.

4.2.2.5 STATISTICAL ANALYSES

ANOVA was performed on all the data as in section 3.2.1.4 in order to analyse the effect of watering frequencies on plant vigour, corm damage and emerging insects.

4.3 RESULTS

4.3.1 Effect of soil moisture or plant vigour on weevil behaviour

The effect of watering frequencies on plant vigour was compared (Table 4.3.1a). The data obtained indicate that the mean corm diameter from the daily (9.76cm) or weekly (9.08cm) watering frequencies were significantly ($P<0.001$) higher (Appendix 36) than the monthly watering (6.94cm) or the drought condition (7.05cm). The mean corm diameter decreased with watering frequency (Plate 4.2).

The effects of the treatments on the plant height followed a similar pattern as that of the corm diameter. The plant height due to either daily (95.7cm) or weekly (86.2cm) watering were significantly ($P<0.001$) higher (Appendix 37) than either the monthly (37.5cm) or the drought (28.4cm) treatment.

There were significant ($P<0.001$) differences (Appendix 38) in plant girth between either the daily watering (24.07cm) or weekly watering (23.42cm) and the monthly watering (14.20cm) or drought (12.56cm) condition.

The mean number of leaves also followed a similar analytical pattern (Appendices 39 &39a) as the plant girth. The daily (9.96) or weekly watering being (9.57) significantly ($P<0.05$) higher than that of either the monthly (5.55) watering or the drought condition (5.08).

At the end of the experiment the mean number of peeper suckers sprouting from the daily watering (1.7) treatment was significantly ($P<0.05$), higher (Appendices 40 & 40a) compared to the other treatments, weekly (0.5), monthly (0.3) or drought (0.0).

The weekly watering and monthly watering were not significantly different but the mean number of peepers in the weekly watering treatment was higher than that of the monthly watering treatment. The drought treatment was significantly ($P<0.05$) lower than either the weekly or monthly watering frequency.

The cumulative growth rate of the various growth parameters over an eight-week period is presented in Figures 4.1, 4.2, & 4.3.

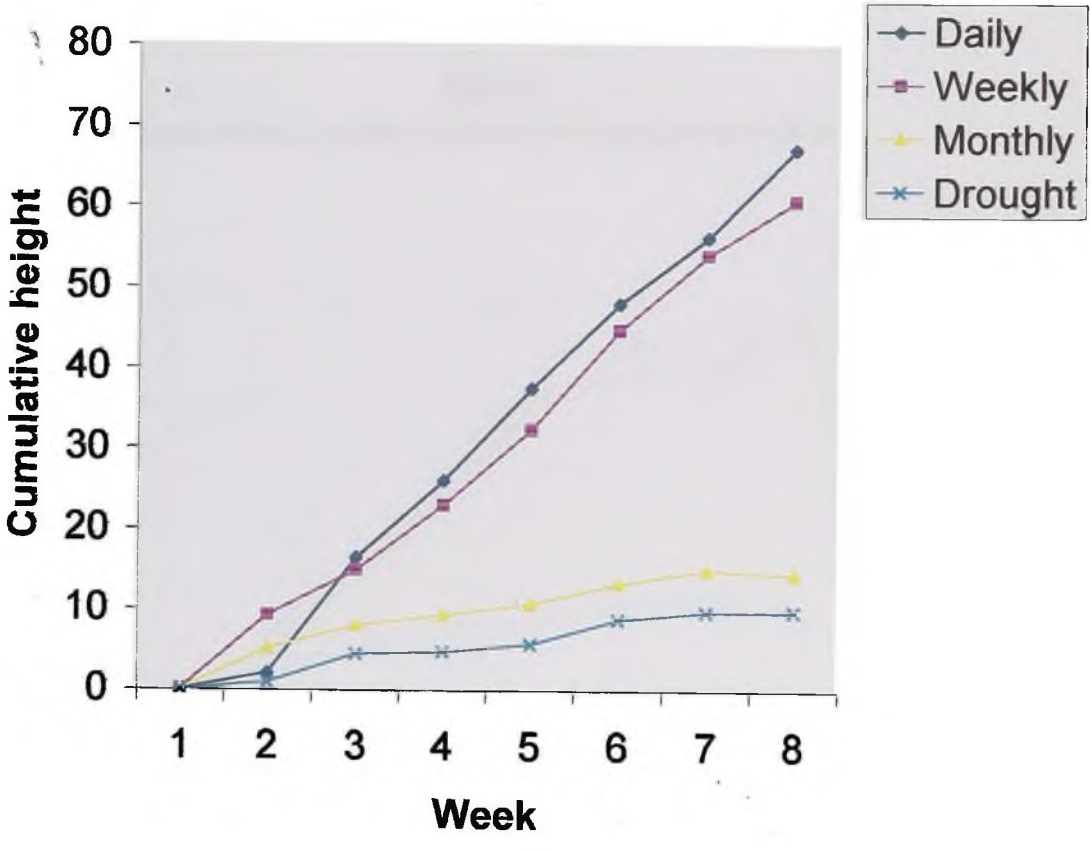

Figure 4.1 Effect of moisture on cumulative plant height growth rate

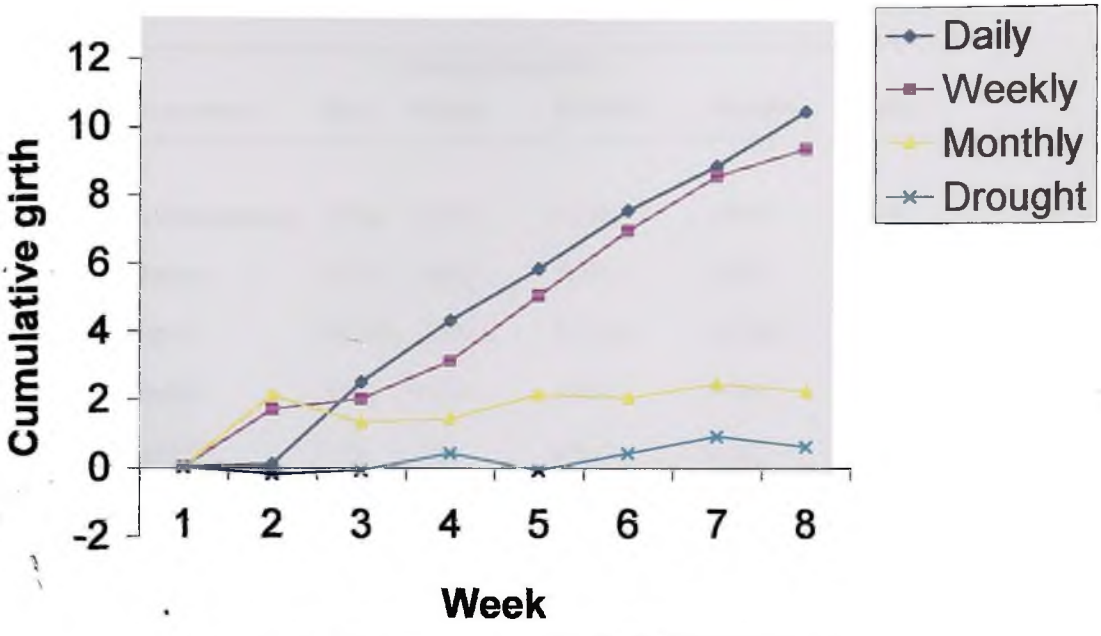

Figure 4.2 Effect of moisture on cumulative plant girth growth rate

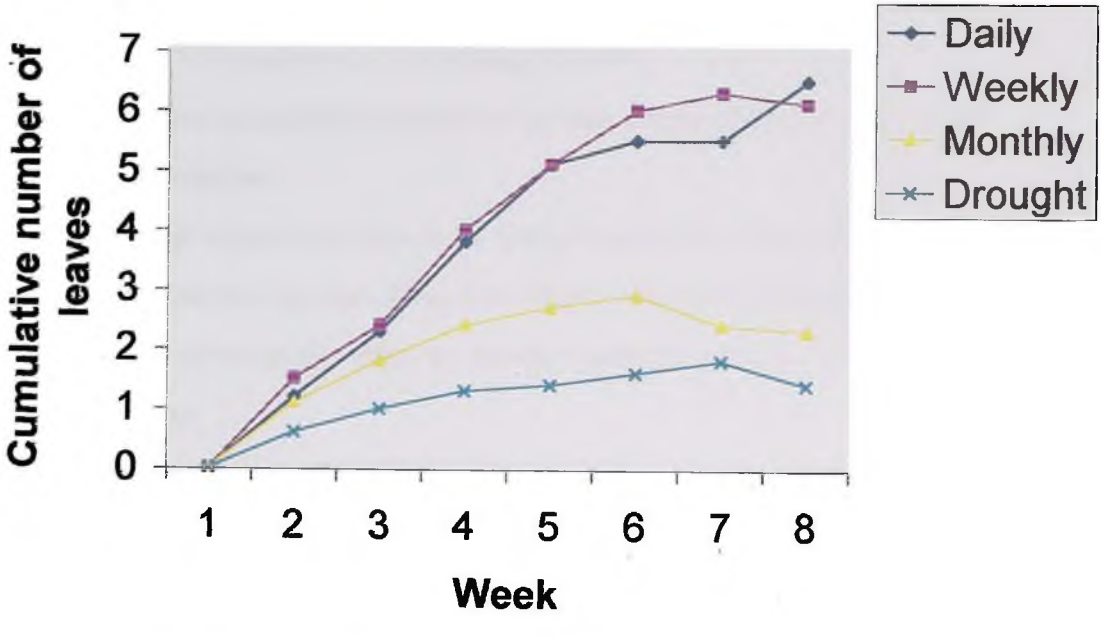

Figure 4.3 Effect of moisture on cumulative rate of leaf growth

Table 4.3.1a: Mean plant vigour due to watering regimes

Plant parameter	Watering frequency				
	Daily	Weekly	Monthly	Drought	Mean
Corm diameter(cm)	9.76a	9.08a	6.94b	7.05b	8.21
Height(cm)	95.7a	86.2a	37.5b	28.4b	61.6
Girth(cm)	24.07a	23.42a	14.20b	12.56b 1	8.56
Leaves(n^{o})	9.96a	9.57a	5.55b	5.08b	7.54
Sucker(n^{o})	1.7a	0.5b	0.3b	0.0c	0.63

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

The effect of the plant vigour on the insect due to watering frequencies is presented in Table 4.3.1b, Appendices 41,41a,42,42a,43 & 433a.

There were no significant differences in the mean number of larvae, pupae or adults for the treatments.

The mean number of larvae from the daily watering (0.64) and the weekly watering (0.65) were not significant. These were however significantly higher than the mean number of larvae from either the monthly watering (0.35) or the drought (0.10) treatment

The number of pupae from the treatments was highest in the daily watering (0.20) and least in the drought treatment (0.05). The number of adult insects trapped after the end of the trial was highest in the daily watering (5.1) and least in the drought treatment (3.1).

Table 4.3.1b: Mean number of insects trapped from the watering regimes

	Watering frequency				
Insect stage	Daily	Weekly	Monthly	Drought	Mean
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

Damage caused by the insect in the various watering frequencies is in Table 4.3.1c using three different damage assessment parameters.

The PCI showed no significant differences (Appendices 44 & 44a) in the damage. However the PCI damage due to the watering frequencies were least in the daily watering (7.1) followed by the weekly watering (11.0), drought (13.2) and monthly watering (14.3)

In the PD assessment, the daily treatment (19.0%) was significantly ($P<0.05$) lower (Appendices 45 & 45a) than either the monthly treatment (42.9%) or the drought treatment (55.6%). Although the daily and weekly (35.1%) treatments were not significantly different, damage due to the weekly treatment was higher. The damage due to the weekly watering was lower than either the monthly or drought treatments but was not significant. The drought treatment had the highest damage.

The Cross section damage analysis showed that damage due to daily watering (16.4%) was slightly higher than the weekly treatment (16.2%) but it was not significant. The daily or weekly watering (Appendices 46 and 46a) had a significantly ($P<0.001$) lower damage than that of the drought situation (54.1%). Damage due to the monthly watering (38.0%) was higher than that of either the daily or weekly

watering. The damage due to monthly watering was again lower than the damage due to the drought situation but was not significant (Plate 4.3).

Table 4.3.1c: Mean corm damage due to the watering regimes

	Watering frequency				
Damage parameter	Daily	Weekly	Monthly	Drought	Mean
PCI	7.7	11.0	14.3	13.2	11.5
PD	19.0a	35.1ab	42.9b	55.6b	38.2
X-SECTION	16.4a	16.2a	38.0ab	54.1b	31.2

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

The cross section damage due to the watering treatments is presented in Table 4.3.1d. Damage in the inner corm cross section (Appendix 47 & 47a) showed that there was a significantly ($P<0.001$) lower damage in either the daily (18.6%) or weekly (17.0%) treatments than damage in either of the monthly (43.0%) or drought (53.0%) treatments. There was however no significant difference between the daily and weekly treatments or the monthly and drought treatments.

In the outer Cross section damage, there were no significant differences among the daily (14.2%), weekly (15.4%) and monthly (32.9%) watering treatments. However the daily and weekly treatments resulted in damage that were significantly ($P<0.05$) lower (Appendices 48 &48a) than the drought (55.0%) treatment. The monthly treatment had a lower damage than the drought condition but it was not significant.

Table 4.3.1d: Mean corm cross section damage location due to watering regimes

	Watering frequency				
Damage location	Daily	Weekly	Monthly	Drought	Mean
Inner	18.6a	17.0a	43.0b	53.0b 3	3.0
Outer	14.2a	15.4a	32.9ab	55.0b	29.4

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

4.4 DISCUSSION

The plantain weevil is positively hydrotactic (Cuille, 1949; Ittyeipe, 1986). Wetted plantain mats have been observed to increase trap catches (Bakyalire and Ogenge-Latigo, 1994) whilst optimum soil moisture also increases plant vigour. The data obtained in this trial suggests that increasing the frequency of watering to attain soil moisture capacity at a lower temperature led to increase in both plant vigour and number of adult weevils attracted to the plantain mat. The increased plant vigour due to soil moisture provided shade at the base of the plant. Negative phototaxis has also been reported to be the overriding factor influencing weevil activity in the field (Bakyalire and Ogenga-Latigo, 1994).

The results obtained in this trial indicate that increased plant vigour resulted in bigger corms, higher and larger stems, more functional leaves and produced more suckers. This observation confirms earlier results by other workers, where soil amendments such as the use of manure and mulches were used to reduce plant stress (Rukazambuga, 1996). The vigorous growing plants also provided mat conditions, which were conducive for weevil attraction. They had bigger corms, which supported a higher number of larvae and pupae. The mean number of larvae found in a treatment

which is at constant water field capacity was 0.64 whilst it was 0.10 in a drought condition.

These results depict the effect of moisture as an attranctant to ovipositing sites. However moisture effect on plant growth outways insect attraction and consequent damage by the weevil. The vigorously growing plants in this trial 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 (1996) manure and mulches were used to enhance plant growth in a similar moisture-damage trial. The moisture and manure created a humid condition at the base of the plant as was in this trial. However the report by Rukazambuga (1996) stated that the vigorously growing plants were sevely attacked than stressed plants. By the banana weevil which was not so in this trial. Perhaps the contradiction between these two trials was as a result of the parameter used as damage. Whilst Rukazambuga (1996) presented his results in absolute terms on area basis (cm^2), this trial presented the data as a percentage of corm size.

In this trial the stunted growth of the water stressed plants made them easily consumed by a few larvae. Even the tunnels created by the larvae as it feeds or hides, could consume the meristem of a stressed plant and kill it. For example, whilst the mean cross section damage due to the daily watering was 16.4%, it was 54.1% in a drought condition. This result confirms earlier reports that the plantain weevil aggravates the problem of plants under stress (Summerville, 1944, Jones, 1986). This is because the larvae will consume a constant corm area if available or continue into the pseudostem (Franzmann, 1972). Plants with larger corms will thus have a

relatively smaller percentage being consumed than a stressed plant with a smaller corm. The percentage damage caused to plantain corms is thus inversely proportional to corm diameter. Stressed plants due to scorching/drying effects will influence the weevil to seek shelter deep in the corms. In such a situation the plant tissue is easily completely consumed.

Plate 4.1 A moisture-controlled micro-plot setup to determine the effect of soil moisture or plant vigour on the weevil

Plate 4.2 Corm sizes due to moisture treatment effects

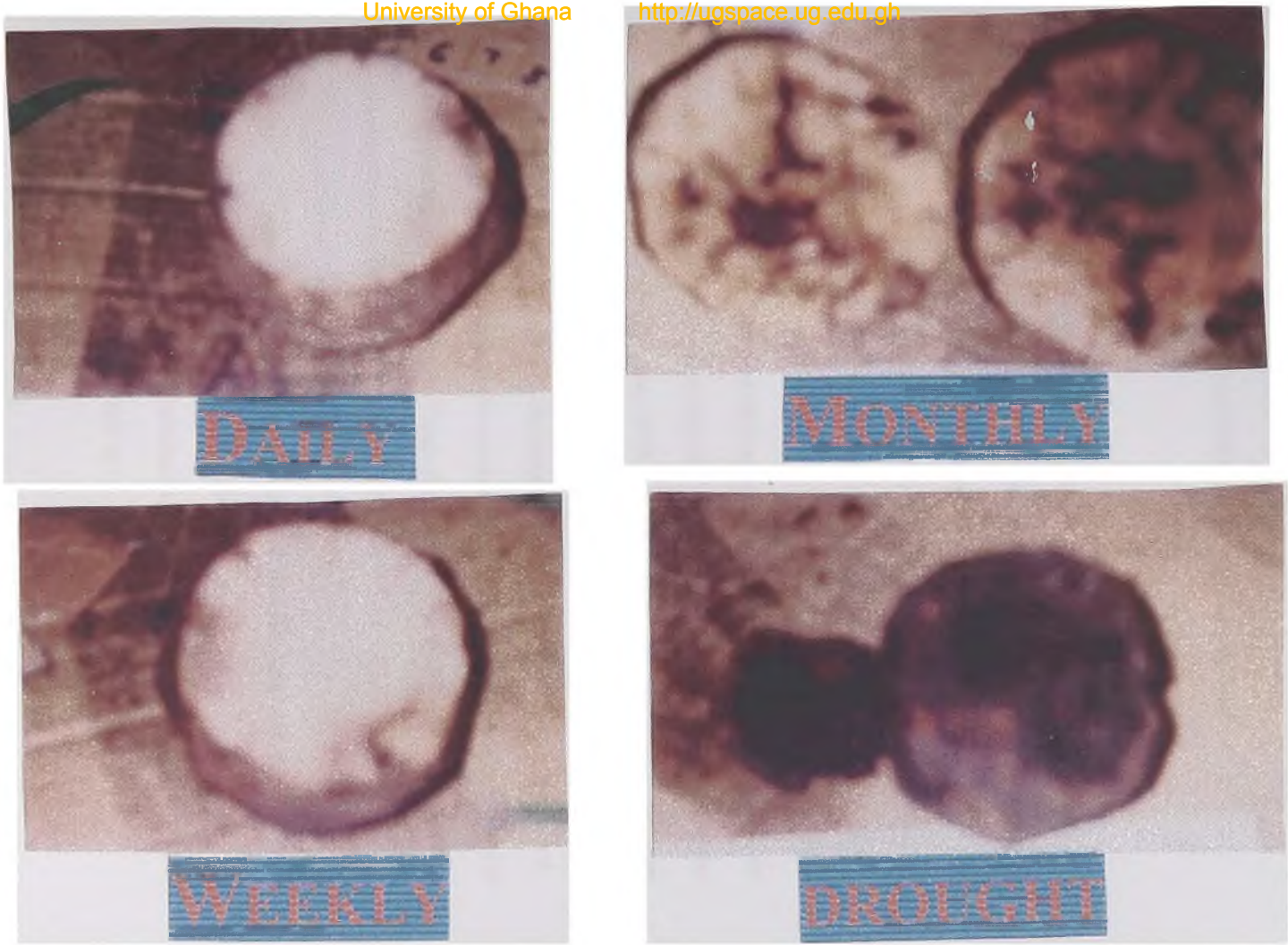

Plate 4.2 Cross-sectional damage due to moisture treatment effects

CHAPTER 5

STUDIES ON WEEVIL FECUNDITY AND THE EFFECT OF EGG INFESTATION LEVELS ON WEEVIL DAMAGE

5.1 INTRODUCTION

Infested planting material has been observed to be a contributing factor to the infestation by weevils in newly established plantain fields. Data on the severity of damage by the weevil is however not available. Different levels of infestation are inevitable since there are vast variations in population densities and distribution in neighbouring farms (Rukazambuga, 1996).

The population of the larva, the destructive stage of the weevil, is a function of the number of eggs produced, laid or hatched. In the field, it is very difficult to detect the number of eggs laid (Franzmann, 1972) because the eggs are embedded in the corm and covered with congealed sap. Hence the corm has to be harvested and thinly pared before the eggs can be accessed. Occasionally, eggs are laid in the roots (Abera *et al.*, 1996) or in the soil which cannot be accounted for. This experiment was conducted to determine the potential number of eggs embedded in gravid females and to establish whether it is a function of the number of eggs laid.

The objectives of this experiment were,

i) to determine the potential fecundity of females collected from different locations in the Eastern Region of Ghana.

iii) to determine the effect of infestation levels on planting material on subsequent damage and population build up.

5.2 MATERIALS AND METHODS

5.2.1. Weevil fecundity levels in Ghana

Female weevils from three locations in the Eastern Region of Ghana were collected and the number of mature eggs present in their ovaries removed for study.

5.2.1.1. EXPERIMENTAL DESIGN

This was a completely randomised design with three treatments replicated ten times. The treatments were the location of the towns selected.

5.2.1.2 WEEVIL COLLECTION

Weevils were collected from three commercial plantain-growing areas in the Eastern Region of Ghana. These communities were Akanteng, Dwenase and Pramkese, all within a 50km radius of ARS, Kade.

In all, 100 adult females were collected from each community for the experiment. Ten females were collected at fortnightly intervals and were dissected along the lateral abdomen.

5.2.1.3 DATA COLLECTED

The number of mature egg follicles present was recorded with the aid of a binocular microscope at magnification of X4.

5.2.2 Effect of of initial infestation of planting material on weevil population and damage

5.2.2.1 PRELIMINARY EXPERIMENT

Prior to the main experiment, a preliminary trial was conducted to determine the level of larval emergence when planting material was infested with adult weevils for seven days.

5.2.2.2 RESULTS

The results from the preliminary experiment indicated that mean number of larvae increased in the planting material as the number of weevils increased. A mean of 0.2 larva emerged from the farmers material collected from a plantation with trap catch of 0.4 weevils per trap, and 2.8 larvae emerged when the planting material was cultured with 4 weevils.

5.2.2.3 MAIN TRIAL

Damage on plantain by weevil as a result of initial infestation of planting material was simulated using plastic pots as soil containers at ARS, Kade (Plate 5.1).

5.2.2.4 EXPERIMENTAL DESIGN

The main trial was a pot experiment in a completely randomised design. Each treatment was replicated 15 times. There were three treatments with each having different initial infestation of planting material before planting.

5.2.2.5 TRIAL ESTABLISHMENT

Research on the initial egg infestation was undertaken by collecting suckers from the farmer's field. These suckers (collected from the farmers' field) were subjected to the following treatments.

i) (culturing each sucker with 2 weevils) confining 2 weevils to each sucker

ii) (culturing each sucker with 4 weevils) confining 4 weevils to each sucker

iii) a control in which planting material was not confined with weevils

A sucker was kept in a 25-litre plastic container lined with moist soil at the bottom and was confined with 2 or 4 weevils and a third treatment with no weevils. This set up was covered and kept at 25°C for 7 days which period the weevils would have laid some eggs. The weevils were then hand-removed from the suckers, and the suckers were planted in 25-litre capacity plastic pots, which have been perforated beneath and filled with topsoil (Plate 5.1). It was mulched after planting and covered with an insect proof net as in Section 4.2.2. The potted plants were managed for 22 weeks which period the pot could contain the roots of the plant and eggs would have grown to adults.

5.2.2.6 DATA COLLECTED

i) Weevil damage assessment

Plants were uprooted after 22 weeks and weevil damage was assessed as in section 3.2.2.2

ii) Weevil adult density

Adult weevil density was estimated within each pot from 4 weeks from date of planting until the 22nd week when plants were uprooted and afterwards by multiple

trapping as in Section 4.2.2.4. The number of larvae and pupae embedded in the corms were also counted.

5.2.2.7 STATISTICAL ANALYSES

Means were calculated for the number of mature egg follicles extracted from female insects. ANOVA was performed on all data as in Section 3.2.1.4 in order to analyse the effect of initial infestation levels on insect population and corm damage

5.3 RESULTS

5.3.1 Weevil fecundity levels in the Eastern Region of Ghana

The number of mature egg follicles obtained from weevils collected from the three locations did not differ significantly (Appendices 49 & 49a) in the number of mature egg follicles present in the ovaries of females. The overall mean number of mature egg follicles was 4.03 per female. The mean number of mature egg follicles from each of the locations is presented in Figure 5.1.

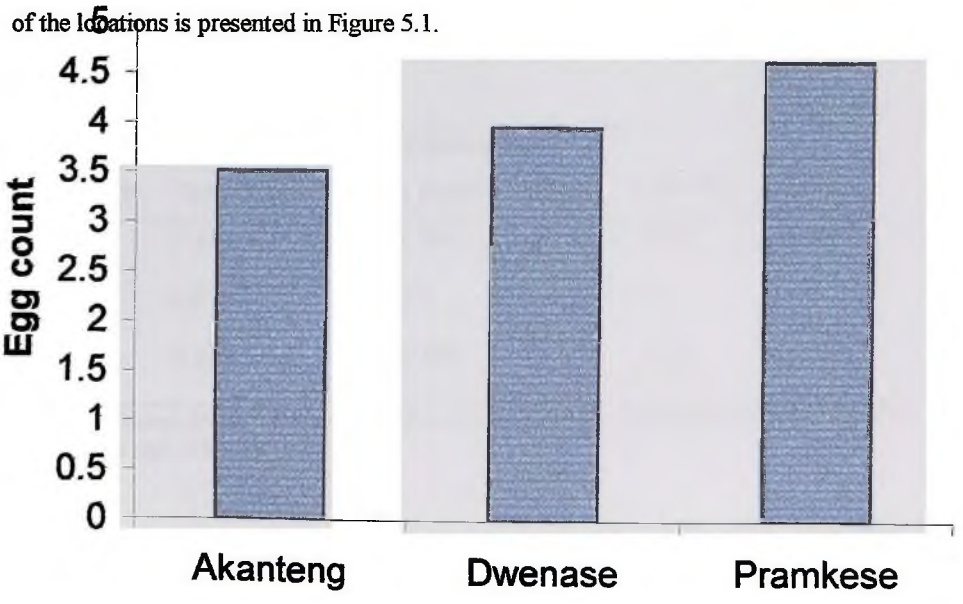

Figure 5.1: Mean number of mature egg follicles extracted from females in three towns of the Eastern Region of Ghana

5.3.2 Effect of egg infestation levels of planting material on weevil dynamics

Table 5.3.2a shows the effect of initial infestation levels of planting materials and subsequent mean number of insects that emerged.

The mean number of larva found in dissected corms from the farmers material (0.83) was significantly ($P<0.05$) lower (Appendices 50 & 50a) than that from treatment cultured with 4 weevils (1.78) or the treatment cultured with 2 weevils (1.50).

In all the treatments no pupa was found associated with the corms (Appendix 51).

The mean number of adults trapped per plant (Appendices 52 & 52a) was significantly ($P<0.05$) higher in the treatment cultured with 2 weevils (1.73) or the 4 weevils infestation (2.33) than that of the farmers material (0.33). The treatment cultured with 4 weevils had a higher number of larvae than the treatment cultured with 2 weevils but this was not significant ($P=0.05$)

Table 5.3.2a: Mean number of insects emerging from the initial infestation levels of planting materials.

	Initial infestation level/plant			
Insect stage	Farmer's	2 weevils	4 weevils	Mean
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

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

Table 5.3.2b indicates the extent of corm damage due to the initial infestation treatments. The damage was assessed using 3 parameters.

The PCI parameter indicates that the treatment cultured with 2 weevils (10.7) or the treatment cultured with 4 weevils (13.6) was significantly ($P<0.001$) higher than that

of the farmers material (4.0) (Appendices 53 & 53a). There was however no significant difference between the treatment cultured with 4 weevils and the treatment cultured with 2 weevils.

The PD gave a similar pattern (Appendices 54 & 54a): treatment cultured with 2 weevils (12.5%), treatment cultured with 4 weevils (14.4%) and farmers' material (3.3%) were similar the PCI.

The corm cross section damage of the treatment cultured with 2 weevils (30.1%) or the treatment cultured with 4 weevils (33.6%) was significantly ($P<0.01$) higher (Appendices 55 & 55a) than that of the farmers material (14.1%).

Table 5.3.2b: Mean corm damage from the initial infestation levels of planting materials.

	Initial infestation level/plant			
Damage parameter	Farmer's	2 weevils	4 weevils	Mean
PCI	4.0a	10.7b	13.6b	9.43
PD	3.3a	12.5b	14.4b	10.07
X-SECTION	8.6a	30.1b	33.6b	24.1

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

Table 5.3.2c gives a comparison of the location of the corm cross section damage. 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%.

The inner corm damage assessment showed that the treatment cultured with 2 weevils (34.5%) or the treatment cultured with 4 weevils (35.5%) was significantly ($P<0.01$) higher (Appendices 56 & 56a) than that of the farmers material (13.2%). The

treatment cultured with 2 weevils and the treatment cultured with 4 weevils were not significantly different.

The outer corm damage of the treatment cultured with 2 weevils (25.7%) or the treatment cultured with 4 weevils (28.7%) was significantly ($P<0.01$) higher (Appendices 57 & 57a) than that of the farmers material (4.0%). The treatment cultured with 4 weevils had a higher damage than the treatment cultured with 2 weevils but it was not significant.

Table 5.3.2c: Mean corm cross section damage location from the initial infestation levels of planting materials.

	Initial infestation level/plant			
Damage location	Farmer's	2 weevils	4 weevils	Mean
Inner	13.2a	34.5b	35.5b	27.7
Outer	4.0a	25.7b	28.7b	19.5

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

5.4 DISCUSSION

The fecundity studies revealed that female weevils have a potential fecundity of about 5 mature egg follicle. Franzmann (1972) reported that the number of eggs produced by weevils was inversely proportional to adult age. Abera *et al* (1996) however gave a definite figure of up to 22 mature egg follicles from a single female adult in Uganda. This fecundity trial revealed that the female weevil had a potential fecundity of up to 18 mature egg follicles. It was however realized that the mean potential fecundity was 5 mature egg follicles per female.

The data obtained from the infestation treatments show that there is a positive relationship between the level of initial infestation and subsequent damage. Earlier results indicated that weevil population and damage increases across crop cycles. Therefore a planting material collected from a third cycle crop will have a higher infestation than a planting material from a plant crop. In this trial the mean number of adult weevils that emerged ranged from 0.33 per plant in the farmers' material to 2.33 in the treatment cultured with 4 weevils. Damage also followed the same pattern with the highest infestation treatment recording as much as 33.6% cross section damage within 22 weeks. Such plants may not be able to reach flowering stage. Again in the highest infestation treatment, there was 48% plant mortality within the experimental period.

Plate 5.1 A pot experiment to determine weevil build up from different initial infestation levels

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSION

The results obtained from this research suggest that *C. sordidus* will become increasingly important in Ghana as management strategies are adopted to increase crop cycles. The weevil appeared on all plantain fields no matter how clean the farms were. The mode of weevil infestation is either through planting material or migration across fields (Gold *et al.*, 1996).

The potential fecundity of weevils in Ghana, which is up to 17 mature egg follicles per female, is comparable to other reports elsewhere (Abera *et al.*, 1996). Earlier reports in Ghana on weevil damage and population were low because data were collected from young fields. There is evidence from this study that the damage of the plantain weevil increases across both crop cycles and plant developmental stages. The adult weevil also had a preference for larger corms. As much as 14% corm cross section damage could occur in flowered plants. These damage figures should be of great concern since at the flowering stage of the plants' growth, plant health becomes crucial for fruit filling. Again if highly infested suckers are used as planting material, the weevil problem will start early in the growth of the plant and will accumulate. The mats shared by the common plants will become deteriorated and may not be able to support any appreciable plant growth.

The 1.7 weevils per mat obtained in a 2nd cycle crop should be a matter of increasing concern. This is because it represents the mean trap catch for only one month. Also because the weevils trapped were destroyed, the subsequent populations were

contributed by only those weevils, which were not caught during each sampling. The total number of weevils caught from each field represent a maximum of 21 weevils per mat (Figure 6.1). This is far more than thresholds reported in other regions. For now the non-availability of virgin and secondary forests does not allow farmers to abandon old infested plantain farms and start new ones. With the increasing limitation on land, farmers will later have to cultivate the same land over and over again. In such a situation, the weevil menace will be evident.

From the data collected so far in Ghana, it is inevitable that the plantain weevil has come to stay as a serious pest of plantains in Ghana. Akomeah et al. (1995) and Afreh-Naumah (1993a) reported that enhanced agronomic practices such as weeding, desuckering and the use of clean planting materials can lengthen the crop cycles. In the fields under study, there had not been any appreciable weeding prior to the trial. Plant stands had many sword and maiden plants giving a high mat stand population. The corms of toppled plants had dead roots all over. In the 3rd cycle crop the plantain stems had deteriorated and hardly had enough vigour to reach flowering. During sampling in August 1999, the requisite number of flowered plants needed for sampling could not be met.

The general observation was that although plants from plots with adequate soil moisture, had a high number of weevil incidence, such plants had a smaller percentage of corm tissue damaged. Further more it was observed that though soil moisture resulted in increased weevil attraction in confined situations, the amount of rainfall was itself not a contributing factor to trap catches. It is the kairomones emitted by the trap and an effort by the weevil to seek moist hiding places, which sends adult

weevils to the traps. Three-day old traps were more efficient than 5-day old traps. Perhaps in the field rainfall wets the whole area and makes everywhere conducive for weevil habitation. Moisture in controlled experiments increases plant vigour, which subsequently reduced the proportionate size of corm tissue consumed by the weevil. Without preference in relation to corm sizes, the weevil has an increasing damage on smaller corms under stress but tends to feed on larger corms when there is a choice for corm size.

From the results obtained, the following recommendations may be integrated to manage the anticipated population build up and the cumulative damage of the plantain weevil;

1. Soil amendment practices that will conserve moisture or increase soil fertility should be practised. This will provide a vigorously growing plant that could compensate for corm tissue damage.
2. It must be ensured that suckers taken from infested fields are cleaned to reduce the early build up of weevil population and damage.
3. Weeds should be controlled since competition of the crop with weeds aggravates the damage caused by the weevil.

In conclusion, it must be emphasised that, it will become extremely difficult and expensive to control the weevil if its population is not managed early. The level of initial infestation should be minimised and plants should be managed to grow vigorously. Weevils in Ghana have an equal potential to reproduce like in East Africa if plantain stands are perpetuated. In the field the weevils' distribution is uneven and will display different population and damage levels under conditions such as crop cycles, frequency or duration of sampling, age 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. The agronomic practices adopted are also bound to influence weevil behaviour as did soil moisture effects in this trial.

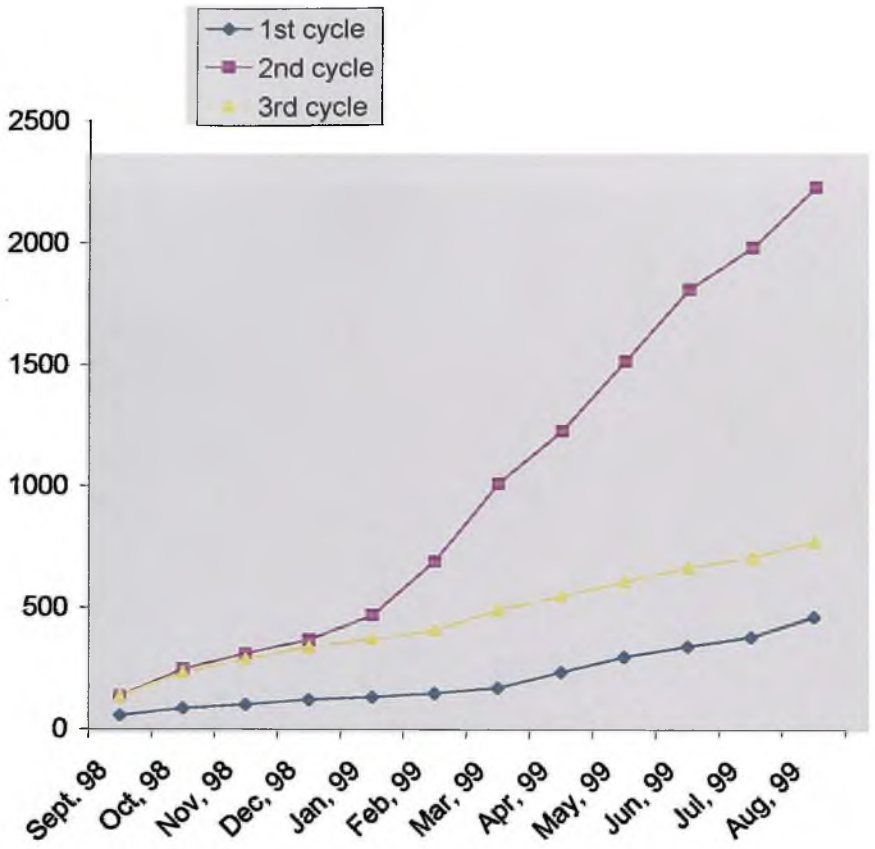

Figure 6.1: Cumulative number of weevils trapped/100 mats in each crop cycle for a 12 month duration

Plate 6.1 A typical mixed crop plantain farm in Ghana

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APPENDICES

1.ANOVA for effect of crop cycles on 3-day trap catch

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	11	36.679	3.334	1.03	
Cycle	2	6.676	3.338	1.03	0.373
Residual	22	71.136	3.233		
Total	35	114.492			

1a. Transformed appendix 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	11	3.3459	0.3042	1.32	
Cycle	2	1.3983	0.6991	3.04	0.068
Residual	22	5.0645	0.2302		
Total	35	9.8087			

2. ANOVA for effect of crop cycles on 5-day old trap catch

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	11	0.38490	0.03499	1.54	
Cycle	2	1.57821	0.78910	34.69	<0.001
Residual	22	0.50039	0.02275		
Total	35	2.46350			

2a. Transformed appendix 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	11	0.28110	0.02555	1.74	
Cycle	2	1.15579	0.57790	39.39	<0.001
Residual	22	0.32278	0.01467		
Total	35	1.75967			

3. ANOVA for effect of crop cycles on total trap catch

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	11	3.2967	0.2997	1.49	
Cycle	2	11.2171	5.6086	27.90	<0.001
Residual	22	4.4219	0.2010		
Total	35	18.9357			

3a. Transformed appendix 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	11	0.90666	0.08242	2.12	
Cycle	2	2.85762	1.42881	36.76	<0.001
Residual	22	0.85519	0.03887		
Total	35	4.61946			

4. Regression of rainfall on trap catch

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	5387	5387	0.84	0.365
Residual	34	217552	6399		
Total	35	222939	6370		

5. Regression of rain-days on trap catch

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	1063.	1063	0.16	0.689
Residual	34	221875.	6526		
Total	35	222939.	6370		

6. Regression of rain-days on trap catch in the third cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	5159.	5159.2	14.25	0.004
Residual	10	3621.	362.1		
Total	11	8780.	798.2		

7. Regression of rainfall on trap catch in the first cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	985.	985.0	2.05	0.182
Residual	10	4799.	479.9		
Total	11	5784.	525.8		

8. Regression of raindays on trap catch in the first cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	472.	471.8	0.89	0.368
Residual	10	5312.	531.2		
Total	11	5784.	525.8		

9. Regression of rainfall on trap catch in the second cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	6092	6092	0.86	0.375
Residual	10	70539	7054		
Total	11	76631	6966		

10. Regression of rain-days on trap catch in the second cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	1374	1374	0.18	0.678
Residual	10	75257	7526		
Total	11	76631	6966		

11. Regression of rainfall on trap catch in the third cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	313.	312.8	0.37	0.557
Residual	10	8467.	846.7		
Total	11	8780.	798.2		

12. Regression of rainfall on toppling in the first cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	0.4	0.35	0.02	0.878
Residual	10	144.3	14.43		
Total	11	144.7	13.15		

13. Regression of rain-days on toppling in the first cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	10.5	10.54	0.79	0.396
Residual	10	134.1	13.41		
Total	11	144.7	13.15		

14. Regression of rainfall on toppling in the second cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	10.1	10.12	0.19	0.675
Residual	10	542.8	54.28		
Total	11	552.9	50.27		

15. Regression of rain-days on toppling in the second cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	6.1	6.07	0.11	0.746
Residual	10	546.8	54.68		
Total	11	552.9	50.27		

16. Regression of rainfall on toppling in the third cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	11.6	11.62	0.59	0.459
Residual	10	196.1	19.61		
Total	11	207.7	18.88		

17. Regression of rain-days on toppling in the third cycle crop

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	0.6	0.55	0.03	0.873
Residual	10	207.1	20.71		
Total	11	207.7	18.88		

18. ANOVA for effect of crop cycles on toppling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	11	0.053608	0.004873	2.82	
Cycle	2	0.001250	0.000625	0.36	0.701
Residual	22	0.038017	0.001728		
Total	35	0.092875			

18a. Transformed appendix 18

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	11	0.0235024	0.0021366	2.87	
Cycle	2	0.0004680	0.0002340	0.31	0.733
Residual	22	0.0163724	0.0007442		
Total	35	0.0403428			

19. Regression of rainfall on toppling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	12.0	11.98	0.45	0.509
Residual	34	912.8	26.85		
Total	35	924.8	26.42		

20. ANOVA for effect of rain-days on toppling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	0.0	0.00	0.00	0.997
Residual	34	924.7	27.20		
Total	35	924.8	26.42		

21. ANOVA for the effect of crop cycles on overall weevil longevity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cycle	2	1569.7	784.9	2.31	0.142
Residual	12	4086.0	340.5		
Total	14	5655.7			

21a. Transformed 21

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cycle	2	0.17658	0.08829	2.30	0.143
Residual	12	0.46126	0.03844		
Total	14	0.63785			

22. ANOVA for the effect of crop cycles on female weevil longevity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cycle	2	1219.7	609.9	0.99	0.400
Residual	12	7383.2	615.3		
Total	14	8602.9			

22a. Transformed appendix 22

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cycle	2	0.16706	0.08353	1.11	0.362
Residual	12	0.90663	0.07555		
Total	14	1.07370			

23. ANOVA for the effect of crop cycles on male weevil longevity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cycle	2	4099.7	2049.9	6.89	0.010
Residual	12	3570.0	297.5		
Total	14	7669.7			

23a. Transformed appendix 23

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cycle	2	0.47389	0.23695	6.94	0.010
Residual	12	0.40989	0.03416		
Total	14	0.88379			

24. ANOVA for effect of crop cycle or plant growth on total cross section damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	148.68	49.56	2.47	
Cycle	2	250.78	125.39	6.24	0.005
Growth	3	366.87	122.29	6.09	0.002
Cycle*Growth	6	121.50	20.25	1.01	0.437
Residual	33	663.11	20.09		
Total	47	1550.94			

24a. Transformed appendix 24

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.052099	0.017366	1.82	
Cycle	2	0.161089	0.080544	8.43	0.001
Growth	3	0.194763	0.064921	6.80	0.001
Cycle*Growth	6	0.036347	0.006058	0.63	0.702
Residual	33	0.315241	0.009553		
Total	47	0.759539			

25. ANOVA for effect of crop cycle or plant growth on corm damage (PCI)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	26.669	8.890	0.99	
Cycle	2	175.287	87.643	9.72	<0.001
Growth	3	310.556	103.519	11.48	<0.001
Cycle*Growth	6	33.807	5.634	0.62	0.709
Residual	33	297.541	9.016		
Total	47	843.859			

25a. Transformed appendix 25

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.3649	0.4550	1.19	
Cycle	2	7.5675	3.7837	9.91	<0.001
Growth	3	13.3713	4.4571	11.68	<0.001
Cycle*Growth	6	0.5723	0.0954	0.25	0.956
Residual	33	12.5975	0.3817		
Total	47	35.4734			

26. ANOVA for effect of crop cycle or plant growth on corm damage (PD)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	93.80	31.27	1.81	
Cycle	2	355.25	177.62	10.30	<0.001
Growth	3	519.64	173.21	10.04	<0.001
Cycle*Growth	6	65.73	10.95	0.63	0.701
Residual	33	569.34	17.25		
Total	47	1603.76			

26a. Transformed appendix 26

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.014035	0.004678	0.74	
Cycle	2	0.132447	0.066224	10.51	<0.001
Growth	3	0.186412	0.062137	9.86	<0.001
Cycle*Growth	6	0.013355	0.002226	0.35	0.903
Residual	33	0.207898	0.006300		
Total	47	0.554148			

27. ANOVA for effect of crop cycle or plant growth on corm damage (inner cross section)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	91.50	30.50	1.52	
Cycle	2	221.87	110.93	5.51	0.009
Growth	3	143.36	47.79	2.38	0.088
Cycle*Growth	6	136.34	22.72	1.13	0.367
Residual	33	663.95	20.12		
Total	47	1257.02			

27a. Transformed appendix 27

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.03517	0.01172	0.86	
Cycle	2	0.18928	0.09464	6.94	0.003
Growth	3	0.10948	0.03649	2.68	0.063
Cycle*Growth	6	0.05408	0.00901	0.66	0.681
Residual	33	0.44979	0.01363		
Total	47	0.83780			

28. ANOVA for effect of crop cycle or plant growth on corm damage (outer cross section)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	220.93	73.64	2.73	
Cycle	2	289.01	144.51	5.35	0.010
Growth	3	732.69	244.23	9.05	<0.001
Cycle*Growth	6	113.51	18.92	0.70	0.651
Residual	33	890.81	26.99		
Total	47	2246.95			

28a. Transformed appendix 28

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.06857	0.02286	2.26	
Cycle	2	0.16238	0.08119	8.04	0.001
Growth	3	0.31576	0.10525	10.42	<0.001
Cycle*Growth	6	0.03145	0.00524	0.52	0.790
Residual	33	0.33322	0.01010		
Total	47	0.91137			

29. ANOVA for effect of crop cycle or plant growth on emerging larvae

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	3.2111	1.0704	7.75	
Cycle	2	0.0357	0.0179	0.13	0.879
Growth	3	2.2689	0.7563	5.48	0.004
Cycle*Growth	6	0.5361	0.0894	0.65	0.692
Residual	33	4.5556	0.1380		
Total	47	10.6074			

29a. Transformed appendix 29

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.73106	0.24369	8.19	
Cycle	2	0.01492	0.00746	0.25	0.780
Growth	3	0.58257	0.19419	6.53	0.001
Cycle*Growth	6	0.11102	0.01850	0.62	0.711
Residual	33	0.98209	0.02976		
Total	47	2.42166			

30. ANOVA for effect of crop cycle or plant growth on pupa population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.020000	0.006667	0.85	
Cycle	2	0.065000	0.032500	4.12	0.025
Growth	3	0.060000	0.020000	2.54	0.073
Cycle*Growth	6	0.115000	0.019167	2.43	0.047
Residual	33	0.260000	0.007879		
Total	47	0.520000			

30a. Transformed appendix 30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.007661	0.002554	0.84	
Cycle	2	0.025054	0.012527	4.13	0.025
Growth	3	0.024066	0.008022	2.65	0.065
Cycle*Growth	6	0.046034	0.007672	2.53	0.040
Residual	33	0.100069	0.003032		
Total	47	0.202884			

31. ANOVA for effect of crop cycle or plant growth on adult population attached to corms

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.25667	0.08556	1.20	
Cycle	2	0.36500	0.18250	2.57	0.092
Growth	3	0.40333	0.13444	1.89	0.150
Cycle*Growth	6	0.36167	0.06028	0.85	0.542
Residual	33	2.34333	0.07101		
Total	47	3.73000			

31a. Transformed appendix 31

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.07300	0.02433	1.33	
Cycle	2	0.10604	0.05302	2.90	0.069
Growth	3	0.10603	0.03534	1.94	0.143
Cycle*Growth	6	0.08363	0.01394	0.76	0.604
Residual	33	0.60262	0.01826		
Total	47	0.97131			

32. ANOVA for effect of crop cycle or plant growth on corm diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	36.767	12.256	4.201	
Cycle	2	25.355	12.678	4.34	0.021
Growth	3	1121.152	373.717	127.95	0.001
Cycle*Growth	6	27.000	4.500	1.54	0.196
Residual	33	96 385	2.921		
Total	47	1306.660			

33. Regression of corm diameter against damage (PCI)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	882	881.62	21.46	<0.001
Residual	232	9530	41.08		
Total	233	10411	44.68		

34. Regression of corm diameter against damage (PD)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	1305	1304.64	15.69	<0.001
Residual	232	19289	83.14		
Total	233	20594	88.38		

35. Regression of corm diameter against damage (cross section)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	1151	1150.61	16.49	<0.001
Residual	232	16190	69.78		
Total	233	17340	74.42		

36. ANOVA for effect of watering frequencies/plant vigour on corm diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	24.4528	8.1509	10.64	0.001
Residual	12	9.1923	0.7660		
Total	15	33.6450			

37. ANOVA for effect of watering frequencies/plant vigour on plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatmen	3	13783.05	4594.35	96.54	<0.001
Residual	12	571.08	47.59		
Total	15	14354.12			

38. ANOVA for effect of watering frequencies/plant vigour on plant girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	435.960	145.320	109.15	<0.001
Residual	12	15.976	1.331		
Total	15	451.936			

39. ANOVA for effect of watering frequencies/plant vigour on number of leaves

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	79.9526	26.6509	28.79	<0.001
Residual	12	11.1074	0.9256		
Total	15	91.0601			

39a. Transformed appendix 39

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	2.78639	0.92880	23.14	<0.001
Residual	12	0.48165	0.04014		
Total	15	3.26804			

40. ANOVA for effect of watering frequencies/plant vigour on number of suckers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	6.67000	2.22333	60.64	<0.001
Residual	12	0.44000	0.03667		
Total	15	7.11000			

40a. Transformed appendix 40

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	1.317162	0.439054	53.91	<0.001
Residual	12	0.097730	0.008144		
Total	15	1.414893			

41. ANOVA for effect of watering frequencies/plant vigour on adult emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	8.788	2.929	2.45	0.114
Residual	12	14.370	1.198		
Total	15	23.158			

41a. Transformed appendix 41

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.54710	0.18237	2.55	0.104
Residual	12	0.85694	0.07141		
Total	15	1.40405			

42. ANOVA for effect of watering frequencies/plant vigour on larval emergence

Source of variation.	d.f.	s.s.	m.s.	v.r.	F pr
Treatment	3	0.8196	0.2732	1.60	0.241
Residual	12	2.0487	0.1707		
Total	15	2.8683			

42a. Transformed appendix 42

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.22514	0.07505	1.72	0.216
Residual	12	0.52346	0.04362		
Total	15	0.74861			

43. ANOVA for effect of watering frequencies/plant vigour on pupa population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.05021	0.01674	0.53	0.672
Residual	12	0.38082	0.03173		
Total	15	0.43103			

43a. Transformed appendix 43

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.01925	0.00642	0.56	0.653
Residual	12	0.13793	0.01149		
Total	15	0.15718			

44. ANOVA for effect of watering frequencies/plant vigour on corm damage (PCI)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	102.04	34.01	2.73	0.090
Residual	12	149.24	12.44		
Total	15	251.28			

44a. Transformed appendix 44

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	2.4789	0.8263	2.81	0.084
Residual	12	3.5249	0.2937		
Total	15	6.0039			

45. ANOVA for effect of watering frequencies/plant vigour on corm damage (PD)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	2811.8	937.3	3.70	0.043
Residual	12	3040.1	253.3		
Total	15	5851.9			

45a. Transformed appendix 45

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatmen	3	0.35250	0.11750	3.82	0.039
Residual	12	0.36893	0.03074		
Total	15	0.72143			

46. ANOVA for effect of watering frequencies/plant vigour on total cross section damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	4051.6	1350.5	5.89	0.010
Residual	12	2751.9	229.3		
Total	15	6803.5			

46a. Transformed appendix 46

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.52844	0.17615	5.97	0.010
Residual	12	0.35393	0.02949		
Total	15	0.88237			

47. ANOVA for effect of watering frequencies/plant vigour on inner corm cross section

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	3872.0	1290.7	5.07	0.017
Residual	12	3052.1	254.3		
Total	15	6924.1			

47a. Transformed 47

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.49116	0.16372	5.23	0.015
Residual	12	0.37540	0.03128		
Total	15	0.86655			

48. ANOVA for effect of watering frequencies/plant vigour on outer corm cross section

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	4390.7	1463.6	6.98	0.006
Residual	12	2517.2	209.8		
Total	15	6907.9			

48a. Transformed appendix 48

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.59200	0.19733	6.65	0.007
Residual	12	0.35621	0.02968		
Total	15	0.94821			

49. ANOVA for the effect of town location on weevil fecundity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	2	6.131	3.065	2.29	0.120
Residual	27	36.116	1.338		
Total	29	42.247			

49a Transformed appendix 49

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	2	0.42473	0.21236	2.26	0.124
Residual	27	2.53683	0.09396		
Total	29	2.96155			

50. ANOVA for the effect of planting material infestation on emerging larva

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	12.991	6.495	2.97	0.068
Residual	28(14)	61.303	2.189		
Total	30(14)	69.419			

50a. Transformed appendix 50

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	2.0148	1.0074	3.94	0.031
Residual	28(14)	7.1666	0.2559		
Total	30(14)	8.3882			

51. ANOVA for the effect of planting material infestation on emerging pupa

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	0	0	*	
Residual	28(14)	0	0	*	*
Total	30(14)	0			

52.ANOVA for the effect of planting material infestation on emerged adult population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	19.600	9.800	7.40	0.002
Residual	42	55.600	1.324		
Total	44	75.200			

52a. Transformed appendix 52

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	2.7016	1.3508	7.40	0.002
Residual	42	7.6642	0.1825		
Total	44	10.3658			

53. ANOVA for the effect of planting material infestation on corm damage (PCI)

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	480.61	240.30	4.39	0.022
Residual	28(14)	1534.05	54.79		
Total	30(14)	1819.35			

53a. Transformed appendix 53

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	21.434	10.717	4.91	0.015
Residual	28(14)	61.082	2.182		
Total	30(14)	73.852			

54. ANOVA for the effect of planting material infestation on corm damage (PD)

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	755.07	377.53	4.82	0.016
Residual	28(14)	2191.21	78.26		
Total	30(14)	2643.87			

54a. Transformed appendix 54

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	0.37020	0.18510	4.95	0.014
Residual	28(14)	1.04723	0.03740		
Total	30(14)	1.27052			

55. ANOVA for the effect of planting material infestation on overall corm cross section damage

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	5940.3	2970.1	7.17	0.003
Residual	28(14)	11598.3	414.2		
Total	30(14)	15131.4			

55a. Transformed appendix 55

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	1.47883	0.73942	7.93	0.002
Residual	28(14)	2.61084	0.09324		
Total	30(14)	3.48859			

56. ANOVA for the effect of planting material infestation on inner corm cross section damage

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	7932.1	3966.1	5.88	0.007
Residual	28(14)	18882.4	674.4		
Total	30(14)	23670.7			

56a. Transformed appendix 56

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	2.1567	1.0783 7	.09	0.003
Residual	28(14)	4.2592	0.1521		
Total	30(14)	5.5511			

57. ANOVA for the effect of planting material infestation on outer corm cross section damage

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	4569.3	2284.7	6.48	0.005
Residual	28(14)	9869.7	352.5		
Total	30(14)	12591.5			

57a. Transformed appendix 57

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Treatment	2	1.44460	0.72230	7.51	0.002
Residual	28(14)	2.69324	0.09619		
Total	30(14)	3.55182			