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INSECTS ASSOCIATED WITH CITRONELLA IN SOUTH-EASTERN GHANA, WITH PARTICULAR REFERENCE TO SHOOTBORERS

by

JOSEPH EASMON SARFO
B.SC. (HONOURS) CAPE COAST (1984)
DIP. EDUC. CAPE COAST (1984)

A thesis submitted to the Department of Zoology, Faculty of Science, in partial fulfilment of the requirements for the degree of MASTER OF PHILOSOPHY of the UNIVERSITY OF GHANA

September, 1993.

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To

Maame Yaa Boatemaa Sarfo
And
Nana Akua Sarfowaa Sarfo

University of Ghana http://ugspace.ug.edu.gh

ZOOLOGY DEPARTMENT
UNIVERSITY OF GHANA
LEGON

This is to certify that this thesis has not been submitted for a degree to any other University. It is entirely my own work and all help has been duly acknowledged.

....
(Joseph E. Sarfo)

Supervisor ....
(Dr. S.Q. Quartey)

INTEGRI PROCEDAMUS

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ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my principal supervisor, Dr. S.Q. Quartey for his patience, useful criticisms and suggestions. My sincere thanks are due to Miss Cobblah of Zoology Department, a supervisor, who helped in the identification of some insects and also made available to me some useful printed materials. I am very grateful to Mr. Deeming (British Museum) for identifying the Chloropidae and Lonchaeidae and for providing me with key for the identification of shootflies. I would also like to thank Dr. C.Y. Brempong-Yeboah of Crop Science Department, Faculty of Agriculture, who as a supervisor, enthusiastically and readily offered assistance whenever consulted. My sincere gratitude also goes to Dr. J.B. Ackonor (Cocoa Research Institute of Ghana – CRIG) for patiently reading through the re-written script and making very useful suggestions. I thank Dr. N.N.N. Nuamah (ISSER, Legon) and Mr. Ken Brew (CRIG) for helping with some statistics. I am also grateful to Dr. (Mrs.) Botchwey and Mr. P. Kwapong (University of Cape Coast) for providing me with very useful printed material.

I appreciate greatly, the concern expressed by the Professors and lecturers of Zoology Department, especially about the delay of the work. I am particularly grateful to Dr. Wilson and Prof. Coker for their useful suggestions. To the technicians of Zoology Department, especially Mr. Titiati, Mr. Ofosu Baako, Mr. Asiedu and all others, I say a big thank you for your patience and immense technical help.

I am greatly indebted to Kwesi of Osofoiaman, Dr. Tagoe, Madam Selina Taylor, Mr. Ababio and all the other farmers who allowed me to use their farms for the study.

Mr. Vincent Acheampong (University of Ghana, Academic Affairs), Mr. F. Aneani (CRIG), Mr. Kwame Vowotor (Food Research Institute) and Mr. Alfred Quartey (University of Ghana, Data Processing Centre) deserve special mention. They, despite the inconvenience to them, stayed for long hours and sometimes late to help me with most of the analysis of my data and the processing of my graphs. I also thank Willie of

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Survey Department, Accra, for his neat cartographic work. I appreciate very much the photographs on the grass-hoppers taken by Mr. & Mrs Effah-Bekoe of Amsterdam, Holland. I am very grateful to Mr. Williams and my colleagues, Mr. Carl Fiati and Mr. Owusu-Boateng for their encouragement especially at difficult times. My special thanks go to another colleague, Mr. Albert Addo Kwafo, Faculty of Agriculture, for coming to my aid by offering me accommodation at a very critical time and also for the other numerous acts of kindness which helped me a great deal in getting this work completed.

I am very grateful to my friends, Mr. Peter Opoku, Survey Department, Accra, and Mr. Paul Forson of K.Y. Merchants, Accra, for the numerous valuable assistance given in diverse ways to make this work a possibility.

My warmest thanks go to Miss Mercy Techie-Menson, Miss Bertha Afful, Miss Theodora Mifetu, Miss Akosua Henewaa Dapaah, Miss Suzzy Micah and Miss Joyce Anane for their encouragement, company and friendship.

Finally, I thank Miss Grace Acheampong (University of Ghana, Academic Affairs), Mr. Kwame Amoako and Mr. Michael Doe Kulogo (CRIG) for accepting to neatly type this work and patiently doing all corrections when they had other pressing commitments.

J.E.S

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ABSTRACT

Insects associated with citronella were surveyed in the south-eastern part of Ghana for 11 months. Using two different sweep nets, intensive and extensive surveys showed that the foliage of citronella was associated with a diverse insect fauna comprising 10 orders and 102 families as follows: Hymenoptera (29), Diptera (32), Homoptera (8), Hemiptera (12), Coleoptera (10), Dictyoptera (2), Orthoptera (3), Lepidoptera (2), Dermaptera (1), and Neuroptera (3).

The shoot of citronella was found to be damaged by dipterous shootflies (Fam: Chloropidae and Fam: Lonchaeidae) and lepidopterous stemborers (Fam: Pyralidae and Fam: Noctuidae). There was no significant difference ($P > 0.05$) between the mean percentage infestation by the shootflies (mean = 1.18%) and that of the stemborers (mean = 0.59%). The chloropid shootflies were identified as *Scoliophthalmus micantipennis* Duda, *Scoliophthalmus trapezoides* Becker, *Anatrichus pygmaeus* Loew, *Aprometopis flavofacies* Becker, *Elachiptera occipitalis* Becker, and unidentified species. The lonchaeid shootfly was *Silba pectita* McAlpine. The pyralid and noctuid stemborers were *Eldana saccharina* Walker and *Sesamia* sp, respectively. Whereas *S. micantipennis*, *A. flavofacies* were found to cause primary damage by attacking fresh stems, *S. trapezoides* caused both primary and secondary damage by attacking fresh as well as already infested stems. The status of the other chloropids and the lonchaeid was not clear, since they were always found in association with other insects in already infested tillers. The lepidopterous stemborers were also found to cause primary damage. The larvae of the stemborers attacked the lower part of the tiller and tunnelled a length of 75.40 ± 12.79 mm while the shootflies tunnelled 32.60 ± 3.90 mm. The larvae live inside the tillers and so can possibly be controlled by systemic inseticides.

Preliminary field investigation showed that the worker caste of unidentified termites attacked the roots and stems of citronella, and this invariably led to complete death of the plant. This was more prevalent in farms older than one year; for example,

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85.7% of the termite infested farms were older than one year. Farmers should therefore not cultivate one farmland for too long. Further investigations showed negligible symptoms of feeding activities of insect foliage pests. For example, less than 0.005%, 0.002% and 0.009%, showed necrosis, curling and defoliation respectively, from insect attack in any farm.

Investigation of the seasonal variation of shootborer infestation of citronella showed two possible peaks: one between February and March, and another around October for both the lepidopterous stemborers and chloropid shootflies. The synchronisation in the build up of the damage by both groups of shootborers shows that they can be controlled simultaneously. Percentage `deadheart' caused by lepidopterous stemborers had a weak linear relationship with rainfall: $y = 0.0017x + 0.6298$. That by the dipterous shootflies also had a weak linear relationship with climatic factors as follows:- rainfall: $y = -0.0024x + 1.3413$; evaporation: $y = -0.8958x + 2.2639$; temperature: $y = -0.5826x + 17.15$; and relative humidity: $y = 0.1292x - 9.8968$; where y = percentage `deadheart' and x = climatic factor.

Comparision of sampling, using only visual `deadheart' symptom and random dissection, showed that using only `deadheart' symptom underestimated the infestation of shootborers by 31.8%. Shootborer infestation should therefore be determined from random dissection of tillers.

The pupa of female *S. micantipennis* measured $3.32 \pm .08$mm in length (n=30) and pupal period averaged 6.72 ± 0.39 days (n = 22). The male pupa measured $3.16 \pm .07$ mm long (n = 30) and the mean pupal period was 7.24 ± 0.05 days (n = 17). The adults of both sexes lived for about the same period: 8.59 ± 0.77 days (n = 29) for the female and 9.41 ± 0.60 days (n = 24) for the male. The adults exhibited sexual dimorphism with respect to their total body lengths, the male being shorter (1.90 ± 0.02mm; n = 30) than the female (2.98 ± 0.03mm; n = 31).

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TABLE OF CONTENTS

		Page
	Declaration	iii
	Acknowledgements	iv
	Abstract	vi
	List of Figures	xi
	List of Tables	xiii
	List of Plates	xiv
1.0	GENERAL INTRODUCTION AND LITERATURE REVIEW	1
1.1	General Introduction	1
1.1.1	Introduction of Citronella in Ghana	1
1.1.2	Citronella farming in Ghana	2
1.1.3	Why this study	4
1.2	Literature review	6
1.2.1	The Citronella plant	6
1.2.2	Importance of Citronella	7
1.2.3	Insect interactions with the Poaceae in general	8
1.2.4	Insect pests of Citronella	9
2.0	INSECTS ASSOCIATED WITH CITRONELLA	11
2.1	Introduction	11
2.2	Materials and methods	11
2.2.1	Sampling Points and Climate	11
2.2.2	Sampling procedures	15

University of Ghana http://ugspace.ug.edu.gh

2.2.2.1 Insects on citronella shoot (leaves and stems).. 15

2.2.2.2 Insects (pests) damaging citronella 16

2.2.2.3 Comparison of the Efficiencies of the Improved and Standard Sweep nets......... 19

2.2.2.4 Comparison of Sampling methods.. 19

2.3 Results 23

2.3.1 Insects on citronella shoot (leaves and stems).. 23

2.3.2 Insects damaging citronella 24

2.3.3 Comparison of the Efficiencies of the Improved and Standard Sweep nets......... 26

2.3.4 Comparison of Sampling methods.. 27

2.4 Discussion.. 35

3.0 INSECT PREFERENCES FOR DIFFERENT SIZES OF HOST PLANT AND NATURE OF SHOOTBORER DAMAGE TO THE SHOOT OF CITRONELLA. 42

3.1 Introduction.. 42

3.2 Materials and Methods 43

3.2.1 Field investigation of preference for size of Citronella tillers by shootborers 43

3.2.2 Boring activity of the shootborers... 43

3.2.3 Field Identification of damage from differential growth (height) of newly ratooned infested and uninfested tillers.. 44

3.3 Results... 46

3.3.1 Field investigation of preference for size of Citronella tillers by shootborers 46

3.3.2 Boring activity of the shootborers... 46

3.3.3 Field identification of damage from differential growth (height) of newly ratooned infested and uninfested tillers.. 47

University of Ghana http://ugspace.ug.edu.gh

3.4 Discussion.. 51

4.0 SEASONAL VARIATION IN INFESTATION OF CITRONELLA BY LEPIDOPTEROUS STEMBORERS AND CHLOROPID SHOOTFLIES 54

4.1 Introduction 54

4.2 Materials and methods.. 54

4.2 .1 Determination of Sample size and measurement of Incidence of 'deadheart' caused by shootborers.. 54

4.2.2 Rainfall, Temperature, R.H. and Evaporation. 56

4.3 Results.. 56

4.3.1 Determination of Sample size and measurement of incidence of 'deadheart' caused by shooborers 56

4.3.2 Rainfall, Temperature, R.H. and Evaporation 58

4.4 Discussion... 67

5.0 ASPECTS OF THE BIOLOGY OF SHOOTFLY, *SCOLIOPHTHALMUS MICANTIPENNIS* (DIPTERA: CHLOROPIDAE).. 70

5.1 Introduction.. 70

5.2 Materials and methods.. 70

5.3 Results.. 74

5.4 Discussion... 80

6.0 SUMMARY AND CONCLUSIONS.. 82

6.1 Summary.. 82

6.2 Conclusions.. 83

REFERENCES... 85

APPENDICES.. 91

University of Ghana http://ugspace.ug.edu.gh

LIST OF FIGURES

Page

Figure 1: Map of Southtern Ghana showing locations where sampling was done 13

Figure 2: The standard and improved sweep nets... 22

Figure 3: Infestation rates as determined by only `deadheart' symptom and by Random dissection.. 28

Figure 4: Dorso-lateral view of female *Scoliophthalmus trapezoides*.......................... 29

Figure 5: Dorso-lateral view of female *Scoliophthalmus micantipennis*......................... 30

Figure 6: Lateral view of female *Anatrichus pygmaeus*...................................... 31

Figure 7: Dorso-lateral view of female *Aprometopis flavofacies*.............................. 32

Figure 8: Lateral view of female *Elachiptera occipitalis* 33

Figure 9: Longitudinal section of tiller attacked by lepidopterous stemborer..................... 48

Figure 10: Longitudinal section of tiller attacked by shootfly.. 49

Figure 11: Daily growth of healthy and infested tillers of ratooned citronella at Osofoiaman in one week in 1991... 50

Figure 12: Percentage 'deadheart' caused by shootflies and lepidopterous stemborers, Osofoiaman Farm B, 1991.. 59

Figure 13: Percentage 'deadheart' caused by shootflies and lepidoperous stemborers, Osofoiaman Farm A, Jan - June, 1991... 60

Figure 14: Mean monthly rainfall, evaporation, relaltive humidity, temperature and percentage 'deadheart' by shootflies and lepidopterous stemborers, Osofoiaman, Farm B, 1991.. 61

Figure 15: Relationship between percentage 'deadheart' by stemborers and rainfall...... 62

University of Ghana http://ugspace.ug.edu.gh

Figure 16: Relationship between percentage 'deadheart' by shootflies and rainfall.......... 63

Figure 17: Relationship between percentage 'deadheart' by shootflies and evaporation...... 64

Figure 18: Relationship between percentage 'deadheart' by shootflies and temperature...... 65

Figure 19: Relationship between percentage 'deadheart' by shootflies and relative humidity 66

Figure 20: Dorsal view of male puparium of *Scoliophthalmus micantipennis* with the tip broken to provide passage for the emerging adult................................... 77

Figure 21: Dorsal view of female puparium of *Scoliophthalmus micantipennis* with the tip broken to provide passage for the emerging adult................................... 78

University of Ghana http://ugspace.ug.edu.gh

LIST OF TABLES

Page

Table 1: Foliar damage by insects to citronella leaves in different farms........................ 24

Table 2: Adult Diptera reared, and Lepidoptera larvae collected, from tillers showing \`deadheart' symptoms from Osofoiaman and other farms in 1991. 25

Table 3: Incidence of termites in sampled farms, in Greater Accra Region, 1991........... 26

Table 4: Analysis of twenty (20) samples of insects each by improved and standard sweep nets, at 10 sweeps per sample. 27

Table 5: Summary and analysis of tillers preferred and damaged by the shootborers....... 47

Table 6: Survival and Development of larvae of shootflies collected from infested tillers 75

Table 7: Length of empty puparia of female and male *Scoliophthalmus micantipennis*.... 76

Table 8: Pupal period of male and female *Scoliophthalmus micantipennis* in the laboratory at 27.4°C.. 76

Table 9: Longevity of adult male and female *Scoliophthalmus micantipennis* in the Laboratory at 27.4°C... 79

Table 10: Total body length of adult male and female *Scoliophthalmus micantipennis* 79

University of Ghana http://ugspace.ug.edu.gh

LIST OF PLATES

Page

Plate 1: Citronella farm.. 3

Plate 2: Rearing of insects from cut citronella shoots... 21

Plate 3: *Zonocerus variegatus* attacking citronella on the farm.................................... 34

Plate 4: Experiment to study the boring activity of shootfly larvae. 45

Plate 5: Experiment to determine oviposition site of *Scoliophthalmus micantipennis* in the laboratory.. 73

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CHAPTER ONE

1.0 GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 General Introduction

1.1.1 Introduction of Citronella in Ghana

Citronella is an essential oil producing Poaceae (Graminae) with origins in Asia. It is however, now cultivated in many tropical and subtropical areas such as Taiwan, Malaysia, Sri Lanka, Indonesia, Seychelles Islands, Zaire, Brazil , Uganda (Skerman and Riveros, 1990). The two main species, *Cymbopogon nardus* and *Cymbopogon winterianus*, have been cultivated in Ghana since 1978 (Laryea, 1988).

Citronella was introduced in Ghana from Sri Lanka by Lever Brothers Ghana Limited (LBG) in 1978 through Dr. David Tagoe, the then Technical Services Manager of LBG, to produce citronella oil locally for the company's soap manufacturing industry. A few tillers each of the following five types of *Cymbopogon* were introduced;

i. *Cymbopogon nardus*

ii. *Cymbopogon winterianus*

iii. Citronella variety Number one

iv. Lemongrass ex Sri - Lanka

v. East Indian Lemongrass

Initial agronomic studies at the University of Ghana showed that it was feasible to cultivate all the five types in Ghana. LBG, however, preferred the citronella to the lemon grass because it had a higher yield of oil and therefore it was of better commercial value. In 1981, LBG's first attempt at cultivating citronella in a pilot scheme at Banso in the Western

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Region failed because of poor soil condition due to high acidity, high incidence of stemborers and rust infection at the site (Laryea, 1988).

LBG attempted another pilot project at Bunso in the Eastern Region in 1982. This was successful and the farm served as the source of planting material for many outgrowers. As at 1989 there was a total of 46 farms of citronella spread over Brong Ahafo, Ashanti, Western, Eastern, Central, Greater Accra and Volta regions (Laryea, personal communication). The farmers formed an association known as Citronella Oil Producers Association (COPA), and they are the core of citronella producers in Ghana. According to Laryea (Personal communication), their number as at 1992 had risen to just over 50 with farms covering over 200 ha from which about 10,000 kg of oil was being produced annually. The number of farmers could have been higher but for the ceiling put on COPA membership by LBG. There are numerous small scale citronella farmers outside COPA.

1.1.2 Citronella Farming in Ghana

Citronella is currently cultivated countrywide except in northern Ghana. According to LBG, sandy loam with fairly distributed annual rainfall of over 900mm is the most preferred condition for the cultivation of citronella. The most suitable time for planting is at the onset of the rains. The planting material is at least a 6-month old tiller pruned of the leaves and roots. The tillers are planted about 8 to 10cm deep in the soil and spaced about 60cm, giving about 27,000 tillers per hectare. Time and frequency of weeding is determined by the farmer. Good husbandry requires that flowers from citronella should be removed since flower production depletes the oil content of the plants. Harvesting of citronella leaves is done when the leaves become mature at which stage the tips become dry and curl backwards. In times

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Plate 1: **Citronella Farm**

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of adequate rainfall, this is about 6 months after planting and subsequent harvests are done at 3-4 month intervals or shorter.

Harvested citronella is dried in the field for about 4 days to reduce the water content and also to reduce the load on the still. Harvesting is therefore not recommended during the very wet periods since the leaves rot during drying. Dried citronella is cleaned of moulds and other foreign bodies before being distilled by steam.

1.1.3 Why this Study

One of the reasons for the failure of the first citronella pilot programme at Banso in 1981 was stemborer attack. Also in 1988, a team from the University of Ghana reported lepidopterous stemborer attack and possible leaf hopper damage at Ayikuma in the Greater Accra Region. According to the report, damage by the insects was so serious at Ayikuma and some areas in the Greater Accra region that severe crop losses and revenue were recorded. There is also the fear that since citronella is cultivated as a monocrop, the insect pest problem will become more serious as cultivation increases.

Apart from the initial investigations, no detailed study has been done on the pest and disease problems of citronella. This study is, therefore, aimed at providing a more detailed information about the insects associated with citronella, and to study the ecology and biology of the major pest(s), with a view to providing baseline information that will be useful in designing an ecologically acceptable and economically feasible pest management programme for the citronella cultivation in Ghana.

The objectives of the study are, therefore,

i. to collect and identify all stages of insects associated with citronella in south

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- eastern Ghana,

ii. to identify the major and potential insect pests and their natural enemies, wher possible,

iii. to determine insect pest preferences for different sizes of host and to characterize the nature of pest damage,

ii. to study the seasonal trends of infestation of the major insect pests of citronella

v. to determine the effects of relative humidity (R.H.), evaporation, temperatur and rainfall on the infestation of the major insect pests of citronella and

vi. to study the biology of the major insect pest(s) of citronella.

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1.2 Literature Review

1.2.1 The Citronella Plant

Citronella is a perennial grass and it is classified as follows :

Family	: Poaceae (= Graminae)
Subfamily	: Panicoideae
Tribe	: Andropogoneae
Genus	: *Cymbopogon*

The genus *Cymbopogon* has about 60 species (Purseglove , 1983) which give varied products including essential oils, fodder, mulch and thatching material (Bor, 1960; Arber, 1965; Purseglove, 1983; Skerman and Riveros, 1990; Bajracharya, 1990; Singh *et al*, 1991). The species include *Cymbopogon nardus* (Rendle - Ceylon/Sri Lankan type) and *C. winterianus* Jowitt - Java type which produces citronella oil (Wijesekera, 1973), *C. citratus* (DC) Stapf, which produces lemon grass oil (Arber, 1965) and *C. martinii* (Roxb) Wats which gives palmrosa oil (Bor , 1960).

Citronella grows in tufts and at maturity, the height varies from about 0.5 to 1m. The plant consists of tillers which vary from two to over a hundred, depending on age and variety. A tiller consists of a short rhizome, made up of a series of nodes separated by short internodes and relatively long sheaths crowned by long narrow leaves. The basal nodes are very close together and the lowest nodes normally give rise to the roots.

The morphological differences between *C. nardus* and *C. winterianus* lie in the shape of their leaves which, according to Senaratne (1956), are narrower in *C. nardus*. *Cymbopogon nardus* is hardier than *C. winterianus* and while the former can thrive even on

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marginal soils and produce for 10 to 15 years, the latter thrives only on well drained sandy loam with abundant rainfall and can produce for only three to four years (Laryea, 1988). The chemical difference between the two species is found in the citronellal component of the oil (Wijesekera, 1973). Thus, *C. winterianus* contains more citronellal (32.7%) than *C. nardus* (5.2%).

1.2.2 Importance of Citronella

Citronella plants are cultivated for their extensively used essential oils, which are mainly terpenes such as geraniol, citronellal and citronellol. The most important oils produced are citronella oil from *C. nardus* and *C. winterianus* (Bor , 1960); lemon grass oil from *C. citratus* (Aber, 1965); and palmrosa oil from *C. martinii* (Bor, 1960).

According to Wijesekera (1973), citronella oil is used in perfumes; as deodorants in mosquito repellants, insecticides, soaps, disinfectants, paints and polishes. It is also used in the preparation of aromatic chemicals derived from citronellol and geraniol. Citronella oil also has great potential in pest control, for it repels stored product pests, such as *Tribolium castaneum* (Hbst)(Coleoptera: Tenebrionidae) and *Bruchus chinensis* (L.) (Coleoptera: Bruchidae), as well as *Periplaneta americana* (L.) (Dictyoptera: Blattidae) (Saraswathi and Rao, 1987). The oil may also inhibit fungal growth and spore germination (Raghavaiah and Jayarmaiah, 1987). In Ghana, Lever Brothers Ghana Limited (LBG) uses citronella oil to perfume the following brand soap products: Key[R] soap, Sunlight[R] soap, and Guardian[R] soap. Lemon grass oil is used in the commercial synthesis of vitamin A and also in scenting soaps, while palmrosa oil is acclaimed to be the best natural source of geraniol used as a soap perfume and also for the flavouring of tobacco (Purseglove, 1983).

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Other products of citronella are also useful. For example, water extract from *C. flexuosus* is a nematicide that suppresses root knot development in tomato and aubergine caused by *Meloidogyne incognita* (Tiyagi *et al*, 1990), leaves of *C. nardus* are used as mulch and as a thatching material (Skerman and Riveros, 1990) whereas the spent grass of *C. flexuosus* is used as fodder (Bajracharya, 1990).

1.2.3. Insect interactions with the Poaceae in general

Citronella belongs to a family of pants (Poaceae) which play host to numerous insects, consisting of plant feeders, predators, parasitoids and casual visitors (Tams and Bowden, 1953; Ingram, 1958; Nye, 1960a; Harris, 1962; Watts, 1963; Byers, 1967; Deeming, 1971). The age, morphological features, texture, turgidity and manner of growth of the plant are among the factors that influence insect attack of the group (Willams, 1954; Mulkern, 1967; Easwaramoorthy and Jayaraj, 1988). Shootborer activity on poaceous plants also tend to fluctuate under the influence of several extraneous factors including the following, wet and dry seasons (Sarel-whitfield, 1929; Rose, 1973; Wilson *et al*, 1973), cropping seasons (Harris, 1962; Endrody-Younga, 1968; Girling, 1978) and weather and climate (Smithers 1960; Harris, 1962; Adeyemi, 1969; Barry, 1972; Balraj *et al*, 1977; Clearwater and Otieno, 1977; Ogwaro, 1979), as well as farming practices (Harris,1962; Girling,1978) and altitude (Ingram, 1958; Nye, 1960b; Reddy,1982).

Insect attack on the family produces several damage symptoms such as `white head' and `deadheart' (Nye, 1960a; Deeming, 1971; Agen-Sampong, 1975), gouted shoots (Goodlife, 1942) and wilted shoots (Simmonds, 1952). It may directly result in decrease in yield (Poos and Johnson, 1936; Wolfenbarger, 1963; Peterson and Granovsky, 1950; Byers,

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1967) or in the transmission of virus and other pathogens for diseases, the symptoms of which include yellows, chlorotic streaks, necrosis of the phloem and tumor (Smith and Brierley, 1956; Day and Venables, 1961; Kennedy *et al*, 1962; Watson and Plumb, 1972).

1.2.4 Insect pests of citronella

There is scanty information on insects associated with citronella because of the lack of systematic literature on both the crop (Gour *et al*, 1991) and insect pests (Sontakke *et al*, 1991). Nevertheless, insects appear to be a problem to the root, stem and leaves of citronella (Sontakke *et al*, 1991, Gour *et al*, 1991). For instance, the worker termite *Microtermes obesi* (Isoptera; Termitidae) and the white grub, *Holotrichia consanguinea* (Blanchard) (Coleoptera: Melolonthidae), attack the root and eventually the stem leading to the death of the plant (Sontakke *et al*, 1991). The same authors reported further that between 20 and 30% of the stems of young citronella are severely infested by the larvae of *Chilo infuscatellus* (Snellen) (Lepidoptera: Pyralidae), a stemborer. Gour *et al* (1991) identified the larva of *Stemmatophora fuscibalis* (Snellen) (Lepidoptera: Pyralidae) as a stemborer of citronella. In Ghana, the stem is attacked by the larvae of *Eldana saccharina* Walker (Lepidoptera: Pyralidae), *Sesamia* sp. (Lepidoptera: Noctuidae) and *Atherigona* sp. (Diptera: Muscidae) (Botchwey, personal communication).

The leaves are attacked by both the adult and the nymph of *Anaphothrips sudanensis* Trybom, *Chloethrips holorphnus* (Karney) (Thysanoptera: Thripidae), *Macrosiphum miscanthi* (Takahashi) (Homoptera: Aphididae), the larvae of *Mythimna separata* (Walker) (Lepidoptera: Noctuidae) and the nymphs of *Colemania phenarioides* Bol (Orthoptera: Acrididae) (Sontakke *et al*, 1991). Infested leaves are characterised by white patches and sap

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sucking by the insects results in some leaves curling inwards longitudinally from the margin while others dry at the tip (Sontakke *et al*, 1991).

Three species of leaf hoppers, *Zygina manensis, Neophotettix nigropictus* and *Typhlocyba maculifrons* (Homoptera: Cicadellidae) have also been found to be associated with the leaves of citronella, but the pest status and the nature of damage caused by these insects were not ascertained (Sontakke *et al*, 1991).

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CHAPTER TWO

2.0 INSECTS ASSOCIATED WITH CITRONELLA

2.1 Introduction

Grasses are generally visited by many insects, some of which are plant feeders, predators, parasitoids and casual visitors. For instance, Watts (1963) collected insects made up of 9 orders, 55 families, 109 genera and 120 species of the above categories on black grama grass. Other poaceous plants like maize, sorghum, millet, wheat, oats, barley, sugar cane and rice also interact with insects in various ways (Tams and Bowden 1953; Ingram 1958; Nye, 1960a; Harris, 1962 and Deeming, 1971).

There is lack of information on the insects associated with citronella. Only few workers like Sontakke *et al* (1991) and Gour *et al* (1991) have provided some information on insects attacking the crop and from their work, the leaves, stems and roots of citronella are attacked by various insects in India (Section 1.2). However, information on insect abundance and activity on the crop can be obtained from surveying the insect complex through various sampling methods including light traps, Malaise traps and sweep nets (Southwood, 1968). Pre-proposal visits to citronella farms in the Greater Accra and Eastern Regions showed the presence of several insects on the crop with those of economic importance occurring in immature stages in the shoot. This study was therefore undertaken to find the occurrence of general insects, insect feeders (pests), potential feeders and the natural enemies of these feeders, where possible.

2.2 Materials and methods

2.2.1 Sampling points and climate

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The studies were carried out mostly on farms in the Greater Accra and Eastern Regions of Ghana (Fig. 1). In the Eastern Region, data were collected from farms at Omenako and Kpankpan-Ayikuma near Suhum. In the Greater Accra region, data were collected from Ashalaja, Ababio and Selina Taylor farms at Ayikuma in addition to data collected from a farm at Botoku, near Pokuase. Detailed studies were carried out at Osofoiaman in the Greater Accra region, where two farms were located. All the farms in the Eastern region were located in the forest zone. The rest were in the coastal savanna.

Osofoiaman is a small village, about 15 km north-west of Accra (Fig. 1). It lies on latitude 5°44′ N and longitude 0°.16′ W. on the southern-most portion of the Akwapim ranges. The main occupation of the people is farming. Pineapples and citronella are the main cash crops which are cultivated, together with food crops like cassava, maize and vegetables. Farm A at Osofoiaman was located at about 200 meters south of the village. It was part of Kate citronella farms and it was located about 40 meters from an older and larger farm. Farm A measured about 88 x 18.5 m and it contained about 1800 citronella hills cultivated without any ploughing. It was bordered by wild grasses, maize and an abandoned farm of plantain and banana. The soil was mainly sandy loam and clay. The latter contributed to the flooding of the farm during rains since it was poorly drained. Farm B belonged to a small scale farmer. It was located about 300 meters N.W. of the village. The size was 58 x 42m with about 1570 citronella hills, also cultivated without ploughing. It was bordered by pineapple and citronella farms, grasses, cassava and maize. The soil was sandy loam and well drained.

The climatic factors are summarized in Appendix I. Even though Osofoiaman lies within one of the driest zones in Ghana (The Accra plains), its climate is ameliorated by relief

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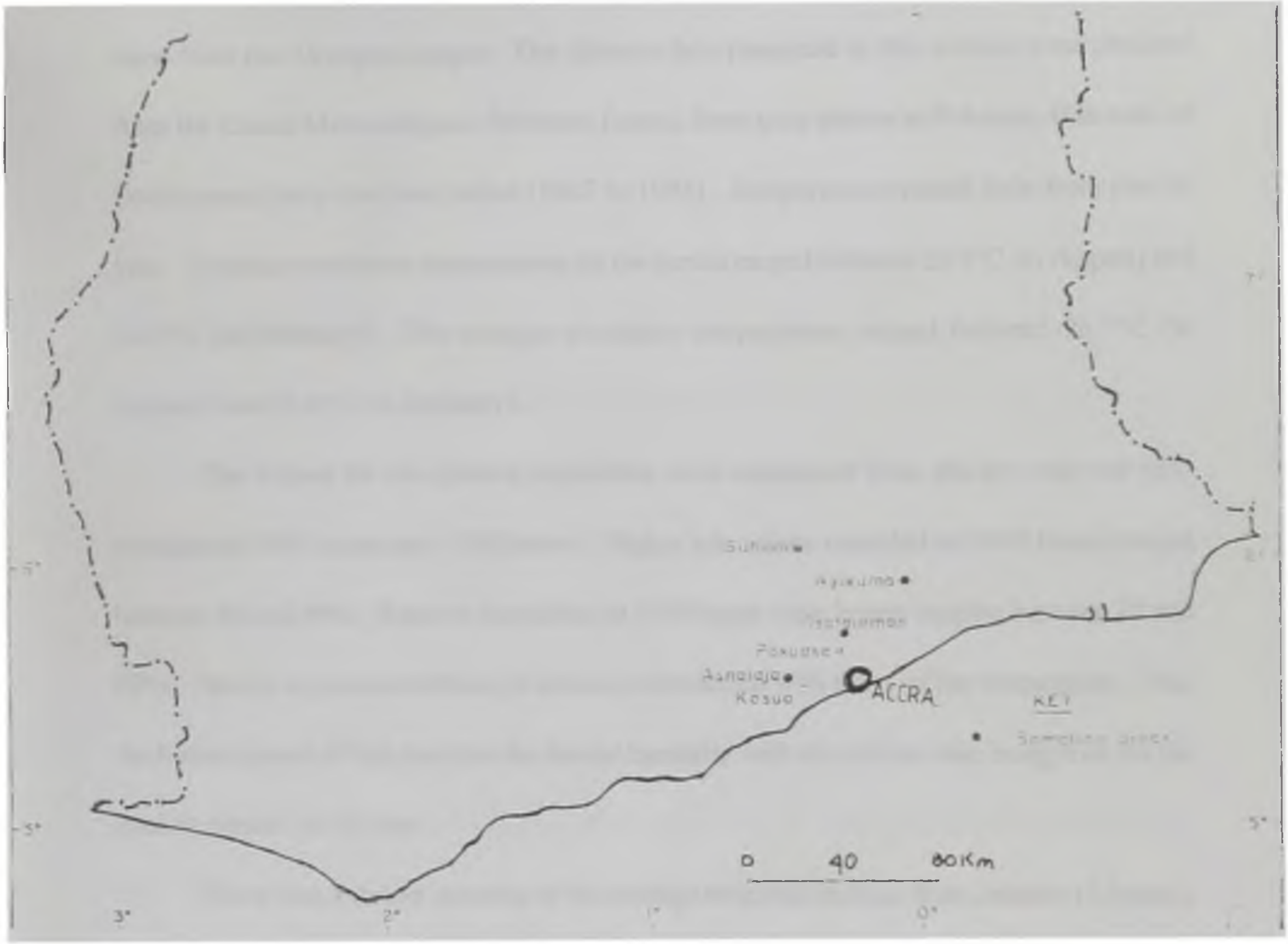

Fig. 1: **Map of Southern Ghana showing locations where sampling was done.**

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rains from the Akwapim ranges. The climatic data presented in this section were obtained from the Ghana Meteorological Services, Legon, from their station at Pokuase, 4km west of Osofoiaman, for a five year period (1987 to 1991). Temperatures varied little from year to year. Average maximum temperatures for the period ranged between 29.3°C (in August) and 34.7°C (in February). The average minimum temperatures ranged between 20.7°C (in January) and 23.6°C (in February).

The values for the relative humidities were calculated from the dry and wet bulb readings at 0900 hours and 1500 hours. Higher r.h. values recorded at 0900 hours ranged between 88 and 94%. Relative humidities at 1500 hours were lower; ranging between 70 and 88%. The r.h. regimes exhibited an inverse relationship with those of the temperature. Thus the hottest period of the year had the lowest humidity with the reverse also being true for the coolest periods of the year.

There was a steady increase of the average evaporation rates from January (1.9 mm.) to April (2.6 mm.) and subsequently decreased over the months to December (1.6 mm.).

The lowest rainfall was 8.8 mm in January and the highest, 202.4 mm in May. The rainfall was bimodal with the first rainy season beginning in April and ending in July. The second one began in September even though August was not completely dry and it ended in November.

The other sites showed similar climate and four distinct seasons were recognized as follows:

1. hot season from March to April and also from October to November,

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2. cool wet season from May to July and September,

3. cool dry season from August with little rainfall, and

4. hot dry season from December to February, which was the driest period with low rainfall and low humidity and very high temperatures and high evaporation. This is the harmattan period of cool nights and hot days and dry winds.

2.2.2 Sampling procedures

2.2.2.1. Insects on Citronella Shoot (Leaves and Stems)

Insects whose interaction with the shoots of citronella were not obvious were sampled intensively and extensively using the sweep net, which is more appropriate for sampling insects on shoot of grasses because it samples about two thirds of the plant height (Nielson, 1957). It is simple to use and provides rapid estimates of insect distribution, activity and abundance (Balogh, 1958). The intensive sampling involved the continual observation of the populations of insects that visited citronella at two areas and was carried out at Osofoiaman Farm A for six months (January to June, 1991.) and at Osofoiaman Farm B for 11 months (February to December, 1991) except in May when heavy rainfall made sweeping impossible.

Investigations on Farm A had to be discontinued in June when the field was completely destroyed by floods. The farms were visited weekly and sweeping done before 10.00 a.m. except when it was raining or when the visit coincided with the harvesting time of the farmer. Sweeping was done with a standard insect net of diameter 47 cm and depth 46 cm. Ten to and fro swings constituted one sample, which was transferred into a killing jar charged with ethyl acetate. Twenty samples, made up of five along each diagonal and each of two opposite sides of the farm were taken. The samples were taken to the laboratory where the

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insects were identified, using keys and museum specimens, and their numbers recorded. Some of the insects were pinned, dried and kept in boxes while others were preserved in 70% alcohol.

The extensive sampling, was aimed at studies on the distribution of insects associated with citronella in the study area and was conducted in six farms at Osofoiaman (Farm C), Botoku, Omenako and Kpankpan Ayikuma near Suhum and Ayikuma near Dodowa (Selina Taylor and Ababio's farms). Each of these six farms was sampled with an improved net (Fig. 2b) at about three-week intervals, between the last week of October and the last week of December 1992. At each farm, 50 x 40 m was demarcated and sweeping done as in the intensive sampling. Insects collected were killed and identified as above. The extensive sampling had to be done between 11.00 a.m. and 3.00 p.m. because of problems from using public transport.

2.2.2.2 Insects (pests) damaging citronella

Insects damaging the leaves: Feeding on the foliage of citronella by insects may be manifested as defoliation of the plant, necrosis or curling of the leaf (Sontakke *et al,* 1991). Thus, this study was initiated in experimental Farm B to find the prevalence of these symptoms and the insects responsible. Moving in a zig-zag fashion from one long side of the farm to the other, every eighth (8th) plant was sampled and all the leaves inspected for defoliation, necrosis and curling. Such leaves were counted and recorded. Sampled plants were marked with pegs and skipped if encountered again. This was done monthly for six months, (February, March, June, September and November in 1991). It was repeated fortnightly, between the last week of October and last week of December, 1992 in Osofoiaman

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(Farm C), Botoku, Omenako, Kpankpan-Ayikuma, Selina Taylor and Ababio farms. The study was done on the same demarcated plots for sweeping as above. (See 2.2.2.1)

Insects damaging the stem: From preliminary studies at Osofoiaman, Ayikuma and Ashalaja, between November, 1990 and January, 1991, insect infestations were observed in the stems of citronella in all the farms visited. The following survey was thus initiated to find out the species of insects involved. The work was done at Osofoiaman Farms A and B, from January to June, 1991 and thereafter continued on Farm B and other farms at Osofoiaman, Botoku, Ayikuma and Ashalaja till December.

`Deadheart' symptom, which is the gradual yellowing and browning of the innermost whorl of the tiller, as a result of damage by insects in the stem, was used to identify tillers infested by the shootborers. At Osofoiaman farms A and B, randomly selected citronella hills were inspected weekly and all tillers counted. Those showing `deadheart' symptoms were removed, using a scapel and classified as either `early deadheart' tiller, `advanced deadheart' tiller or `secondarily infested' tiller in the case of Diptera. The inner whorl of a healthy tiller was pale green but infested tiller classified as `early deadheart'; (i.e. freshly attacked) had the inner whorl just beginning to wilt and changing from pale green to greenish yellow. An `advanced deadheart', had the inner whorl wilted and the colour ranging from yellow to brown and may have multiple infestation by Diptera. The `secondarily infested' tiller was a condition where the tiller had already been attacked by a Lepidoptera before the Diptera. Those tillers that had been attacked by Lepidoptera only, were classified as `Lepidoptera'. All the tillers showing `deadheart' were taken to the laboratory and dissected, to determine the

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causes of the `deadheart'. Tillers with dipterous larvae were carefully closed again and the portions with the larvae cut into 5-8 cm pieces, which were then stood in 10 x 2 cm tubes having moist cotton wool at the bottom, corked but opened frequently to allow in air (Plate2). The moist cotton wool prevented the cut tillers from drying quickly. The set up was inspected daily until adult flies emerged. If pupae of the Diptera were obtained from the tillers, they were placed individually in 10 x 2 cm tubes without moist cotton wool until adult flies emerged. Representative adults were labelled and sent to the British Museum for identification. Subsequently, all adults were identified using the keys provided by the British Museum. A key (Appendix 4), was eventually prepared for the shootflies identified in this study. The larvae of the Lepidoptera were either preserved or reared to adulthood and later identified. To preserve the larvae, they were killed in hot water of about 60°C, passed through 40% and 60% alcohol and finally stored in 70% alcohol. The hot water ensured that the larvae maintained their colour patterns.

Farms at Ayikuma, Botoku and Ashalaja were also inspected monthly till December, 1991, for `deadheart' tillers and treated as those obtained from Osofoiaman Farms A and B.

Insects damaging citronella root: Farms at Osofoiaman, Botoku, Ayikuma and Ashalaja were visited every two months between January and December, 1991, and citronella plants inspected for damage by root pests. Ten blocks of plots measuring 4 x 4 m were randomly selected and all the hills inspected. The presence of termitaria around the plants, and or the wilting of the leaves other than the inner whorl of the tiller, indicated the presence of root feeders, especially termites, in the roots. Such plants were uprooted and the underground parts examined. Termites were the only insects seen and some of them were collected for

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identification.

Natural enemies: Thirty- eight adults, 57 pupae and 172 larvae of the shootflies and 5 lepidopterous stemborer larvae which died during rearing and 320 termite pests collected were kept in glass tubes sterilized by boiling and inspected for parasitoids and fungal growth. Predators were not screened but observations were made of insect activities in the field for predation.

2.2.2.3 Comparison of the Efficiencies of Improved and Standard Sweep Nets: It was observed from the intensive survey that the standard sweep net (Fig. 2a) caught rather low numbers of insects, especially smaller insects. The opening of the net was so wide that before the contents could be removed, swifter as well as and smaller insects would escape. An improved net was therefore designed and its efficiency compared with that of the standard sweep net. The improved net (Fig. 2b) had a narrower opening of diameter, D, 36.5 cm and a total depth, P, of 74 cm as against 52.5cm and 55.5cm, respectively, of the standard net. The nets were made of grey baft but the improved one had a detachable sac, T, of muslin material at the bottom of the net. After a collection has been made the detachable sac is closed by constricting the mouth with string, S. To determine their respective efficiencies, twenty samples were taken for each of the nets on a plot of citronella at Pokuase similar to what was done in the intensive sampling. The number of insects caught in one sample was counted, the time to make ten sweeps and get the insects into the killing bottle determined with stop watch, and insects caught per unit time, calculated for each net.

2.2.2.4 Comparison of Sampling Methods: Very low levels of infestation were recorded using `deadheart' symptoms alone to score infestation. In this experiment, therefore, results

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from this method were compared with those of another one to find out if there was any difference. Based on the assumption that infested tillers that manifested in `deadheart' symptom and those that did not, stood equal chance of being sampled, two methods for sampling shootborer infestation, viz, sampling using visual `deadheart' symptom and sampling by random dissection were compared as follows; some 366 tillers were randomly removed and inspected for `deadheart' symptom. Then they were all dissected carefully and inspected for shootborers. Percentage infestation as determined from the incidence of `deadheart' was compared with that from random dissection, the null hypothesis being that there was no difference between the two. The comparison was replicated in 4 different farms.

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Plate 2: **Rearing of insects from cut citronella shoots.**

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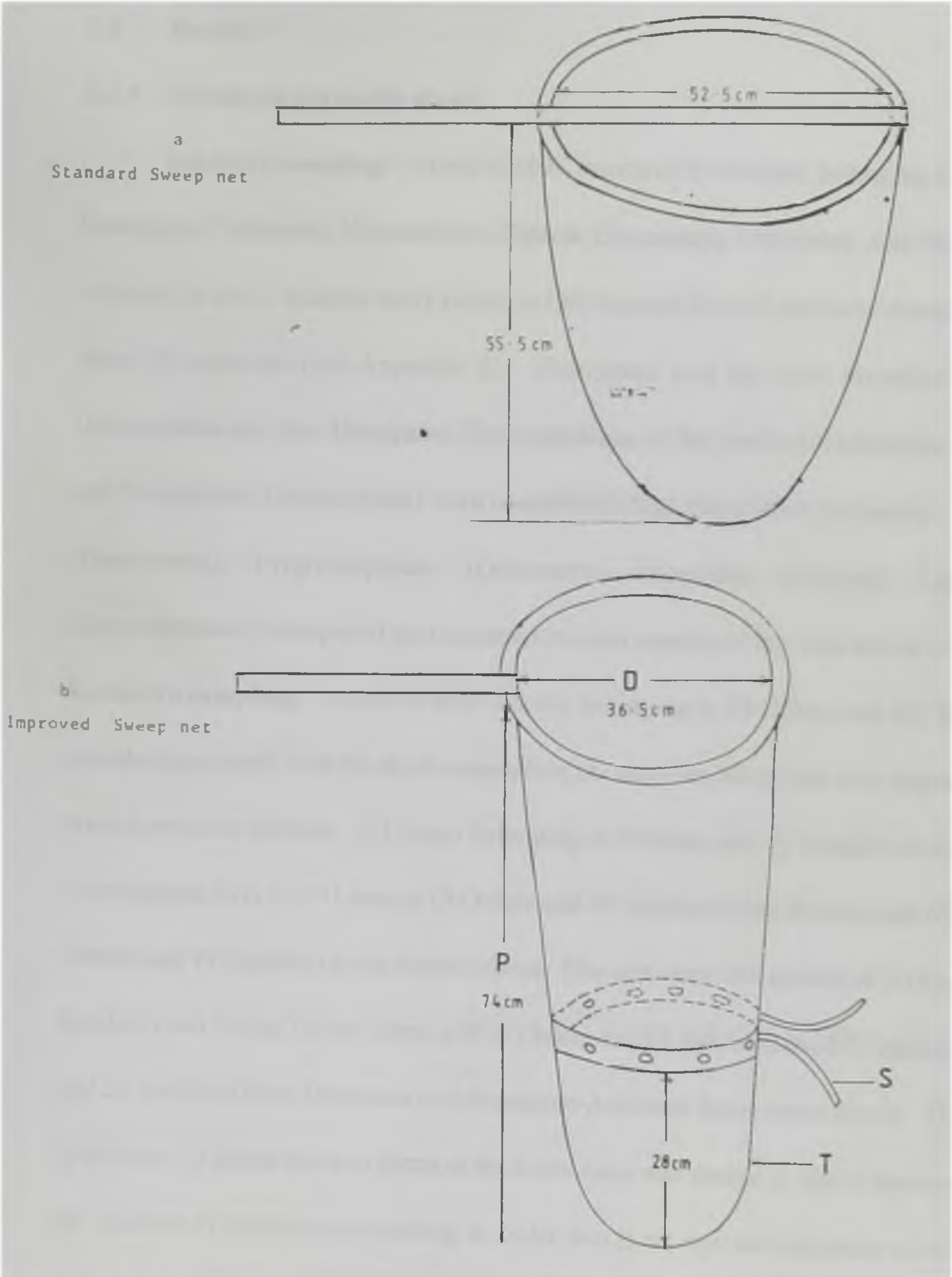

Fig. 2 **The standard and Improved sweep nets**

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2.3 Results

2.3.1 Insects on citronella shoot

Intensive sampling: A total of 1093 insects of 20 families, belonging to eight Orders; Hemiptera, Coleoptera, Hymenoptera, Diptera, Dermaptera, Orthoptera, and Dictyoptera were collected in the 11 months study period at Osofoiaman Farm B and were associated with the shoot of citronella (see Appendix 2). Homoptera was the most abundant followed by Hymenoptera and then Hemiptera. The populations of the families: Cercopidae (Homoptera) and Formicidae (Hymenoptera) were consistently high throughout the survey. Forficulidae (Dermaptera), Pyrgomorphidae (Orthoptera), Diopsidae (Diptera), Lagriidae and Chrysomelidae (Coleoptera) also occurred in most months of the year but in low numbers.

Extensive sampling: A total of 4567 insects, belonging to 10 Orders and 102 families were recorded associated with the shoot citronella in the other six farms (see also Appendix 3). The breakdown is as follows; 751 insect belonging to 8 Orders and 52 families were recorded at Osofoiaman farm C, 951 insects (9 Orders and 49 families) from Botoku and 682 insets (10 Orders and 49 families) from Abobio farms. The rest were 716 insects of 10 Orders and 47 families from Selina Taylor farms, 649 (9 Orders and 53 families) and 907 insects (10 Orders and 55 families) from Omenako and Kpankpan-Ayikuma farms respectively. The spectrum of diversity of insect fauna in farms in the forest zone was similar to that in the savanna. Also the member of families representing an order was in no way an indication of the degree to which such groups contributed to the total insect population. For example, Homoptera had eight families yet contributed 1613 insects but Hymenoptera with 12 families and Coleoptera with 10 contributed 160 and 83 insects, respectively.

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2.3.2 Insects damaging citronella

Insects feeding on citronella leaves: The results (Table 1) showed that percentage necrosis in citronella leaves at the 7 different farms ranged between 0.0001% and 0.004%; that of curling was 0.001 and 0.008%. and defoliation between 0.0002% and 0.008%. This shows that negligible proportions of citronella leaves were attacked by insects.

Zonocerus variegatus

Zonocerus variegatus was the main species of Pyrgomorphidae (Orthoptera) collected in this study. It occurred in 8 months of the year in the intensive survey (Appendix 2) and in all farms in the extensive one, forming 73% of the Orthoptera group (Appendix 3). During the study, no feeding activity by the insect was observed in any of the farms visited. After the study period, however, it caused damage to citronella at a farm at Botoku near Pokuase. The damage was done by the adults and nymphs alike and large numbers of the species attacked the leaves at the edge of the blade and ate progressively towards the midrib which was left intact (plate 3).

Table 1: **Foliar damage by insects to citronella leaves in different farms.**

Farm	Total number of leaves inspected	Percentage leaves showing		
		Necrosis (%)	Curling (%)	Defoliation (%)
Osofoiaman farm B	18,314	0.00047	0.00025	0.0003
Botoku	17,917	0.00049	0.00012	0.008
Osofoiaman farm C	15,564	0.0002	0.00089	0.0004
Omenako	13,709	0.0033	0.0013	0.0003
Kpankpan-Ayikuma	16,315	0.0041	0.0079	0.0009
Selina Taylor's	31,794	0.00084	0.00047	0.0003
Ababio's	27,842	0.00011	0.000411	0.0002

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Insects in citronella stem: The results (Table 2) showed 8 identified and 2 unidentified species of Diptera and also 2 identified ones of Lepidoptera. The Lepidoptera was present only in freshly infested tillers while the Diptera occurred in fresh as well as already infested ones. From Chi-square analysis of the data (Appendix 5), the numbers of different insects reared from the different stages of `deadheart' were significantly different ($X^2 = 192.29$; $p < 0.05$). The predominant insect therefore was *Scoliophthalmus trapezoides* (Fig. 4) followed by *Anatrichus pygmaeus* (Fig.8b), *S. micantipennis* (Fig. 5), species D, E, *Sesamia* sp., *Aprometopis flavofacies* (Fig. 7), *Silba pectita, Elachiptera occipitalis* (Fig. 8) and *Eldana. saccharina.*

Table 2: **Adult Diptera reared, and Lepidoptera larvae collected, from tillers showing `deadheart' symptoms from Osofoiaman and other farms in 1991.**

Insects	Total number of insects reared/ collected	Number of insects from `deadheart'		
		`Early'	`Late' or `advanced'	`2°'
Diptera: Chloropidae *Scoliophthalmus trapezoides* Becker	64 (48)	21 (17)	35 (26)	8 (5)
Scoliophthalmus micantipennis Duda	45 (39)	39 (35)	6 (4)	0 (0)
Anatrichus pygmaeus Loew	46 (17)	0 (0)	14 (6)	32 (11)
Elachiptera occipitalis Becker	3 (2)	0 (0)	0 (0)	3 (2)
Aprometopis flavofacies Becker	5 (5)	5 (5)	0 (0)	0 (0)
D	32 (18)	0 (0)	8 (5)	24 (13)
Diptera: Lonchaeidae *Silba pectita* McAlpine	4 (2)	0 (0)	3 (1)	1 (1)
Diptera: Phoridae E	15 (7)	0 (0)	10 (5)	5 (2)
Lepidoptera: Noctuidae *Sesamia* sp	11 (11)	11 (11)	0 (0)	0 (0)
Lepidoptera: Pyralidae *Eldana saccharina* Walker	2 (2)	2 (2)	0 (0)	0 (0)

( ) Number of `deadheart' tillers.

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Insects damaging citronella root

The results have been summarised in Table 4. Of the 12 farms visited, seven showed termite infestation; three severe, i.e. >10% and four mild i.e. <10%. Six of the infested farms were more than one year old, while one was less than one year old. The termites were not identified but their damage, which was caused by the workers, resulted in wilting and complete death. The hills were girdled with soil sheathing at, or just below, ground level. Examination of uprooted affected hills showed that the workers had eaten around the roots and into the stems, and had them filled with soil.

Table 3: Incidence of termites in sampled farms, in Greater Accra Region, 1991.

Location	Farm	Age of Plants		Total No. of hills inspected	Percentage infestation (%)
		> 1yr.	< I yr.		
Ayikuma	Tagoe farms	"		1972	37.2
	Vas farms I		"	1916	0
	" " II	"		2304	4.0
Ashalaja	New Match farms I	"		1920	14.0
	New Match farms II		"	1692	4.3
Botoku	Farm I		"	1713	0
	" II		"	1841	0
	" III	"		2024	3.1
Osofoiaman	Kate farms I		"	1724	0
	" " II	"		2074	23.0
	Experimental farm B I		"	1676	0
	Experimental farm B II	"		1978	0.7

Natural enemies: No parasitoids were observed form the dead insects, neither were there any pathogenic fungi. Also no predatory activity was observed in the field.

2.3.3. Comparison of Efficiencies of the Improved and Standard Sweep Nets: The results

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are summarised and analysed in Table 4 below. There were significant differences in insects caught in 20 samples at 10 sweeps per sample ($t = 4.14$; $P < 0.05$), in time to handle one sample ($t = 4.54$; $P < 0.05$), and in the rate of catch between the improved and standard nets ($t = 6.30$; $P < 0.05$). The former caught more insects and also it was quicker to handle its catch than the latter.

Table 4: Analysis of twenty (20) samples of insects each by Improved and Standard Sweep nets at 10 sweeps per sample.

	Type of Sweep net	Range	Mean $x \pm$ S.E.	$t_{38 d.f.}$ (0.05)
Time for 1 sample (seconds)	Improved	58.0-75.3	65.62±.99	* 4.54
	Standard	77.0-164.0	100.18±7.55	
Number of insects caught	Improved	10 - 45	23.0±1.9	*4.14
	Standard	3 - 31	12.3±1.7	
Rate (Catch per second)	Improved	0.133-0.703	0.353±.029	*6.30
	Standard	0.034-0.295	0.133±.029	

* Significant at $p < 0.05$.

2.3.4 Comparison of Sampling Methods: The results are summarized in Appendix 6 and further illustrated in figure 3. The percentage infestation estimated from `deadheart' symptoms alone underestimated the real infestation level which is determined from random dissection. The difference between the two methods was higher at Osofoiaman and Ashalaja than the remaining 2 farms.

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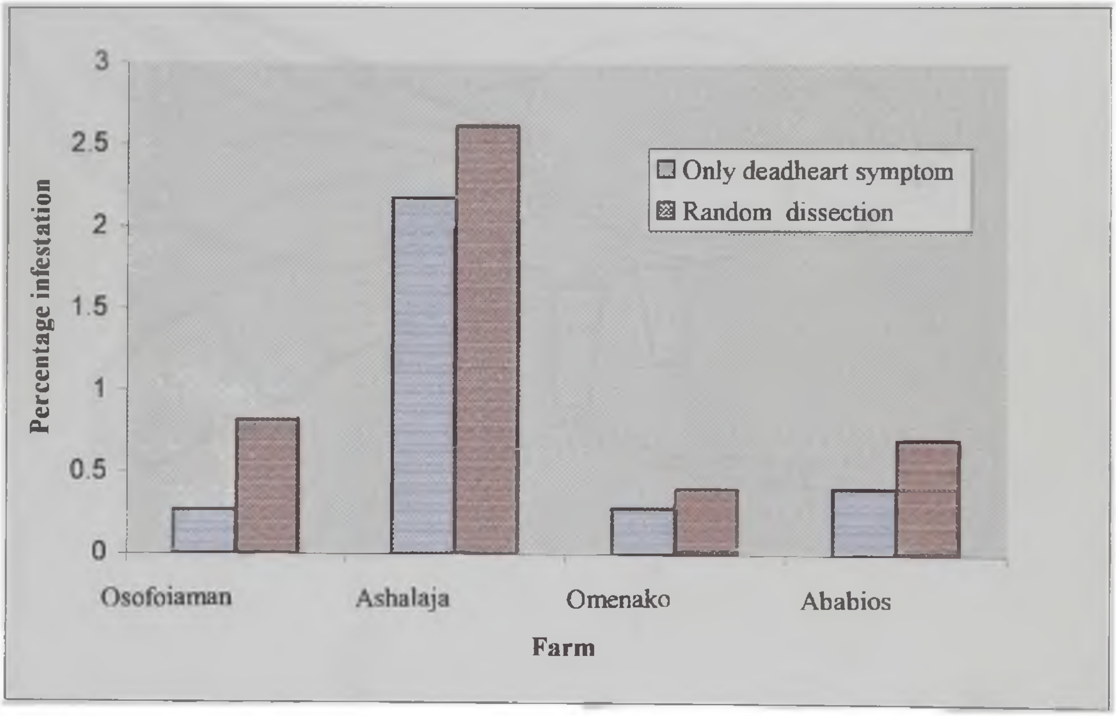

Fig.3 : Infestation rates as determined by only "deadheart" symptom and by random dissection

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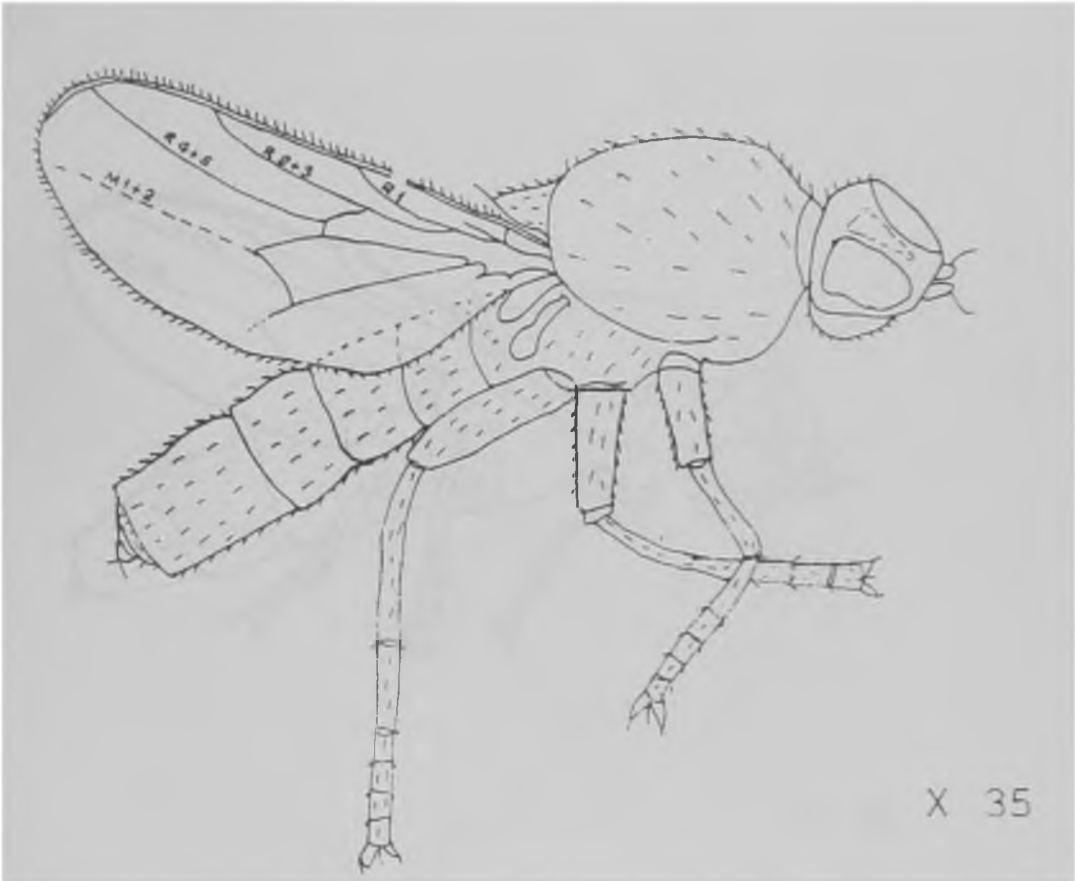

Fig.4: **Dorso-lateral view of female *Scoliophthalmus trapezoides***

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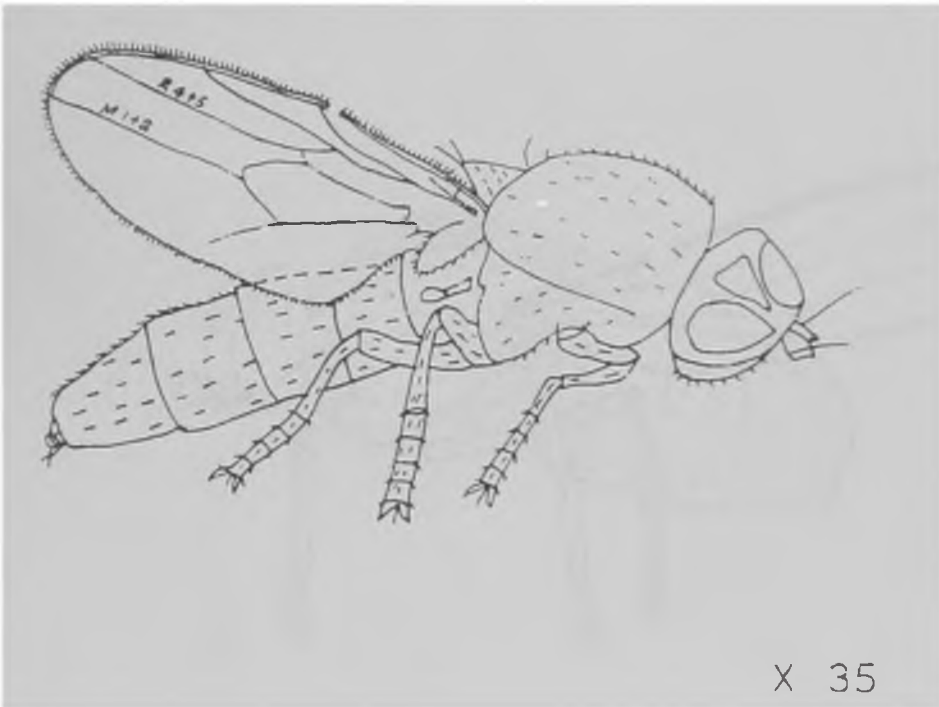

Fig. 5: **Dorso-lateral view of female *Scoliophthalmus micantipennis***

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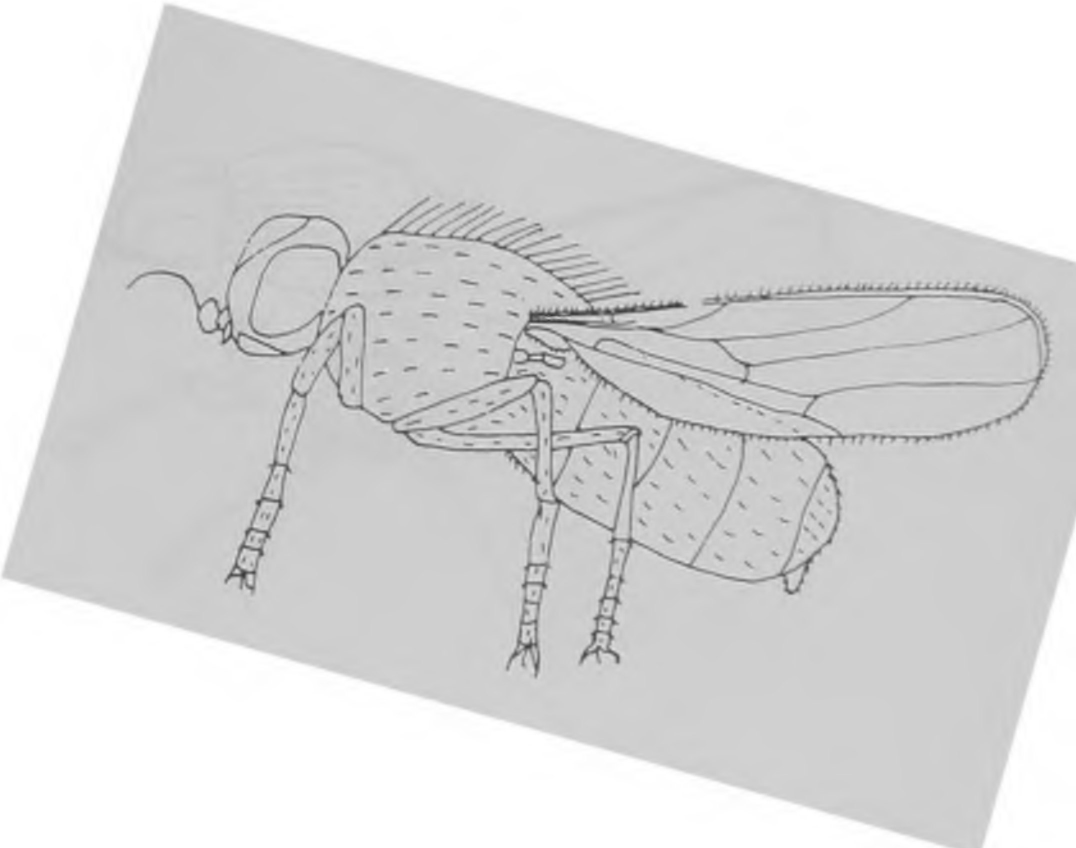

Fig. 6: **Lateral view of female *Anatrichus pygmaeus***

X 40

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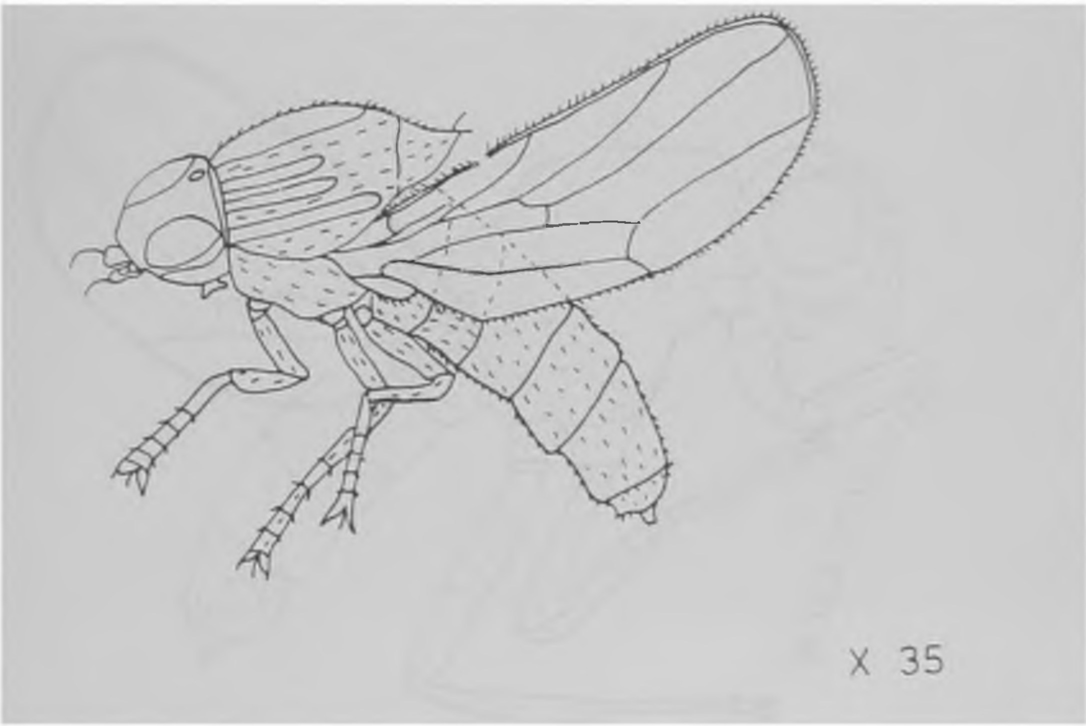

Fig. 7: **Dorso-lateral view of female *Aprometopis flavofacies***

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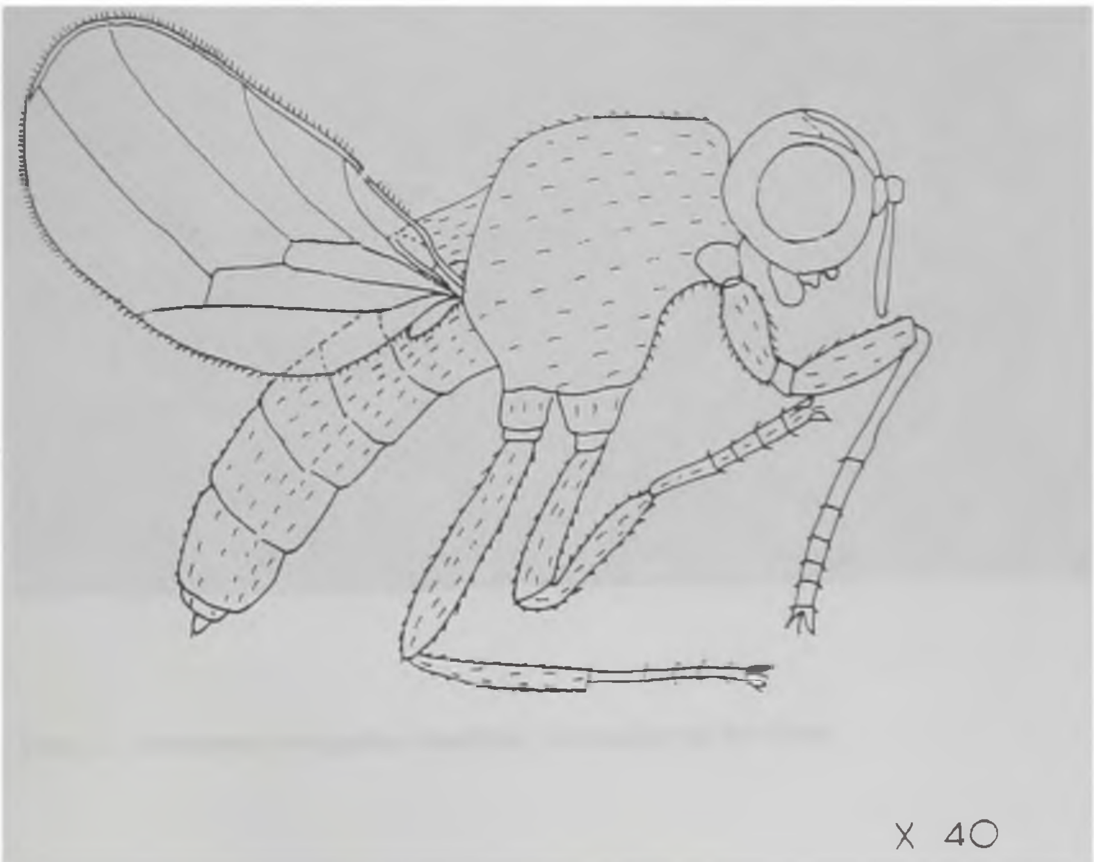

Fig. 8: **Lateral view of female *Elachiptera occipitalis***

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Plate 3: *Zonocerus variegatus* attacking citronella on the farm.

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2.4 Discussion

Insects on citronella shoot

The relative abundance of insects with respect to months might not be reliable in the intensive survey because of the inconsistency in the number of collections made per month; For instance, no collection was made in May, 1991 because sampling coincided either with rain or harvesting. Nevertheless, the results show that the vegetative growth of citronella supported a remarkably rich and diverse insect fauna. Thus from both intensive and extensive surveys, a total of 5660 insects belonging to 10 Orders and 103 families were found associated with the shoot of citronella and fairly distributed over the study area. The insects are mainly grass feeders, their parasitoids and predators.

The grass feeders include Cercopidae, Cicadellidae and Aphididae (Homoptera) whose feeding activities result in viral transmission (Watson and Plumb, 1972; Borror *et al*, 1976). Included also are Coccinellidae (Coleoptera) which attack leaves of maize and rice in Ghana (Schumutterer, 1969; cited by Scheibelreiter and Inyang, 1974); Pyrgomorphidae (Orthoptera), Chloropidae and Lonchaeidae (Diptera) some species or which have been found to interact with citronella in this present study. Most of the grass feeders appear innocuous presently but they may subsequently assume important status as citronella cultivation continues. They are therefore a potential threat.

The predators include Chaemaeyiidae (Diptera), Sphecidae (Hymenoptera) and Mantidae (Opthoptera). Several members of Chaemaeyiidae and Sphecidae prey upon the grass feeders Aphididae, Cicadellidae and Delphacidae (Homoptera) (Watts, 1963; Thomas, 1968, Evans, 1968) which are found in large numbers on citronella. Significantly the

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species of Mantidae were green in colour or a combination of that colour to offer them good camouflage within the citronella leaves for their predatory activities. Among the parasitoids are Diapriidae, Braconidae, Eulophidae and Ichneumonidae (Hymenoptera), some species of which have been found by Simmonds (1952) to parasitise on other chloropids such as *Oscinella frit*. These parasitoid families are therefore important because they could be investigated for use in the biological control of the Chloropidae that damage citronella.

Insects damaging the leaves

Though the results showed large number of grass feeding families like Cercopidae, Cicadellidae, Psyllidae, Delphacidae, Aphididae (Homoptera), Pentatomidae, Lygaeidae, Tingidae (Heteroptera), Corimelaenidae, Curculionidae, Cerambycidae, Lagriidae, Meloidae, Elateridae, Pselapidae (Coleoptera) and Pyrgomorphidae, Tettigonidae (Orthoptera), none of their adults was observed feeding on the leaves of citronella during the survey. Results from further investigation also showed negligible symptoms of feeding activities by insect foliage pests. For example, less than 0.005%, 0.002% and 0.009%, showed necrosis, curling and defoliation respectively, resulting from insect attack. The present findings are similar to those made by Sontakke *et al* (1991) who, however, failed to indicate the extent of the damage. The absence of major foliage insect pests might be due to the repellent properties of the essential oils present in the leaves (Saraswathi and Rao, 1987; Bosch, 1971).

However, *Zonocerus variegatus* L. (Orthoptera: Pyrgomorphidae) is a potential foliage pest of citronella because of the isolated case of the species feeding extensively on the leaves at Botoku in 1992 (Plate 3) after the study period. Even though the insect ate any vegetation available and not only citronella it still poses a threat because of the extent of its

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damage and its strong presence in citronella farms.

Insects damaging citronella stem

The results showed that the major insects that damaged citronella were found in the stem. The dipterous shootflies (Chloropidae), are particularly dominant. The presence of Chloropidae in citronella in this study shows their affinity for poaceous plants and wide distribution, especially in Africa. This is because species of the family, including *Scoliophthalmus trapezoides, Scoliophthalmus micantipennis, Anatrichus pygmaeus* and *Aprometopis flavofacies* have also been reported (Deeming, 1971; Le Pelley,1959) as attacking sorghum, maize, millet, guinea corn and wild grasses in Nigeria, Kenya, Tanzania, Uganda, Cameroun, Zimbabwe, Senegal and Nigeria.

The results also suggest that the shootborers occupy at least three different feeding niches in citronella, primary feeding, secondary feeding and scavenging. Follow up experiments to determine the specific species occupying the different niches were unsuccessful because the insects failed to oviposit in captivity. However, species that damage fresh tillers are considered primary feeders if there is no evidence of the presence of other species, whereas those damaging previously infested tillers are secondary feeders and those found in tillers already attacked by Lepidoptera, apart from possibly being secondary feeders, might be scavengers or saprovores, or parasitoids or predators (Deeming, 1971).

In line with Demming's (1971) classification therefore, *A. flavofacies*, *Sesamia* sp. and *E. saccharina* recorded in the present study, may be considered primary feeders of citronella, since they attacked only fresh tillers. The conclusions on *Sesamia* sp and *E.*

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saccharina agree with observations elswhere (Tams and Bowden, 1953; Ingram, 1958; Nye, 1960a and Harris, 1962). *S. micantipennis* is also considered primarily as a primary feeder because as high as 86.7% of them attacked fresh tillers. The conclusions on the status of *S. micantipennis* and *A. flavofacies* agree with those made by Deeming (1971) who, working in Samaru in Nigeria, concluded that these insects cause primary damage to sorghum and millet tillers, respectively.

Scoliophthalmus trapezoides was considered both a primary feeder and a secondary feeder since it damaged both fresh (32.8%) and already infested tillers (54.7%). The status of *S. trapezoides* as a secondary feeder, agrees with the conclusion made by Deeming (1971), who found the insect causing secondary damage to sorghum and maize tillers. The status of *A. pygmaeus, S. pectita, E. occipitalis* and chloropid sp. D, was not clear since they were frequently found in both tillers already infested by other Diptera and Lepidoptera. However, the larvae of *A. pygmaeus* have been reported by Sabrosky (1962), cited by Deeming (1971), as being predaceous on other larvae.

The role of the Phoridae reared from citronella could also not be determined, but some species of the family have been recorded (Ingram, 1958) as being parasitoids of the Lepidoptera, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). In this study, they were probably attracted by the presence of the Lepidoptera, *E. saccharina* or *Sesamia* sp in the citronella tillers.

The primary feeders are the most important insects since they initiate the attack on the plants (Deeming, 1971). Of the primary feeders observed in the present study, *S. micantipennis* constituted about half the number and it is therefore considered the most

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important feeder of citronella. This observation agrees with a conclusion made by Deeming (1971) that *S. micantipennis* is one of the most important primary feeders of sorghum.

Insects damaging citronella root

Results from the study showed that only unidentified species of termites belonging to the family Termitidae (Isopterea) cause damage to the roots of citronella. This observation is in line with that made by Sontakke *et al* (1991) in India. .The damage observed was not as widespread as that by the shootborers, as the termites were found in only 58.3% of the farms visited whilst the shootborers were present in all the farms. Despite their limited distribution, the termites pose a great threat to the citronella industry because their damage could result in the destruction of a whole hill, leading to herbage loss and reduction in oil yield.

The incidence of termites in citronella farms is probably related to the history of cultivation. In particular, long term cultivated farms have higher incidence than short term ones. For this reason 85.7% of infested farms had more than one year of cultivation as against only 16.7% which had less than one year. This observation agrees with the one by Wood *et al* (1977) who found long term cultivated soils to have higher population densities of termites than soils in the first year of cultivation. The reason found for this is that as the farms are cultivated, the availability of roots of natural vegetation decreases in the soil with the duration of cultivation (Black and Wood, 1989). The termites are therefore forced to forage more intensively on the surface (Wood *et al* 1980)

The exact relationship between age of citronella farm and severity of termite damage could not be established, because the exact ages of the farms could not be determined. It is however, suggested that the area be further investigated, since it could help determine how

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long citronella farm could be kept in the savanna without attracting too many termites.

Natural enemies

The insects collected from the shoot included predator and parasitoid families but no parasitoids were found in the field or from laboratory screening. This is in sharp contrast to the results by Simmonds (1952), in which numerous hymenopteran parasitoids from Chalcidae, Pteromalidae, Diapriidae, Prototrupidae and Cynipidae were found associated with *Oscinella frit* (Diptera, Chloropidae). Predators were not screened for, however, the absence of parasitoids and pathogenic fungi is probably because the shootborer populations were very low, as depicted by the low infestations (Fig. 13) and that not many insects could be screened.

Comparison of Sweep Nets: Results of the comparison of the sweep nets showed that the standard sweep net is less efficient for assessing insect population as observed by Strickland (1961) also. Thus the standard net caught about a third (0.13 ± 0.02) of the insects caught by the improved one (0.35 ± 0.02). Also it took longer time to collect a sample using the standard net (100 ± 7.6s) than using the improved one (65.6 ± 0.1s). Furthermore, the improved net caught the smaller insects more than the standard one. For example as many as 25 small adult chloropid shoot flies whose larvae damage citronella tillers were caught with the improved net as against none by the standard net at Osofoiaman Farm B. The improved net should therefore be developed further for use in sampling insects on the Poaceae.

Comparison of Sampling Methods: T-test analysis, after square root transformation of the data showed that the percentage infestation determined from only `deadheart' symptom (mean, 0.77%) was significantly lower than that determined from random dissection (mean, 1.13%) ($t = 3.18$; $P < 0.05$). The null hypothesis is therefore rejected. Indeed there is a

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function of y = 1.078x + 0.3 between the two rates where y = percentage infestation by dissection and x that by only 'deadheart'. Thus, shootborer infestation determined from only visual 'deadheart' symptom underestimate the actual infestation by (1.078x + 0.3) – x, about 31.8% on the average, probably because freshly attacked tillers without `deadheart' symptoms were missed. The results are by no means conclusive, considering the small number of replicates, i.e. 4, and also the fact that it was not possible to repeat the work in the replicates. Therefore, there is the need to investigate further to establish a very reliable relationship between the two methods for predictive purposes.

In conclusion, the major insects damaging citronella were found to be dipterous shootflies and lepidopterous stemborers. The minor ones were termites which attacked the root and the stem. No natural enemies were found. The dipterous shootflies belonged mainly to Chloropidae. *Zonocerus variegatus* is a potential pest of the leaves even though the leaves are not seriously damaged by insects. The major feeders are more important, hence a further look is taken of their damage in the next chapter.

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CHAPTER THREE

3.0 INSECT PREFERENCES FOR DIFFERENT SIZES OF HOST PLANT AND NATURE OF SHOOTBORER DAMAGE

3.1 Introduction

In the previous chapter, the most significant insects causing damage to citronella were found to be lepidopterous stemborers and dipterous shootflies which bored into the stem. Earlier investigations found that the major pests of citronella were those that bored into the stem and led to an externally visible symptom known as the `deadheart' symptom. The damage may be severe as in the case of *Chilo infuscatellus* Snellen (Lepidoptera: Pyralidae) (Sontakke *et al*, 1991) or mild as in the case of *Stemmatophora fuscibasilis* Snellen (Lepidoptera: Pyralidae) (Gour *et al*, 1991). Severe borer infestation may result in serious losses in crop and revenue, as occurred with *Eldana saccharina* Walker (Lepidoptera: Pyralidae), *Sesamia* sp. (Lepidoptera: Noctuidae) and *Atherigona* sp. (Diptera: Muscidae) (Botchwey, personal communication).

Infestation by a particular insect may be influenced by several factors including size and age of the host plant. Thus, bigger and taller hosts are preferred by lepidopterous stem borers (Patch, 1929; Chiang *et al,* 1960; Walker, 1963) while shootflies prefer smaller as well as shorter tillers (Deeming, 1971; Simmonds, 1952). In pre-proposal studies conducted at Mayera, Ashalaja and Ayikuma, smaller and shorter tillers appeared to be preferred by the chloropid shootflies. In this work, therefore, field studies were carried out to investigate insect preferences for different sizes of host plants. This could help in the selection of materials for planting. A laboratory investigation of the boring of the insects was also carried out where

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possible to study the nature of damage done to the tiller.

3.2 Materials and methods

3.2.1 Field investigation of preference for size of citronella tillers by shootborers.

This preliminary investigation was conducted in the field to find out if the insects exhibited any preference in their choice of citronella tillers for attack.

A total of 70 tillers in two groups of 35 tillers each, already infested by each group of shootborers were randomly removed from farms at Omenako, Ashalaja and Ayikuma from October to December 1992. Measurements were taken of the tiller heights, diameters and lengths of tunnels in the laboratory. The lengths and heights were measured with straight-edged ruler while the diameters were measured with a micrometer screw guage. Measurement of the diameters were taken from two opposite sides of the base of the sheath in the region of the apex immediately above the uppermost exposed node. The results were analysed statistically, following the procedure by Walker (1963) and Endrody-Younga (1968).

3.2.2. Boring activity of the shootborers

In the previous chapter, adult shootborers were reared from infested tillers collected from the field. This experiment was therefore designed to find out how the insects bored into the tiller, their activity inside it and the effects of their activity on the tiller. Different larval instars of the shootborers were collected from field infested tillers and put on leaves and sheaths of potted citronella in the laboratory (Plate 4). They were inspected daily and boring activities such as point of entry into stem, direction of boring and effect on leaves were studied. After a larva had bored into a tiller and the inner whorl began to wilt, the tiller was dissected and the active larva transferred onto another tiller. In this way 13 lepidopterous

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larvae were made to bore into 35 tillers. Shootfly larvae obtained either died or pupated without attacking the plant.

3.2.3. Field identification of damage from differential growth (height) of newly ratooned infested and uninfested tillers

In the field, damage by shotborers has been most easily identified by only one index i.e. `deadheart'. This limits the ability of the farmer to detect early infestation in situations where `deardheart' symptom may not be showing particularly in freshly ratooned crop. This study was therefore undertaken to detect early infested crop without `Deadheart' symptom. A farm measuring 50 m by 40 m and lying adjacent to Farm B at Osofoiaman, was harvested five months after planting. Every fifth hill was selected along two opposite sides of the farm and also along the two diagonals. Five tillers were randomly selected from each hill and labelled. Thus a total of 60 hills and 300 tillers were sampled. The heights of the labelled tillers were measured with straight-edged ruler every morning for seven consecutive days until the infested tillers began to show `deadheart' symptom. The average growth of the infested tillers was compared with that of the healthy tillers.

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Plate 4: **Experiment to study the boring activity of shootfly larvae.**

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3.3 Results

3.3.1 Field investigation of preference for size of citronella tillers by shootborers

The results have been summarised and analysed in Table 5. The mean tiller heights of infested tillers by the shootborers were very close; so were the mean diameters. The range of heights of tillers infested were also similar. They ranged from short to tall tillers. Thus the shootflies attacked tillers ranging from 255 mm to 413 mm while the lepdopterous stemborers attacked those from 278 mm to 413 mm. Testing at 5% level of significance there was no difference between the means. Therefore the larvae of lepidopterous stemborers attacked citronella tillers that were similar in height and diameter to those attacked by the shooflies.

3.3.2 Boring activity of the shootborers

Lepidopterous stemborers: In the laboratory, boring was done by larvae of *Sesamia* sp and *E saccharina*. Both entered or left the tiller through entry/exit holes at a mean height of 21.0 ± 14.7mm (Table 5) above the apex of the rhizome at the base of the tiller. On entering the tiller, a larva tunnelled vertically upwards and/or downward producing a lot of frass and creating a cavity at the apex of the rhizome (Fig. 9). Tunnels measured from field sampled tillers had mean length of 75.4 ± 23.6mm (Table 5). Tunnelling destroyed the apical region of the rhizome; it also caused the inner whorl to wilt to produce the `deadheart' symptom.

Shootflies: No boring was done in the laboratory. Therefore, the point of initial attack could not be determined. However, from field observations, the larvae tunnelled 32.7 ± 23.6mm; (Table 5) or ate the tissue of the inner whorl which became rotten to produce the `deadheart' symptom. The rotten material normally extended along the inner whorl to the apex of the

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rhizome which became destroyed. The attack also resulted in constrictions within the inner whorl (Fig. 10). If the constriction was pushed out of the tiller on top of a healthy growing inner whorl, the plant overcame the attack of the larva.

Table 5: Summary and analysis of tillers preferred and damaged by the shootborers.

	Mean Tiller height (mm) x ± s.d.	Mean Tunnel length (mm) x ± s.d.	Mean height of entry/exit hole (mm) x ± s.d.	Mean Diameter of infested Tillers (mm) x ± s.d.
Lepidoptera	355.3±37.7	75.4±23.6	21.0±14.7	10.3±2.5
Diptera	324.5±36.9	32.7±23.6	-	10.2±2.7
t_{34df} (0.05)	N.S.	*6.55		N.S.

*Significant at $p < 0.05$

3.3.3 Field identification of damage from differential growth (height) of newly ratooned infested and uninfested tillers.

Three hills, i.e. numbers 13, 17 and 30, had both infested and healthy tillers present and both types of tillers increased in height with time (Fig. 11; Appendix 7). The curves coincided closely showing that the height of the infested and uninfested tillers had similar growth. Nevertheless, a slight deflection of the curves of the infested tiller numbers 13 and 17 after the fifth day showed that they had a slight delay in growth.

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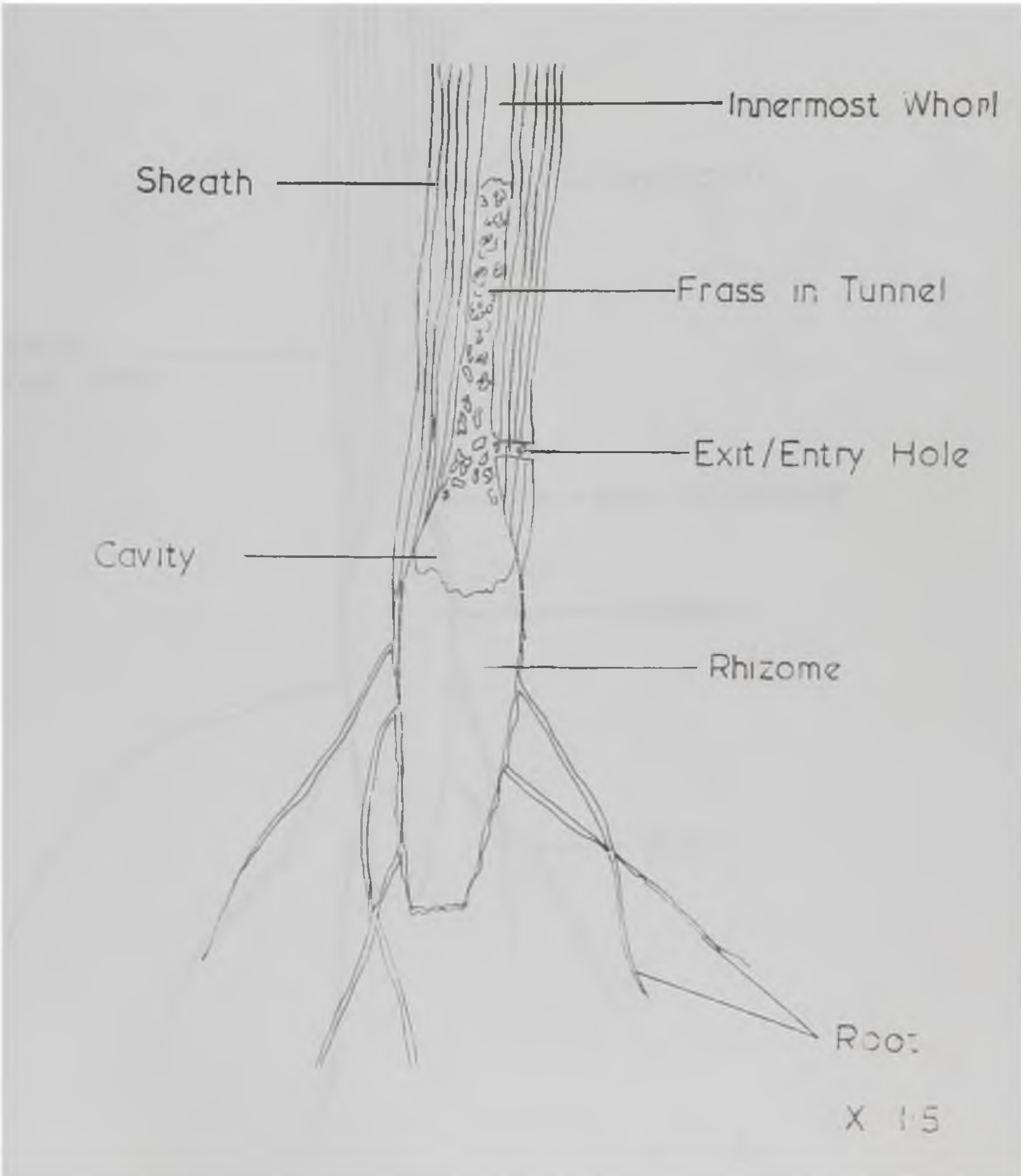

Fig. 9: **Longitudinal section of tiller attacked by lepidopterous stemborer.**

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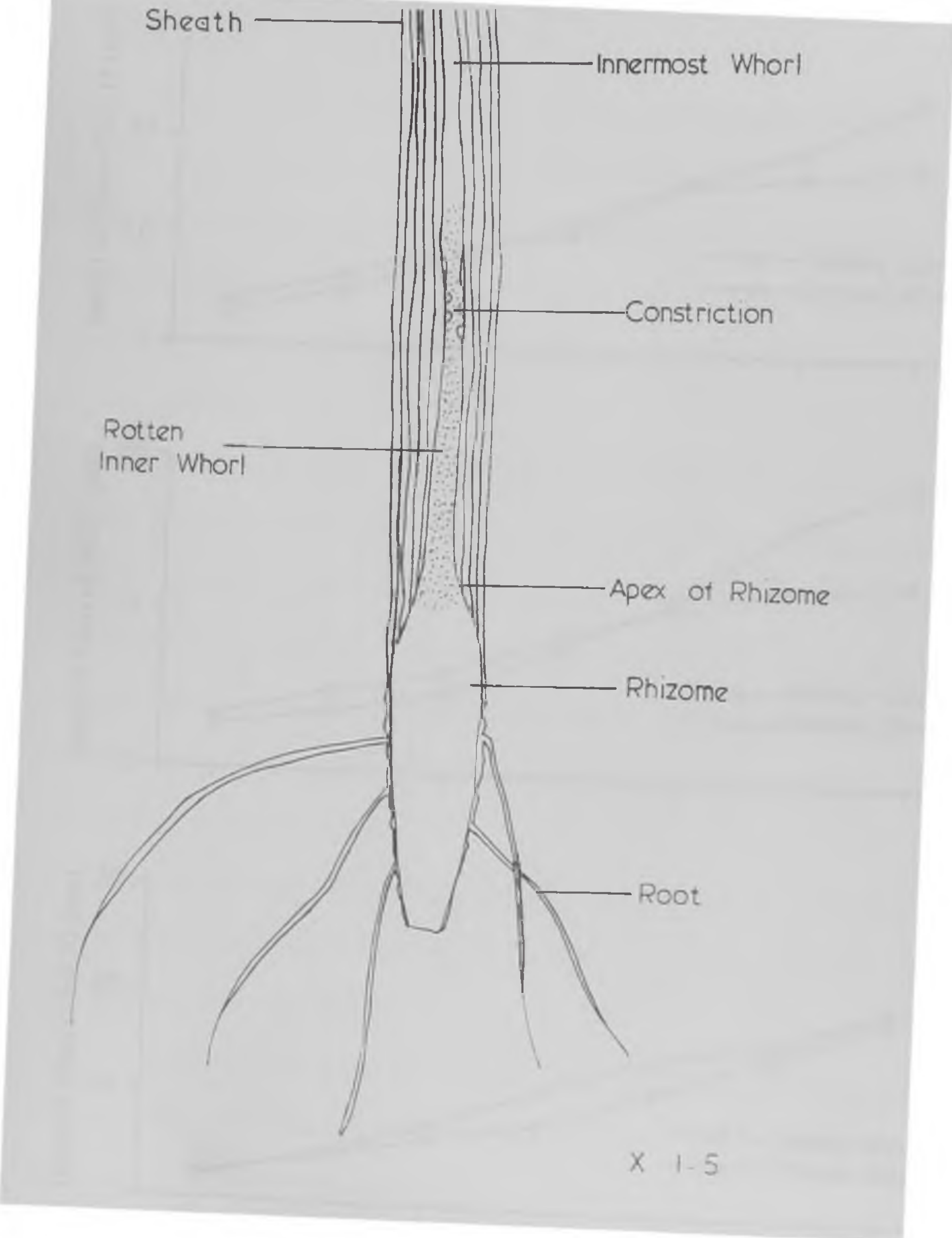

Fig. 10: **Longitudinal section of tiller attacked by shootfly**

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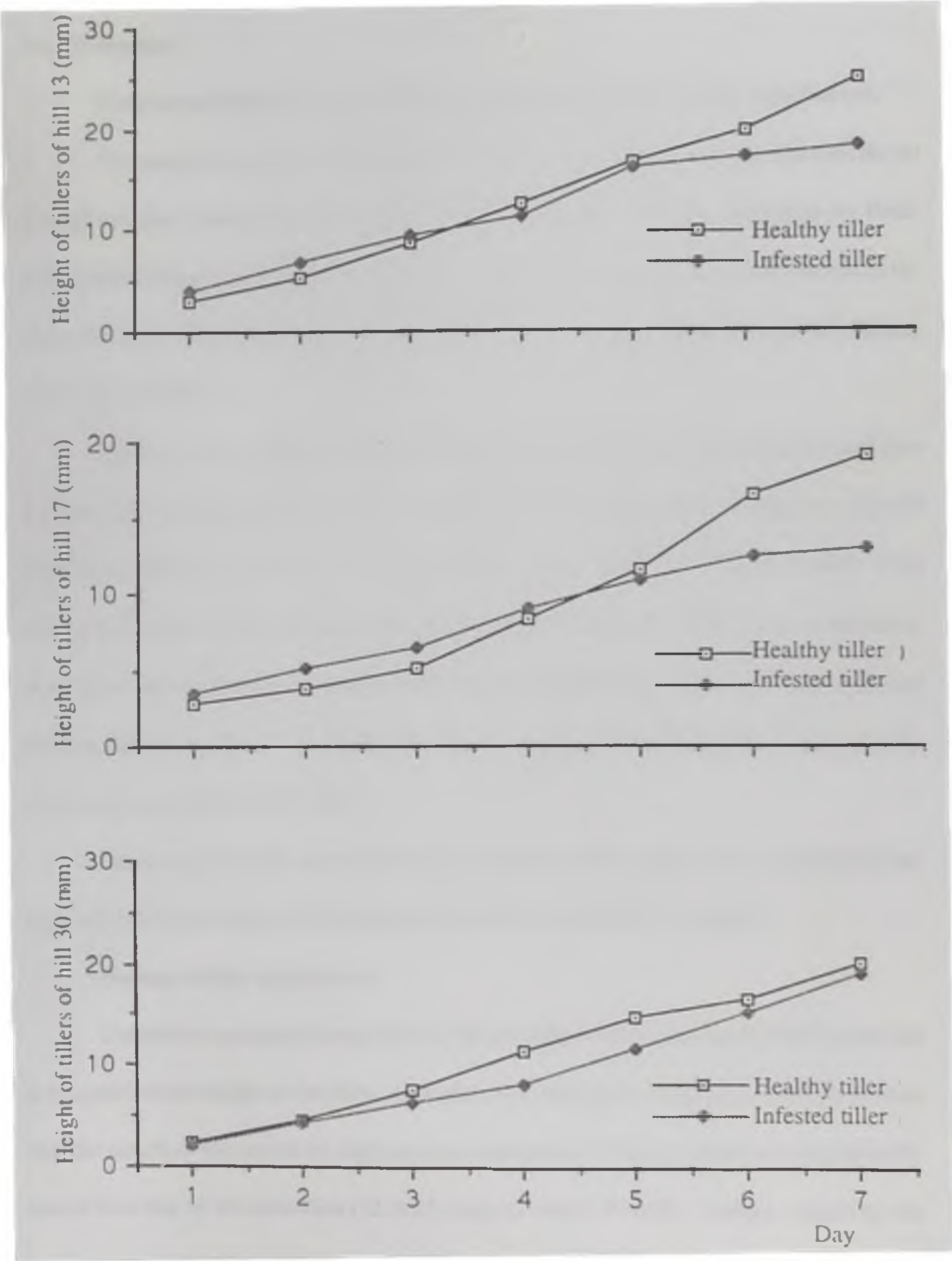

Fig. 11: **Daily growth of healthy and infested tillers of ratooned citronella at Osofoiaman in one week in 1991.**

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3.4 Discussion

Field investigation of preference for size of citronella tillers by shootborers.

The results showed that the incidence of shoot flies and lepidoterous stemborers do not depend on tiller diameter and/or height. This is in contrast with the suggestion by Patch (1929) and Chiang *et al* (1960), that lepidopterous stemborers prefer taller hosts, as well as the observations by Simmonds (1952) and Deeming (1971) that shoot flies prefer smaller, shorter tillers for infestation.

Infestation by a mixture of stemborer populations of *Busseola* and *Sesamia* and also a purely *Busseola* population depend on the size of the hosts but that by a purely *Sesamia* population shows no preference for size (Walker, 1963; Endrody - Younga, 1968). It is therefore in consonance with the above findings that as observed in this study, a stemborer population almost entirely of *Sesamia* (Table 2) shows no preference for size. The results also confirm that the stemborer population in citronella in South-Eastern Ghana consists mainly of *Sesamia* as indicated in Table 2.

However, the results are preliminary and further investigations ought to be carried out, especially at different ages of the plant for definite conclusions to be drawn.

Damage of the shootborers

Correlation analysis showed that for the two shootborers the length of the tunnel did not depend on the height of the tiller. However, t-test analysis on field data (Table 5) showed that the length of the tunnel by lepidopterous stemborers (75.4±23.6mm) was significantly longer than that by the shootflies (32.7±23.6mm) ($t = 6.55$; $P<0.05$). Indeed, tunnels by the shootflies were less than half the length of those made by the lepidopterous

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stemborers. This may probably be due to the bigger size and more powerful mouth parts of the lepidopterous larva. *Sesamia sp and E. saccharina* entered straight into the stem through the sheaths, and this is in conformity with the observation made by Ingram (1958) and Harris (1962), who reported that the young Lepidoptera larvae, especially of *Sesamia* sp, bore straight into the stems of cereal crops.

The point of entry of the shootflies could not be determined either in the field or laboratory because of high mortality in the larvae but according to Simmonds (1952), in wheat, larvae of other Chloropidae e.g. *Oscinella frit* bore into any part of the stem or between the tissue layers of leaves and descend to the lower part of the shoot.

The entry/exit points of the lepidoptera larvae were lower down the tiller close to the apical region of the rhizome. This observation agrees with that by Girling (1972), who reported that the larvae of *E. saccharina* bore into the lower part of the sugar-cane plant. The apex of the citronella rhizome is very soft and this might have served as a good source of food for the larva. It was also observed that the larvae frequently rested in the cavities they made in the rhizome. At that low position in the rhizome, they could easily be missed during harvesting, making it possible for them to re-infest the ratoon crop, which therefore suggests this might be an adaptive behaviour.

Damage by the larvae of the shootborers caused `deadheart' symptom which results from the mechanical damage to the scattered vascular bundles during the boring activity (Nye 1960a.). In addition to this, observations in the present study suggest that the `deadheart' could also have been caused by the eating of the meristematic tissue at the apex of the rhizome by the larvae and also from the rotting of that point. The production of `deadheart' symptom

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by the Chloropidae has also been observed by Deeming (1971) on other cultivated cereals and wild grasses. Nonetheless, there may be other symptoms from Chloropidae damage. For example, Goodlife (1942) found them to produce swollen nodes and internodes referred to as gouted shoots while Simmonds (1952) reported the wilting of shoots of cereals from their damage.

Whereas the frass and entry/exit holes are very characteristic of the lepidopterous stemborer attack, attack by larvae of the shootflies could be differentiated by the rotting and/or constrictions in the inner whorl. Agents causing the rotting were not determined but the destruction of the innermost part of the tiller agrees with Deeming's (1971) observation on *S. trapezoides* and *S. micantipennis* in sorghum and millet tillers. It also agrees with the report by Simmonds (1952) that *O. frit* destroyed the central part of the wheat stem.

Field identification of damage from differential growth (height) of newly ratooned infested and uninfested tillers.

Dissection of infested tillers showed the destruction of the apical meristem of the stem. It follows then that growth in infested tillers as expressed in their heights will slow down even if it does not cease completely. Therefore, assuming that harvesting affected both infested and healthy tillers equally; that tagging did not affect the physiological state of the plant; and that all healthy tillers in a citronella hill grow almost at the same rate, the differences in height would indicate infested and healthy tillers. The result in this study only showed slight differences in growth of infested and uninfested tillers after harvesting, i.e. after six days (Fig. 11). The differences were too small to be recognised visually without measuring. Therefore they can not be used to detect early infestation which is not showing "deadheart".

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CHAPTER FOUR

4.0 SEASONAL VARIATION IN INFESTATION OF CITRONELLA BY LEPIDOPTEROUS STEMBORERS AND CHLOROPID SHOOTFLIES

4.1 Introduction

Infestation of crops by insect pests tend to fluctuate in response to several factors both biotic and abiotic (see section 1.2). However, weather and climate are commonly accepted as dominant influences on the behaviour, abundance and distribution of insects. Thus, Reddy (1982) found the distribution of shootborer species to be influenced by rainfall, while the fluctuations in the incidence of pests with rainfall pattern has been reported by Adeyemi (1969), Harris (1962), Smithers (1960) and Easwaramoorthy and Jayaraj (1988). Temperature also has an effect on the dynamics of insect numbers (Balraj *et al*, 1977; Reddy, 1982); so also is relative humidity (Girling, 1978; Easwaramoorthy and Jayaraj, 1988). Climatic factors may also induce diapause in shootborers (Barry, 1972; Clearwater and Otieno, 1977; Ogwaro, 1979).

There is lack of information on the effect of climatic factors on shootborer infestation of citronella but such information is required for use in control planning. Therefore these studies on the progress of infestations in relation to rainfall, evaporation, temperature and relative humidity were carried out with this objective in mind.

4.2 Materials and methods

4.2.1 Determination of sample size and measurement of incidence of 'deadheart' caused by shootborers

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Sample size: Two citronella farms at Osofoiaman were used in this study. Farm A measured 88m x 18.5m and Farm B, 58m x 42m. All the citronella hills in the farms were pegged and numbered. The tiller was the sampling unit and preliminary studies were carried out to determine the sampling size, following the procedure by Hansen *et al*, (1962).

ie.

$$n = \frac{K^2 NV^2}{ND^2 + K^2 V^2}$$

where n = sampling size,

N = total number of tillers on farm,

V = ratio of failure to success in finding infestation in the tiller,

K = the probability that the sample result will have no error greater than $\pm$ D,

and D = allowable error.

Incidence of "deadheart": The incidence of `deadheart' by the shootborers was measured for both farms A and B. The work started in January 1991 and February 1991 in farms A and B, respectively. Farm A was monitored until June when it was abandoned because the farm became flooded and most of the citronella hills got destroyed.

From the procedure above, sampling size of between 1100 and 1200 tillers (see 4.3.1) were randomly selected from a box of numbers for a farm. Each farm was visited weekly. For any citronella hill sampled, the leaves were carefully inspected for eggs, larvae and adults as well as external damage symptoms. The tillers were counted and those showing `deadheart'

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symptoms were recorded, removed with a scapel and dissected in the laboratory to determine the cause of the 'deadheart' symptom. Percentage infestations by the respective shootborers were then calculated.

4.2.2. Rainfall, Temperature, R.H. and Evaporation

Figures for rainfall, evaporation and temperature including wet and dry bulb readings were obtained from the meteorological substation at Pokuase. Mean relative humidity values were calculated from wet and dry bulb readings at 0900 Hours and 1500 Hours GMT. A stepwise regression analysis was done between infestation and climatic factors after square root transformation of percentage infestation.

4.3 Results

4.3.1 Determination of sample size and measurement of incidence of 'deadheart' caused by shootborers.

Sample size: The total number of tillers and the infestation levels in both farms were similar from the studies, so results from one farm were used to determine the sample size for the two, as follows:

Total number of hills on farm = 1530

Mean hill size = 34.6 tillers

Total number (N) of tillers on farm = 53000

Number of tillers sampled = 1478

Number of tillers infested = 135

$$V = \frac{(1478 - 135)}{135}$$

$$= 9.95$$

$$K = 1$$

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D = 0.3 (ie 70% confidence level)

$$n = \frac{K^2 Nv^2}{ND^2 + K^2 V^2}$$

By substitution,

$$n = \frac{53000 \times 98.964}{53000 \times .09 + 98.964}$$

$\therefore$ **simple size** = 1077 tillers

Incidence of "deadheart": The results for incidence of `deadheart' by shootborers in Farm B have been illustrated in Fig. 12 (see also appendix 9); those of Farm A in Fig. 13 (see also Appendix 8). In Farm B, where sampling spanned the period February to December 1991, percentage infestation by lepidopterous stemborers showed two possible peaks: a questionable peak around February and a distinct peak in October. That by the shootflies showed similar trend in the same months. Combined infestation was similar to that by the shootflies because the infestation by the shootflies was generally higher. In Farm A, where sampling spanned the period January to June 1991, the infestation levels for the lepidopterous stemborers peaked in February and dropped thereafter. That for the shootflies peaked in March and dropped to a low in May. However, it was beginning to rise in June when work was abandoned because of the excessive flooding of the field. Combined infestation also followed the trend by the shootflies. By comparing data from farms A and B, it appears there are two peaks in infestation. Analysis of variance following square root transformation of the mean percentage infestations showed no significant difference between infestation by the shootflies and stemborers ($P > 0.05$). Nevertheless, damage in Farm A by both groups of insects during

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the same period was higher than in Farm B. For instance, from February to June, the mean percentage incidence of `deadheart' by shootflies in Farm A was 0.65% and that of Farm B was 0.44%. Similarly, that by stemborers in A was 0.29% compared to 0.19% in Farm B. Generally, infestations were low in both farms (Figs.12 and 13).

4.3.2 Rainfall, Temperature, R.H and Evaporation

The following results have been illustrated in Fig. 14 (see also Appendix 10). Rains started late in February at Osofoiaman and the wettest month was May. February and December were the driest months. Temperature did not vary much within the months. Mean monthly temperatures ranged between 25.5°C in August and 29.1°C in February and March. The r.h. too did not vary much within the year; the lowest was 80% and the highest 91.5%. Mean evaporation had two peaks, 2.3 mm in March and 1.9 mm in December. There were weak linear relationships between `deadheart' by both groups of shootborers and rainfall, and between `deadheart' caused by shootflies and other climatic factors of evaporation, temperature and relative humidity. A regression analysis of percentage `deadheart' by lepidopterous stemborers and rainfall gave a relationship of $y = -0.0017x + 0.6298$ (Fig 15: Appendix 11). The relationship of shootflies and the climatic factors were as follows: rainfall, $y = -0.0024x + 1.3413$ (Fig. 16: Appendix 12); evaporation, $y = -0.8958x + 2.2639$ (Fig. 17: Appendix 13); temperature, $y = -0.5826x + 17.15$ (Fig. 18: Appendix 14); and relative humidity, $y = 0.1292x - 9.8968$ (Fig. 19: appendix 15); where y = percentage `deadheart' and x = climatic factor.

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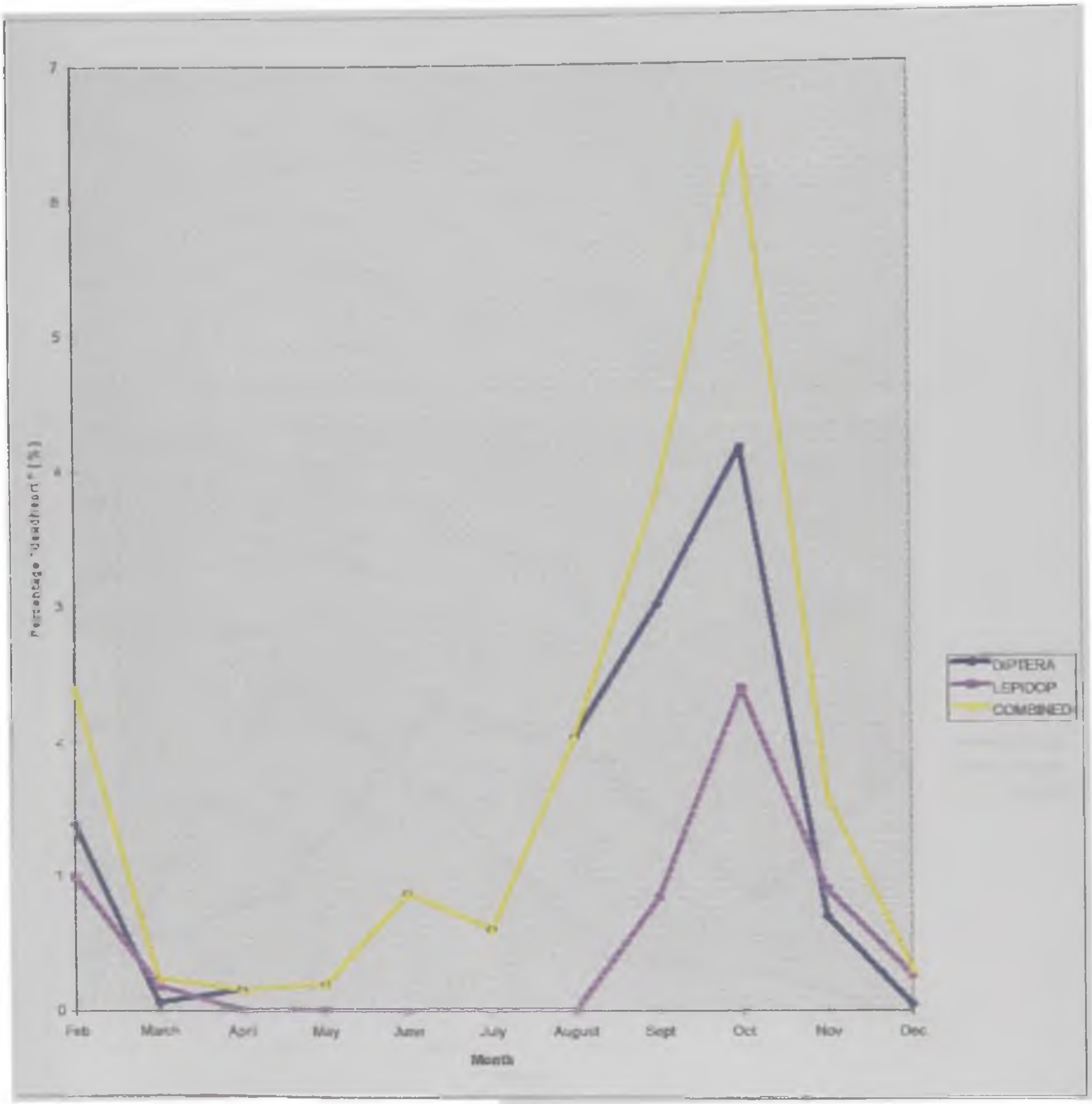

Fig. 12: **Percentage `deadheart' caused by shootflies and lepidopterous stemborers, Osofoiaman farm B, 1991.**

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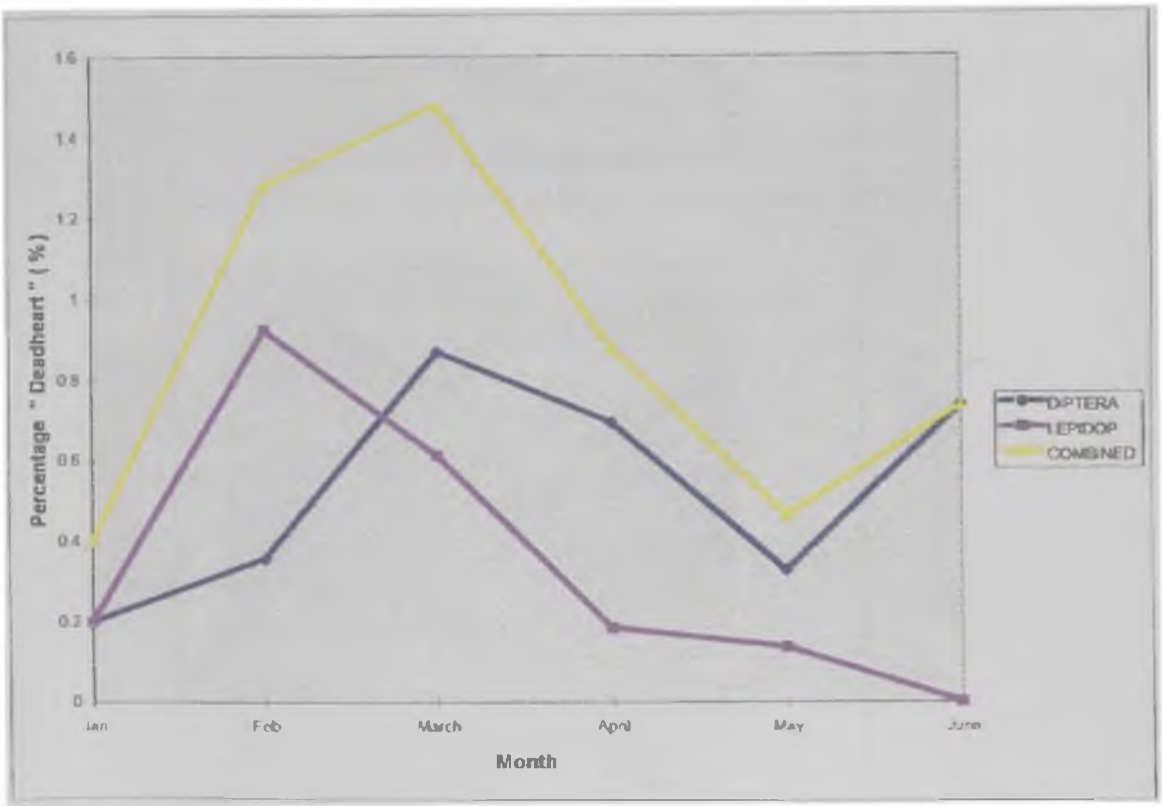

Fig. 13: **Percentage `deadheart' caused by shootflies and lepidopterous stemborers, Osofoiaman farm A, January - June, 1991.**

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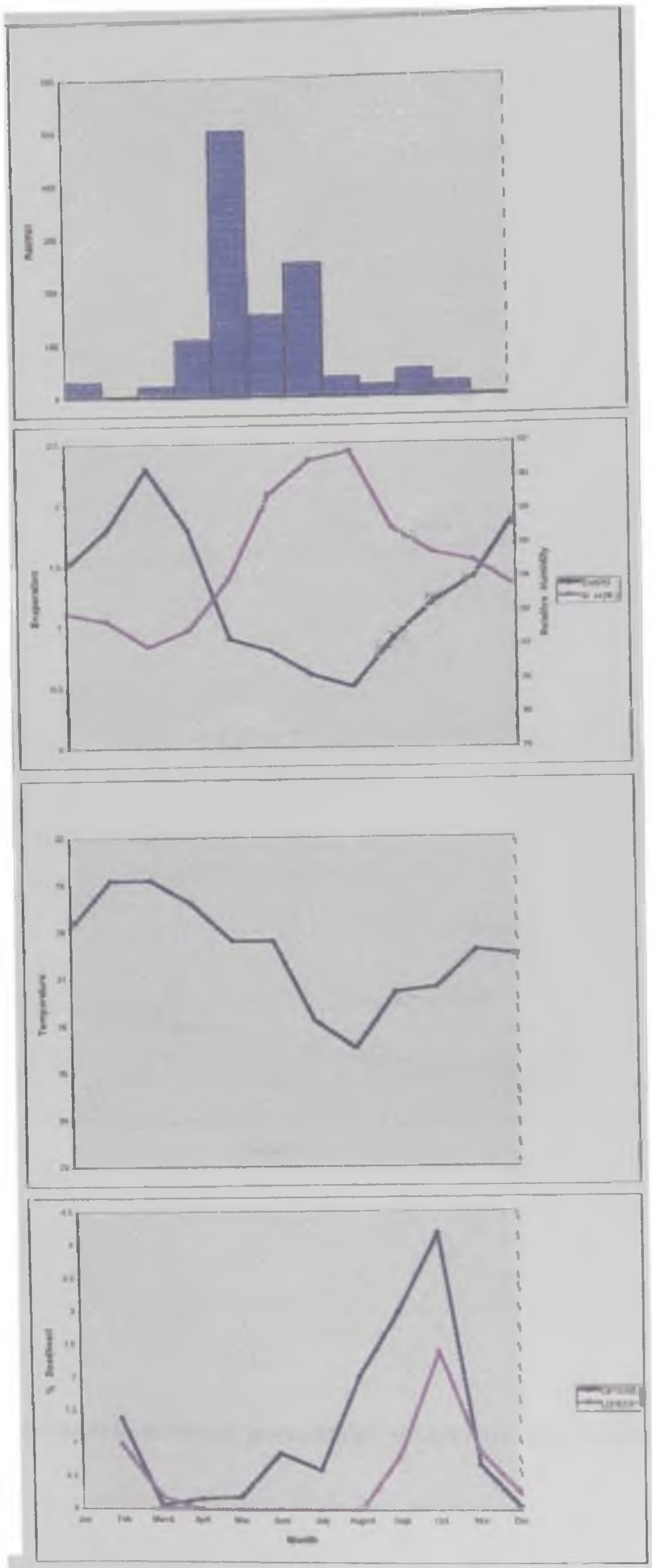

Fig. 14: Mean montly rainfall, evaporation, temperature, relative humidity and percentage 'deadheart' by shootflies and stemborers, Osofoiaman farm B, 1991.

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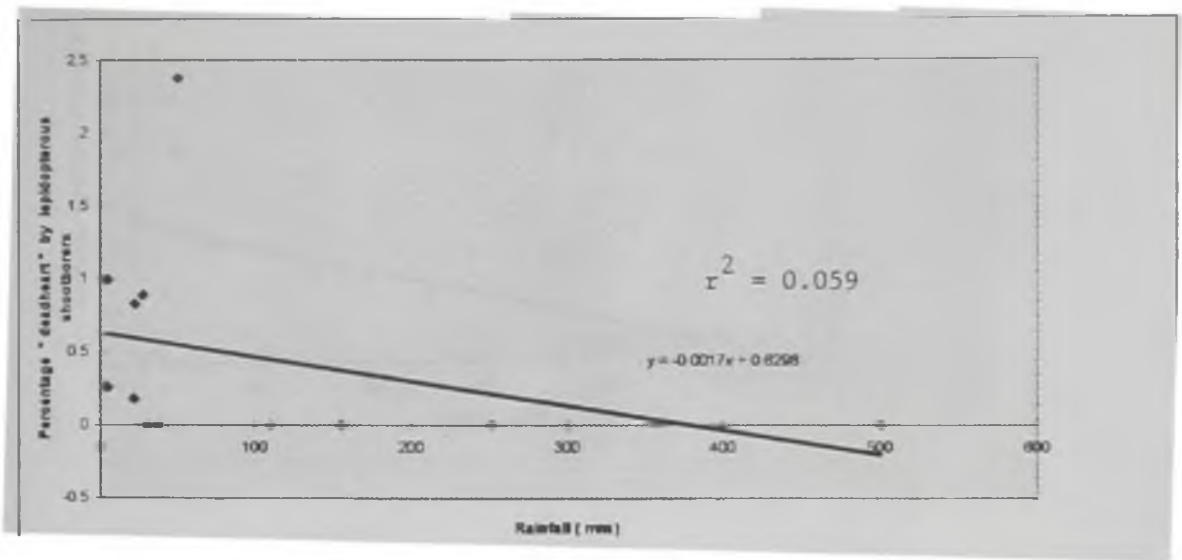

Fig. 15: **Relationship between percentage `deadheart' by stemborers and rainfall.**

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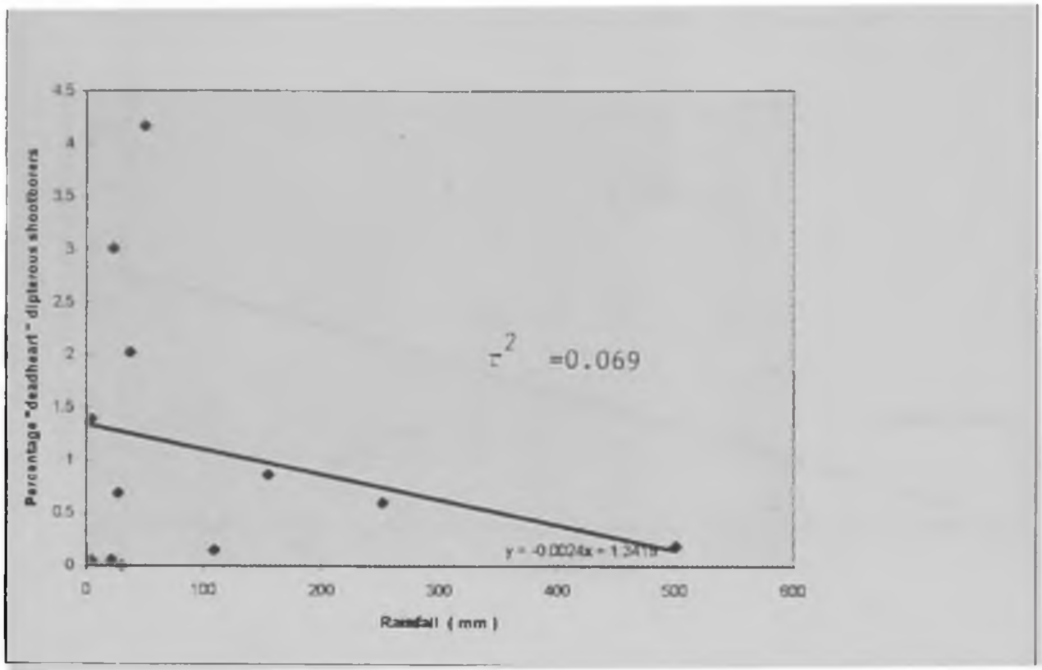

Fig. 16: **Relationship between percentage 'deadheart' by shootflies and rainfall.**

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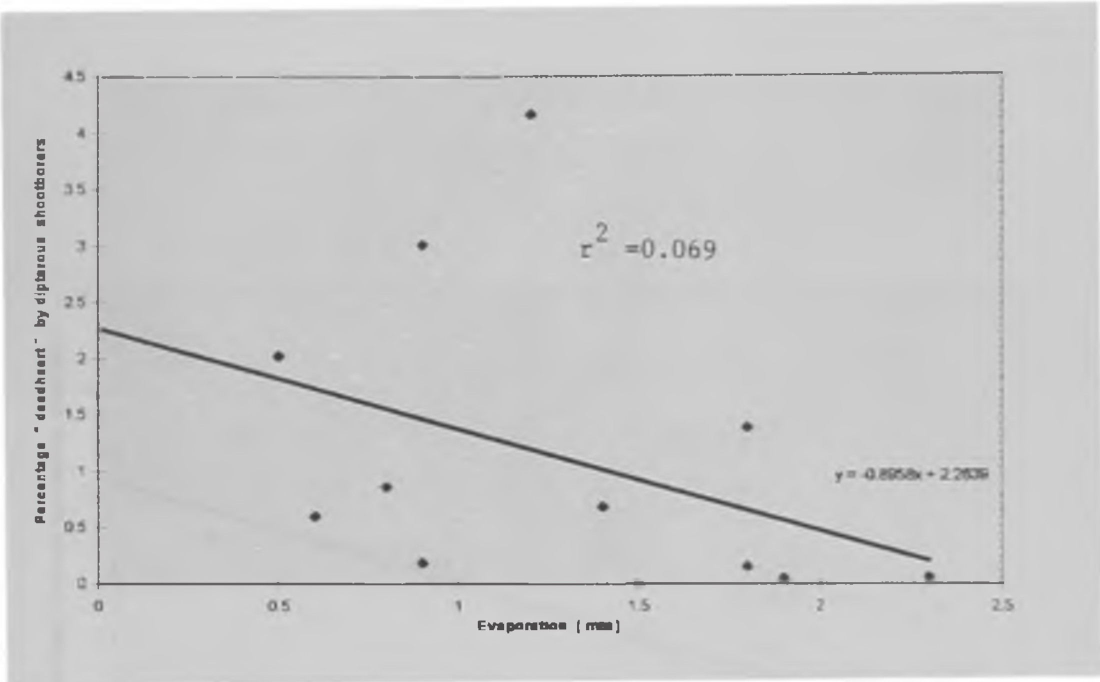

Fig. 17: **Relationship between percentage 'deadheart' by shootflies and evaporation.**

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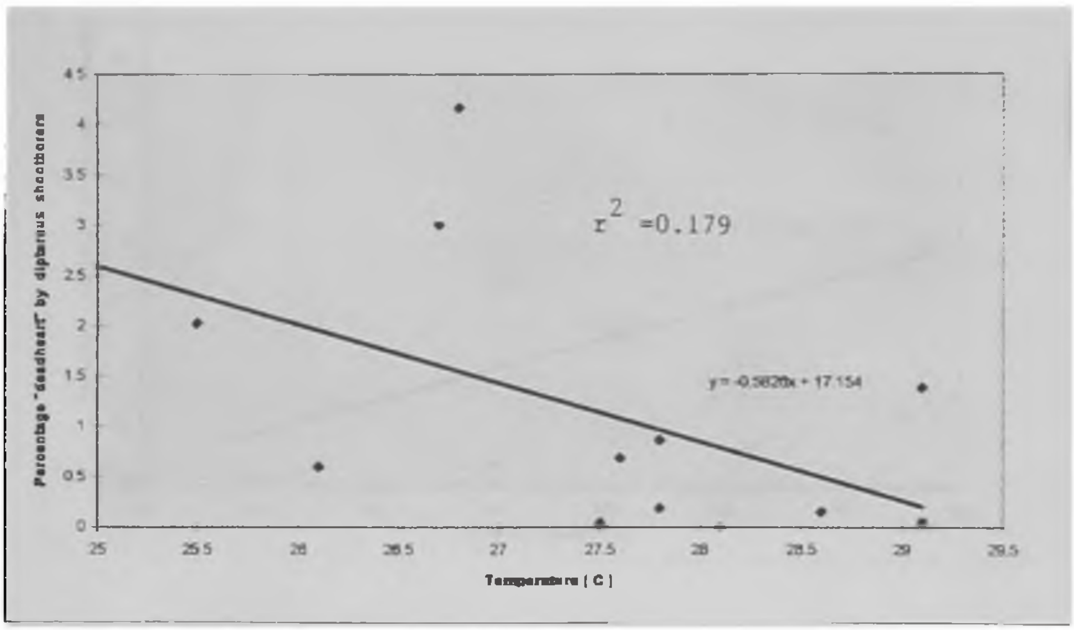

Fig. 18: **Relationship between percentage `deadheart' by shootflies and temperature.**

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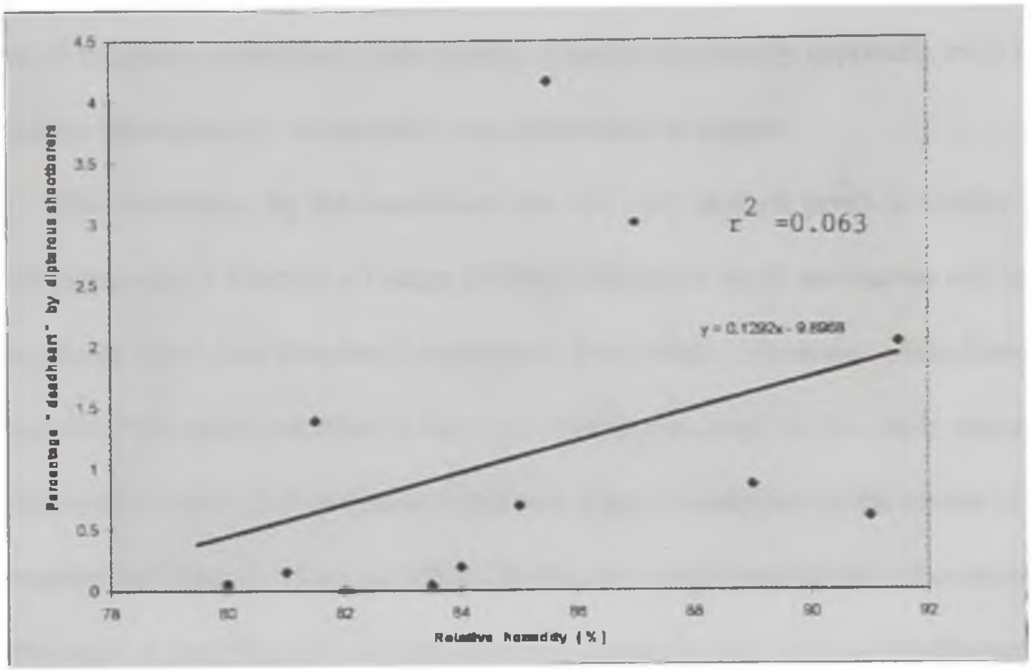

Fig. 19: **Relationship between percentage `deadheart' by shootflies and relative humidity.**

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4.4 Discussion

Incidence of 'deadheart' by shootflies and lepidopterous stemborers

Results of borer incidence in Farm A were not complete and therefore may not give much information but the fact that work had to be abandoned as a result of flooding, shows the unsuitability of marshy areas for the cultivation of citronella.

In Farm B, the results showed no significant difference ($P > 0.05$) between the means of infestation rates by the shootflies (1.2%) and stemborers (0.6%). Therefore, as far as insect attack of the plant is concerned, both groups of insects are equally important, even though percentage infestation by the shootflies was observed to be higher.

That infestation by the stemborers has two very distinct peaks is similar to the observation made by Endrody - Younga (1968) of infestation by *E. saccharina* and *Sesamia botanephaga* Tams and Bowden (Lepidoptera: Noctuidae). However, while Endrody – Younga's (1968) peaks occurred in July and October, the peaks in this study occurred in February and October. The two peaks imply two distinct generations of the insects in a year as suggested by Endrody - Younga (1968). By the same reasoning, the shootflies show three generations in a year (Fig. 12), an observation which agrees with the number of generations a year of other Chloropidae reported by Cunlife (1925), Sabrosky and Wilbur (1936) and Simmonds (1952).

The simultaneous rising and falling of infestation levels makes it possible for both shootflies and lepidopterous stemborers to be controlled together, assuming both react equally to same control measures. It also suggests that both groups of insects respond similarly to the

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factors influencing their attack on citronella.

Relation between incidence of 'deadheart' and Rainfall, Evaporation, Temperature and Relative Humidity.

The linear relationships between the infestation rates and the above-mentioned climatic factors are rather weak, implying weak influences of these factors on infestation. Nevertheless, rainfall appears to be the dominant factor impacting on both groups of insects. Thus, infestations are always low in high rainfall and vice versa (Fig. 14).

The low infestations from April to July indicate that low populations of the larvae attack the crop during periods of high precipitation. In the case of the lepidopterous stemborers, this agrees with the observation of Jerath (1965) in Nigeria, who reported very low larval density of *E. saccharina* during the wet season. Also low infestation in the period above supports the suggestion by Easwaramoorthy and Jayaraj, (1988) that high amounts of rain might be directly responsible for less borer incidence. In this work, high level of surface run-off occurred in both Farms A and B during high precipitation and since the exit/entry holes were so low above the ground surface, the tunnels became susceptible to flooding, thus rendering the larvae vulnerable during heavy and continuous rains. This probably contributed to the absence of damage by the stemborers during the rains (Fig. 14). The gradual build up of infestation by the larvae of the chloropids from August could imply corresponding build up of adult population from the end of the rainy period in July (Fig. 14), which would agree with the conclusion by Sabrosky and Wilbur (1936) that adult chloropids emerge after periods of heavy rains. It is, however, at variance with the findings of Cunlife (1925), and Simmonds

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(1952) which show no such relationship with rainfall.

There was a sharp drop in infestation by both groups of insects from November to December, when evaporation was very high and there was no precipitation (Fig. 14). In the case of the shootflies, this implies that there are very few adults during drought conditions as was reported for other chloropids (Sabrosky and Wilbur, 1936). During this period the plants are perhaps too dry to attract and support the insects.

The influence of the relative humidity and temperature on the shootflies was not so obvious, considering the relatively very low fluctuations in their trends as the infestation fluctuated (Fig. 14). However, their effects might be reflected in the influence of evaporation, since evaporation is the combined effects of temperature and relative humidity (Messenger, 1959). Balraj *et al* (1977) observed that high temperatures are lethal to the larvae and eggs of lepidopterous shootborers, especially *Chilo partellus* and Adeyemi (1969) reported that larvae of *Sesamia calamistis* undergo dormancy in unfavourably high temperatures. In this work, no relationship was found between the stemborers and temperature.

The above results are only preliminary and considering the fact that the pattern of attack, especially by shootflies, varies considerably from year to year (Deeming, 1971), the seasonal infestations will have to be monitored for more years in order to determine a definite pattern in relation to climatic factors.

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CHAPTER FIVE

5.0 ASPECTS OF THE BIOLOGY OF SHOOTFLY, *SCOLIOPHTHALMUS MICANTIPENNIS* (DIPTERA: CHLOROPIDAE)

5.1. Introduction

As pointed out in the previous chapter, both chloropid shootflies and lepidopterous stemborers were important, even though the former caused a higher incidence of 'deadheart'. Prominent among the chloropids was *S. micantipennis* which caused the highest level of primary damage and so was considered important enough to require further study. Information on its biology, which may be useful for its management is lacking. Indeed, most of the available information on Chloropidae centres on *Oscinella frit* (L.) in Europe.

For *O. frit*, Simmonds (1952) reports differences in aspects of the life history, such as the number of generations in the year, the length of the various stages, life span and fecundity of the adults. In this chapter, attempts were made at studying the reproduction and developmental biology in *S. micantipennis* with the objective of providing useful information for management strategies.

5.2 Materials and methods

All experiments were conducted in the laboratory under room temperature of about 27°C and relative humidity of 80%.

Mating behaviour and oviposition: The objectives of these studies were to determine the following:

1. Frequency of mating

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2. Time of mating
3. Duration of mating
4. Interval between last mating and oviposition
5. Oviposition sites
6. Nature of eggs laid
7. Batch size of eggs
8. Incubation period
9. Hatchability of eggs.

Cut citronella shoots with leaves were placed in 15.3cm x 2.6cm glass tubes containing moist cotton wool to keep the tillers fresh. Newly emerged adults of *S. micantipennis*, reared from infested citronella tillers, were etherized and their sexes determined using their external genitalia. A male and female pair was introduced into each tube. The tubes were covered with a fine net held in place by a rubber band (plate 5), left in the laboratory and inspected daily at 30-minutes interval starting from 0700 hours to 2000 hours GMT. Each morning the insects were momentarily immobilized by placing the tubes in a freezer for about one minute, and the citronella shoot and cotton wool removed and inspected under the microscope for eggs. Temperatures at 0900 hours and 1500 hours were recorded and used to calculate the mean daily temperature. A total of 45 pairs of *S. micantipennis* were observed.

Twenty tubes without citronella shoots were also supplied with a pair of adult *S. micantipennis* each and inspected as above. Also insect pairs were confined to the leaves of potted citronella plants in 15 tubes. A section of the leaf was confined together with insects

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inside a 10 x 2 cm tube which had the two open ends plugged with cotton wool such that the proximal and distal ends of the leaf remained outside the tube. Insects were fed on 10% sugar solution. In all the above experiments the insects were inspected till they died. A search for oviposition sites was conducted in the field using hand lens to carefully inspect the total surface of both healthy and `deadheart' tillers for eggs.

Larval stage: Unidentified larvae from infested tillers were removed, classified arbitrarily as young and old, and reared separately in petri dishes by placing them singly between fresh sheaths of citronella. Every morning the sheath was spread out and washed in tap water in a petri dish and the water inspected under the microscope for exuviae. The idea was to trace the development of *S. micantipennis* from larvae collected from the field since no eggs could be obtained from the laboratory or field. The arbitrary classification was unscientific. It was nevertheless used because the instars were not known and also could not be identified by Dyar's law, due to the unavailability of information on larval sizes, measurements of which had to stop because of the unacceptably high death rate in the delicate larvae when exposed under the microscope.

Pupal stage: Larvae in advanced stage of development, not feeding and less mobile, that is about to pupate were collected from infested citronella tillers and put singly in 15.3 x 2.6cm glass tubes containing wet cotton wool. The tube was covered with a cork and inspected daily at 0700 hours and 1500 hours. The date they started developing puparia was recorded. Their date of emergence was also recorded and the sex determined by examining the external genitalia. The lengths of the puparia were measured using an eyepiece micrometer fitted to a microscope.

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Plate 5: Experiment to determine oviposition site of *Scoliophthalmus micantipennis* in the laboratory

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Adult Longevity: This study was to determine the life span of the adult male and female. Fifty-three pupae made up of 24 male and 29 female from infested tillers in the field were put singly in 7.7 x 2.6cm tubes. They were inspected daily at 0700 hours and 1500 hours until they emerged and died. The insects were fed on 10% sugar solution soaked in cotton wool and the tubes were covered with fine cloths held in place by rubber band.

Sexual dimorphism in adults: Observation from laboratory rearing showed that adult specimens of the shootflies occurred in two distinct groups; smaller specimens and bigger ones. Therefore, 30 small and 31 large specimens of *S. micantipennis* which were freshly killed in ethyl acetate were measured from head to abdomen, using an eyepiece micrometer fitted to a microscope. The idea was to determine if there existed any sexual dimorphism in species.

5.3 Results

Mating behaviour and oviposition: Out of 80 set-ups, only two pairs of insects were found mating in tubes with cut citronella shoots. The first pair stayed in copula between 0700 hours and 0912. The second pair stayed in copula between 1100 hours and 1417 hours. In both cases the male mounted the female on the latter's back between the wings. The male bent the tip of its abdomen until its extruded copulatory organ was inserted into the genital opening of the female. They remained in copula even when disturbed. The females mated within one and 17 days after emergence and died between 3 and 8 days later respectively. The males also mated within one and 17 days after emergence but died 2 days later. No eggs were found laid in any of the experiments.

Larval stage: No exuvia was detected in any of the 53 set-ups. Thirty-four out of the

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37 `young' ones died by the seventh day, and four of the 16 `old' ones died while 12 pupated within five days (Table 6).

Table 6: **Survival and Development of larvae of Shootflies collected from infested tillers**

Classific Ation	Total No. of Larvae	State of Larvae	Day(s) after collection								
			1	2	3	4	5	6	7	8	>9
`Young'	37	Dead	17	22	28	30	32	34	34	34	34
		Pupated	0	0	0	0	0	0	0	2	3
`Old'	16	Dead	1	1	2	2	4	4	4	4	4
		Pupated	9	9	10	10	12	12	12	12	12

Pupal stage: The pupa was exarate adecticous. This means it had no functional mandibles to use in escaping from the puparium and also the appendages were free of any secondary attachment to the body. It was also coarctate which means it was enclosed in paparium formed from the preceding larva. The pupa initially was pale but this changed to deep brown after a day or two. The length of the puparium of the female ranged between 2.3mm and 3.9mm with a mean of 3.3±0.1mm (n=30) and that of the male ranged between 2.2mm and 3.9mm with a mean length of 3.2±0.01 mm (n=30) (Table 7). There was no significant difference ($P > 0.05$) between the lengths of male and female puparia but the male puparium had bands of striations which were absent from the female one.

The pupal periods ranged between 4 and 9 days with a mean of 6.7 ±0. 4 days (n=22) for females and from 4 to 13 days with a mean of 7.2±0.1 days (n= 17) for males (Table 8). There was no significant difference ($P > 0.05$) between them (Table 8). At the end of pupation, the puparium of both sexes split horizontally at one end and a small cap opened at the end of the split (Fig. 20

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and Fig. 21) from which the adult emerged. This happened in both sexes.

Table 7. Length of empty puparia of female and male *Scoliophthalmus micantipennis*.

Sex	Total Number of puparia (n)	Range in Length (mm)	Mean length (x ± S.E.)mm	t_{58df}; P = 0.05
Male	30	2.18 – 3.92	3.16 ± 0.08	
Female	30	2.23 – 3.94	3.32 ± 0.08	n.s

Table 8: **Pupal period of male and female *Scoliophthalmus micantipennis* in the laboratory at 27.4°C**

Sex	Total Number of puparia (n)	Range in Length (mm)	Mean length (x ± S.E.)mm	t_{37df}; P = 0.05
Male	17	4-13	7.24 ± 0.49	
Female	22	4-9	6.72 ± 0.39	n.s

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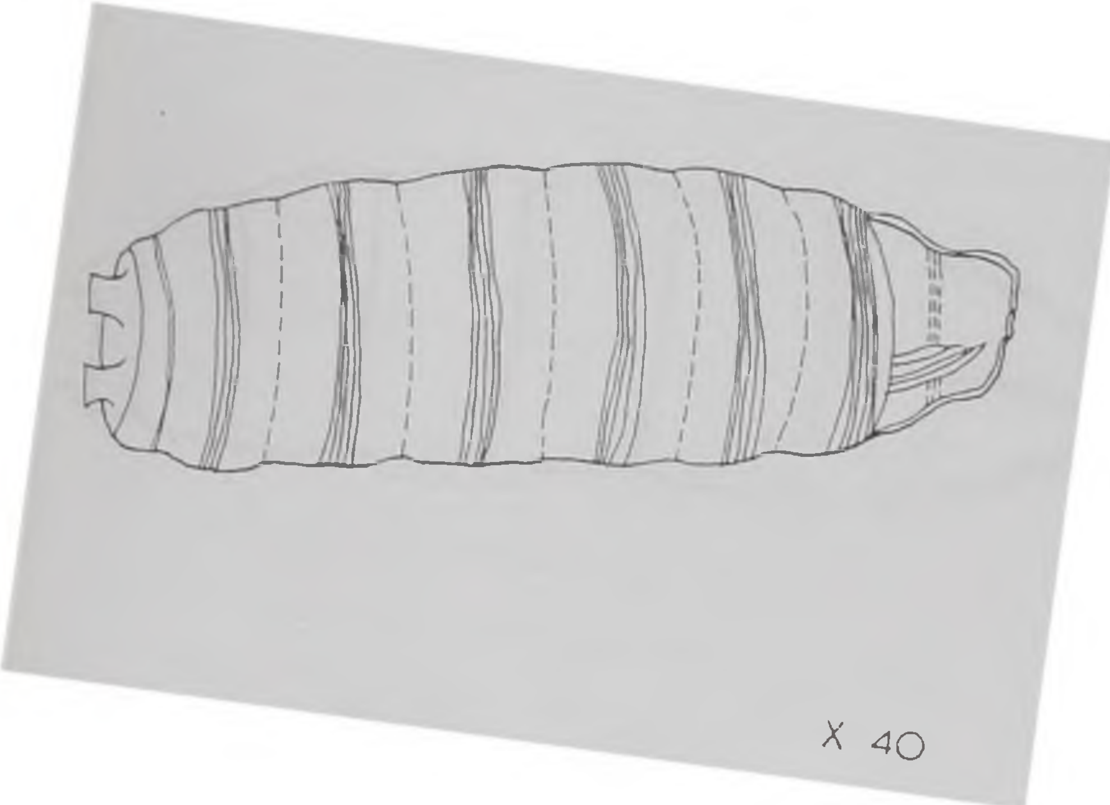

Fig. 20: **Dorsal view of male puparium of *Scoliophthalmus micantipennis* with the tip broken to provide passage for the emerging adult.**

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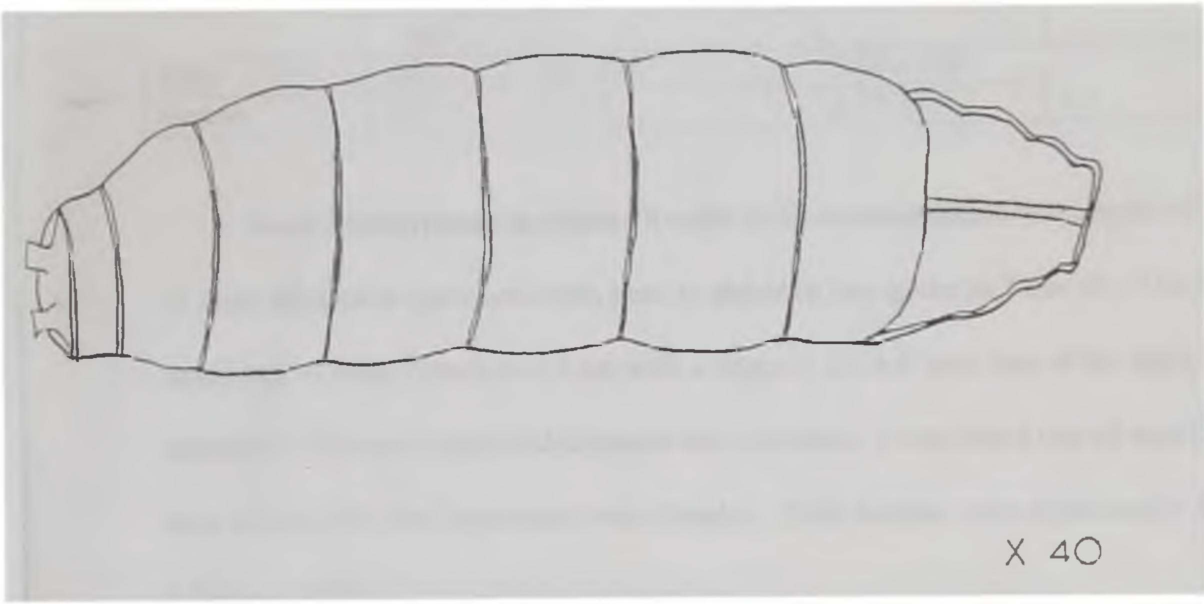

Fig. 21: **Dorsal view of female puparium of *Scoliophthalmus micantipennis* with the tip broken to provide passage for the emerging adult.**

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Adult longevity: There was no significant difference ($P > 0.05$) between the survival periods of the sexes; the female lived for 8.6 ± 0.8 (n = 29) and the male 9.4 ± 0.6 days (n=24) after emergence (Table 9). The newly emerged adults were pale with shorter wings. The body however, became darker and the wings longer, later.

Table 9: Longevity of adult male and female *Scoliophthalmus micantipennis* in the laboratory at 27.4°C.

Sex	Total Number of insects (n)	Range (days)	Mean longivity (x ± S.E.) days	t_{51df}; P = 0.05
Male	24	4-15	9.41 ± 0.60	
Female	29	1-17	8.59 ± 0.77	n.s

Sexual dimorphism in adults: Results of the measurements of the lengths of 30 small and 31 large specimens (measured from head to abdomen) are given in Table 10. The length of the small ranged from 1.9mm to 2.5mm with a mean of 2.0 ±.0 mm; that of the large ones ranged between 2.4mm and 3.3mm and the mean was 3.0±0mm. It was found that all smaller specimens were males while the larger ones were females. Their lengths were significantly different ($t = 5.226$, $p < 0.05$).

Table 10: Total length of adult male (small) and female (large) *Scoliophthalmus micantipennis*

Sex	Total Number insects (n)	Range in Length (mm)	Mean length (x ± S.E. (mm)	T_{51df}; P = 0.05
Male (small)	30	1.9 – 2.5	1.96 ± 0.02	
Female (large)	31	2.4 – 3.3	2.98 ± 0.03	*5.226

*Significant at p < 0.05

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5.4 Discussion

Mating behaviour and Oviposition: In contrast to the report by Simmonds (1952) that Chloropidae such as *O. frit* mate readily on emergence, only 2 pairs of *S. micantipennis* mated in this study. That *S. micntipennis* remained in copula for a long time (over 2 hours), however, agrees with Simmonds' (1952) observation. Even though the low number of insects that mated makes it difficult to draw definite conclusions, the long copulation period observed may provide opportunity for attacking them with contact insecticide during their mating season. The male is smaller (mean = 2.0 ± 0mm) than the female (mean = 3.0 ± 0mm) making it convenient for the female to carry the male on its back during mating. Despite this apparent convenience, the mating did not appear to have been a productive one since it did not result in oviposition. The observation that no eggs were laid in captivity cannot be attributed to the inability of the insects to mate as a result of wrong identification since even in situations where mating took place, no eggs were laid. Although oviposition in Chloropidae is unpredictable (Aldrich, 1920), the observation in this study was probably due to unsatisfactory conditions in captivity. This is because workers such as Aldrich (1920), Steel (1931) and Simmonds (1952) who succeeded in their studies on mating and oviposition in *O. frit* had to rigidly control the temperature and r.h. at 24°C and between 90-100 percent, respectively. This could however, not be done in this study and might have contributed to the failure to achieve oviposition.

Larval and Pupal development: Studies on the larval stages did not yield the desired results because of high mortality. For instance, over 90% of the 'young' larvae died by the

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seventh day (Table 6). Deeming (1971) also reported high death rate of larvae of Chloropidae and listed the problem as one of the major difficulties hampering the studies of the immature stages of the chloropid shootflies.

In the pupa, the presence of striations on the male puparium is probably the only observable difference between the sexes, since there is no significant difference ($p > 0.05$) between their lengths. However, Goodlife (1942) found sexual dimorphism in the lengths of other chloropids such as *Chlorops pumilionis* Bjerk. The pupal period (4 – 13 days) of *S. micantipennis* as observed in the present study shows wider variation than the 9–10 days reported by Simmonds (1952), for *O. frit.* probably as a result of the variability of larval stages collected for the study.

Adult: Even though not many morphological characters were measured, it was found that the total lengths of the adults differed significantly ($t = 5.226$: $p < 0.05$) between the two sexes. Thus the adult *S. micantipennis* exhibit sexual dimorphism in their lengths, the males are shorter than the females. Sexual dimorphism in body lengths has also been reported by Goodlife (1942) in adult *C. pumilionis* and has been used for taxonomic purposes. Sexual dimorphism, therefore, appears to be a common phenomenon in the Chloropidae. The range in body length of 1.9 – 3.8mm of *S. micantipennis* found in the study, falls within the 1.5 – 5.0mm range for Chloropidae reported by Sabrosky (1962). The adults of *S. micantipennis* survived for about the same period. However, the range of the survival of the females was rather wide. The early deaths might have been caused by some pathogenic infection.

Not much could be obtained for the life cycle of *S. micantipennis* in this study, but as the major primary feeder of citronella, there is the need for complete information on the life history which may be taken up in further work.

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CHAPTER SIX

6.0 SUMMARY AND CONCLUSIONS

6.1 Summary

1. Two species of aromatic citronella, *Cymbopogon nardus* and *Cymbopogon winterianus* were introduced into Ghana from Asia by Lever Brothers Ghana (GH) Ltd. (LBG) in 1978 and cultivated by farmers. By 1988 insects had started attacking the crop, but no detailed work has been done on the insect pests. This work was therefore undertaken to provide detailed information on the pests that could be used for their management.

2. Data were collected from 12 farms in the Eastern and Greater Accra regions all in the south-eastern part of Ghana where the crop is extensively grown. However, the greater part of the work was done at Osofoiaman near Pokuase in Greater Accra. Two farms were used initially but one had to be abandoned due to flooding.

3. Sweeping was done intensively for eleven months in one farm and extensively in six others for three months to survey insects associated with the shoot of citronella.

4. Random sampling for `deadheart' was done for one year at Osofoiman. The insect feeders were identified and the incidence of their damage in relation to climatic factors was monitored for one year. A comparison of the rate of infestation was made using two methods namely, `deadheart' symptoms and random dissection of shoots.

5. Studies on some aspects of the reproductive and developmental biology of the major chloropid shootfly *S. micantipennis* were also done in the laboratory.

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6.2 Conclusions

It was found that the vegetative portion of citronella was associated with diverse insect fauna: insects comprising 10 orders and 103 families visit citronella. Among these insects, those that damage citronella are the shootflies (Dipterea: Chloropidae) and stemborers (Lepidoptera: Noctuidae and Pyralidae) and termites. The chloropid shootflies are *Scoliophthalmus micantipennis*, *Scoliophthalmus trapezoides*, *Anatrichus pygmaeus*, *Aprometopis flavofacies*, *Elachiptera occipitalis* and a yet to be identified chloropid shoot fly. The lepidopterous stemborers are *Sesamia* sp (Fam: Noctuidae) and *Eldana saccharina* (Fam: Pyralidae) while the termites are yet to be identified. The shootflies and stemborers are equally important as far as damage to the tillers is concerned.

The primary feeders are *S. micantipennis*, *A. flavofacies*, *Sesamia* sp. and *E. saccharina*. *Scoliophthalmus trapezoides* is considered as both primary and secondary feeder. The major feeder among the primary feeders of citronella is *S. micantipennis* because it is the greatest number of insects causing primary damage.

Damage to the tillers of citronella is done by the larvae of the shootborers. They tunnel the tiller to cause the inner whorl to wilt and become pale resulting in the `deadheart' symptom. The larvae live inside the tillers and so can possibly be controlled by systemic insecticides. The incidence of the damage was found to have weak linear relationship with relative humidity or temperature or evaporation or rainfall. It shows two possible peaks for both the stemborers and shootflies. It is also low between January and July, and high between August and November. There is synchronisation in the build up of the incidence of damage by both groups of shootborers.

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It is therefore recommended that they are controlled simultaneously.

Farms that are over one year old appear susceptible to termite attack; farmers should therefore not cultivate one farmland for too long but if they do, they should start control measures against termites early, about one year after cultivation. Also, whenever there is outbreak of the grasshopper, *Zonocerus variegatus,* preventive measures should be taken for the insects could attack the plant.

It has been found in the study that improved sweep net locally designed is more effective in sampling insects on citronella. It is by no means perfect and it needs some improvement to increase its efficiency. For example, the opening should be enlarged because during sampling it was found to be too narrow especially for the very swift insects. The handle also needs lengthening. It is found that the shortness of the handle made the user bend too low.

As much as possible, experimental farms should be established for such future studies so that many experiments and also random dissection can be carried out to get the true infestation of the insects. This is because this study has shown that infestation as determined only by `deadheart' symptom is an underestimation of the true situation by about 32%.

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* Original not seen

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APPENDICES

Appendix 1: Average of climatic factors at Osofoiaman over 5 years (1987-1991)

Month	Mean Rainfall (mm)	Mean Evaporation (mm)	Temperature (°C)		Relative Humidity (%)	
			Mean Maximum	Mean Minimum	0900 Hrs	1500 hrs
January	8.84	1.95	33.84	20.65	88	70
February	20.68	2.4	34.7	23.6	89	70
March	43.32	2.58	34.44	23.13	89	74
April	60.48	2.58	34.42	23.3	89	72
May	202.38	1.85	33.22	22.92	90	78
June	153.44	1.3	31.9	22.44	90	82
July	119.7	1.13	30.04	21.96	93	86
August	60.88	0.93	29.25	22.2	94	88
September	106.22	1.0	30.76	22.5	90	82
October	91.16	1.22	31.56	22.08	90	82
November	91.52	1.33	32.74	22.48	89	82
December	35.26	1.63	32.96	21.16	92	78

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Appendix 2: Weekly sweep net collection of insects associated with citronella, Osofoiaman Farm B, 1991

	FEB.			MARCH			APRIL				JUNE		JULY	AUG.		SEPT.		OCT.		NOV.		DEC.	
HOMOPTERA																							
Flatidae	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
Cicadellidae	6	8	3	2	2	4	2	1	0	0	1	2	0	3	0	5	0	0	0	0	4	3	2
Cercopidae	12	13	23	12	13	16	8	10	12	4	2	7	13	33	16	25	10	17	11	11	7	8	10
Dictyoptera	4	1	1	2	2	1	2	1	1	0	2	1	0	1	3	2	3	1	3	3	1	2	1
HEMIPTERA																							
Scutelleridae	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0	1	0	1	0	0	2	1	1
Pentatomidae	0	10	7	4	3	1	0	0	1	0	0	0	1	3	0	0	1	2	4	2	4	4	3
Brachyplatidae	1	2	0	0	1	5	4	3	2	1	0	0	1	2	2	1	0	5	2	5	2	3	0
Pyrrhocoridae	0	2	0	1	2	0	0	0	0	1	1	2	0	0	1	0	1	0	1	0	1	0	0
Reduviidae	4	1	0	0	0	0	2	0	0	0	0	1	0	1	0	1	0	0	1	0	1	0	1
DERMAPTERA																							
Forficulidae	1	7	12	4	6	1	0	0	7	1	0	2	4	2	1	3	1	1	2	1	2	1	2
ORTHOPTERA																							
Pyrgomorphidae	1	2	9	8	3	1	2	1	0	0	0	1	0	1	2	0	0	1	2	1	2	4	5

Appendix 2 continued

DIPTERA																							
Diopsidae	1	13	5	0	2	1	0	1	1	2	1	0	1	1	1	0	1	3	0	3	0	1	0
Asilidae	0	2	2	0	1	0	0	1	1	0	0	1	0	1	0	0	0	0	1	0	1	1	0
DICTYOPTERA																							
Mantidae	2	3	2	3	0	0	0	0	2	0	1	0	0	0	0	0	2	1	1	1	1	0	0
COLEOPTERA																							
Chrysomelidae	1	3	2	3	1	1	0	0	1	0	2	3	2	1	2	3	0	0	3	0	3	1	1
Lagriidae	2	1	2	2	1	0	2	1	2	2	0	1	0	1	2	1	0	3	2	3	2	2	1
Coccinellidae	0	3	1	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	1	1	0
HYMENOPTERA																							
Braconidae	1	2	2	2	0	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Ichneumonidae	2	4	6	3	2	0	0	2	3	0	0	2	1	0	1	1	0	0	0	0	0	0	0
Formicidae	12	15	10	11	17	11	15	20	13	12	8	9	10	13	10	10	17	10	9	10	9	8	13

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Appendix 3: Sweep net collection of insects associated with citronella in the other farms, October- November, 1992.

Insect	Farm					
DIPTERA	Osofoia-Man Farm C	Botoku	Selina-Taylor	Ababio	Omenako	Kpan-kpan Ayik-uma
Chloropidae	153	89	72	75	29	71
Cecidomycidae		1	-	-	-	3
Tephritidae	-	3		3	5	8
Lonchaeidae		1				
Agromyzidae				3	-	1
Dolichopodidae		-		3	-	2
Curtonotidae	-		1	6	3	-
Platystomatidae	-			-	-	2
Ottidae		-	-	1		
Pipunculidae				-	-	1
Ceratopogonidae	-				1	1
Empididae				-	5	
Chamaemyiidae					1	-
Drosophilidae					1	3
Muscidae	16	11	3	7		35
Sarcophagidae	1		-		9	
Sepsidae	1		-	1	-	
Sciaridae	2				-	18
Phoridae	2	2	-		3	1
Mycetopilidae	1		1	-	-	-
Heleomyzidae	1	4			-	1
Lauxaniidae		1	2	2	7	-
Asteiidae		2	-	-	2	
Sciomyzidae	-	1			-	
Culicidae	-	1	1	-		
Syrphidae		1			4	

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Appendix 3 continued.

Scatopsidae	-	2	-		-	6
Piophilidae	-	-	-	1		-
Dixidae	-	-	-	-	4	-
Calliphoridae	1	-	1	-	-	1
Ephydridae	7	-		-	-	
Dichlopodidae		-		2	2	-
HYMENOPTERA						
Formicidae	205	440	109	139	139	241
Evaniidae	2	4		2	4	2
Ichneumonidae	4	3	-	-	-	
Tiphiidae	2	1	2	1	-	
Bracondiae	10	4	9	20	13	7
Vespidae	-	1		1	1	
Eulophidae	1	2	5	4	2	3
Mymaridae	-	1				1
Erytomidae	-	3	2	2	4	4
Encycrtidae	1	3	1	2	1	
Eupelmidae	2	1		3		1
Dryinide	1	2				
Agaonidae	1	2	1	4	-	-
Pteromalidae	5	2	11	10	5	1
Sphecidae	2	1	3	5	1	2
Chalcidae	7	-	4	3	26	1
Prototrupidae	1		1			-
Bethylidae	3	-				-
Colletidae	1		1		1	-
Diapriidae	1			-		
Torymidae	1		28	2	1	1
Eucharitidae	1		-			
Perilampidae	1		2	2	6	1
Pompilidae	-	-		-	2	1

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Appendix 3 continued.

Platygasteridae	-	-	1		-	
Andrenidae	1	-		-	-	-
Cynipidae	-	-	-	-		1
Ceraphronidae	-	-	-	-	-	2
Gasteruptiidae	-	-	1	-		-
COLEOPTERA						
Chrysomelidae	7	1	-	2		
Curculionidae	4	3	5		7	
Cerambycidae	2	-		8		
Coccinellidae	1	1			1	-
Lagriidae	8	2	7	1	1	6
Meloidae		4	-	-		
Pselaphidae		1				
Elateridae	-	2		1		
Anthribidae			-	6	-	-
Staphylinidae	-	-			1	1
LEPIDOPTERA						
Noctuidae	2	3			1	1
Coleophoridae	2	-	1	1	-	-
DICTYOPTERA						
Mantidae	1	2			1	4
Blattidae	1	6	2	2	-	1
DERMAPTERA						
Forficalidae		5	1	2	1	2
NEUROPTERA						
Chrysopidae		-	1	4		2
Myrmeleontidae			-	1		-
Coniopterygidae		-	-		-	2
ORTHOPTERA						
Pyrgomorphidae	62	51	20	29	12	6
Tettigonidae		7	6	4	6	4
Gryllidae	10	10	-	-	6	4

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Appendix 3 continued.

HEMIPTERA						
Corimelaenidae	1	9	1	-		12
Pentatomidae	2	1	2			2
Lygaeidae	-	1	21	35	13	5
Reduviidae	1	-	1	-	1	
Scutelleridae	1		-		3	
Tingidae			1	1	2	
Rhopalidae		-	5	11		
Miridae	-		3	3	7	3
Nabidae			4			3
Piesmatidae			-		1	
Coreidae		-	-		2	1
Alydidae		-		-		1
HOMOPTERA						
Cercopidae	129	33	92	153	24	17
Cicadellidae	64	115	259	90	124	324
Delphacidae	2	2	1	8	51	61
Flatidae	1		1		8	2
Aphididae	1		5	6	8	18
Membracidae	-	-			1	-
Dictyopharidae		1	2	8		
Psyllidae		2	-			

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Appendix 4: **Key to shoot fly species recorded from citronella tillers**

The adult Chloropidae are small flies - for example, the species identified in the survey ranged between 1.9mm and 3.8 mm and Sabrosky (1962) puts the size as ranging between 1.5 and 5.0mm long. The head has characteristically well developed ocellar triangle. The bristles on the body are reduced and so also is the wing venation. The insects have an incomplete subcostal vein and the costal vein is broken near the end of R_1. The adult Lonchaeidae have a complete subcostal vein. The key below is meant to provide an easier and quicker way of identifying the species identified in this study without having to go through long keys which may not be available anyway.

1 Subcostal vein complete .... Lonchaeidae (*Silba pectita*) -

Subcostal vein not complete 2

2 Body predominantly black. Mesopleuron haired 3

Body of various colours other than black.

Mesopleuron bare 6

3 Subcosta continues beyond apex of M_{1+2} 4

Subcosta does not go beyond M_{1+2} but just beyond

apex of R_{4+5} .... *Scoliophthalmus trapezoides*

4 Mesonotum and Scutellum thickly beset with long erect

spine like bristles. Tergites fused .... *Anatrichus pygmaeus*

Mesonotum and scutellum without long erect spine

like bristles 5

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5 Arista thickened and flattened body, wings and legs more or less narrowly enlongated ....Species D

- Arista not thickened and not flattened. Body, wings and legs reltively short. Haltere with black knob. Hind cross-vein strongly oblique ....*Scoliophthalmus micantipennis.*

6 Body predominantly dark brown. Facial carina absent. Scutellum flattened and trapezoidal .... *Elachiptera occipitalis*

- Body predominantly bright yellow with 4 dark horizontal bands at the dorsal part of the thorax. Scutellum flattened and rounded facial carina present .... *Aprometopis flavofacies*

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Appendix 5: **Chi-square analysis of adult Diptera reared and Lepidoptera larvae collected from tillers showing various forms of 'deadheart'.**

Insect	Count	Early	Advanced	Secondary	Row Total
Scoliophthalmus trapezoides	1	21	35	8	64 28.2%
Scoliophthalmus micantipennis	2	39	6		45 19.8%
Anatrichus pygmaeus	3		14	32	46 20.3%
Elachiptera occipitalis	4			3	3 1.3%
Aprometopis flavofacies	5	5			5 2.2%
Species D	6		8	24	32 14.1%
Silba pectita	7		3	1	4 1.8%
Phoridae	8		10	5	15 6.6%
Sesamia sp	9	11			11 4.8%
Eldana saccharina	10	2			2 0.9%
	Column Total	78 34.4%	76 33.5%	73 32.2%	227 100.0%

Chi-square

192.29033

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Appendix 6: **Comparison of rate of infestation estimated from only 'Deadheart' symptoms and from random dissection of shoots at four different farms.**

Farm	Infestation rate of tillers (%)	
	Only 'Deadheart'	Dissection
Osofoiaman (Farm B)	0.27	0.82
Ashalaja	2.14	2.61
Omenako	0.28	0.4
Ababio's	0.4	0.7

Appendix 7: Daily Growth of healthy and infested tillers after ratooning

Day	Height of tillers of Hill 13 (mm)		Height of tillers of Hill 17 (mm)		Height of tillers of Hill 30 (mm)	
	Healthy	Infested	Healthy	Infested	Healthy	Infest- ed
1	3.0	4.10	2.87	3.50	2.25	2.0
2	5.17	6.70	6.70	5.20	4.62	4.30
3	8.45	9.30	9.30	6.50	7.65	6.3
4	12.25	11.20	11.20	9.0	11.4	8.0
5	16.33	16.0	16.0	11.0	14.5	11.5
6	19.50	17.0	17.0	12.4	16.42	15.0
7	24.33	18.0	18.0	13.0	20.0	19.0

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Appendix 8: **Weekly percentage 'deadheart' by shootflies and stemborers, Osofoiaman farm A, January-June, 1991**

Date	Percentage 'Deadheart'	
	Lepidoptera (%)	Diptera (%)
28/1/91	0.2	0.2
4/2	0	0
11/2	0	0.18
18/2	0.25	2.01
25/2	1.17	1.5
4/3	0.41	0.81
11/3	0.18	0.18
18/3	1.7	2.33
25/3	0.15	0.15
¼	0.15	2.3
8/4	0.23	0.62
15/4	0.30	0.23
22/4	0	0.23
29/4	0.23	0.08
6/5	0.08	0.38
13/5	0.31	0.15
20/5	0	0.31
27/5	0.15	0.46
3/6	0	1.38
10/6	0	0.99
17/6	0	0.23
24/6	0	0.34

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Appendix 9: **Weekly percentage 'deadheart' by shootflies and stemborers, Osofoiaman Farms B, 1991**

Date	Percentage 'Deadheart'	
	Lepidoptera (%)	Shootflies (Diptera) (%)
12/2/91	0.73	1.76
19/2	0.43	0.97
26/2	1.82	1.43
5/3	0	0
12/3	0.73	0
19/3	0	0
26/3	0	0.23
2/4	0	0.15
9/4	0	0.08
16/4	0	0
23/4	0	0.23
30/4	0	0.31
7/5	0	0.54
14/5	0	0
21/5	0	0.08
28/5	0	0.15
4/6	0	1.69
11/6	0	0.92
18/6	0	0.15
25/6	0	0.69
2/7	0	0.92
9/7	0	0.15
16/7	0	0.23
23/7	0	0
30/7	0	1.7
6/8	0	1.15
13/8	0	3.3
20/8	0	2.34

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Appendix 9 continued.

27/8	0	1.3
3/9	0	3.6
10/9	0.07	2.75
17/9	0	3.5
24/9	3.25	2.19
1/10	3.86	1.3
8/10	1.06	3.3
15/10	3.7	3.56
22/10	4.41	6.88
29/10	1.66	2.5
5/11	0.74	1.04
12/11	0.53	1.07
19/11	0.72	0.36
26/11	1.56	0.29
3/12	0.78	0.14
10/12	0	0
17/12	0	0

Appendix 10: **Mean monthly Temperature, Rainfall, R.H and Evaporation at Osofoiaman 1991**

	Mean Relative Humidity (%)	Mean Evaporation (mm)	Mean Temperature (°c)	Mean Rainfall (mm)
January	82	1.5	28.1	30.8
February	81.5	1.8	29.1	4.4
March	80	2.3	29.1	21.4
April	81	1.8	28.6	109.7
May	84	0.9	27.8	500.7
June	89	0.8	27.8	154.8
July	91	0.6	26.1	251.7
August	91.5	0.5	25.5	37.6
September	87	0.9	26.7	22.5
October	85.5	1.2	26.8	50.2
November	85	1.4	27.6	27.6
December	83.5	1.9	27.5	4.5

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Appendix 11 : Regression analysis matrix of percentage 'deadheart' by lepidopterous stemborers
on Rainfall.

Response variate : LP
Fitted terms : Constant, RF

Summary of analysis

	d.f.	s.s	m.s.	v.r	F pr.
Regression	1 5.54	4.543	3.77	0.059	
	43	51.81	1.205		
	44	56.36	1.281		
	-1	-4.54	4.543	3.77	0.059

Percentage variance accounted for 5.9
Estimates of regression coefficients

	estimate	s.e.	t	t pr.
Constant	0.6298	0.210	3.97	<.001
RF	-0.0017	0.00115	-1.94	0.059

Appendix 12 : Regression analaysis matrix of percentage 'deadheart' by dipterous shootflies
on Rainfall

Response variate : DP

Fitted terms : Constant, RF

Summary of analysis

	d.f	s.s.	m.s.	v.r.	F pr.
Regression	1	5.54	4.543	3.7	0.059
	43	51.81	1.205		
	44	56.36	1.281		

Percentage variance accounted for 6.9

Estimates of regression coefficients

	estimate	s.e	t	r pr.
Constant	1.3413	0.265	5.73	<.001
RF	-0.0024	0.00145	-2.06	0.046

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Appendix 13 : Regression analysis matrix of percentage 'deadheart' by dipterous shootflies on Evaporation

Response variate : DP
Fitted terms : Constant, EV

Summary of analysis

		d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1		6.29	6.286	3.77	0.059
		43	84.30	1.960		
		44	90.59	2.059		

Percentage variance accounted for 6.9

Estimates of regression coefficients

	estimate	s.e.	t	t pr.
Constant	2.2639	0.437	4.27	<.001
EV	-0.8958	0.325	-1.79	0.080

Appendix 14 : Regression analysis matrix of percentage 'deadheart' by dipterous shooflies on Temperature.

Response variate : DP
Fitted terms : Constant, TP

Summary of analysis

		d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1		17.94	17.944	10.62	0.002
		43	72.64	1.688		
		44	90.59	2.059		

Percentage variance accounted for 17.9

Estimates of regression coefficients

	estimate	s.e.	t	t pr.
Constant	17.15	4.90	3.50	<.001
TP	-0.5826	0.178	-3.26	0.002

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Appendix 15 :Regression analysis matrix of percentage 'deadheart' by dipterous shootflies on Relaltive Humidity

Response variate : DP
Fitted terms : Constant, RH

Summary of analysis

	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	7.66	7.659	3.97	0.053
	43	82.93	1.929		
	44	90.59	2.059		

Percentage variance accounted for 6.3

Estimates of regression coefficients

	estimate	s.e.	t	t pr.
Constant	-9.8968	4.69	-1.74	<.001
RH	-0.1292	0.0548 -1.99	0.053	