SPECIES COMPOSITION, BIOLOGY AND MANAGEMENT OF SWEET POTATO WEEVILS (*CYLAS SPECIES*) IN SOUTHERN GHANA.

BY

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A THESIS PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF PHILOSOPHY (ENTOMOLOGY) OF THE UNIVERSITY OF GHANA

INSECT SCIENCE PROGRAMME*
UNIVERSITY OF GHANA
LEGON
SEPTEMBER 2000

*JOINT INTERFACULTY INTERNATIONAL PROGRAMME FOR THE TRAINING OF ENTOMOLOGISTS IN WEST AFRICA
COLLABORATING DEPARTMENTS: ZOOLOGY (FACULTY OF SCIENCE) &CROP SCIENCE (FACULTY OF AGRICULTURE)

DECLARATION

I hereby declare that, with the exception of references to other people's work which have duly been cited, this work is the result of my own tireless original research and that this thesis has neither in whole or in part been presented for another degree elsewhere

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ABSTRACT

Species composition of sweet potato weevils (*Cylas spp*) on two sweet potato varieties was determined in the southern parts of the country. One species, *Cylas puncticollis* Boh. was found to be present in the southern part of Ghana.

Studies on the biology of *Cylas puncticollis* were evaluated on two varieties, red and white varieties, under laboratory conditions at 27.0°C and 70% RH. The incubation period of the eggs were 4 days on the red variety and 5 days on the white variety. Larval stages ranged from 10-11 days on the red and 10-12 days on the white. The pupal stage lasted 6-8 days on the red and 7-8 days on the white. Three larval instars were identified. Total developmental period from the egg stage to the adult stage ranged from 19-23 days on the red variety and 19-25 days on the white variety.

Limited copulation significantly ($P<0.05$, t-test) increased oviposition and longevity periods of female weevils on both varieties. However, there was no significant difference in the number of eggs laid by females with limited copulation and those with unlimited copulation. Average percentage hatchability of eggs laid by females with limited copulation was 79.5 % and that of females with unlimited copulation was 85.7%.

Cores from sweet potato [*Ipomoea batatas* (L.) Lam] root tubers (red and white varieties) were presented to *Cylas puncticollis* in choice- and no- choice bioassays. The red variety was significantly ($P<0.05$) preferred for oviposition in the choice bioassay.

The effect of treatments (fertilizer, furadan, a combination of fertilizer and furadan) on sweet potato weevil populations was evaluated on two varieties in two separate fields . In

both fields analysis showed that there was no significant difference (P>0.05,AOV) between the treatments on the weevils' population.

Treatment effect on weevils' infestation (damage) of tubers on the two varieties was assessed during harvesting. The effects of the treatments did not differ significantly (P>0.05) from each other and from the control. However, furadan moderately reduced tuber infestation (damage) during the two planting seasons.

DEDICATION

To my Dear wife, ANNIS ADDO and my beloved mother, the late GRACE MANKOSAH ANTWI. May her soul rest in perfect peace

ACKNOWLEDGEMENT

This thesis was begun with the support of the African Regional Post- graduate Programme in Insect Science (ARPPIS) at the university of Ghana, Legon and ended with similar support from my family members for which I am deeply grateful.

Throughout the time of the research and the composition, I have received unflagging co-operation from my Supervisors-Dr D. D. Wilson and Miss M. A. Cobblah. It is their guidance, criticisms and concrete suggestions that have made this work fruitful.

I wish to express my profound gratitude to the co-ordinator of the ARPPIS programme for keeping me on my toes all the time, making sure the work is completed. Special thanks go to Dr. Mrs. Botchey of the University of Cape-Coast who also read through the thesis and made valuable corrections and suggestions. I am also grateful to all the lecturers on the ARPPIS programme, as well as the staff of the Zoology and Crop Science Departments, University of Ghana, whose facilities were put at my disposal for the field and laboratory work.

Many friends and colleagues have also helped make the thesis a reality: the first and special mention go to Mr. Yaw Awuah Nkansah of Abosseokine Auto Spare Parts, who made his Isuzu pickup and other vehicles available to me when the field work was going on at Tubaman; F.M, who assisted me for the field work; Mr. Aboah, driver attached to the Zoology Department who always had to wake up very early in the morning to pick me to the farm at Tubaman,Weija; Mr Kofi Adasi and Kwame Sefa for their encouragements and sometimes reading through the manuscript and making useful corrections; Mr. Asante of the Crop Science Department for his assistance in the analysis of some of the results. Other people whose contributions are special to me are the farmers, and traders of Agbogbloshie and the Kaneshie markets who had the patience and gave very useful information about the problems of sweet potato and how they try to solve them

Special appreciations also go to two tireless Secretaries-Miss Lydia Asiedu Darko of the ARPPIS programme office and Mrs. Caroline Asiedu-Danquah of the distant education office of the University of Ghana, Legon. These two ladies lightened my labour by type setting some parts of the thesis for me. I can also not forget my roommate, Tunji Dada at Valco Trust Hostel and my 1997/98 ARPPIS mates who gave me absolute peace and co-operation during our stay on campus.

For other help and advice, I am very much grateful to Mr.Evans Asare Darko, Miss Veronica Amo-Darko, Elizabeth Darko, Mr J. K Annor, Mr. Clement Adu, Mr. Philip Opoku Antwi, Dorothy Abossey, Mr. Christopher Narku Nortey, Ruth Fuah and family and all the 1997-1999 students on the ARPPIS programme, especially Eric Folcan of Cameroon.

Unfortunately, I cannot mention the names of all those who in one-way or the other contributed to make this work possible. To them I will say "God bless you all"

Above all, I wish to express my sincere and profound appreciation to the ALMIGHTY JEHOVAH for his sustenance during the thick and thin periods.

TABLE OF CONTENTS

CHAPTER 3

CHAPTER 4

CHAPTER 5

LIST OF TABLES

TABLES **PAGE**

LIST OF FIGURES

FIGURES **PAGE**

LIST OF PLATES

PLATE PAGE

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND INFORMATION

Sweet potato, *Ipomoea batatas* (L) Lam., is one of the most widely grown and adaptable crops in the world, and farmers across tropical, subtropical and warm temperate areas depend on it for its high yield on marginal lands (Horton, 1989).

Sweet potato ranks seventh among all food crops worldwide, with annual production of 115 million metric tons (FAO, 1984). Of the root and tuber crops, sweet potato ranks third in acreage (7.9 million ha.) behind white potato, *Solanum tuberosum* L, (20.1 million ha.) and cassava, *Manihot esculentum* Crantz, (14.8 million ha) (FAO, 1984). It is grown in more than hundred countries, and is among the world's root and tuber crops it ranks second in importance to the white potato (Horton, 1987).

Developing countries account for 98% of the world production of sweet potato (Gregory *et al.*, 1990; Horton 1988). Since 1961,sweet potato production has increased by 20% in developing countries (Gregory *et al.*, 1990)

Sweet potato is an important staple food in areas of subsistence farming and is a drought-tolerant crop (Bouwkamp, 1985). Its production adapts well to both low and high technology input agricultural systems.

1.1 ORIGIN AND SPREAD OF SWEET POTATO

Sweet potato plant, *Ipomoea batatas* (L.) Lam. originated in Central America or Northwestern South America. Its cultivation is believed to have occurred about 3000 BC (O'Brien, 1972). According to FAO (1994), the ancient Peruvian and Mayan civilizations of tropical America, as well as the tropical Pacific Islands grew sweet potato extensively.

It is also believed that Columbus introduced the sweet potato into Europe after voyages of discovery, while Spanish and Portuguese explorers and traders subsequently introduced it into Africa and Asia (FAO, 1994). It is now grown circumglobally in tropical and sub-tropical latitudes and constitutes one of the seven most important crops on a worldwide basis (Chalfant *et al.*, 1990; FAO, 1984; Jones, 1970)

In Ghana, the sweet potato is an important food crop. It is widely grown on subsistence basis, and serves primarily as an insurance crop for the food security of smallholder households in certain areas of the country. Relatively, sweet potato is a short season crop that requires little labour and inputs outside the farmers' household. In addition, it is relatively very efficient in the production of carbohydrates, proteins and vitamins. It is also very useful based on its cash income generation per unit land area, time and other inputs (Wilson, Pers. Com.).

1.2 USES

Sweet potato is used as a staple food, vegetable (both fleshy roots, tender leaves, and petioles), snack food, animal feed, for industrial starch extraction and fermentation, and for various processed products (Bouwkamp, 1985; Kays, 1985; Lin *et al.*, 1985, Sakamoto and

Bouwcamp, 1985). Though, the use of sweet potato for human consumption has declined, its use as animal feed and raw material for the manufacture of industrial products has increased (Gregory *et al.*, 1990). According to Anonymous (1989) two factors account for this decline in usage of the crop. These are the limited knowledge of its nutritional value and its low cultural status in some regions of the world.

Among the ten leading food crops, sweet potato ranks third in terms of calories produced per square meter (Bouwkamp, 1985). With the exception of protein and niacin, it provides over 90% of food nutrients per calorie required for most people (Watt and Merrill, 1975).

In Ghana, sweet potato is an important food crop that is either boiled or fried. Sometimes the tuber is boiled, mashed and mixed with corn dough as a sweetener before frying. This is locally called 'awiesu' or 'bandfo bese'.

1.3 CROPPING PATTERN

The crop is commonly monocropped in small patches scattered around the farm or the farm hut. It is also sometimes inter –or relay cropped with other crops such as maize, cassava, sorghum and plantain where it acts as live mulch and suppresses weeds. Yields of plants grown in mixed cropping systems are usually below those of plants grown in monoculture (Singh *et al.*, 1984). This is due, in part, to the shading effect of upper storey crops on the lower storey sweet potato crop. Shading of greater than 25% results in longer vine length and slower growth during the first few weeks in the field (Robert-Nkrumah *et al.*, 1986). Therefore, in areas of weevil infestation, damage could be more devastating to shaded plants due to the reduced ability of the plant to compensate for weevil feeding.

In the tropics, sweet potato is normally propagated from vine tip cuttings harvested from fields, which are ready for harvest. Ray *et al,* (1983) suggested that, this practice enhances the severity of weevil infestation. The vines are planted on ridges, mounds, or even on flat land. The tillage method is often traditional and is influenced by such factors as soil type, fertility and drainage conditions.

1.4 CHARACTERISTICS AND FUTURE PROSPECTS

According to the FAO, 1994 report, the sweet potato possesses several characteristics that make it the ideal crop for plugging gaps in household and national food security. They include the following:

1. Drought tolerance
2. Tolerance of low fertility
3. Low labour requirement
4. Early maturing.

Another emerging potential for sweet potato is that, it is one of the eight crops chosen by the United States National Aeronautic and space Administration as a possible food source for long term manned space mission (Hill *et al.*, 1988). This was chosen mainly because of its palatability, versatility and nutritional contents of the roots and shoots.

1.5 PRODUCTION CONSTRAINTS

Like all the tropical tuber crops, sweet potato production is constrained by problems such as inadequate quantity and quality of planting materials, diseases and pests. In terms of quantity, sweet potato planting material (shoot tips and pieces) is more perishable and less storable than yam, cassava or cocoyams. It usually requires nurseries of sweet potato plants to be maintained through the dry or adverse season. In a situation where such facilities are not available, shortage of planting material usually results FAO (1994).

Concerning the quality of planting materials, many varieties used by subsistence farmers are susceptible to disease and pest infestation. Fortunately, recent research advances have led to the release of varieties such as TIS 2498 and TIS 9265,which are high yielding, resistant to the sweet potato virus and relatively tolerant to sweet potato weevils (FAO, 1994).

The problems of insect pests both in the field and during storage are the most important causes of yield losses. Sweet potato weevils, of the genus *Cylas* (Chalfant *et al.*, 1990) are the most destructive insect pests of the crop. Even at low populations, the weevils reduce yield and quality of root tubers (Prohold, 1983). According to Akazawa *et al.*, (1960), attack by the weevils elicit the production of bitter tasting and toxic sesquiterpenes which render infested roots unfit for human consumption.

1.6 PEST MANAGEMENT

The control of sweet potato weevils has been met with some degree of difficulties. The larva, which is the most destructive stage of the insect, feed on stem and storage roots. Their presence inside the tubers protects them from contact pesticides and most arthropod natural enemies.

In spite of this, numerous chemical insecticides, which include Furadan and Karata have been tested for the control of *Cylas* spp (Sutherland, 1986). Control achieved by post-planting application of chemical insecticides appears to be due to mortality of adult weevils in search of feeding or oviposition sites. Movement of adult weevils may facilitate the contact between the toxicant and the insect, thereby resulting in insect mortality. This method may require frequent applications to be effective (Sakae, 1988). However, frequent application of insecticides is not cost-effective due to the low market price for sweet potato in developing countries. In addition, the health hazards associated with it may not be worth it. It is therefore important that more environmentally friendly and cost effective control measures be adopted to manage the insect pest problems and also to increase yield.

1.7 JUSTIFICATION

Though the sweet potato plants are attacked by various pests, the sweet potato weevil (SPW) of the genus *Cylas* are the most destructive (Wolfe, 1991; Talekar, 1982) and limit production worldwide (Chalfant, 1990). Despite the threat posed by *Cylas* spp to sweet potato production, the identities of the various species present in various locations in Africa such as Ghana are still in doubt (Wolfe, 1991). This stems from the similarity among the species.

In Ghana, there is an urgent need to confirm the distribution and species composition of *Cylas* weevils. Wolfe (1991) and Parker *et al.*, (1992) considered that the cosmopolitan species, *C. formicarius* is absent in the West African sub–region. Hill (1975) indicated that *C. puncticollis* is not present in Ghana. Forsyth (1966) did not make mention of *C puncticollis* though *C. brunneus* and *C. formicarius* were listed. It is contended, however, that all the three species of pest status are present (Wilson pers. comm.). These contentions and doubts presuppose that information about the weevil complex in Ghana is lacking and need to be resolved.

For efficient control or pest management practices to be successful there is the need for correct or accurate identification and knowledge of distribution of the pest species. Studies on the biology of the pests are equally important in devising an appropriate pest management strategy.

As Furadan and fertilizer (NPK) are commonly used in sweet potato farms, it is vital to assess the effect of these chemicals on the weevil population with respect to the yield (damaged and undamaged tubers). The results obtained in such a study could be used in future agronomic and cultural practices for the control of sweet potato weevils.

1.8 **OBJECTIVES**

The objectives of this research work form part of the ultimate objective to develop an integrated management programme (IPM) for the control of sweet potato weevils in Ghana.

The objectives are as described below:

a. Conduct a preliminary survey to find out the level of knowledge farmers and traders have on the sweet potato weevils, the control practices and the general problems they encounter with the cultivation and sale of the sweet potato

b. Survey to collect and determine the species composition of sweet potato weevil (SPW) in selected areas of the Eastern, Central, and Greater Accra regions of Southern part of Ghana.

c. Study the biology and oviposition preference of the species that would be collected.

d. Determine the effect of fertilizer (NPK), and Furadan on the SPW population and their effects on tuber yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 INSECT PESTS ASSOCIATED WITH SWEET POTATO

Several insect pests attack sweet potato. The pests that have been recorded include various members of Lepidoptera, Thysanoptera, Orthoptera, and Hemiptera (Chalfant *et al.*, 1990; Kay, 1973; Talekar, 1988; Wyniger, 1962). Among Coleopterans, members of Elateridae, Scarabaeidae, Chrysomelidae, and Curculionidae attack sweet Potato (Polland, 1984; Wyniger, 1962).

The most commonly recorded insect pests of sweet potato could be categorised into leaf feeders and root tuber feeders. Among the pests that attack sweet potato plant, the most destructive is *Cylas spp*. It attacks roots, leaves, and stems. It seriously reduces market value and storage quality of roots after harvest (Hahn and Leuschner, 1981).

2.2 TAXONOMY, DISTRIBUTION AND IMPORTANCE OF *CYLAS* SPP

The sweet potato weevils (*Cylas spp*) belong to the order Coleoptera, family Curculionidae and the subfamily Cylaninae (Borror and Delong, 1964; Comstock, 1967). Currently, they are put in the family Apionidae (Kissinger, 1968).

Weevils' senso lato constitute the most important insect threat on a worldwide basis and certain species of *Cylas* particularly are problematic (Edmond, 1971; Sutherland, 1986). It is considered a soil insect because of its subterranean habit while attacking the root tubers (Lily, 1956). Most species of *Cylas* are confined to Africa-Madagascar with a secondary center of diversity in India-Southeast Asia (Wolfe, 1991). *Cylas puncticollis* is found within the African continent. It has the widest distribution in central southwestern Africa, especially in Chad, Niger and in Egypt in the northern part of Africa. *Cylas brunneus* is known in West and central Africa. Specimens of *Cylas brunneus have* been collected in association with *C. puncticollis* in Nigeria, Rwanda, Burundi and Kenya (Wolfe, 1991).

According to Singh (1973), Golding first recorded *C. puncticollis* Boh in Nigeria in 1946 as a serious pest of sweet potato. Libby (1968) reported that there are two species of the sweet potato weevils in Nigeria, namely *C. puncticollis* Boh. and *C. brunneus* (F). These two species differ in size. Whereas *C puncticollis* is longer and more robust, *C.brunneus* is shorter and sluggish. Field and storage observation indicate that *C.puncticollis* is the predominant species in both situations (Soenargio, 1976).

Cylas formicarius is the only species that occurs circumglobally. It however, appears to be rare in Continental Africa because substantial numbers of specimens of *C.formicarius* have only been collected in eastern Kenya and South Africa (Wolfe, 1991).

2.3 SYMPTOMS AND ECONOMIC IMPACT BY *CYLAS SPP* ATTACK

The adult stage of *Cylas spp* feed on the epidermis of vines by scraping oval patches off young vines and petioles. In addition, they feed on external surfaces of storage roots resulting in round feeding punctures. The Larvae tunnel tubers and vines. The tunnels may be partially filled with frass, and in response, tuberous roots produce terpene-like chemicals that render the damage roots inedible (Sato *et al.*, 1982). Feeding inside the vines causes malformation, thickening and cracking of the vines. The Leaves may become pale green, and growth or overall vigour of the plant may be adversely affected (Sherman and Tamashiro, 1954).

Most studies on weevils' damage have been done using *C. formicarius*. This insect has been noted as a destructive pest of sweet potato throughout tropical to subtropical Asia, Pacific, Caribbean, United States and several countries in Africa.

Low-level infestations reduce quality and marketable yield (Proshold, 1983). Terpenoids that are produced by sweet potato in response to SPW feeding may make even slightly damaged roots unfit for human consumption (Uritani *et al.*, 1975, Akwazawa *et al.*, 1960). Yield losses of up to 60-80% have been attributed to SPW (Hua 1970; Subramanian *et al.*, 1977; Mullen 1984).

Losses due to weevils' infestation range from 5 to 80%, the duration of the crop in the field being the most significant factor exacerbating the pest damage. In Indonesia, Kemner (1924), noted that the weevils damage become more significant the longer the crop remained in the field unharvested. In Kerala, India, this insect can cause yield losses of 19-54% and in Malaysia up to 80% Ho (1970). At IITA (International Institute of Tropical Agriculture, Nigeria) crop losses of up to 80% have been reported in experimental plots where both tubers and stems were attacked. The attack on stems tends to enhance the build-up of the insect population in the tubers. Such population build-ups have been realised to be slow during the first two months because of the restricted breeding space in the stem, but rapidly increasing in the second half of the growing season when tubers are available (IITA, 1978).

Jansson *et al.*, (1990) reported an exponential increase of the weevils' population at one per plant per day. Most of the increase in population density occurs late in the growing season when storage roots are more abundant .At this time, a greater percentage of the weevil population is found in the storage roots.

2.4 EFFECT OF SWEET POTATO WEEVILS ON YIELD

A moderate level of resistance of sweet potato varieties to infestation of the sweet potato weevil, *Cylas formicarius elegantulus* (summers), has been demonstrated. However, complete immunity does not exist (Mullen *et al.*, 1980). Little has been done to examine the effect of sweet potato weevil infestation on yield. Cockerham *et al.*, (1954) observed that the effects of weevil infestation on yield were minimal. Talekar (1982) reported similar results for *C. f. formicarius* (Fabricius) in Taiwan. However, Pillai and Nair (1981) reported yield losses of 10-100% due to weevils' infestation. Subramaniam *et al.*, (1977) and Pillai *et al.*, (1981) reported losses of 35-70% depending on the season.

2.5 BIOLOGY OF *CYLAS SPP*

With the exception of *C. formicarius*, detailed studies on the biology of the other species are rare. Generally, the eggs are laid singly in cavities in the roots or stems. The egg hole is then covered with a grayish mass, which hardens to form a protective cap over the developing egg (Reinard, 1923; Gonzale, 1925)

Egg incubation period ranges from 4 days at 0^0C to 7.9 days at 20^0 C (Mullen, 1981). Cockerham *et al.*, (1954) reported an incubation period of 4 to 56 days at mean temperatures of 20^0C and 10.5^0C respectively.

Larvae feed inside roots or stems where oviposition occurs for 25-35 days during which they complete three larval instars (Sherman and Tamashiro, 1954). Larval developmental period lasted for 16.2 days at 30^{0}C and 58.2 days at 20°C (Mullen, 1981), whereas Cockerham *et al.*, (1954) reported a range of 12-154 days under field conditions in the United States of America.

Pupation takes place within the sweet potato roots or stems. The pupal period lasts 4-8 days (Franssen 1935; Sherman and Tamashiro, 1954). In the laboratory, pupal period lasted for 5 and 10.7 days at 25 and 20°C respectively (Mullen, 1981). Cockerham *et al.*, (1954) also reported a mean pupal period of 7.5 days at 25.6 - 27^{0}C. Adults mate soon after emergence but oviposition does not occur for a minimum of 4.5 days at 30^{0}C or 7.7 days at 20°C (Mullen, 1981)

There is a great variation in adult survival. Franssen (1935) reported female's maximum survival to be 113 days. Subramanian (1959) found males and females surviving for 94 and 109 days respectively in India. Under laboratory conditions survival averaged 238 days at 15^{0}C (Mullen, 1981).

Female weevils begin laying eggs about four days after adult emergence and continue to lay eggs for over 75 days thereafter (Jansson and Hunsberger, 1991). *Cylas formicarius* requires between 22-78 days to develop from the egg stage to adult emergence depending on temperature (Chalfant *et al.*, 1990). Between 27 and 30^{0}C, only about 33 days on the average are needed to complete development (Chalfant *et al.*, 1990)

Gonzales (1925) reported a fecundity of 90-340 eggs per female which Cockerham *et al.*, (1954) reported 1 to 319 eggs. Mullen (1981) found a single female to lay between 1 to 179 eggs. For all these studies, fecundity varied with the number of mating and crowding.

Some few studies have been reported on the biology of *C puncticollis.* Nwana (1979) reported an incubation period of 2-4, a larval period of 17-23 days and a pupal period of 4-6. At IITA (International Institute of Tropical Agriculture), an incubation period of 3-4 days, larval period of 11-12 days, preoviposition period of 3-4 days and a total life cycle of 22-27 days were recorded

Tomu (1982) reported mean developmental period (days) of *C. puncticollis* on different varieties. Pupal period ranges from 6.5-8.6 days whilst total egg-adult developmental period varied from 22-28 days on all the different varieties. Development, fecundity and longevity of the *Cylas spp* are temperature dependent.

2.6 CONTROL PRACTICES

Economically effective control measures for SPW in regions with large resident populations are lacking (Jansson *et al.*, 1987). There are no insecticides that will adequately control weevils in an infested field (Stall *et al.*, 1984). This stems from the fact that, the immature stages of SPW are spent within vines and / or roots. This makes *Cylas spp* very difficult to control with applications of conventional chemical insecticides. Despite this difficulty, numerous chemical insecticides have been tested for the control of *C. formicarius*. Sutherland (1986a) listed 59 different insecticides, including botanicals of unknown chemical compositions.

Weevils' population can be reduced by such cultural practices as crop rotation, clean cultivation, good sanitation and mulching because the insect has a limited flight activity (Cockerham *et al.*, 1954; Sherman and Tamashiro, 1954).

Weevil resistant sweet potato varieties also form an essential component in the integrated pest management of *Cylas spp* (Martin and Jones, 1986), has been shown that surface chemical factors in the sweet potato play a role in susceptibility to the weevils (Wilson *et al.*, 1988).

2.6.1 PRE-PLANT APPLICATION

Pre-plant insecticide applications have been used to exterminate weevils from the planting material (vine cuttings) before planting. Insecticides with adequate water solubility are presumably transported through the vine and kill the weevil in that plant part. This type of treatment is usually more economical than post-plant insecticide applications. If combined with proper sanitation and other measures to prevent immigration of weevil from infested plants, it may result in satisfactory control of the weevil (Sherman and Mitchell, 1953; Sherman and Tamashiro 1954; Talekar, 1983).

2.6.2 POST-PLANT APPLICATION

Control of weevil is difficult with conventional spraying, dusting, fumigation or side dressing of insecticides, once weevils are present within the crown or the tuberous root. Control achieved by post-plant applications appears to be due to mortality of weevil adults searching for feeding or oviposition sites. Several researchers have obtained satisfactory control of the weevil by spraying vines or soil around stem (Waddill, 1982)

During an eight-year study in Louisiana, Flyod (1955) recorded percentage of infested roots, to be 0.1, 0.15...10.5 (average 3.0) when calcium arsenate dust was applied at the rate of 4.54kg/0.4ha to the crowns of the plants. However, with the application of granulated chlordane at the rate of 2.27kg/0.4ha to the soil, the percentage of infested roots were found to be from 2.2 to 27.0 with an average of 10.0. Singh (1973) observed that application of Didigam, Lindane and DDT at 400g-a.i/ha and soil application of Furadan at 100g ai/ha, gave good control of *C. puncticollis*.

2.7 FERTILIZER APPLICATION

Sweet potato usually responds to Nitrogen (N) fertilization (Bachillo and Hugo, 1976). It is generally accepted that approximately 100kg N/ha is optimal for high storage root yields (Anonymous, 1970).

High amount of slow-release fertilizer (19N-3P-10K) delayed storage root formation by 9 to 18 days. Wilson (1973) found that increasing N above optimal levels delayed storage root development by three weeks or more. As with the other growth characteristics, delayed storage root development due to improper fertilization might increase the likelihood of weevil attack. Bourke (1985) concluded that the beneficial effects of N fertilization were realized in greater leaf area duration, which in turn improved other growth and yield parameters.

2.8 HOST PLANT RESISTANCE

Many attempts have been made to find sources of resistance mainly to *Cylas spp* and to incorporate the resistance in agronomic varieties. This area of research has been followed at

IITA (International Institute of Tropical Agriculture) in Nigeria and the Asian Vegetable Research and Development Center (AVRDC) in Taiwan.

These efforts have been hampered by differences in weevil infestation among trials, location, and seasons. At times among replicates of a single accession in a trial, among plants in the same plot, and even among storage roots within one plant (Talekar, 1982, 1987)

A study of the chemical basis of resistance to the sweet potato weevil, *C. puncticollis* showed that sugar content contributed very little to tuber resistance whereas carotene content contributed significantly. The most susceptible varieties had low moisture content, and low carotene content whereas the most resistant varieties had high carotene content (Mullen *et al.*, 1980,1981; Asian Vegetable Research and Development Center (AVRDC), 1978).

Cuthbert and Davis (1971) however found that sweet potato lines with high carotene content suffered greater injury by the *Diabrotica-Systena* complex than lines with low carotene. In addition, depth of tubers was a major contributing factor to tuber resistance. Soenarjo (1976) found a very close genetic association between tuber damage and depth of tuber. It shows that increased depth of tuber also increased tuber resistance. Therefore, selection can be done for both traits simultaneously since this character contributed significantly to tuber resistance both genetically and physically.

Utilization of resistance as a means of preventing or minimizing losses due to insect pests' infestation might considerably reduce the need for insecticidal control. This will ultimately be of great value to farmers in the developing countries who are not so familiar with the proper use of insecticides.

According to Beck (1965), the first point in the insect-plant relationship at which the plant may show resistance is resistance to oviposition. Resistance of soybean varieties to the soybean pod borer, *Grapholillia glicinivorella* (M) appears to be one of oviposition preference, in which the moths tend to lay more eggs on hairy pods, than on smooth pods (Nisnijima, 1960). Resistance in the field may have been due to escape, for example, by having long thin storage roots set deep in the soil and scattered within growing hills (Cockerham *et al.*, 1954; Jayaramaiah, 1975), tolerance (Velusamy and Heinrichs, 1986), antixenoxis (nonpreference)(Kogan and Ortman, 1978), antibiosis (Painter, 1951), or a combination of any of these. The latter two types of plant resistance, which involve modification of the insect behavior and metabolism, have been shown to have a chemical basis and the factors responsible for variety differences and oviposition stimulation reside in the periderm of the storage root (Nottingham *et al.*, 1987).

CHAPTER THREE

GENERAL MATERIALS AND METHODOLOGY

3.1 EXPERIMENTAL LOCATIONS AND CONDITIONS

Various aspects of the experiments were conducted at different locations. Rearing of the weevils, the choice and no choice tests, as well as studies on the biology of the weevils were conducted in the laboratory of the Zoology Department, University of Ghana, Legon. The temperature and humidity conditions of the laboratory were 27.0^{0}C and 70%RH respectively.

The effect of different treatments on the population dynamics of the weevils, was conducted in the field at the irrigation project site situated at Tubaman near Kasoa in the central region.

Collection of sweet potato weevil (SPW) specimens were made by surveying farmers fields and/or visiting market women/men who purchase their products from the following areas:

Pokuase

Tubaman (Kasoa)

Aburi

Nkawkaw

Begoro

Afram Plains

Cape Coast

Plate 1(a): Weevil trap consisting of plastic basket and a root tuber being examined *by a field assistant.*

Plate 1(b): Adult emergence or breeding cage.

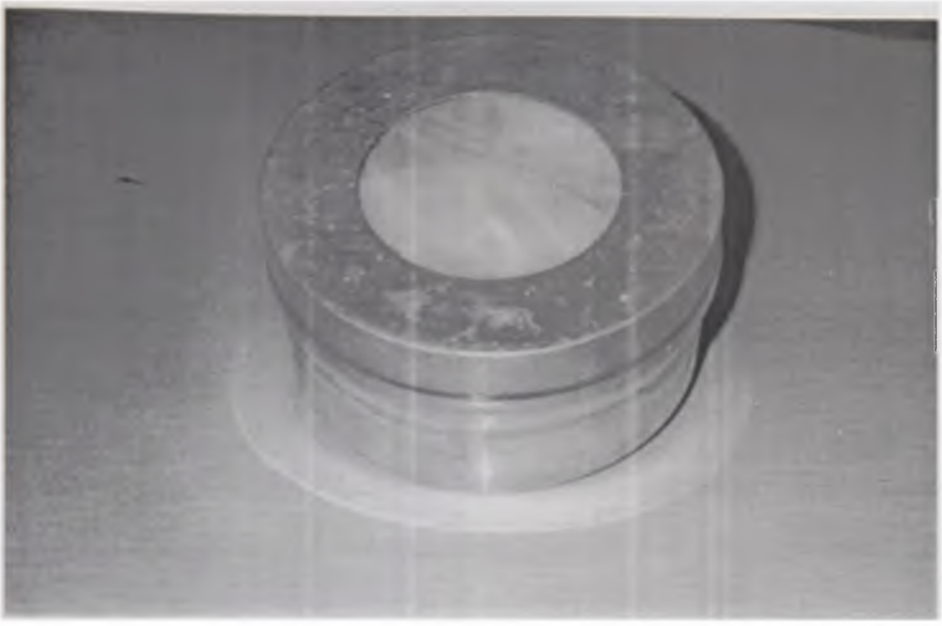


Plate 2(a): Oviposition cage with the lid

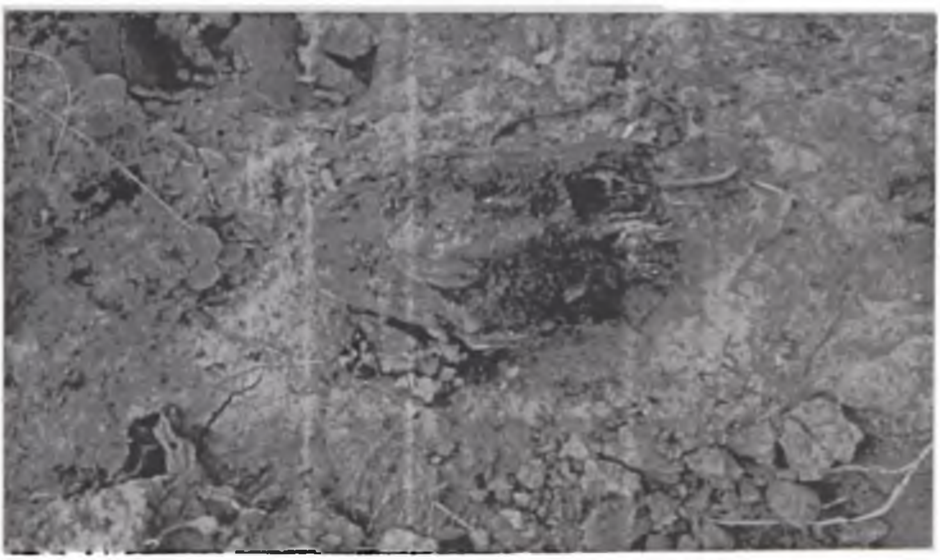


Plate 2(b): A rotten sweet potato root tuber due to weevil infestation and flooding.

3.2 ADULT EMERGENCE CAGE

The cage is wooden frame with nylon mesh covering the sides, and the top. The bottom is covered with plywood. Sweet potato root tubers that had been oviposited upon (Plate 1b) were placed in a cage. All the SPW, which were used in the experiments, were obtained from the general breeding cage.

3.3 WEEVIL TRAPS

The weevil traps were fresh sweet potato tubers covered with perforated plastic baskets (Plate1a). They were inspected every week after which all old tubers were replaced with new ones.

3.4 OVIPOSITION CAGE:

This is a cylindrical metal cage (Plate 2a) with diameter 17cm and height 10cm. It is covered with a lid, which has a circular hole of diameter 10cm in the middle. This hole was covered with a nylon mesh for aeration.

3.5 FALCON TISSUE CULTURE PLATE AND BORER

The falcon tissue culture plate (plate 3a) was used for choice and no-choice bioassay. It is rectangular made of transparent plastic. It has twenty-four (24) round wells of equal diameter of 1.6cm, depth of 2cm and an area of $2cm^2$ drilled in this culture plate. In addition, it has a lid used to cover the plate after the sweet potato cores and the insects have been introduced into the culture plate. The cork borer (plate 3b) is also made of metal and was used to make the potato cores.

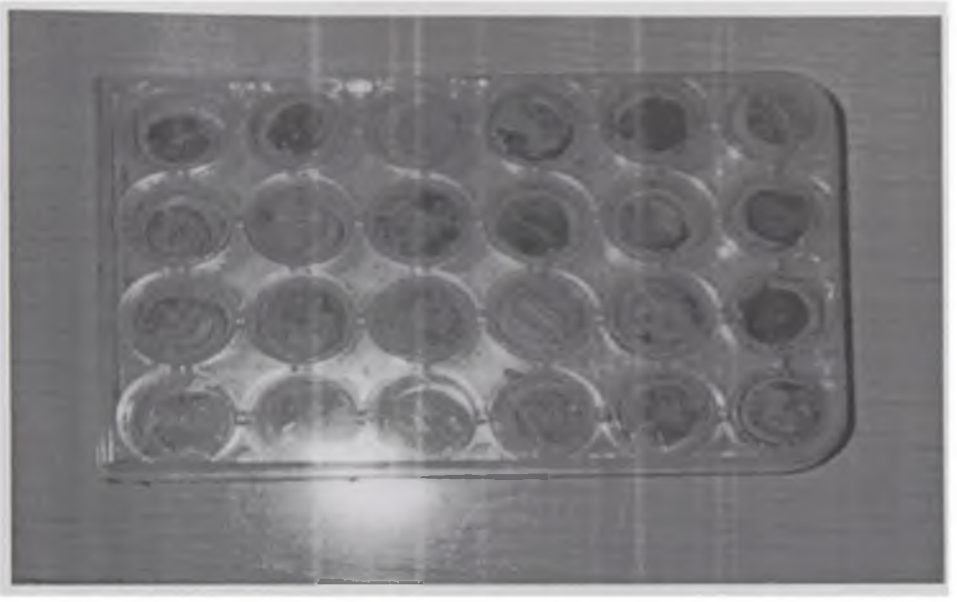


Plate 3(a): Falcon tissue culture plates with 24 wells.

Plate 3(b): Cork borer (No. 11).

Plate 4: Sweet potato farm at Tubaman near Kasoa showing the vegetative phase of the plant.

3.6 EXPERIMENTAL SITE

The field was situated at Tubaman near Kasoa in the central region of Ghana. Its size was approximately one acre (plate 4). There were eight ridged rows, four for the Red sweet potato variety (Frema) and the other four for the white variety. The length of each row was about 50m and a width of about 1.5m. Average distance between ridges was 200cm. There were twelve traps on each ridge, separated by an average distance of 2.0m.

3.7 PLANTING MATERIALS

First planting season was established to propagate vine cuttings and enough tubers for both field and laboratory work respectively. Two separate plots were cleared and ploughed. Four ridges were made on each plot and two days later, the field was irrigated. White and red sweet potato vines were obtained from farmers' fields and the University of Ghana Agriculture farms respectively. Fifteen weeks later the vines were harvested and used for the second planting. Later the root tubers were also uprooted and used for the laboratory work.

CHAPTER FOUR

PRELIMINARY SURVEY

4.1 INTRODUCTION

Knowledge of the status of global sweet potato, its utilization and associated problems is very limited. The best source of data has usually being the FAO'S basic data unit (Horton *et al* 1989). Unfortunately, this source may not be very reliable, particularly in developing countries like Ghana where most sweet potato are grown for on-farm use in isolated areas.

As a prelude to the main objectives of the study to determine the species composition of *Cylas* in the southern part of the country, a preliminary survey was conducted. This was to find out from both farmers and traders as to their knowledge about sweet potato weevils in particular, and in a broader sense, other constraint that may limit the production of sweet potato in Ghana in a near future.

4.2 MATERIALS AND METHODS

4.2.1 PRELIMINARY SURVEY

The study was carried out by administering forty questionnaires to farmers and traders. These were those who engaged in the production and sale of sweet potatoes. Twenty-two of the respondents were traders and the remaining eighteen were farmers.

The study areas include the following:

a. Agbogbloshie market

b. Kaneshie Market

c. Pokuase

d. Kasoa (Tubaman)

e. Cape Coast

f. Aburi

g. Afram Plains

h. Begoro

The above named areas cover the Greater Accra, Central, Eastern and the Volta regions. In administering the questionnaires (appendix A), all the traders and some of the farmers, particularly those from the Afram plains and Begoro were reached in the market centers in the early hours of the day. The rest of the farmers were reached in their farms.

4.2.2 DETERMINATION OF *CYLAS SPECIES* COMPOSITION

Farmers' fields of selected areas of the following locations were visited once every month over a period of eight months. The locations visited include: Tubaman (Kasoa), .Mankesim, .Pokuase, .Aburi and Cape coast.

Samples of weevil infested sweet potato from Afram plains and Begoro, were also taken from the Kaneshie and Agbogbloshie markets and examined.

In the field, weevil traps (Plate 1a) were set up using fresh sweet potato tubers. A minimum number of five weevils were taken from each location on every visit. Samples of *Cylas* collected were identified using the key provided by (Wolfe, 1991).

The following features were considered for determining which species of *Cylas* was present at each location: Hind femora, length from tip of snout to elytral apex, distance between eyes on dorsal view, pronotum in lateral view and general body colour as well as sclerite of aedeagus.

4.3 RESULTS

4.3.1 PRELIMINARY SURVEY

The survey covered was conducted using 40 people who either cultivated or sold sweet potato in the part of southern Ghana. Data gathered from the survey is shown in table 1 and fig 1. Those who cultivated sweet potato were all males and they represented 45% of the respondent. Those who sold sweet potato were females and represented 55% of the respondent. The age range of the farmers was between 26-42 years. 25% of the farmers have been cultivating sweet potato for the past 4 years, 15% for between 5-8 years and 5% for over 9 years. With regard to the women, 20% have been selling the commodity for 0-4 years, 28% for 5-8 years and 7% for 9 years and over. A total of 45% of the respondents have been dealing in sweet potato for 0-4 years, 43% for 5-8 years and 12% for 9 years and over. All the traders and the farmers have knowledge of the sweet potato weevils. 7.5% of the farmers use some pesticides to control weevils' infestation whereas none of the traders used pesticides.

Table 1: Shows the percentage number of respondents, their knowledge on SPW, pesticides use and the period within which they have traded or cultivated sweet potato.

Respondents	No.of resp	% no.of resp	Age range	Period (yrs) within which persons (%)have worked			Knowledge of SPW	Pesticide use
				0-4	5-8	9+		
Farmers	18	45	28-40	25	15	5	45	7.5
Traders	22	55	26-42	20	28	7	55	0
Total	40	100		45	43	12	100	7.5

However the traders treated infested root tubers in various ways (fig 1). 81.8 of the respondents cut off the infested parts of the tuber while a few of them (9.1%) throw the whole tuber away and the remaining (9.1%) used either of the two ways depending on the gravity of infestation.

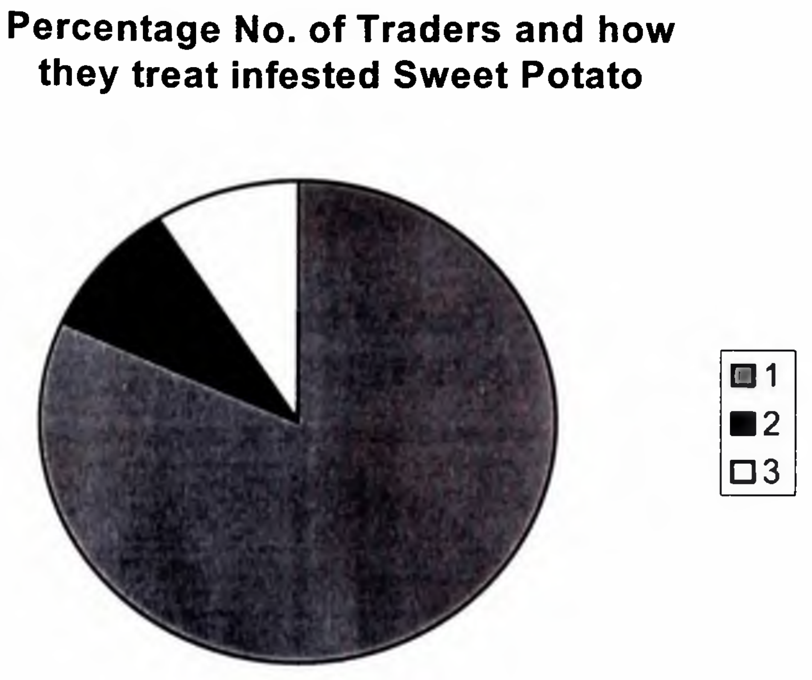


Figure 1 shows the relative percentage of traders and how they treat infested sweet potato tubers

1- Traders who cut off infested parts of sweet potato

2 - Traders who discard infested tubers

3 - Neither 1 nor 2.

4.3.2 DETERMINATION OF SPECIES COMPOSITION

Samples of the weevils were taken from farmers' fields and from the markets over a period of eight months. Out of the 415 weevils collected no *Cylas formicarius* and *Cylas brunneus* were identified (table 2). The identified species was *Cylas punticollis* (Plate 5a). The highest number of weevils was collected from Tubaman. Only a few weevils were collected from Aburi, which had only backyard farms.

Table 2 shows the comparative number of *Cylas* species found in the various locations

LOCATION	NUMBER SAMPLED	*CYLAS* SPECIES PRESENT *puncticollis*	*brunneus*	*Formicarius*
Tubaman	180	180	*	*
Mankesim	53	53	*	*
Cape coast	42	42	*	*
Pokuase	30	30	*	*
Begoro	35	35	*	*
Aburi	25	25	*	*
Afram plains	50	50	*	*

4.4 DISCUSSION

4.4.1PRELIMINARY SURVEY

Almost all the people who cultivate sweet potato in the southern part of the country are males. The females basically serve as middlemen (traders) linking the producers and the consumers. The age range of the traders (26-42 years) is wider than that of the farmers (28-40 years). This suggests that as those in the production sector grow old, they tend to quit the farming business. This point can be buttressed from the fact that, a higher percentage number of the farmers (24%) form those who have been cultivating sweet potato for between 0-4 years (table 1). Over the years the number reduced to 15% (5-8years) and then to 5%(9 years and above). On the contrary the interest of the traders seems to rise with time. Whereas 20% form those who have been in the trade for 0-4 years, 28% of them account for those who have been selling for the past 5-8 years.

All the respondents have knowledge of the sweet potato weevils and how devastating they are to the sweet potato industry. A few of the farmers (7.5%) use some kind of pesticides to control the weevils' infestation. Some of the chemicals mentioned were furadan, a soil insecticide and karate, which is used to spray the foliage when the sweet potato becomes infested with the Hawkmoth larvae (*Agrius convulvulus*). The fact that all the respondents recognise SPW as a serious pest, it suggests that the weevils are a real threat or could be potential threat to future production in Ghana. This confirms the findings of Edmond (1971) and Hill (1983) that *Cylas spp* is a worldwide major pest of sweet potato. Although the use of pesticides in the control of SPW is not widespread in Ghana, the possibility remains that, since other farmers are use pesticides , there could in future be a spill over in the use of chemicals in other parts of the country.

Plate 5(a): Adult Cylas puncticollis.

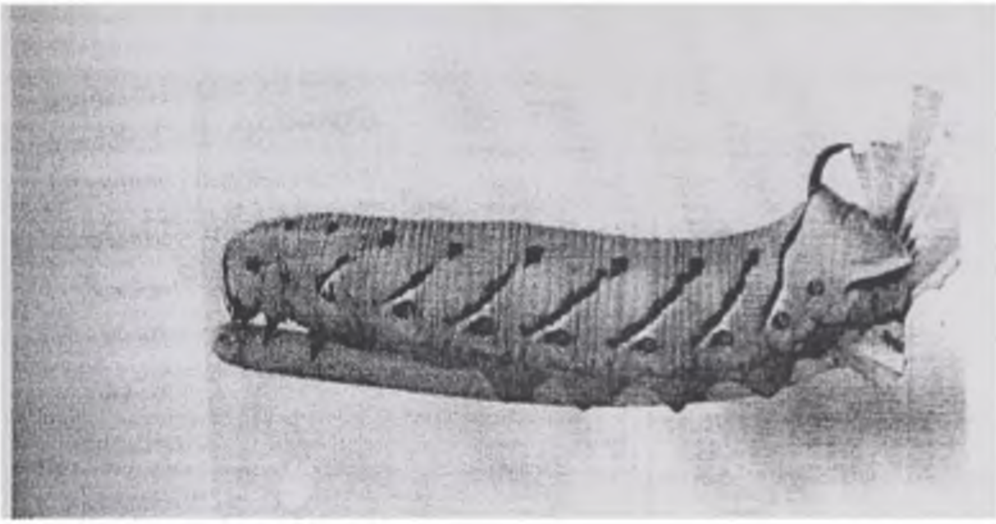


Plate 5(b): Hawkmoth Larvae (Agrius convulvulus) becomes serious. Field observations showed that the farmers in Kasoa and Tubaman use pesticides. The background of these people indicates that they are predominantly engaged in the cultivation of other vegetables, which they often sprayed with pesticides. It was a healthy observation that none of the traders use pesticides to treat the weevil-infested tubers, as would be lethal to consumers.

4.4.2 OTHER OBSERVATIONS

Other information gathered from the preliminary survey worth noting are that sweet potato production is rapidly expanding in the southern part of the country especially in the central and eastern regions. Areas with particular reference include the Afram plains and its environs, as well as Cape coast and Mankesim. Traders in Agbogbloshie and Kaneshie who were interviewed revealed that most of the their products come from the Afram plains, eg, Kotosu, Ekyi and Amanfrom. Begoro, Kasoa and Tubaman were also mentioned. According to them, products from Afram plains start coming into the market in the latter of July and ends late in September or the middle of October. This depends on the rainfall pattern as occurred in the production areas.

Sweet potato from Begoro has two production seasons. The first season starts in April/May and ends in November, but generally Kasoa and its surrounding villages have unstable supplies of sweet potato in terms of quantity. Traders in the central region mentioned the following areas, as being the sources of their product. These are Gomoa, Domenase, Dwekwaa, Mankesim and some surrounding villages in the cape coast municipal area. Supplies from these areas start in late July through to September.

Apart from SPW, which the farmers encounter frequently, Hawkmoth (*Agrius spp*) (Plate 5b) larvae were also mentioned as another pest of importance to sweet potato in Ghana. According to some of the farmers, this pest can cause up to 100% foliage destruction.

With regard to marketing, most of the traders interviewed intimated that selling of sweet potato is a profitable venture. Some reasons given are that, a lot more of people these days patronize it as compared to some years back. Also, sweet potato does not easily get rotten as against other root tubers. In addition, they attributed the profitability of the trade to the fact that they get the product at reasonable prices from the farmers. On the part of the farmers their major concern is about the fact that when they do not harvest the tubers in time they could lose as much as 50% of their expected yield due to weevils' infestation. According to some of the farmers, traders sometimes reject infested tubers entirely; otherwise they purchase them at give away prices. Some of the farmers however revealed that in the absence of weevils, especially in weevil free field, they make a lot of profit. They attributed their profit to the fact that they do not purchase pesticides and other chemicals for agronomic practices. Also in the absence of flooding and severe weevils infestation, they could allow the tubers to remain in the soil for some time till their products become profitably marketable.

4.4.3 DETERMINATION OF *CYLAS SPECIES* COMPOSITION

The SPW found in all the locations was *Cylas puncticollis*. No *C. formicarius* and *C. brunnues* were identified among the sampled weevils. The absence of *C. formicarius* might confirm the findings by Parker *et al* (1992) that the cosmopolitan species of *C. formicarius* is absent in the West African sub region. Hills (1975) indicated that *C. puncticollis* is not present in West Africa, and Forsyth (1966) mentioned *C. formicarius* and *C. brunneus* as the *Cylas species* in Ghana, without making mention of *C. puncticollis*. However, this study contradicts their findings since *C. puncticoillis* were present in all the locations sampled. The absence of C. *brunneus* in this study also contradicts Forsyth (1966) findings. He identified SPW in Aburi where presumably, sweet potato was largely cultivated in those days. During the preliminary study however, it was realized that sweet potato cultivation was below subsistence level in Aburi. This might have accounted for the very low number of sweet potato weevils collected in Aburi and hence the failure to identify *C. brunneus* in this part of the sampled area. Though only the *C. puncticollis* was found among the weevils, which were sampled, it cannot be conclusively said that the rest of the other two species are completely absent. In any case, it presupposes that even if *C. formicarius and brunneus* are present they may not be widespread as compared to *C. puncticollis*. It might also suggest that all the three species of *Cylas* do not coexist in the same location. This assertion could be confirmed by the fact that, in the works of Parker *et al* (1992), Hills (1975); and Forsyth (1966), none of them indicated the presence of all the three species of *Cylas* in the same location.

CHAPTER FIVE

BIOLOGY AND OVIPOSITION PREFERENCE OF *CYLAS PUNCTICOLLIS*

5.1 INTRODUCTION

In investigating the effects of chemical treatments on the pests and host -plant resistance, it is of paramount importance to have in-depth knowledge of the biology of that pest. Based on this appropriate control and / or management practices could be effectively adopted to minimise the effects of the insect pest in question on the crop.

Cylas spp have been extensively studied. However, most of the scientific researches have been concentrated on *Cylas formicarius*. Information on the biology of *C. puncticollis* such as its developmental stages is lacking in essential details in Ghana hence the need for such investigation to obtain information on the biology of *C. puncticollis* in Ghana.

An equally essential component in the integrated management of sweet potato weevils is the development of weevil resistant sweet potato varieties (Edmond, 1971; Sutherland, 1986). According to Beck, (1965), the first point in an insect-plant relationship at which the plant may show resistance, is when the resistance is geared towards oviposition. A successful laboratory resistance screening technique would greatly enhance the efficiency of selecting resistant lines or discarding susceptible ones in order to reduce weevils' infestation in the field for improved yield.

5.2 MATERIALS AND METHODS

5.2.1 LIFE CYCLE

The study of the life cycle was carried out by exposing thirty sweet potato root tubers of both varieties of approximately uniform size to a large number of ovipositing females taken from the general breeding cage. The female weevils were exposed to the tubers for 48 hours to ensure adequate egg-laying capability (Wilson *et al.*, 1988). After this period, all the tubers that had been oviposited upon were transferred to a different cage. Thereafter, a tuber was taken daily from the breeding cage (plate 1b) and examined thoroughly for the presence of eggs, larvae, pupae and adult weevils. Tubers were examined by dissection using forceps and knife to cut around infested portions of the tubers. This procedure was continued until adult weevils emerged.

The life cycle and the morphological stages of the weevil were determined on the red (plate 6a) and white (plate 6b) sweet potato varieties. The various developmental stages (larvae, pupae and adult) of the insect recovered were killed in 70% ethanol and immediately transferred into 10% saline solution. The body length was measured using binocular microscope equipped with micrometer. The morphology of the different developmental stages was also studied.

5.2.2 LARVAL INSTAR DETERMINATION

Larvae were reared on sweet potato cubes of size (1.5 x 1.5 x 2.0 cm^3) to determine the number of instars. Cavity was made in the potato cube and a newly hatched larva less than 24 hours was placed in the cavity and plugged immediately with a piece of sweet potato. The cube was opened daily and examined under the microscope for cast exuvium. The larva was daily transferred to newly prepared cube using fine brushes until pupation and the number of exuviae recovered was recorded. The development of twenty newly hatched larvae was studied in this way.

Plate 6 (a): The tuber of the red Sweet potato variety

Plate 6 (b): The tuber of the white sweet potato variety

5.2.3 STUDIES ON FECUNDITY

Forty-eight newly emerged unmated male and female weevils were used for this study. These virgin weevils were paired (24 pairs), and each pair was confined to approximately uniformly small sizes of tubers in the oviposition cage. Daily observations were made to determine the preoviposition period.

After the first egg laying had been recorded, males from a set of 12 pairs were removed and the other twelve pairs were left until the end of the experiment. Each female in the first group and each pair in the second were transferred everyday to a new tuber.

The number of eggs laid on the tubers was recorded and the tubers were subsequently stored individually in the emergence cage for adult emergence. From this study, oviposition period, fecundity and longevity of female and male weevils were determined.

5.2.4 DETERMINATION OF OVIPOSITION PREFERENCE

Sweet potato weevils were reared on sweet potato storage roots in silver made cages (plate 2b) under laboratory conditions of 27.0°C and 70% rh. Sweet potato used for rearing and bioassays were cultivated at the irrigation project field at Tubaman near Kasoa in the central region of Ghana, harvested, cured in the sun, and stored in plastic baskets at laboratory conditions. Roots used in this study had been in store for two to five months.

Adult female weevils were transferred to fresh potatoes every six to seven days, and the old ones incubated at room temperature until new generation emerged. Emerging weevils were collected weekly and held in cages with sweet potatoes until required for bioassays. To ensure adequate egg- laying, female weevils that were collected for the bioassays were held in cages for at least three days before being used (Wilson *et al.*, 1988).

The bioassay used was an adaptation of one described by Mullen *et al.*, (1980), with slight modification. Three Falcon tissue plates of equal sizes were used (Plate 3a). Two of the culture plates were for no-choice bioassay and the other one for choice bioassay. Cores of storage roots were taken with a cork borer (No.11) (Plate 3b) and placed in the Falcon tissue culture plates, such that the cores fitted in the wells (diam. 1.6 cm, depth 2cm) with only the root periderm exposed. Two sweet potato varieties, red (frema) and the white were used.

In the no-choice bioassay only one variety was presented in a 12-well plate in each of two cages to 24 gravid female weevils to give a female to core ratio as 2:1. In the choice bioassay, the cores of both varieties were used. All the 24-wells were randomly filled with equal number of the two varieties and exposed to 48 female weevils under the same experimental conditions (refer to general materials and methods). After 48 hours, the plugged oviposition punctures were counted (Nottingham *et al.*, 1987). Data were analysed by t-test.

5.3 **RESULTS**

5.3.1 LIFE CYCLE AND MORPHOLOGY OF THE DEVELOPMENTAL STAGES

The relative developmental periods of *C. puncticollis* as observed on the white and red sweet potato varieties are shown in table 3. The developmental period from the egg stage to the adult ranged from 21 to 24 days with an average of 22.5 days on the red variety, 24 to 27 days on the white variety with an average of 25.5 days.

Eggs

The eggs were laid singly into the tubers, and then plugged with faecal matter. The incubation period in the laboratory was 4 days for the red variety and 5 days for the white sweet potato variety.

Larvae

Three larval stages were observed. The mean body length of newly hatched larvae based on 20 individuals was 1.41mm (sd=0.043). The second instar is opaque white with the cephalic structures not well sclerotised. The average body length is 2.27mm (sd=0.028). The third instar is opaque white and the cephalic structures well developed and sclerotised. The average body length is 5.91mm (sd=0.056). The larval period was in the range of 10-11 days and 10-12 days when reared on the red and white varieties respectively (refer to plate 6 for larvae and pupae).

Table 3: Relative periods (in days) of various stages of *C. puncticollis* on red and white skin sweet potato

Life stage	Developmental periods on sweet potato variety (in days)	
	Red	White
Incubation period	4	5
Larval period	10-11	10-12
Prepupal period	1	2
Pupal period	6-8	7-8
Total developmental period	21-24	24-27

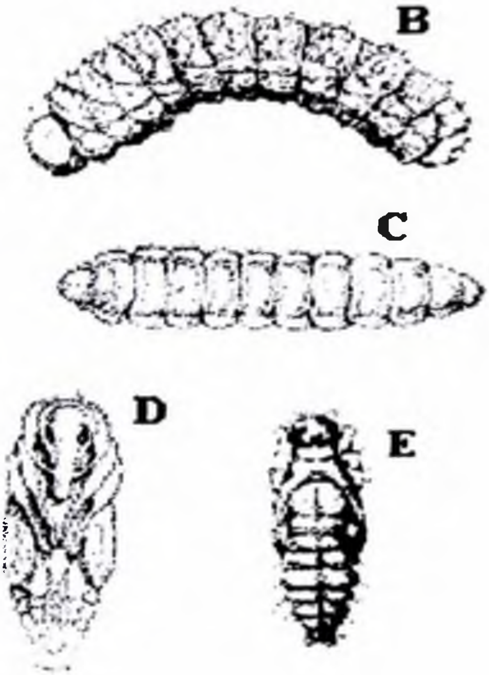


Plate 7*: Life stages of sweet potato weevil. B&C show the lateral and ventral view of larvae; D&E show the ventral view of the prepupa and pupa stages.*

Pupa

Two stages were identified: the prepupa and the pupa (Plate 8). The prepupa is an immobile stage. In its matured stage, it is creamy white. The mean body length was 5.43mm (sd=0.039). This stage lasted 1 day on the red and 2 days on the white. The pupa is whitish when it first appears. The eyes, head and the snout are folded ventrally to partially cover part of the thoracic region. The pupa appears immobile but when disturbed, the abdominal section of it twists in a circular manner. This stage lasted between 6-8 days and 7-8 days on the red and white varieties respectively. The mean body length is 5.41mm (sd=0.018) (Plate 6).

Adult

The adult has an elongated body with a narrow head and thorax (Plate 5a). On the red sweet potato variety, it took between 21-24 days after oviposition for the adult weevil to appear. On the white variety however, it took 24-27 days. Based on 20 weevils the female adults body length from the tip of the snout to the tip of the abdomen average 7.35mm (sd=0.025). That of the male adult is 7.15mm (sd=0.025) (appendix L)

5.3.2 FECUNDITY STUDY

Female SPW which had continuous mating (unlimited copulation) throughout the duration of the study, exhibited a pattern as illustrated in table 4a and 4b. The average preoviposition period was 3.7 days and a mean oviposition period of 62.0 days. Within this period, an average female laid 299.5 eggs and longevity ranged from 53-76 days, with a mean of 68.0

days. A female lived an average of 6 days after the last oviposition. Male longevity averaged 53.5 days.

Table 4a: Longevity, Preoviposition, Oviposition periods and Fecundity of mated females of *C puncticollis* (Unlimited Copulation) in days.

ale	Preoviposition	Oviposition	Female longevity	Male longevity	Eggs laid	Adults emerged
1	3	65	70	56	298	250
2	4	69	75	52	305	298
3	4	52	60	66	275	195
4	4	70	75	59	400	365
5	3	69	72	48	235	200
6	3	58	63	50	295	213
7	3	47	53	50	351	305
8	4	65	71	53	361	323
9	4	68	76	49	224	190
10	4	68	72	54	205	185
11	4	68	73	57	315	282
12	4	45	56	48	325	275
Mean	3.7	62	68	53.5	299.5	256.8
SD	0.49	9.1	7.9	5.3	57.9	60.1

Table 4b: Longevity, Preoviposition and Oviposition periods and Fecundity of mated females of *C. puncticollis* (limited copulation)

Female	Preoviposition period	Oviposition period	Female longevity	Eggs laid	Adult emerged
1	4	64	72	258	265
2	3	81	87	375	294
3	3	73	79	208	130
4	4	46	50	254	230
5	4	85	88	298	250
6	3	85	90	395	300
7	4	65	69	369	265
8	4	70	77	418	385
9	4	60	65	208	190
10	4	72	80	385	250
11	3	68	75	326	253
12	3	82	89	295	200
Mean	3.6	70.9	76.8	315.8	251
SD	0.5	11.5	11.7	73.3	63.3

Female weevils with limited copulation (table 4b) had an average preoviposition period of 3.6 days and an average oviposition period of 70.9 days. Within this period, each female laid an average of 315.8 eggs and longevity ranged from 50 to 90 days, with an average of 76.8 days. Each female on the average lived for 5.9 days after the last oviposition.

There was no significant difference ($p>0.05$) in the preoviposition periods of the two categories of female (table 5). No significant difference was also recorded in the number of eggs laid and the number of adults that emerged when females with unlimited copulation were compared with females that had limited copulation (table 5). There was however, a significantly higher oviposition and longevity periods in females with unlimited copulation than those with limited copulation.

Table 5: Comparative longevity, oviposition, number of eggs laid and the number of Adults emerged. Data are means. SD in parenthesis.

Parameter (days)	**A**	**B**	**Prob. level**	**Conclusion**
Preoviposition period	3.7(0.49)	3.6(0.5)	0.309	NS
Oviposition period	62(9.1)	70.9(11.5)	0.047	SIG
Longevity	68(7.9)	76.8(11.7)	0.043	SIG
No. of eggs	299.1(57.9)	315(73.3)	0.543	NS
No. of adults	256(60.1)	251(63.3)	0.821	NS

A- Females with unlimited copulation.

B- Females with limited copulation.

SIG- Significance

NS- Not significance

5.3.3 OVIPOSITION PREFERENCE

The results from the bioassays indicate that there is oviposition preference between the two sweet potato varieties. More oviposition punctures were made on the red variety cores than on the white (table 6) in both the choice and the no-choice bioassays. In the choice bioassay, the number of oviposition punctures made on the red cores was significantly ($P<0.05$, t-test) greater than that made on the white cores. In the no-choice bioassay however, there was no significant difference in the number of oviposition punctures made on the two sweet potato varieties.

Table 6: Oviposition punctures made by SPW on root cores of two sweet potato varieties in limited- and no- choice bioassays

TEST	RED VARIETY	WHITE VARIETY	PROB. LEVEL
Choice	5.5±(0.49)	3.58±(0.57)	0.018*
No-choice	6.08± (0.38)	4.92± (0.48)	0.071

Prob.level marked * shows significant difference ($P<0.05$,t-test) between means ($\pm$ se)

5.4 DISCUSSION

5.4.1 LIFE CYCLE AND MORPHOLOGY OF THE LIFE STAGES

The developmental periods of *C. puncticollis* from the egg stage to the adult stage differed on the two sweet potato varieties. On the red variety, it average 22.5 days and on white it was 25.5 days. The incubation period was higher on the white variety than on the red variety.

Three different larval stages were observed. This confirms the findings of Cockerham *et al.*, (1954) who identified three larval instars for *C. formicarius*. The newly hatched larva is concave shaped and legless grub with a seemingly transparent body length. The second instar is opaque white with its cephalic structure not well sclerotised. The third instar is robust and cylindrical in shape. The cephalic structures are well developed and sclerotised. There are hair- like structures on the head capsule. Three pads bearing broad leg pads could be found on the thoracic segments. The growth ratio from the first instar through to the third larval instar in terms of the body length size was approximately 1:2:4 respectively. This shows a high growth rate, which can be attributed to the vigorously feeding habit of the larva.

The prepupal and the pupal periods were longer on the white variety than on the red variety. At the pupa stage, the process of tanning starts around the eyes, wing pads and the legs. The head and the snout fold ventrally and this covers part of the thorax.

The adult of *C. puncticollis* is uniformly black (Plate 5a). The head, snout, legs and antennae, thorax and the elytral are all metallic black or blue-black in colour. Dorsal view of *C. puncticollis* shows the two eyes very closed to each other. Both males and females have long antennae with the distal segment forming a thick club. The club of the female antennae is bulbous shape and short. The club of the male antennae looks rectangular and is longer than the rest of the segments put together. In addition, the male's antennae are clothed with relatively longer hair-like structures. These antennal characters are the main features used to distinguish the male from the female *C. puncticollis*. The tibiae and tarsi of the males are also characterised by small bristle. Generally, the female weevils are longer and more robust than the males.

The results indicated that, the relative periods of the various stages of the weevils spent on the white sweet potato was longer than the period spent on the red variety. Cases of apparent resistance in sweet potato to the SPW, *C. formicarius* have been reported (Cockerham and Harrisson, 1952; Mullen *et al.*, 1980). Waddill and Conover (1978) found significant differences in susceptibility to some varieties and selection of white-fleshed sweet potato. Although the white skin variety of the sweet potato cannot be said to be resistant to *C. puncticollis,* the results of the study suggest that the red sweet patato variety is comparatively more susceptible to C. *puncticollis.*

5.4.2 FECUNDITY STUDY

Adult females lay their eggs in small pockets, which they make at the base of the vines, and in the tubers. Only one egg is laid in each pocket and then plugged with faecal matter. The faecal matter hardened to provide protection for the eggs and the subsequent larvae.

Female weevils with limited copulation laid more eggs (315$\pm$ 73) than the females with unlimited copulation (299.5$\pm$57.9). However, this difference is not significant. This suggests that the number of mating prior to oviposition does not have effect on the number of eggs laid. The average percentage hatchability of eggs laid by females with limited copulation was 79.5 % while that of females with unlimited copulation was 85.7%. With reference to the number of eggs laid by the two categories of females and their respective eggs hatchability, there is an indication that frequent mating enhances the hatchability of eggs.

The optimum number of days that was required for effective fertilization of eggs throughout the extended oviposition period was 4 days. This period could be subjective taking into consideration that the number of times copulation takes place during the preoviposition period is not known. Length of oviposition period differed significantly among females with unlimited and limited copulation (table 5). Those with limited copulation had a longer oviposition period than the females with unlimited copulation. This suggests that repeated mating extend the oviposition period, which might be required for maximum productivity to be realised. Longevity also differed significantly. Females with limited copulation lived longer than females with unlimited copulation. It presupposes that, the longer the oviposition period, the longer the female weevils lived. This may also enhance the fecundity of the females as indicated in the respective number of eggs laid by the two female groups.

5.4.3 OVIPOSITION PREFERENCE

The sweet potato weevils generally laid more eggs on the red cores than on the white cores of the sweet potato. The relative levels of oviposition preference found for the two sweet potato varieties may indicate that in the periderm of the root tubers, there exist some kind of chemical or physical factors, which either stimulate or suppresses oviposition by weevils. Wilson *et al.*, (1988) demonstrated the presence of a chemical oviposition stimulant in the periderm of storage roots of some susceptible varieties. In the bioassay, the oviposition punctures made on the red core were found to be significantly higher than those made on the white cores. However, in the no-choice test, there was no significant difference in the oviposition punctures made on the cores of the two varieties. This suggests that varieties of different kinds stimulate weevils to oviposit at different rates. Nottingham *et al.*, (1987) have suggested that oviposition could be used to assess resistance or susceptibility of sweet potato in the laboratory. Beck (1965), also found that the first point in insect-plant relationship at which the plant may show resistance is when the resistance is geared towards oviposition. This implies that, the red variety may be more susceptible than the white. In view of the fact that development of insect-resistance to sweet potato lines could be a viable component in integrated pest management, it will be important to determine the chemical factors in the white varieties. This could provide the basis for incorporating multiple levels of resistance to the weevils.

CHAPTER SIX

EFFECT OF TREATMENTS ON SWEET POTATO WEEVIL POPULATIONS AND THE INFLUENCE ON WEEVILS TUBER DAMAGE

6.1 INTRODUCTION

Growth and development of the sweet potato can be quite variable, depending on cultural practices, genotype and environmental conditions. All these have significant effects on weevil population dynamics (Jansson *et al*, 1991). Sweet potato responds well to fertilizer, particularly if the land has been cropped for some time. High amounts of slow-release fertilizer (19N-3P-10K) delayed storage root development due to improper fertilization and increased likelihood of weevil attack. Several insecticides applied at intervals in the field have been found effective in controlling the weevils. Such insecticides include 0.1% fenthion, 0.1% fenitrothion, or 0.1% cabaryl. Soil application of 1.0% heptachlor or chlordane has also been found effective (Hua, 1970; Subramaniam *et al.*, 1973). This implies proper use of fertilizer and or insecticides with other appropriate measures might help reduce or aggravate pest population.

This part of the study is to determine the effect of fertilizer (15N-15P-15K) and insecticide (furadan) on the population dynamics of the sweet potato weevils (*Cylas spp*) on weevils' tuber damage on two sweet potato varieties.

6.2 MATERIALS AND METHODS

6.2.1 LAND PREPARATION AND EXPERIMENTAL LAYOUT

Effect of treatments was evaluated by conducting field experiments at Tubaman, near Kasoa in the central region of Ghana. The land was ploughed, hallowed and divided into two separate fields. Two sweet potato varieties – red (frema) and the white were separately examined in each of the two fields to determine the effect of the three treatments: fertilizer, insecticide and a combination of fertilizer and insecticide on the population of the sweet potato weevils.

On each field were four long ridges each of which was sub-divided into four plots making a total of 16 plots per field. Planting of vines was done by hand by inserting 50-70% of the length of the vines into the soil at an angle. The vines were at 25-30 cm apart on ridges of 200 cm apart. Plots were 60-75 cm apart.

Fertilizer treatment was applied at 1400kg/ha as a continuous band around each vine (Jansson *et al.*, 1987). Furadan was applied at the recommended rate of 5.0 grams to the soil around the vine cutting. The combined treatment of furadan and fertilizer were applied at the same recommended rates around the vines. Also included on the field were control plots that were randomized with the other three treatments.

6.2.2 EFFECTS OF TREATMENTS ON WEEVILS POPULATION

Traps of 2.0m apart were set on all the plots, and were examined two weeks after application of the treatments. The numbers of SPW trapped under each treatment were

Plate 8(a): field workers harvesting sweet potato tubers.

Plate 8(b): Heap of harvested sweet potato tubers and field workers during weighing.

compared. Also, the populations of the SPW in the two fields were compared. The sweet potato tubers were harvested after sixteen weeks of cultivation. The experiment was repeated on different plots.

6.2.3 EFFECT OF TREATMENTS ON TUBER DAMAGE BY WEEVILS

The effect of the treatments: Furadan, fertilizer and a combination of furadan and fertilizer on sweet potato weevil population and damage due to them was studied on the 2 sweet potato weevils on the field.

Four months after planting, five sweet potato plants close to each trap points on the plots were randomly selected and harvested. The root tubers in each plot were separated into damaged and undamaged tubers based on whether they have been infested (punctured) by the weevils or not. The percentage weight of infested roots in each variety under each treatment was determined (Plate 8b). Mean percentages of damaged roots under each treatment were compared using analysis of variance.

6.3 **RESULTS**

6.3.1 TREATMENTS EFFECTS ON SWEET POTATO WEEVILS POPULATION

Second Planting: The effect of treatments on the sweet potato weevils' population is given in appendix B&C. Analysis of variance showed that there was no significant difference ($P>0.05$) in the number of sweet potato weevils trapped on the white variety each of the treated plots (appendix B). The highest mean population of weevils was recorded on the control plot (7.33) and the lowest (6.44) was recorded in the furadan treated plot (appendix

F). The relative changes in the weevil's population on the control field over a period of nine weeks are shown in fig 2. There was an increase in weevil's population from week one to week three and then a drop in week four. There after, a sharp increase in the population occurred by five. Weevil's population declined steadily from week six to week nine.

There was significant difference ($P<0.05$) in the number of weevils trapped over the nine-week period on white sweet potato variety (appendix B).

Similarly, on the red variety's field, the control plot recorded the highest weevils population (10.17) over the nine-week period, followed by the fertilizer treated plot (9.25). The least mean number (8.86) of weevil's population was recorded in the furadan treated plot (appendix F). The study showed that the SPW population trapped did not differ significantly ($P>0.05$) among the treatments (appendix C).

A gradual increase of SPW population from week one to week three was observed (fig 2). It dropped by the fourth week and then rose again by the fifth week. There after, there was a gradual decrease in the population till the ninth week. The weevil population differed significantly ($P<0.05$) over the nine-week period (appendix C).

Third Planting: Results of treatment effects on SPW obtained for the white variety is shown in appendix G, the control recorded the highest weevils population (9.94) followed by the combined treatments of furadan and fertilizer (9.42). The fertilizer recorded the lowest (8.42). The weevil's population did not differ significantly ($P>0.05$) among the treatments over the nine-week period (appendix E).

Population dynamics of the weevils in the field during the third planting is shown in fig 3. It shows an increase in the population of the weevils from week one to week seven and then a decrease.

Fig. 2

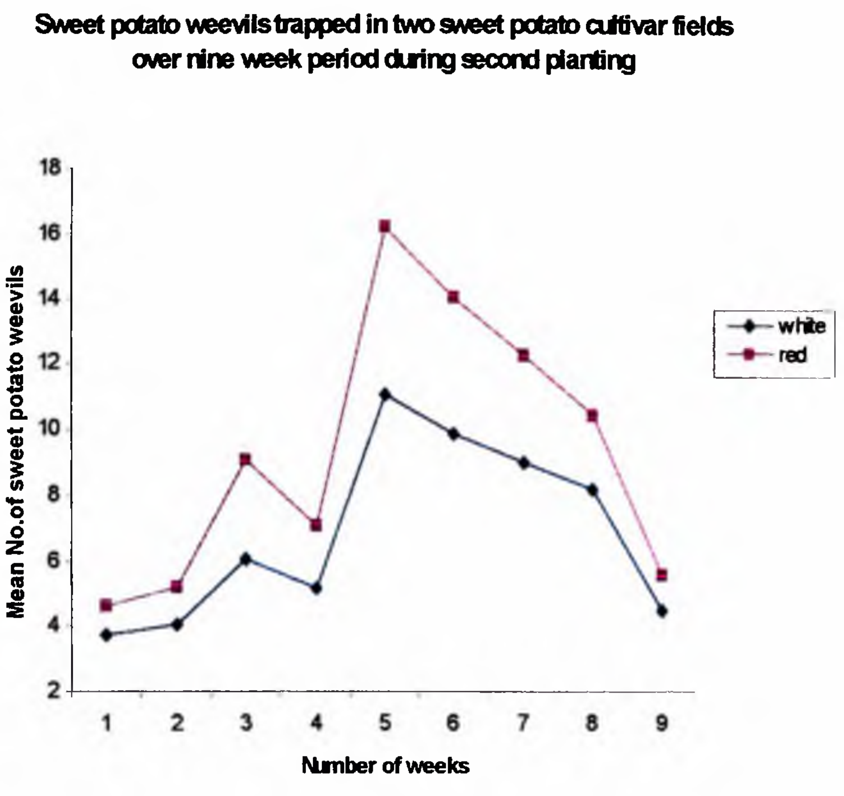
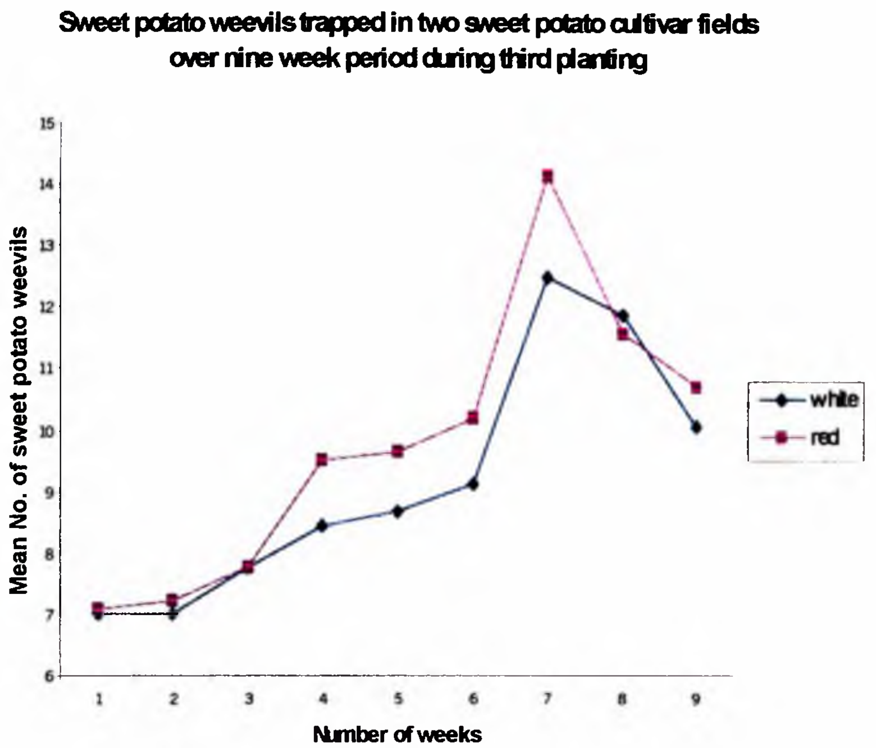

Sweet potato weevils trapped in two sweet potato cultivar fields
over nine week period during second planting
Mean No.of sweet potato weevils
18
16
14
12
10
8
6
4
2
1
2
3
4
5
6
7
8
9
Number of weeks
white
red

Fig. 3


Sweet potato weevils trapped in two sweet potato cultivar fields
over nine week period during third planting
Mean No. of sweet potato weevils
15
14
13
12
11
10
9
8
7
6
1
2
3
4
5
6
7
8
9
Number of weeks
white
red

from the eighth week to the ninth week. The total number of weevil's population over the nine-week period differed significantly (P<0.05) among the weeks (appendix E).

Results of treatments effects obtained in the red variety field are shown in appendix G. The highest weevil's population (11.14) was recorded in the control plot followed by the combined treatment of furadan and the fertilizer (10.61). The fertilizer plot recorded the least (8.56). The weevils' population trapped over the nine-week period differed significantly (P<0.05) among the treatments (appendix D). Fig 3 also shows the mean weevil's population trapped over the nine-week period. There was an increase in the population from week one to week seven, and then a drop from week eight to week nine. A significant difference in the weevil's population over the nine-week period was observed (appendix D).

6.3.2 EFFECT OF TREATMENTS ON TUBER DAMAGE BY WEEVILS

The effects of treatments on weevil infestation damaged of sweet potato root tubers are given in table 7. Damage was assessed based on whether a root tuber has been infested or not. In both the red and the white variety fields, and in all the plots under treatments, damage was done to the root tubers. Tuber damage did not differ significantly among treatments (P>0.05) (appendices H, I, J & K). However, furadan treated plots recorded the least percentage damage (infestation) for both varieties during the two planting seasons. The percentage damage caused in the fertilizer only treated plots was very close to that found in the control plots. The results also show that, during the two planting seasons more damage was done to the red variety than the white. In addition, more tuber damage was caused during the second planting season than the third season.

Table 7: The relative percentage weight (Kg) of tuber damage due to SPW under various treatments during second and third planting seasons. Third planting data in brackets

Variety	treatments				grand mean
	Fert	Fura	Fert&Fura	Control	
RED	33.8(31.5)	23.8(13.3)	33.9(24.4)	34.0(20.4)	31.4(22.4)
WHITE	15.7(16.6)	9.4(6.1)	26.8(16.9)	23.2(7.4)	18.8(11.7)

Fert: Fertilizer

Fura: Furadan

6.4 DISCUSSION

6.4.1 TREATMENT EFFECTS ON SWEET POTATO WEEVILS POPULATION

The effects of the treatments on the weevil populations did not differ significantly among the various treatments (appendices B and C). The relatively high weevil population recorded in the control plots may suggest that the various treatments had some kind of toxic effects on the population dynamics of the weevil. Hua, (1970) and Subramanian *et al*., (1973) found that soil application of 1.0% heptachlor or Chlordane has effect on the control of SPW. However, the fact that there was no significant difference among the treatments, may be that none of the treatments was more effective than the other in the control of the SPW population in the field. The combined effects of fertilizer and furadan recorded relatively high population in the entire field and during both planting seasons. Though no concrete conclusion could be drawn for this pattern, it is probable that the two chemicals had antagonistic effect thereby suppressing the maximum effect, which the separate treatments could have had on the weevil's population.

Other workers have also reported the gradual increase in the population of the weevils over the nine-week period. Jansson *et al*, (1990) showed that in the field, *Cylas spp* increases exponentially with most of the population density occurring late in the growing season when storage roots are more available. Their findings might seem to conflict with the results of this study which showed a drastic drop in the weevil's population in the latter part of the growing season. The drop in the curves may not be the actual population growth pattern in the field but probably during the latter part of the growing season more storage roots are available, and the tendency is for the weevils to attack the roots instead of the vines and the leaves. It was observed in the field that when the root tubers matured, parts of the soil cracked and created crevices. These served as entry points for the weevils to attack the tubers. The movement of the weevils into the soil might have accounted for the seemingly drop in the population during the latter part of the growing seasons. The population build up curves obtained for both varieties and during the two growing seasons showed the red variety's curve being over and above that of the white variety. This is an indication that more weevils were present in the red field than in the white field. The abundance of weevil on the red variety suggests that the weevils preferred the red to the white variety. The relative preference to the red variety could be for either feeding or oviposition, which are mediated by different host-plant chemicals. Wilson *et al.*, (1988) showed that surface chemical factors in the sweet potato do play a role in susceptibility to the weevils. These chemicals have been shown to reside in the root periderm and are responsible for differences in feeding and oviposition preference of the sweet potato varieties (Nottingham *et al.*, 1987). It can be suggested from the results of this study that the red variety is more susceptible to weevil attack.

6.4.2 EFFECT OF TREATMENTS ON TUBER DAMAGE BY WEEVILS

The two varieties were both found to be susceptible to weevil's damage (infestation). The effect of various treatments on infestation did not differ significantly from each other However, furadan treated plots recorded the least percentage damage (infestation) in both varieties during the two planting seasons. This suggests that it could be used to reduce weevils damage to a certain extent in sweet potato fields.

Comparing the three treatments, damage on fertilizer treated plots was found to be very close or equal to the tuber damage caused in the control plots. Bourke (1985) found that nitrogen fertilization increases leaf area, which in turn improves other growth and yield parameters. It is believed that improved growth characters might increase the likelihood of weevil attack. The results of this study seem to have confirmed this observation.

Weevils' damage to the red variety was generally more severe than that to the white variety. This also confirms results of the population study on SPW where higher numbers were recorded on the red variety than on the white variety. This result also suggests a positive correlation between SPW numbers and tuber damage.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

The study has shown that the cultivation of sweet potato in certain parts of the country, especially the Eastern, Greater Accra and the Central regions is becoming popular. Farmers and traders were unanimous on the key pest status of the *Cylas species*, which according to them is capable of causing as much as fifty percent damage to root tubers. Another pest, which has been found to cause damage to sweet potatoes in Ghana, is the Hawkmoth larva *Agrius convolvulus* (plate 5b). Farmers claimed this pest could cause 100% foliage destruction in one farm. In spite of the problems of pests, most of the farmers do not use pesticides as a means of controlling the pests. A few of them however use insecticides such as Furadan and karate to protect their farms from insect pest damage. None of the traders were found to use insecticides as means of protecting their tubers in storage.

Some other problems, which are faced, by the farmers and the traders were identified. According to the farmers they sometimes become discouraged as traders reject even slightly infested tubers or buy them at very low prices. On the part of the traders, they face tough competition when there is glut of yams (*Diascorea spp*) in the market and this makes them operate at a loss or with very marginal profit.

Only *Cylas puncticollis* was found to be present in the Eastern, Greater Accra and the Central regions of Ghana. The absence of *Cylas formicarius* and *Cylas brunneus* may suggest that the three species do not coexist in the same location. There may also be a possibility that the species are seasonal and therefore could not be found at the same time in the same location.

Cylas puncticollis has a total life cycle ranging from 21 to 27 days depending on the variety. Developmental period was longer on the white sweet potato variety. Three larval stages were identified. Adult females lay their eggs in small pockets at the base of the vines or in the tubers. It was shown that the number of matings prior to oviposition does not significantly affect the total number of eggs laid. The average hatchability of eggs laid by females with limited copulation was 79.5% while that of females with unlimited copulation was 85.7%. It implies that few mating extend oviposition and longevity period among females. The optimum period required for effective fertilization of eggs was four days. Females with limited copulation had a significantly longer oviposition period and longevity period than those with unlimited copulation.

A significantly higher number of eggs were laid on the periderm of the red variety than on the white. *Cylas puncticollis* therefore seem to prefer the red variety for oviposition. It also suggest that the red variety is more susceptible to the sweet potato weevils because in the previous study on the biology the developmental period was shorter on red variety than on the white.

Relative to the control plots, the other treatments could not significantly reduce the weevils' population on the two varieties. However the control plots recorded the highest weevils population. In sweet potato farms, weevils' population increases with time especially in the first three-quarters of the growing period. The highest weevils' population was recorded on the red variety.

Effect of treatments on tuber damage did not differ significantly from each other, nevertheless tuber damage in the furadan treated plots were very minimal as compared to the other treatments. Fertilizer seems to promote weevils' infestation and hence tuber damage. Generally, damage to the red variety was higher than in the white, implying that the red variety is comparatively more susceptible to *Cylas puncticollis*.

Further work should be done to establish the species composition in the country especially in areas such as Afram plains, Kasoa, Bawjuase, etc. where the sweet potato is widely cultivated. Institutions such as Council for Scientific and Industrial Research (CSIR), the universities in the country, Ghana Atomic Energy Commission and the Plant Protection Agency should collaborate with the Ministry of Food and Agriculture to collect and compile the list of all the sweet potato varieties that are cultivated in the country so as to find out those which are resistant or susceptible to pests and diseases. The resistant ones should be developed and multiplied for use by farmers.

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APPENDIX A

AFRICAN REGIONAL POST GRADUATE PROGRAMME IN INSECT SCIENCE

(ARPPIS), UNIVERSITY OF GHANA, LEGON, GHANA

Questionnaire to determine the level of knowledge of farmers and traders on the sweet potato weevils, and the general problems they encounter with the cultivation and sale of sweet potato.

ADMINISTERED TO: Market women/men and farmers.
SEX: M/F
AGE RANGE.

NB: Please the response will be treated confidentially.

1. How long have you been involved in this work?

a. Less than two years.
b. Bet. 2-4 years
c. Bet. 5-8 years
d. Above 9 years

2. Are you a trader?

Yes ☐ No. ☐

If the response is yes then answer the ff.

3. List the source of your sweet potato, and indicate the period you have been getting them.
E.g.: Town X------June etc.

4. Is the selling of sweet potato a profitable venture?

Yes ☐ No ☐

5. If yes, why and if no why? Give reasons.

----

6. Are you familiar with the picture shown to you?

Yes ☐ No ☐

7. If yes, how often do you encounter them in your product?

a. Occasionally
b. Often
c. Not at all.

8. How do they affect your product(s).

a. Eat the sweet potato.
b. Change the taste of the sweet potato.
c. Reduce the market price of the sweet potato.
d. Enhance rotting of the sweet potato.

9. How do you solve the SPW problem?

a. Spraying them (name the type of insecticides).
b. Cutting off the infested part.
c. Throwing the infested sweet potato away.

10. Do you know of any other king of insect pest associated with the sweet potato.

Yes ☐ No ☐

Answer the following if you are a farmer.

11. In which of the following regions do you have your farm?

a. Eastern
b. Greater Accra
c. Volta
d. Ashanti

12. What is the name of the town or village where your farm is situated?

13. Are you familiar with the insect shown in the picture?

Yes ☐ No ☐

14. Do you have a problem with SPW?

Yes ☐ No ☐

15. Do you bother to control them?

Yes ☐ No ☐

16. If yes, how?

a. Using insecticides
b. Flooding
c. Crop rotation
d. Earthing up the soil
e. Others. Mention them.

17. If you have been using insecticides, name the types and how you apply them.

----

18. Which of the following varieties of sweet potato do you cultivate?

a. White/light skin.
b. Red/purple skin
c. Both
d. Any other.

19. In your opinion, which of the above is more prone to the SPW infestation?

a. White/light skin
b. Red/purple skin
c. No idea.

20. Other comments: ---

Thank you for your patience and information

APPENDIX B

***** ANALYSIS OF VARIANCE (SECOND PLANTING) *****

Variate: White potato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	277.687	92.562	15.85	
Block.*Units* stratum					
WEEKS	8	973.472	121.684	20.84	<.001
Treatment	3	19.799	6.600	1.13	0.340
WEEKS.Treatment	24	158.639	6.610	1.13	0.323
Residual	105	613.062	5.839		
Total	143	2042.660			

APPENDIX C

***** ANALYSIS OF VARIANCE (SECOND PLANTING) *****

Variate: Red potato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	513.39	171.13	14.15	
Block.*Units* stratum					
WEEKS	8	2231.35	278.92	23.06	<.001
Treatment	3	34.17	11.39	0.94	0.423
WEEKS.Treatment	24	368.21	15.34	1.27	0.205
Residual	105	1270.11	12.10		
Total	143	4417.22			

APPENDIX D

***** ANALYSIS OF VARIANCE (THIRD PLANTING) *****

Variate: Red potato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	15.74	5.25	0.28	
Block.*Units* stratum					
WEEKS	8	661.81	82.73	4.35	< .001
Treatment	3	189.74	63.25	3.33	0.022
WEEKS.Treatment	24	248.19	10.34	0.54	0.956
Residual	105	1996.01	19.01		
Total	143	3111.49			

APPENDIX E

***** ANALYSIS OF VARIANCE (THIRD PLANTING) *****

Variate: White potato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	146.41	48.80	3.33	
Block.*Units* stratum					
WEEKS	8	502.51	62.81	4.29	<.001
Treatment	3	47.63	15.88	1.08	0.359
WEEKS.Treatment	24	227.93	9.50	0.65	0.888
Residual	105	1536.84	14.64		
Total	143	2461.33			

APPENDIX F

VALUES FOR FIGURE 2

	WEEKS								
VARIETY	1	2	3	4	5	6	7	8	9
RED	4.56	5.13	9.06	7.06	16.19	14.06	12.25	10.44	5.50
WHITE	3.69	4.00	6.06	5.12	11.06	9.88	9.00	8.19	4.44

APPENDIX G

VALUES FOR FIGURE 3

	WEEKS								
VARIETY	1	2	3	4	5	6	7	8	9
RED	7.06	7.19	7.75	9.50	9.63	10.19	14.13	11.56	10.69
WHITE	7.00	7.00	7.75	8.44	8.69	9.13	12.50	11.88	10.06

APPENDIX H

Analysis of variance (second planting)

Variate: Red. % Weight of damage roots

Source of variation	d.f	s.s	m.s	v.r	F pr
Reps stratum	3	1292.9	431.0	1.67	
Reps.*units* stratum					
Treatements	3	308.8	102.9	0.40	0.758
Residual	9	2326.4	258.5		
Total	15	3928.2			

APPENDIX I

Analysis of variance (second planting)

Variate: white % Weight of damage roots

Source of variation	d.f	s.s	m.s	v.r	F pr
Reps stratum	3	766.4	255.5	1.17	
Treatments	3	721.3	240.4	1.10	0.398
Residual	9	1967.7	218.6		
Total	15	3455.4			

APPENDIX J

Analysis of variance (third planting)

Variate: Red % Weight of damage root

Source of variation	d.f	s.s	m.s	v.r	F pr
Reps stratum	3	953.9	318.0	2.14	
Treatments	3	693.9	231.3	1.56	0.266
Residual	9	1336.9	148.5		
Total	15	2984.7			

APPENDIX K

Analysis of variance (third planting)

Variate: White % Weight of damage root

Source of variation	d.f	s.s	m.s	v.r	F pr
Reps stratum	3	164.20	54.73	0.77	
Treatment	3	400.31	133.44	1.88	0.203
Residual	9	638.23	70.91		
Total	15	1202.74			

APPENDIX L

Table 2 shows the comparative number of *Cylas* species found in the various locations

INSTARS					ADULT	
FIRST	SECOND	THIRD	PREPUPA	PUPA	FEMALE	MALE
1.40	2.30	5.82	5.40	5.41	7.37	7.15
1.38	2.31	5.90	5.45	5.38	7.35	7.14
1.45	2.32	5.85	5.41	5.43	7.40	7.18
1.43	2.28	5.95	5.39	3.39	7.38	7.17
1.32	2.25	5.92	5.43	5.42	7.32	7.16
1.39	2.28	5.96	5.45	5.38	7.33	7.19
1.41	2.25	5.78	5.39	5.39	7.30	7.10
1.42	2.24	5.92	5.48	5.43	7.38	7.12
1.42	2.32	5.96	5.47	5.40	7.36	7.13
1.43	2.23	5.98	5.40	5.42	7.37	7.10
1.45	2.23	5.98	5.39	5.43	7.35	7.12
1.46	2.24	5.90	5.48	5.42	7.34	7.15
1.46	2.26	5.87	5.47	5.39	7.29	7.14
1.38	2.27	5.88	5.38	5.38	7.32	7.13
1.37	2.26	5.95	5.49	5.41	7.38	7.16
1.40	2.25	5.98	5.49	5.39	7.32	7.18
1.42	2.24	5.99	5.37	5.40	7.33	7.12
1.32	2.30	5.96	5.46	5.42	7.32	7.14
1.48	2.25	5.89	5.42	5.43	7.36	7.14
1.39	2.29	5.88	5.40	5.42	7.35	7.15
MEAN 1.41	2.27	5.91	5.43	5.41	7.35	7.15
SD 0.043	0.028	0.056	0.39	0.018	0.029	0.025