RIVERS STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY, NKPOLU,
PORT HARCOURT, NIGERIA

BIOLOGY AND PREDATION EFFICIENCY OF AN APHIDOPHAGOUS COCCINELLID *Cheilomenes lunata* ON THE COWPEA APHID (*Aphis craccivora*)

BY

AMIFOR PHILIP NWADEI B.Sc. (HONS)

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF A MASTER OF PHILOSOPHY (M. PHIL) DEGREE IN APPLIED ENTOMOLOGY

OCTOBER, 1988

D E C L A R A T I O N.

I, AMIFOR PHILIP NWADEI, hereby declare that, the work presented in this thesis does not include any work submitted for another degree in this or any other university. All work contained therein was undertaken by me and is original except as specified in the text in which case detailed references are given.

October, 1988.

AMIFOR PHILIP NWADEI.

We certify that this research was supervised by us as institutional and university supervisors.

Dr. J.K.O.AMPOFO, ICIPE, Nairobi, Kenya

Dr. S.K.FIREMPONG, ICIPE, Nairobi, Kenya

Professor R. KUMAR, RSUST, P.H. Nigeria

D E D I C A T I O N.

This thesis is dedicated to my wife,

OBIAGELI V.L.S. AMIFOR

A C K N O W L E D G E M E N T S

I am extremely grateful to ARPPISS (African Regional Postgraduate Programme in Insect Science) Academic Board, particularly Professor Thomas R. Odhiambo (Director, ICIPE) and Dr. M.E. Smalley for awarding me a scholarship to undertake this study.

I am particularly indebted to my university supervisor Professor R. Kumar (Dean, Post Graduate School, RSUST, Port Harcourt, Nigeria) for his continous support and encouragement before my entry into the ARPPIS programme and throughout this research.

I am deeply grateful to Drs. J.K.O. Ampofo and S.K. Firempong (ICIPE supervisors) for all the expert and valuable directives they gave me during this study. I sincerely enjoyed their frienship throughout my stay at Mbita, Kenya.

I am also grateful to Dr. S. Nokoe (Head, Biomathematics Research Unit/Population modeller, ICIPE) and Dr. Henry F. Magalit (Biostatistician/Senior Research Scientist, Crop Pest Research Programme) for their advice and assistance in data analyses and interpretations.

I am sincerely thankful to Mrs. Grace A. Kwanya and Beverly A. Mbati for their secretarial assistance, and to Florence Adhiambo Peters for her assistance in field data collection.

Finally, I wish to express my sincere appreciation to my wife, Mrs. O.V.L.S. Amifor for the wonderful manner in which she endured my long absence from her during this study.

TABLE OF CONTENTS

Page

TITLE PAGE..... i

DECLARATION..... ii

DEDICATION..... iii

ACKNOWLEDGEMENT... iv

ABSTRACT..... vi

TABLE OF CONTENTS. viii

LIST OF TABLES.... xv

LIST OF FIGURES... xix

1. GENERAL INTRODUCTION..... 1

2. REVIEW OF LITERATURE..... 8

2.1 Coccinellids as biological control agents..... 8

2.2 General biology of coccinellids..... 9

2.2.1 Oviposition..... 9

2.2.2 Fecundity..... 10

2.2.3 Growth and developmental rate..... 11

2.2.4 Longevity..... 11

2.3 Searching behaviour..... 12

2.3.1 Neonate larval searching behaviour..... 12

2.3.2 Larval movement on host plant..... 13

2.3.3 Field observation on larvae in aphid colonies protected by ants..... 14

2.4 Efficiency of aphidophagous coccinellidae in reducing aphid populations..... 15

2.4.1 Synchronisation..... 15

2.4.2 Predatory behaviour and voracity..... 16

2.4.3 Parts of the aphid body seized..... 17

2.4.4 Reproductive rate of the aphid..... 17

2.4.5 Functional responses..... 18

2.5 Aphid defence behaviour..... 19

2.6 Efficiency in prey capture..... 20

3. GENERAL MATERIAS AND METHODS..... 22

3.1 Location of experimental site..... 22

3.2 Field plot design..... 22

3.3 Field cages..... 24

3.4 Rearing in screen-house:..... 24

3.4.1 Aphis craccivora..... 24

3.4.2 Cheilomenes lunata..... 26

3.5 Laboratory rearing of:..... 26

3.5.1 Cheilomenes lunata..... 26

3.5.2 Aphis craccivora..... 28

3.6 Aphid counting techniques..... 28

3.7 General sampling procedures..... 31

4. BIOLOGY OF CHEILOMENES LUNATA AND APHIS CRACCIVORA.... 33

4.1 Introduction..... 33

4.2 Material and Methods..... 34

4.2.1 On the Biology of C. lunata..... 34

4.2.2 On the Biology of A. craccivora..... 37

4.3 Results..... 37

4.3.1 On the Biology of C. lunata..... 37

4.3.1.1 Copulation..... 37

4.3.1.2 Oviposition rate and egg structure... 38

4.3.1.3 Egg hatchability..... 38

4.3.1.4 Description of larval instars and pupae..... 40

4.3.1.4.1 First instar..... 40

4.3.1.4.2 Second instar..... 40

4.3.1.4.3 Third instar..... 43

4.3.1.4.4 Fourth instar..... 43

4.3.1.4.5 Pupae..... 46

4.3.1.5 Duration of stages in life cycle..... 50

4.3.1.6 Longevity of adult C. lunata..... 50

4.3.2 On the Biology of A. craccivora..... 50

4.3.2.1 Pre-larviposition period and larviposition site..... 50

4.3.2.2 Larviposition rate..... 52

4.3.2.3 Post-larviposition period and parental care..... 52

4.3.2.4 Growth and developmental periods..... 56

4.4 Discussion..... 56

4.4.1 On the biology of C. lunata..... 56

4.4.2 On the biology of A. craccivora..... 58

5. SEARCHING BEHAVIOUR OF CHEILOMENES LUNATA..... 61

5.1 Introduction..... 61

5.2 Materials and Methods..... 61

5.3 Results..... 62

5.3.1 Movement of fed adult coccinellids on aphid infested cowpea ant-free seedling..... 62

5.3.2 Movement of fed adult coccinellids on ant attended aphid colonies on cowpea seedlings..... 63

5.3.3 Movement of fed adult coccinellid on aphid-free cowpea seedling..... 63

5.3.4 Movement of unfed adult coccinellid on ant-free aphid infested cowpea seedling..... 65

5.3.5 Movement of unfed adult coccinellid on aphid infested ant attended seedlings..... 65

5.3.6 Movement of unfed adult coccinellid on aphid-free cowpea seedling..... 67

5.3.7 Movement patterns of unfed first instar coccinellid larva on cowpea leaf..... 69

5.3.8 Movement patterns of fed first instar coccinellid larva on uninfested cowpea leaf..... 71

5.3.9 Movement patterns of fed first instar coccinellid on aphid infested cowpea seedlings..... 71

5.4 Discussion..... 74

6. SYNCHRONISATION BETWEEN CHEILOMENES LUNATA AND COWPEA APHID POPULATIONS..... 76

6.1 Introduction..... 76

6.2 Materials and Methods..... 76

6.3 Results..... 79

6.4 Discussion..... 84

7. PATTERNS OF APHIS CRACCIVORA DEFENSIVE BEHAVIOUR..... 88

7.1 Introduction..... 88

7.2 Materials and Methods..... 88

7.3 Results..... 89

7.4 Discussion..... 90

8. PREY STAGE PREFERENCE, CAPTURE EFFICIENCY, VORACITY AND HANDLING TIME BY *CHEILOMENES LUNATA*..... 94

8.1 Introduction..... 94

8.2 Materials and Methods..... 95

8.2.1 Preferred prey stage..... 95

8.2.1.1 Laboratory test on preferred prey stage of *C. lunata*..... 95

8.2.1.2 Field test on preferred prey stage of *C. lunata*..... 95

8.2.2 Prey capture efficiency..... 97

8.2.3 Voracity..... 98

8.2.4 Handling time of prey..... 100

8.3 Results..... 100

8.3.1 Preferred prey stage..... 100

8.3.2 Prey capture efficiency..... 103

8.3.3 Voracity..... 106

8.3.4 Handling time of prey..... 110

8.4 Discussion..... 113

8.4.1 Preferred prey stage..... 113

8.4.2 Prey capture efficiency..... 115

8.4.3 Voracity..... 116

8.4.5 Handling time of prey..... 118

9. FUNCTIONAL RESPONSE OF *CHEILOMENES LUNATA* TO DIFFERENT PREY DENSITIES..... 119

9.1 Introduction..... 119

9.2 Materials and Methods..... 120

9.3 Results..... 120

9.4 Discussion..... 128

10. EFFECT OF PREDATION ON FIELD APHID POPULATIONS..... 131

10.1 Introduction..... 131

10.2 Materials and Methods..... 133

10.3 Results..... 135

10.4 Discussion..... 136

11. SUMMARY..... 140

LITERATURE CITED..... 145

APPENDICES

L I S T O F T A B L E S

	Title	Page
Table 1	Systematic sampling plan for N=222 and K=10	...32
Table 2	Oviposition rate of C. lunata over a period of 14 days in the laboratory	...42
Table 3	Measurement of antennal length, head length and width, thoracic length and width, and abdominal length and width of C. lunata larval instars	...49
Table 4	Mean duration of the life stages in life cycle of C. lunata	...51
Table 5	Larviposition rate of A. craccivora during the entire live period in the laboratory	...55

Table 6 Number of times twelve fed adult C. lunata were observed on parts of infested cowpea seedling while searching for aphids..... ...64

Table 7 Number of times twelve fed adult C. lunata were observed on parts of infested cowpea seedling attended by ants while searching for aphids..... ...64

Table 8 Number of times twelve fed adult C. lunata were observed on parts of aphid free cowpea seedling while searching for aphids..... ...66

Table 9 Number of times twelve unfed adult C. lunata were observed on parts of infested cowpea seedling but ant free while searching for aphids..... ...66

Table 10 Number of times twelve unfed adult C. lunata were observed on parts of infested cowpea seedling attended by ants while searching for aphids..... ...68

Table 11 Number of times twelve unfed adult C. lunata were observed on parts of aphid free cowpea seedling while searching for aphids..... ...68

Table 12 The percentage of adult A. craccivora that escaped capture by the different instars of C. lunata..... ...90

Table 13 The percentage of 4th instar A. craccivora that escaped capture by the different instars of C. lunata..... ...90

Table 14 The percentage of 3rd instar A. craccivora that escaped capture by the different instars of C. lunata..... ...91

Table 15 The percentage of adult A. craccivora that escaped capture by the different instars of C. lunata in the field..... ...91

Table 16 Stages prey preferred by C. lunata adults in both in the laboratory and field..... ...102

Table 17 Proportion of food intake by the individual growth stages of C. lunata..... ...111

Table 18 The average time taken by the different instars of C. lunata to consume the different A. craccivora instars..... ...112

Table 19 Mean number of prey consumed by ten adults of C. lunata at different prey densities within two hours..... ...129

L I S T O F F I G U R E S

	Title	Page
Figure 1	Out-lay of plots in the field.....	...23
Figure 2	Portion of the screen house showing cowpea plants for rearing A. craccivora.....	...25
Figure 3	Lunch box for laboratory rearing of C. lunata.....	...27
Figure 4	Rearing arena for A. craccivora in the laboratory.....	...29
Figure 5	Aphid counting techniques in the laboratory.....	...30
Figure 6	Sleeve cage used for selecting C. lunata couples for biological studies.....	...36

Figure 7 Newly laid eggs of C. lunata..... ...39

Figure 8 First larval instar of C. lunata..... ...41

Figure 9 Second larval instar of C. lunata..... ...44

Figure 10 Third larval instar of C. lunata..... ...45

Figure 11 Fourth larval instar of C. lunata..... ...47

Figure 12 C. lunata pupae..... ...48

Figure 13 Larviposition site of A. craccivora on cowpea leaf..... ...53

Figure 14 Daily larviposition rate of A. craccivora under laboratory condition..... ...54

Figure 15 Movement patterns of unfed first instar larva on cowpea leaf..... ...70

Figure 16 Movement patterns of fed first instar larva on cowpea leaf..... ...72

Figure 17 Movement patterns of unfed first instar larva which encountered aphid colony..... ...73

Figure 18 Field plot arrangement for studies on synchronisation between A. craccivora infestation on beans and the appearance of C. lunata..... ...78

Figure 19 Activity patterns of C. lunata on infested cowpea plots in relation to day..... ...80

Figure 20 The incidence of C. lunata per site over day..... ...81

Figure 21 Percentage incidence of C. lunata per site over time..... ...85

Figure 22 Arrangement for studies on field test of preferred prey stage..... ...96

Figure 23 Experimental set-up for studies on C. lunata voracity..... ...99

Figure 24 Prey capture efficiency of the different instars of C. lunata..... ...104

Figure 25 Mean number of A. craccivora consumed by the different instars and adults of C. lunata per day..... ...107

Figure 26 Relationship between developmental stages of predator/prey and the number of aphid eaten:
(a) negative relationship between the number of aphid consumed and their stage of development
(b) positive relationship between the stage of development of C. lunata and the number of aphids consumed..... ...108

Figure 27 Functional response of adult male C. lunata with increasing densities of first instar A. craccivora..... ...122

Figure 28 Functional response of adult male C. lunata with increasing densities of third instar A. craccivora..... ...123

Figure 29 Functional response of adult male *C. lunata* with increasing densities of adult *A. craccivora*..... ...124

Figure 30 Functional response of adult female *C. lunata* with increasing densities of first instar *A. craccivora*..... ...125

Figure 31 Functional response of adult female *C. lunata* with increasing densities of third instar *A. craccivora*..... ...126

Figure 32 Functional response of adult female *C. lunata* with increasing densities of adult *A. craccivora*..... ...127

Figure 33 Sleeve cage for evaluating the effect of *C. lunata* on field aphid populations..... ...134

Figure 34 Population growth rate of *A. craccivora* in the presence/absence of *C. lunata*..... ...137

Chapter 1.

GENERAL INTRODUCTION.

Cowpeas, (Vigna unguiculata (L.) Walp), also known as black-eye beans or southern peas are among the major food legumes in Africa. They are extensively grown also in central and south America, the southern United States and Asia (Singh, 1980). More than 70 percent of world cowpea production is concentrated in three countries: Nigeria, Brazil, and Niger (Singh et al., 1983). Cowpeas provide more than half the plant protein in human diets in Africa. It is eaten in the form of dry seed, green pods, green seeds and tender green leaves. It is also utilized for fodder and as a quick growing cover crop. On the account of their ability to fix nitrogen efficiently, cowpeas provide between 73-240 kg of nitrogen/ha (Ayanaba, 1979).

In Africa, production levels are low owing to vast array of insect pests that attack and damage nearly all plant parts throughout their growth cycle and even during storage (Singh, 1980; Singh et al., 1983). For example, in Nigeria, Taylor (1964) recorded 69 insect pest species and in Ghana, over 150 species of insects have been associated with the crop (Agyen-Sampong, 1978). Irrespective of where the crop is grown, the following insect are encounted as major field pests:

Aphis craccivora (Koch), Acanthomia horrida (Germar.), Anoplecnemis curvipes (Fabr.), Callosobrucus maculatus (Fabr.), Maruca testulalis (Geyer), Megalurothrips sjostedti (Trybom), Riptortus dentipes (Fabr.), and Sericothrips occipitalis (Hood), (Singh, 1980; Singh and van Emden, 1979; Singh and Jackai, 1985).

A craccivora is a major pest of cowpea in the savanna region of the world, and may become a serious pest during the brief dry spell in the cropping season (Singh et al., 1983). It has been reported in India, Philippines, Japan and Taiwan as a major pest of cowpeas, chick-peas, green-grams, peas and lentils (Bernado, 1969; Singh, 1977a; Rose et al., 1978). In Africa, it was reported as pest of cowpeas in Egypt, Tanzania, Nigeria, Uganda and Zimbabwe (Le Pelley, 1959; Booker, 1965; 1970; Nyiira, 1971; Hammad, 1978; Kayumbo, 1978 and Mariga et al., 1985). A. craccivora is primarily a pest of cowpea seedlings, but its attack can also occur during the podding stage of the crop. They cause direct damage to the plant by removal of sap. Severe attack results in distortion of leaves, stunting of plants and poor nodulation of the root system (Singh and Jackai, 1985). Yield is reduced, and in extreme cases the plant dies (Singh and van Emden, 1979). Indirect and more serious damage is through the transmission of cowpea aphid-borne mosaic virus (CAMV) (Raheja and Leleji, 1974; Kaiser and Massambi, 1975; Atiri et al., 1984; MacFoy and Dabrowski, 1984; Atiri and Thottappilly, 1985;). The virus causes a widespread mottling,

interveinal chlorosis and vein banding. Infected plants become stunted, bushy and flowering may be retarded or inhibited (Raheja and Leleji, 1974 and Bishara et al., 1984).

Chemical methods of controlling A craccivora are currently the quickest and the most effective (Booker, 1965 and Agyen-Sampong, 1978; Singh and Allen, 1980). Cowpea growers have for long recognized the usefulness of insecticides, but factors such as their poor availability and high costs have kept this technology beyond their reach. Furthermore, the changing attitudes of growers towards the use of insecticides is influenced by the increasing knowledge of the dangers associated with their use (DeBach and Bartlett, 1951; Kumar, 1984). In addition, pest resistance to insecticides have been reported by World Health Organisation (WHO) (1972), Gearghiou and Taylor (1977) and Sawicki (1979). Lastly, pesticides are known to effect non target organisms, especially, populations of parasites and predators (Ripper, 1956).

The use of resistant cowpea cultivars offers a promising alternative method of control for A. craccivora. Several cowpea varieties have been screened for aphid resistance at the International Institute for Tropical Agirculture (IITA) and the International Centre of Insect Physiology and Ecology (ICIPE) (Singh, 1978; Pathak and Olela, 1986). Atiri et al., (1984) observed that though aphid populations were lower on resistant

varieties, the incidence of infection with cowpea aphid-borne mosaic virus (CAMV) was greater in the aphid resistant lines than either the aphid susceptible or tolerant lines. This was due to the increased probing activities of the aphids on the resistance lines. They therefore concluded that resistance to aphid infestation in cowpea did not provide resistance to infection with CAMV. This disease may cause between 15-100 percent loss of cowpea (Raheja and Leleji, 1974; Kaiser and Massambi, 1975). Therefore, the need to look for an alternative aphid control method became inevitable.

Many studies on aphids infesting crops have shown the existence of a complex of aphidophagous insects that could be used advantageously in the integrated control of aphids (Bouchard et al., 1984). Such natural enemies belong to the orders: Diptera, Neuroptera, Hemiptera, Hymenoptera, Coleoptera and Acarina (Way et al., 1969; Firempong and Kumar, 1975). Of these complexes, aphidophagous coccinellids have proved to be the most efficient (Dunn, 1949; DeBach, 1975). Hagen and van den Bosch (1968) reviewing the effectiveness of coccinellid predators in controling aphids concluded that an efficient predator should be able to reduce the population of its prey to a level that is not injurious to the host plant.

Hodek et al., (1972) discussed some methods used to measure predator impact on prey populations. They include: (1) direct inspection of the relationship between effect and density; by key factor and life-table analyses; (2) changing physiological state of the host plant; (3) comparison of host population with predators and a completely analogous population where natural enemies were either completely missing or varied in number to a known extent; and changes of the individual's efficiency as prey density increases (functional response) or changes in the number of the predator through reproduction or dispersal (numerical response). van Emden (1964) observed that a high abundance of natural enemies especially of the family coccinellidae was responsible for reducing aphid population levels below damage thresholds in sugar-beet in southern parts of the European USSR and Japan.

At present, our knowledge on the efficiency of naturally occuring coccinellid predators in Africa is meagre. In South Africa, Brown (1972 and 1974) studied the predatory behaviour of four species of coccinellids (Lioadalia flavomaculata (DeGeer), Scymnus morelleti (Mulsant), Exochomus concavus (Fursch) and Cheilomenes lunata (F.)) associated with wheat aphid, Schizaphis graminum (Rondani) and the defence behaviour of the wheat aphid against S. morelleti and E. concavus. Firempong and Kumar (1975) reported two species of coccinellids, Scymus scapuliferus

(Mulsant) and Platynaspis furruginea (Weise), as predators of Toxoptera aurantii (Boy) on cocoa in Ghana. Ofuya (1986) has worked on Cheilomenes vicina (Mulsant) in Nigeria.

It is apparent from the literature that there is very little information on C. lunata, especially in east Africa where the species is abundant (Le Pelley, 1959). The present study was therefore undertaken to investigate the biology and predatory efficiency of the most common aphidophagous coccinellids in cowpea fields at the ICIPE research station and its environs at Mbita in the South Nyanza Province of Kenya. The study was undertaken under the following headings:

(1) **Biology:** C. lunata oviposition rate, fecundity, larval growth, and development and longevity of the adults as they influence the aphid population.

(2) **Searching behaviour:** The behaviour of C. lunata leading to the location and attack of the prey in both the laboratory and on cowpea plants growing in the field.

(3) **Predation efficiency:** number of encounters made before the successful capture of an aphid, time spent in consuming different stages of the prey, the daily consumption rate, predator preference among the different prey stages.

(4) **Aphid defensive behaviour towards the predator:** The evasive/defensive behavior employed by A. craccivora to effect avoidance/escape from their predator in both the laboratory and the field.

(5) **Functional response of the predator to different prey densities:** The reaction of C. lunata adults to different prey densities.

(6) **Synchronisation:** The time lapse between aphid infestation of the crop and the appearance of the aphidophagous coccinellid beetles in potted cowpea plants in the open field.

(7) **The effect of C. lunata predation on aphid populations in the field:** To compare the results obtained in laboratory experiments with those in field situation.

Chapter 2.

REVIEW OF LITERATURE

2.1 Coccinellids as biological control agents.

The increasing interest in the study of biological control agents is undoubtedly due in part to their self perpetuation nature and also to the harmful side effects of toxic chemicals (Kumar, 1984; Hodek, 1967). Much work has been done in the use of aphidophagous coccinellids with a view to reduce the population of aphids to a level that is not injurious to their host crops (Dunn, 1949; Hodek et al., 1965; Bonbasch and Tokmakoglu, 1965; Getecka, 1965; Yakhontov, 1965; Brown, 1972; DeBach, 1975; Firempong and Kumar, 1975; Radwan and Lovei, 1983; and Ofuya, 1986). Coccinellid predators are considered the most important insect enemies of aphids (Milne and Bishop, 1987; Aalbersberg et al., 1988), and in some temperate countries, these predators have been effectively used in the integrated control management of several aphid species (Sundby, 1966; Hagen and van den Bosch, 1968, Tamaki and Weeks, 1972).

In East Africa, a wide range of coccinellid species such as C. lunata and C. aurora have been recorded as predators of aphids and other hemipteran pests of legumes (Le Pelley, 1959;

de Purry, 1968; Davies, 1969; Ingram, 1969). However, specific studies conducted to assess the species range and predation efficiency on aphid pests of beans and other pulses appears to be scanty in East Africa.

2.2 GENERAL BIOLOGY OF COCCINELLIDS.

2.2.1 Oviposition.

The biology of C. lunata has apparently not been studied in East Africa and there is, therefore, no information on the species. However, studies on related species eg. Cheilomenes sexmaculata (Fabr.) are available. For example, Cheilomenes sexmaculata (Fabr.) lay their eggs singly or in longitudinal rows, varying from 4-14 eggs/row. The incubation period was 3-5 days at room temperature of 35.5°C (Modawal, 1941). Firempong and Kumar (1975) observed that eggs of some coccinellid species are hidden and therfore difficult to find. They concluded that since the larval instars were found within aphid colonies the eggs may have been laid within the aphid colonies. However, Bansch (1965) observed that the distance between aphidophagous coccinellid eggs and aphid colonies was between 15 and 20 cm. The differences in the results may be due to the different coccinellid species used by both workers.

According to Okrouhla et al. (1983), egg development of Cheilomenes sulphurea (Ol.) lasted from 3-6 days depending on temperature. They gave the temperature of 12.7°C as the lower limit for egg development. The incubation period for A. variegata was 1.5, 2.0 and 2.2 days at constant laboratory temperatures of 32°C, 29.6°C and 25°C respectively (Kapur, 1942).

2.2.2 Fecundity

Females of most aphidophagous coccinellids lay their eggs in batches ranging in size from 12 to 100 (Hodek, 1967). Modawal (1941) observed that the maximum number of eggs laid by a single female C. sexmaculata over a period of seven days was 231; the number of eggs laid at one time being between 43 and 108. Kapur (1942) recorded egg batches containing between 4 and 42 for Adonia variegata (Goeze). Ruzicka et al., (1981) observed that generally the fecundity of a species of conccinellid varies with the location of collection and physical condition of the prey used as food when they studied the reproductive rate and longevity in Semiadalia undecimnotata (Schneider) and Coccinella septempunctata (L.). They also noted that there was a slight difference between the fecundity of the two species (mentioned above) from south eastern France due to different physiological conditions. No reference has been made to C. lunata in the available literature in this respect.

2.2.3 Growth and developmental rate.

It has been generally observed that there are 4 larval instars in the life cycle of coccinellid predators, irrespective of the species or location of study (Kapur, 1942; Okrouhla et al., 1983). The general developmental period of the coccinellids varies with the location and the environmental temperature. Radwan and Lovei (1983) also observed that the prey used as food affected the developmental perod of the larvae. Okrouhla et al. (1983) noted that the developmental rate and feeding capacity in C. sulphurea throughout the entire period of development (from egg to adults) lasted from 16 to 31 days while the larval stage took between 7 and 15 days. Modawal (1941), noted that C. sexmaculata larval life lasted 13 to 15 days at room temperature of 20°C, while the whole developmental period took 23 to 30 days at a mean room temperature of 20°C. Using three different constant temperatures of 25°C. 29°C and 34.6°C, Kapur (1942) observed that the life cycle of A. variegata ranged between 11.3 to 19.6 days.

2.2.4 Longevity

Hodek (1967) observed that the life span of coccinellids is quite variable; in species with a long period of inactivity, longevity is about one year. Modawal (1941) observed that the

average duration of C. sexmaculata adult life varied from 7-14 days. Ruzicka (1980) comparing the longevity of Coccinella septempunctata (L.) females with continuous oviposition to females with oviposition arrest found mean longevity of 51 days for the former and 131 days for the latter. The longevity of males is about 1.5 times longer than for females (Ruzicka, 1980; and Ruzicka et al., 1981). Currently, there is no information on the longevity and fecundity of C. lunata.

2.3 Searching behaviour.

2.3.1 Neonate larval Searching behaviour

Banks (1956) studying the searching behaviour of individual neonate coccinellid larvae on beans observed that they remained on the empty egg shells for 12-24 hours after hatching before dispersing. In another experiment, he (Banks, 1957) noted that the active life of a newly emerged larva of Propylea quatuordecempunctata (L.) was, on an average, 40 percent of the total life from hatching to death at full maturity. Larvae appeared to search in a random manner, and were unable to perceive the prey until a physical contact was made (Fleschner, 1950). Banks (1953), noted that larvae spent a considerable amount of time searching various parts of the plant already searched including sites where no aphids were

located. These observations by Banks (1953) seem to suggest that coccinellid larvae cannot perceive their prey from a distance.

Dixon (1959) reported of cannibalism in Ist larval instars of Adalia decempunctata (L) on eggs. Banks (1957) and Firempong and Kumar (1975) compared the activities of coccinellids in darkness and in light. Both observed that these predators made only limited movement in the dark. In light, they were up to six times more active than in the dark. This is an indication of diurnal nature of coccinellids.

2.3.2 Larval movement on host plant.

On hatching, coccinellid larvae make their way to the top of the bean plant. They then descend the stem and wander again over the lower parts of the plant, usually repeating this behaviour for several hours (Banks, 1957). Firempong and Kumar (1975) made similar observation when they studied the searching behaviour of Platynaspsi ferruginea (Weise) on cocoa seedlings. Banks (1957) observed that 76-85 percent of the larval time was spent on leaves and a comparatively shorter time was spent on stems. Coccinellid larvae crawl over bean leaves with frequent changes of direction but the insect cannot move far without coming to the edge of the leaf along which it has a marked

tendency to crawl. This was the observation made by Banks (1957) when he studied the activities of unfed and fed first instar larvae. Firempong and Kumar (1975) reported similar movement of P. ferruginea larvae on cocoa leaves. When a larva discovered a colony of aphids, the searching behaviour was then concentrated in that area (Firempong and Kumar, 1975). Banks (1953), tentatively concluded that coccinellid larvae, while capable of making a thorough search of their surroundings, may be inefficient in finding their prey.

2.3.3 Field observation on larvae in aphid colonies protected by ants.

Various species of ants are associated with aphid colonies. The ants feed on the honey dew excretions from the aphids and protect the aphid colony in return from its natural enemies. Coccinellid larvae are attacked by attendant ants of aphid colonies in the open field. Banks (1957) observed how the larvae of Coccinella septempunctata (L.) were attacked by an ant. The coccinellid, hurriedly dropped the aphid and ran rapidly on to the petiole and up the stem, crawling over the mass of aphids. In another experiment Banks (1953) placed a larva on a stem heavily infested with aphids attended by ants in a plot of beans. The larvae remained on the stem for a few hours only and when it attacked an aphid it was itself attacked

by the ants. These observations show clearly that the presence of attendant ants reduces the searching ability of coccinellid larval predators.

2.4 Efficiency of aphidophapous coccinellidae in reducing aphid population.

The term efficiency is defined as a qualitative measure on a continuous scale. In terms of predation efficiency, one end of this scale will be the virtual eradication of the prey population, and at the other end a negligible reduction in the rate of increase of prey numbers (van Emden, 1965). Many factors influence the effectiveness of predators in the field, but the majority fall into one or the other of the following categories: (i) Synchronisation between the prey and the predator, (ii) Predatory behaviour and voracity of the predator, (ii) the reproductive rate of the prey, and (iv) Functional responses shown by the predator to different densities of the prey (van Emden, 1965; Iperti, 1965; Yakhontov, 1965).

2.4.1 Synchronisation

Synchronisation here is used for the time lapse between the incidence of aphid and the appearance of aphidophagous coccinellids. It is envisaged that the earlier the appearance

of the coccinellids in the aphid colonies the greater will be the control effect exated by the predator (Iperti, 1965). Most workers recognise the importance of synchronisation between predators and prey (Iperti, 1965), but not much work has been done in this aspect of the predator-prey relationship.

2.4.2 Predation behaviour and voracity.

The number of aphids consumed by a predator is a function of the potential voracity of the predator (Iperti, 1965; van Emden, 1965). Voracity is affected by the defensive behaviour of the prey (Dixon, 1958; Way and Banks, 1962; Firempong and Kumar, 1975). Modawal (1941) observed in C. sexmaculata that the average number of aphids (Macrosiphium granarium L.) eaten by the adult predator per day was 44. Ofuya (1986) observed that in both female and male Cheilomenes vicina (Mulsant.) the number of A. craccivora consumed decreased as the prey advanced in age. Okrouhla et al., (1983) obtained similar results for C. sulphurea.

Dixon (1959) appears to be the only work in the literature on how long it takes a coccinellid predator to consume a prey. He noted that the time taken by a coccinellid to consume an aphid of a particular instar increases with the level of development of the prey. In the case of A. decempunctata,

instar IV larvae took twelve times longer to consume an adult aphid than they did for the first instar.

2.4.3 Part of the aphid body seized

Coccinellids generally grab their prey with the aid of their forelegs and mandibles before eating. Firempong and Kumar (1975) found that the legs of T. aurantii were the main part of the body seized by the coccinellid predator, P. ferruginea. Thus they called it an "appendage seizer". In South Africa, Brown (1972) recorded that Lioadella flavomaculata (DeGeer) seized the prey Schizaphis graminum (Rondani) by the head, thorax and more frequently the abdomen. However, a small number of first instar coccinellid larvae also caught their prey by the antennae and legs. This observation is totally different from that of Firempong and Kumar (1975), possibilly because of the behavioural differences in the predators and prey used.

2.4.4 Reproductive rate of the aphid.

One major factor that maintains a predator-prey system in equilibrium is the reproductive rate or turnover of the prey. When the prey reproduces faster than it is consumed, the regulatory effect of the predator will not be felt (van Emden, 1965). Infact, Way and Banks (1962) are of the opinion that the

characteristic seasonal collapse of aphid populations occur when intra-specific competition allow the predator populations to catch up and overtake the reproductive rate of the aphid.

2.4.5 Functional Responses

A study of functional response is important in evaluating the efficiency of a predator in the control of its prey (Hodek et al., 1984). This aspect of predator-prey relationship is studied by many workers (e.g. Mogi, 1969; Sabelis, 1985) by using small arenas. The limitation of this method has been pointed out by Murdoch (1973) as regarded the time span observations are made and the size of the cages used. For the above reason, Hodek et al., (1984) tackled this problem in C. sulphurea using both large and small arenas. Their results showed that prey numbers affected the feeding rate much more than the size of the arenas. TOther species of coccinellids in which studies have been made on their functional response include: Harmonia axyridis Pallas (Mogi, 1969); Propylea japonica Thunrerg (Kawauchi, 1979) and Coccinella septempunctata L. (Sinha et al., 1982).

In considering the impact of a predator population upon a prey population over the very short term, the functional response and local predator movements in relation to prey

density may be adequate indicators of predatory potential (Murdoch, 1971). In addition, the activities of the average predator may be affected by predator density if predators interact (Murdoch, 1971). C. lunata responses to prey density is not available in the literature hence the idea to study it's responses in relation to different aphid density.

2.5 Aphid defence behaviour

Different species of aphids differ in their ability to avoid predation by their coccinellid predators. Some e.g. Hyalopterus pruni (Geoffroy) avoid capture by producing subtances which make them unpalatable (Dixon, 1958). Other species such as Aphis sambuci L. have similar properties and when ingested, proved toxic to certain species of coccinellidae (Hodek, 1967). More palatable aphid species avoid capture by employing various behavioural responses which have a defensive or evasive function. Dixon (1958) investigated the responses of the nettle aphid, Microlophium evansi (Theobald), against A. decempunctata and observed that the prey avoided capture by kicking, walking away and/or dropping from the leaf. When eventually seized, it immobilized the predator with a defensive secretion from the siphunculi. Similar use of chemical defence was reported by Firempong and Kumar (1975) in their studies on the cocoa aphid T. aurantii.

Other methods of escape such as leaping have been recorded for Eucallipterus tiliae L. (Dixon, 1958). Studies by Brown (1974) on the defensive behaviour of the wheat aphid S. graminum against A. decempunctata showed that this prey avoided capture by kicking , bulking or swivelling , walking away or springing and dropping. Some aphid species escape seizure by leg shedding, and pulling themselves free from their attackers (Brown, 1974).

2.6 Efficiency in prey capture.

Two factors which determine the capture efficiency of a predator is the defensive behaviour shown by the prey (Brown, 1974), and the ability of the predator to subdue its prey (Brown, 1972; Firempong and Kumar, 1975). In most species efficiency in prey capture increases as larval age increases (Dixon, 1959; and Iperti, 1965). Firempong and Kumar (1975) observed in P. ferruginea that captures by the first instar coccinellid predators were few and limited to early aphid instars, and often more encounters were needed before a successful capture. Similarly, Ofuya (1986) observed that all the larval instars of C. vicina consumed more of the first and second instars of the prey than the third and fourth instars, which in turn suffered heavier predation than the adult stage. The ability to capture aphids depends not only on the species of

coccinellid and it's stage of development but also with the species of aphid that is attacked (Brown, 1972). In South Africa, Brown (1972) observed that though C. lunata was equally efficient like other species (L. flavomaculata, Scymnus morelleti Mulsant, and Exochomus concavus Fursch.) which he studied, it never achieved importance because of it's relative scarcity in the field. At the ICIPE research station, South Nyanza, Kenya, C. lunata is the most abundant coccinellid species in cowpea fields and may be important in the suppression of aphid populations. However, its basic biology and predation efficiency are largely unknown.

It is apparent from this review that much has been done on the biology and ecology of aphidophagous coccinellids and they have been utilized in some control programmes in the temperate regions. However, in Africa where most of the coccinellid species exist, little is known about their biology and predation efficiency apart from studies by Brown (1972 and 1974); Firempong and Kumar (1975); and Ofuya (1986). It is therefore the aim of this thesis to study the biology, searching behaviour, predation efficiency, functional respose to different prey densities of A. craccivora, using C. lunata as a model. Such information could be useful in biological/integrated control of aphids on cowpeas.

Chapter 3

GENERAL MATERIALS AND METHODS

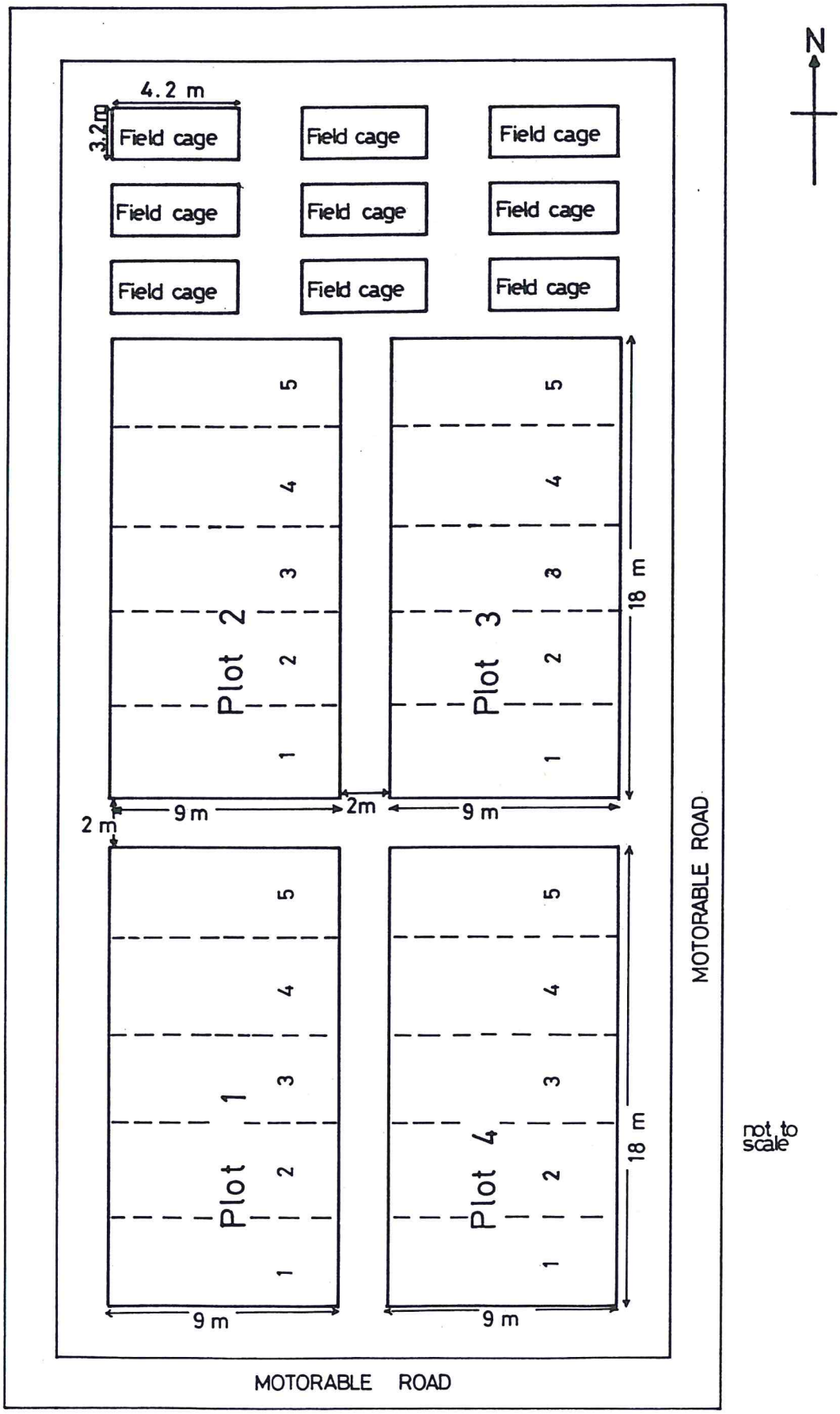
3.1 Location of experimental site.

All the experiments were conducted at Mbita Point Field Station (MPFS) in the South Nyanza Province of Kenya which is about 1240 m above sea level. The soil type varies from dark sandy clay (cotton soil) to dark greyish clay soil (Rachilo et al., 1980). The mean annual rainfall is 900 mm. There are two rainy seasons. The first, known as long rains, lasts for about four months (March to June), and the second, known as short rains lasts only two months (October to November). Between these periods, the area is dry and hot and field temperatures as high as 35°C are common (Okech, 1986). During these spells of dry weather, aphids are the main insect pests of grain legumes.

3.2 Field plot design.

The experiments were conducted on a field measuring 20 x 54 m. This area was divided into four plots. Each plot measured 18 x 9 m, and was separated from one another by a path, 2 m wide. Each plot was subsequently divided into five sub-plots with 222 cowpea plants in each subdivision (Fig. 1).

FIG. 1. OUT-LAY OF PLOTS IN THE FIELD



The total number of plants per plot was 1110. Thus, there were about 4440 cowpea plants on the whole.

3.3 Field cages.

These were constructed in the open field with wooden frames covered by netting wire mesh. They were eight in number, and each measures 3.2 x 4.2 m, with a lockable entry door. They were used for field rearing of aphids and C. lunata and for cage exclusion/inclusion tests.

3.4 Rearing in screen house:

3.4.1 Aphis craccivora.

A. craccivora was reared in the screen house on cowpea cultiva (Vita 1 variety) (Fig. 2). The choice of Vita 1 was based on the fact that its leaves have a large surface area and is therefore able to support large populations of aphids. Furthermore, it is rated as highly susceptible to aphids infestation at IITA. Vita 1 was planted at a specing of 20 x 30 cm within and between rows respectively. The plants were initially infested at the seedling stage (8-10 days after germination) with A. craccivora collected from infested cowpea fields around MPFS. To maintain the culture, cowpeas were

Figure 2 Portion of the sceen-house showing cowpea plants for rearing A. craccivora.

planted every fortnight, and were infested at the seedling stage since aphids are mainly pests of seedlings. The plants were irrigated by placing the water pipe directly on the soil to avoid the aphids being washed off the plants.

3.4.2 Cheilomenes lunata.

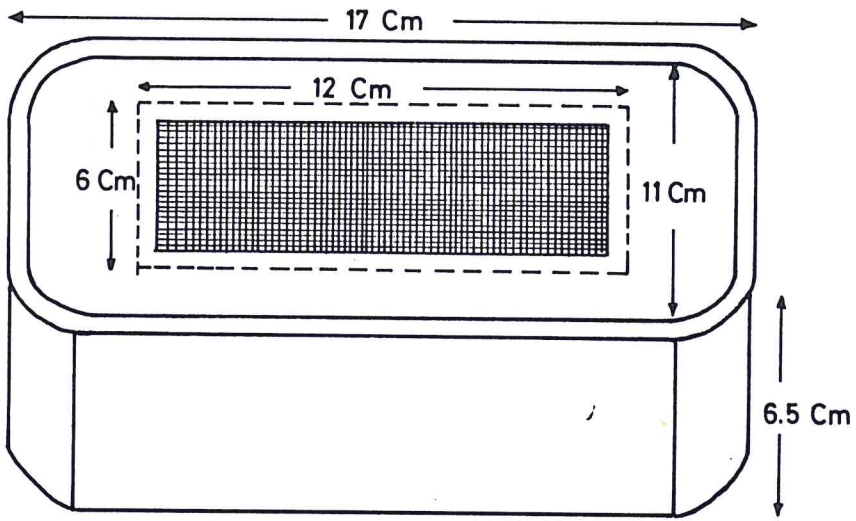
C. lunata cultures were maintained in the screen house using aphids as food. The initial collections from the field (experimental plots) were introduced into aphid cultures in the screen house and allowed to feed, grow and multiply within the aphid cultures.

3.5 Laboratory rearing of:

3.5.1 C. lunata.

C. lunata were reared in the laboratory for the purpose of age determination. Individuals (adults, pupae, larvae and eggs) were placed in a plastic container (17 x 11 cm), with a hole (12 x 6 cm) bored through the lid and the opening covered with a cotton material sown tightly with a needle and cotton thread to allow easy flow of air (Fig. 3). Food for the predators were providnother by a path, 2 m wide. Each plot was subsequently divided into five sub-plots with 222 cowpea plants in each subdivision (Fig. 1).

FIG 3. LUNCH BOX FOR LABORATORY REARING OF C. LUNATA.



3.5.2 A. craccivora.

The same procedure for rearing aphids in the screen-house was used except that in the laboratory, the cowpea plants were sown in metal trays (35 x 50 cm). Netted wooden cages (2 x 2 m) were placed over the trays to protect the aphids and plants from attack by predators and harbivores

3.6 Aphid counting technique.

Aphids for the experiments were placed on the undersurface of a freshly detached cowpea leaf in a petri-dish (9.0 cm diameter) lined with a moist circular Whatman's filter paper of the same diameter (Fig. 5). The aphids were allowed fifteen minutes to settle and feed on the sap of the cowpea leaf. Aphids were collected from the rearing cages (described above) into a lunch box with a fine camel hair brush. The lunch box was placed in a water tray (50 x 30 cm) . The aphids were then picked with a moist camel brush one after the other to prevent the inclusion of other predator or parasitiods. A tally counter was used for keeping record of the number of aphids picked.

Figure 4 Rearing arena for A. craccivora in the laboratory.

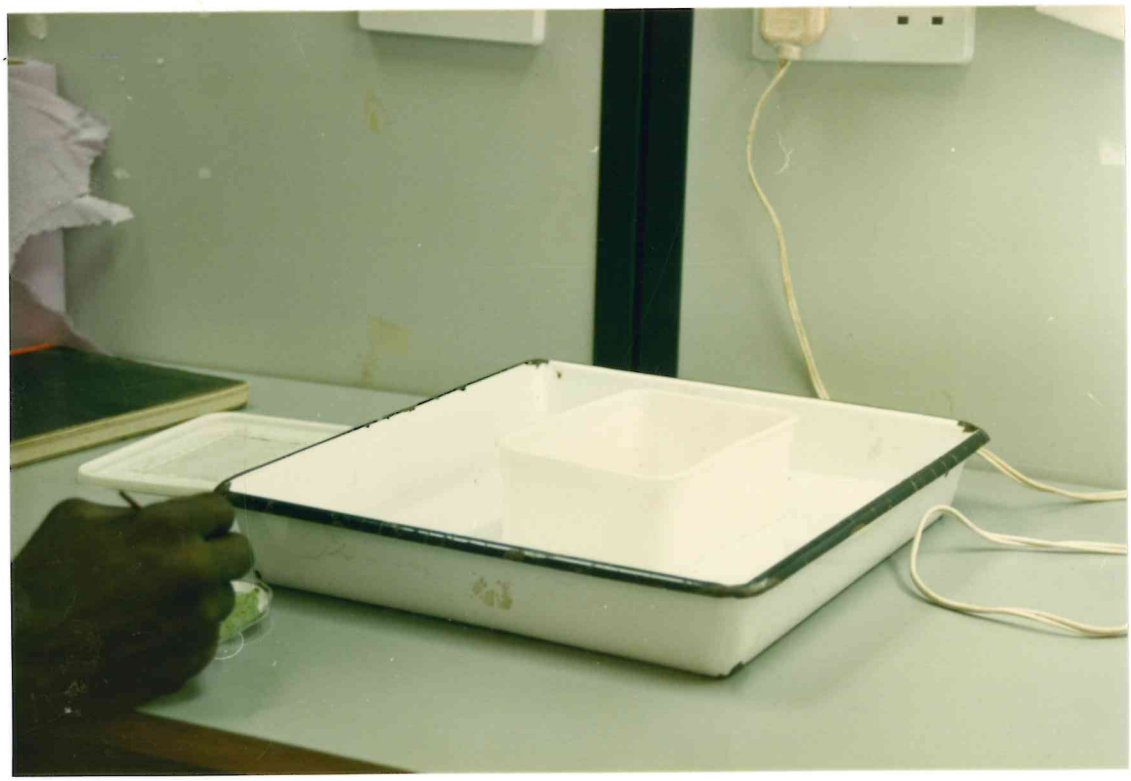


Figure 5 Aphid counting techniques in the laboratory.

3.7 General sampling procedures

The sampling technique employed was systematic sampling. Prior to sampling, an axis of the plot was chosen as a base line from which all the plants in each subplot (222) were numbered and taged. A plant was randomly selected from the first 10 in each subplot and examined in situ, using the base line as a starting point. Then, every 10th plant from the one just sampled was subsequently sampled until a total of 22 plants had been sampled for each subplot as shown in Table 1. The number and species of the aphidophagous coccinellids found were recorded. The sampling was done independently of plots. For detailed results, see appendix 1.

Table 1. Systematic sampling plan for N=222 and K=10.

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110
111	112	113	114	115	116	117	118	119	120
121	122	123	124	125	126	127	128	129	130
131	132	133	134	135	136	137	138	139	140
141	142	143	144	145	146	147	148	149	150
151	152	153	154	155	156	157	158	159	160
161	162	163	164	165	166	167	168	169	170
171	172	173	174	175	176	177	178	179	180
181	182	183	184	185	186	187	188	189	190
191	192	193	194	195	196	197	198	199	200
201	202	203	204	205	206	207	208	209	210
211	212	213	214	215	216	217	218	219	220
221	222.								

Chapter 4.

BIOLOGY OF *CHEILOMENES LUNATA* AND *APHIS CRACCIVORA*.

4.1 INTRODUCTION.

The biology of any species of coccinellid depends on the prevailing temperature, the prey used as food and the location from which the coccinellid was collected (Hodek, 1973; Ruzicka *et al.*, 1981 and Okrouhla *et al.*, 1983). Hagen (1962) put the range of development of different coccinellid species from different locations as between 10 and 83 days at 35°C. and 15°C. respactively. Okrouhla *et al.*, (1983) reviewed the biology of coccinellids and concluded that the duration of development ranged from 9.4 to 33.3 days depending on the species, location and temperature.

In Africa, very little published information is available on the biology of the family coccinellidae. These few studies deal mainly with the bionomics and life histories of only a few species (Ibrahim, 1955; Kamal, 1951; Brown, 1972; Ofuya, in press). Two aphid species have been reported as pests of cowpea in Africa: *A. craccivora*, which is the main aphid infesting cowpea throughout Africa and Asia, and *Aphis fabae* (Scopoli),

which has been reported as a minor pest in East Africa (Singh and van Emden, 1979). Colonies inveriably consists of females and reproduction is parthenogenetic (Singh and Jakai, 1985). Partenogenetic reproduction evolved in aphids in the Permian, 200 million years ago, and has been of paramount importance in determining their population structure and high rate of increase (Dixon, 1987). The pest status of many aphids is due partly to their high reproductive potential (Dixon, 1987). In the present study, laboratory and field experiments were set up to determine the importance of C. lunata as a biological control agent for A. craccivora. These studies involved: matting, oviposition, adult longevity, Biology of the larval instars, developmental periods of the prey, etc.

4.2 MATERIALS AND METHODS

4.2.1 On the Biology of C. lunata

The females used for these studies were collected from the field and rearing cages as pupae and were kept in the laboratory in separate petri-dishes till emergence. In this way the starting materials for the biological studies were unmated (naive) adult coccinellids.

Prior to the experiment, the coccinellids were placed in sleeve cages (Fig. 6) to choose their mates. Copulating pairs were subsequently collected and placed in a lunch boxes (Fig. 3). Food was provided liberally in a petri-dish (see counting techniques in chapter 3) and placed in the lunch box containing the paired couples. Fresh supply of aphids were provided two times a day. The set up was observed at 3 hrs interval to monitor oviposition. Couples which laid eggs were transferred to a new lunch box to avoid cannibalism of the eggs (Okrouhla, 1983) and the number of eggs recorded. Females were given substitute males whenever each of the latter died.

Newly emerged larvae were individually reared (as described under laboratory rearing methods for C. lunata in chapter 3). The date of each moult was recorded until the larva pupated. After each moult the exuviae were removed with moistened camel hair brush. For the biological studies, the coccinellids were divided into batches of 10 individuals; each individual being kept separately in a lunch box. In a second study, the longevity of adult coccinellids was studied. Newly emerged adults were placed in lunch boxes (as described in chapter 3) and food given as before until death occurred.

Fig. 6 Sleeve cage used for selecting C. lunata couples.

4.2.2 On the Biology of A. craccivora

The biology of the females coccinellid was studied in the laboratory in petri-dish lined with moistened filter paper. A clean cowpea leaflet with a newly moulted adult aphid was placed on the filter paper with the uppermost surface facing downwards. The number of larviposited nymphs were recorded after every 24 hours under a stereomicroscope until the aphid died. The aphids used for this study were collected from the rearing cage as adults and were placed in the laboratory to larviposit. The young ones were then separated and observed as they changed from one instar to the next by moulting until they became adults. The adults were then placed in petri-dishes as described above. This methodology ensured that larviposited adults were not used for the study. The experiment was considered as terminated on the death of the larvipositing female. There were 4 batches of 5 females/batch.

4.3 RESULTS

4.3.1 On the Biology of C. lunata

4.3.1.1 Copulation.

The Pre-mating period in the laboratory was 3 days and the pre-oviposition period varied between 6-7 days. Mating took

place several times during the day and throughout their life. The duration of copulation varied between 10 minutes and 2 hours 45 minutes (see appendix Table 1).

4.3.1.2 Oviposition rate and egg structure

A newly laid egg is oval and yellow in colour, with smooth and shiny surface (Fig. 7). Its mean lenght is 1.32 mm, and mean width 0.58 mm at the broadest region. Few hours before hatching there is a change in colour to creamy white. Unfertilized eggs do not change colour. The incubation period is between 3 and 4 days at mean monthly laboratory temperatures of 25.95°C, 27.37°C and 28.52°C for November, December and January respectively (Table 4). Eggs were laid vertically in batches consisting of 20 to 40 eggs. Sometimes, the number per batch was as high as 68 and as low as 5 (see appendix Table 2). The maximum number of eggs laid by a single female within two weeks was 721 whereas the minimum recorded number of eggs per female within the same period was 347 (Table 2). The mean number of eggs laid by a female was 554.

4.3.1.3 Egg hatchability.

It was generally observed that C. lunata eggs has a high percentage hatchability. Nearlly all the eggs in each batch observed have 100% hatchability (see appendix Table 3).

Fig. 7 Newly laid eggs of C. lunata

4.3.1.4 Description of the larval instars and pupae

4.3.1.4.4 FIRST INSTAR.

Twenty four hours after emergence first instar (Fig. 8) is 1.91 mm. long and 0.60 mm. broad across the metathoracic segment (Table 3); brownish yellow in colour; head and legs darker; antennae moniliform and 3 segmented; dorsal shield of the prothorax large with many small setae, chitinized and covers the greater part of dorsum; meso- and metathorax with reduced oval dorsal shield and several satae; yellow spots present on mid-dorsal areas of meso- and metathoracic regions; abdomen 9 segmented; first abdominal segment with a pair of creamy spots at the lateral sides ; 4th abdominal segment creamy white with two black areas separating the creamy colour into 3 areas; last abdominal segment roundish with several hairs; appendages fairly long and less hairy.

4.3.1.4.2 SECOND INSTAR.

Newly moulted second instar (Fig. 9) 3.41 mm. long and 1.38 mm. wide across the metathoracic region (Table 3); body dark brown; head and legs darker with short hairs; antenna moniliform and 3 segmented; thoracic tergites with a pair of setae at their margins and sclerotized in the middle; faint yellow spots on the three thoracic segments; abdomen 9

Fig. 8 First larval instar of C. lunata

Table 2 Oviposition rate of C. lunata over a period of 14 days.

	Oviposition	
Eggs	Mean	Range
Total number/batch	553.50 ± 63.44	347 - 721
Number of batches/female	22.17 ± 2.59	16 - 31
Maximum batch size/female	49.00 ± 4.74	38 - 68
Minimum batch size/female	8.33 ± 2.22	5 - 19

No. of replicates = 6

segmented; first to third abdominal segments with single light yellow spot on mid-dorsal areas; 4th abdominal segment as in first instars above.

4.3.1.4.3 THIRD INSTAR.

The third instar (Fig. 10) 5.17 mm. long and 1.50 mm. broad across the metathoracic segment (Table 3); body dark-brown; head and legs darker; antennae moniliform and 3 segmented; orange white spot present on each thoracic tergite plate; abdomen 9 segmented; 1st to 3rd abdominal segments with orange spot on the dorsal portions; yellow banding of the 4th abdominal segment with two black areas; yellow band at the posterior end of 7th abdominal segment; 9th abdominal segment oval and hairy; appendages very hairy.

4.3.1.4.4 FOURTH INSTAR.

Newly emerged 4th instar larva (Fig. 11) 8.70 mm long and 2.8 mm. broad across the metathoracic segment (Table 3); dark brown; head shiny black; legs black with lots of hair; antennae moniliform and 3 segmented; yellowish banding present between head and prothorax; dorsal shield of prothorax with many setae; yellow spot present on the mid-dorsal area of the thoracic segments; abdomen 9 segmented; light orange spots on the mid-dorsal areas of 1st to 3rd abdominal segments, 4th abdominal

Fig. 9 Second larval instar of C. lunata

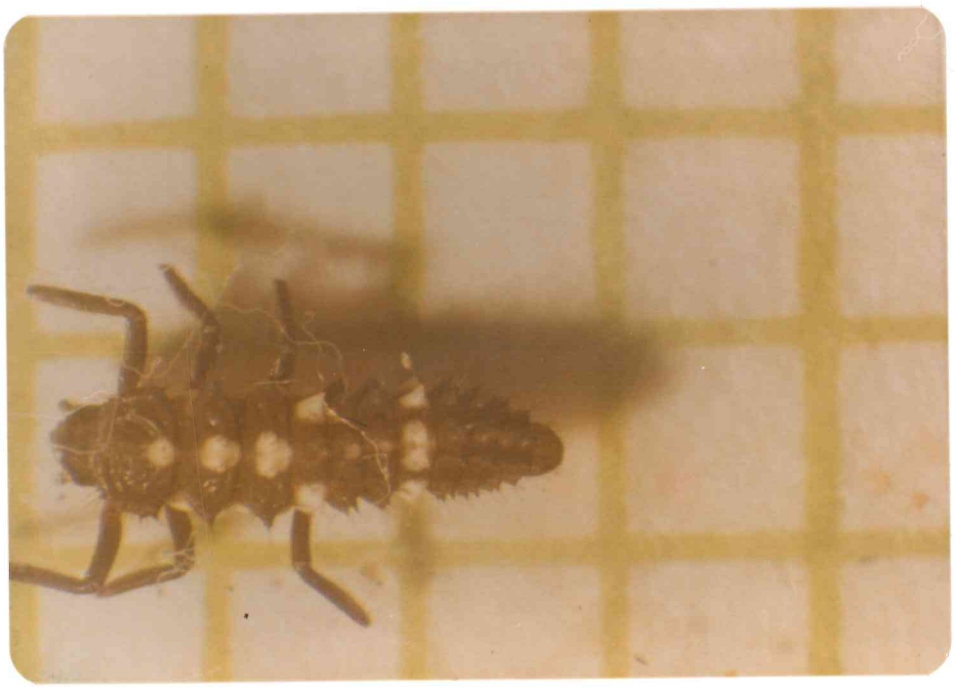


Fig. 10 Third larval instar of C. lunata

segment yellowish with two black areas separating the yellow into three portions; pairs of ridges with black spots on either sides of the dorsal spots; pale-yellow banding at the posterior end of 7th abdominal segment; pairs of abdominal setae present on the lateral sides of each segment; last abdominal segment hairy and oval. In older fourth instars, all bandings assume orange coloration. At this stage the larva becomes less active and move sluggishly. Feeding is drastically reduced. When fully grown, the 4th instar larva attaches itself by the posterior end to some suitable surface and pupates.

4.3.1.4.5 PUPAE (n=30)

Newly formed pupae 5.81mm long and 3.84mm wide are orange in colour with four symmetrically arranged black spots on the body segments (Fig. 12). The first and fourth symmetrically arranged lines are continuous. They stretched from the 4th abdominal segment to the 6th. The remaining two which are mid-dorsally located are 14 in number. They are located in pairs in segments 3,4,5,6,8,10 and 12. The pupa is capable of making slight sedentary movements on the substratum to which it was attached. The head and appendages are dark in colour and are not covered with the orange secretions during pupation. The legs are folded towards the body.

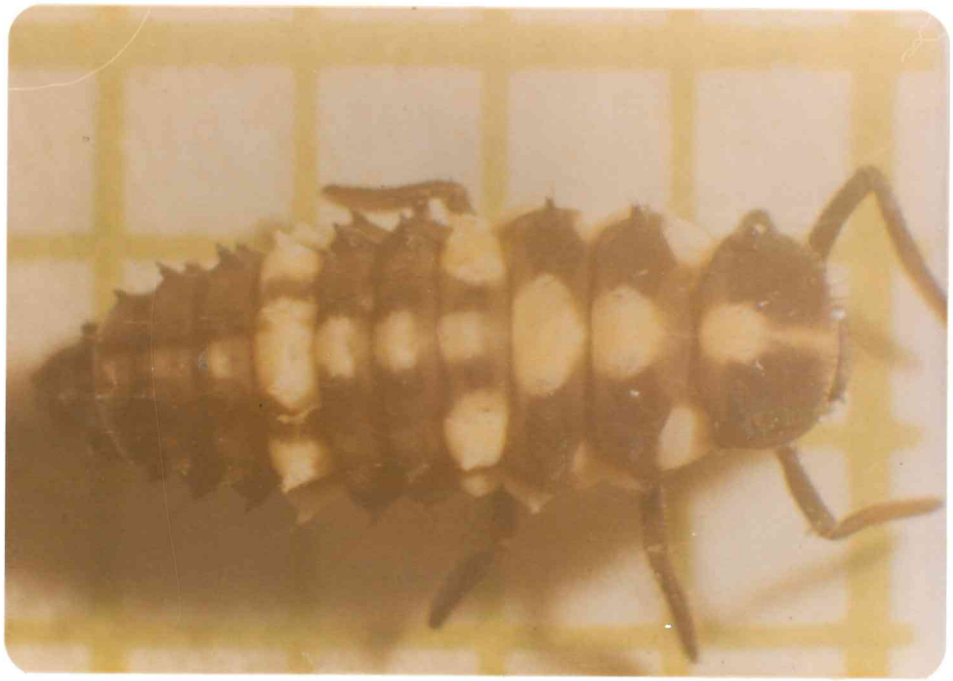


Fig. 11 Fourth larval instar of C. lunata

Fig. 12 C. lunata pupae

Table 3. Measurement of antennal lenght, head lengh and width, thoracic length and width, and abdominal length and width of C. lunata larval instars.

C. lunata instar	Measurement	Antenna	Head	Thorax	Abdomen	Mean total (Head to Abd.)
		Mean (mm) ± SE				
I	Length	0.15 ± 0.00	0.31 ± 0.01	0.75 ± 0.02	0.85 ± 0.04	1.91 ± 0.04
	Width		0.41 ± 0.00	0.60 ± 0.00	0.60 ± 0.00	
II	Length	0.18 ± 0.01	0.40 ± 0.01	1.38 ± 0.04	1.62 ± 0.03	3.41 ± 0.06
	Width		0.61 ± 0.00	1.03 ± 0.00	1.03 ± 0.00	
III	Length	0.33 ± 0.01	0.56 ± 0.01	2.16 ± 0.04	2.40 ± 0.05	5.17 ± 0.09
	Width		0.75 ± 0.00	1.50 ± 0.00	1.50 ± 0.00	
IV	Length	0.45 ± 0.01	0.62 ± 0.01	3.48 ± 0.04	4.42 ± 0.13	8.70 ± 0.09
	Width	—	1.00 ± 0.00	2.80 ± 0.00	2.80 ± 0.00	—
20 replicates/instar						

Abd. = Abdomen

4.3.1.5 Duration of stages in life cycle

The duration of the life cycle of C. lunata varied from November to January as a result of the changes in the prevailing temperatures. It was observed that the higher the temperature, the less the number of days taken to complete the whole development. For instance, at the mean monthly laboratory temperatures of 25.95, 27.37 and 28.51°C, it took a mean of 16.55, 14.05 and 13.60 days respectively to develop from egg to adult.

4.3.1.6 Longevity of adult C. lunata

The results showed that C. lunata adults live longer than their aphid prey and has a longevity that varied from 39 and 194 days while that of A. craccivora was between 4 and 20 days. The mean longevity for 14 adults was found to be 106.21 ± 14.90 (see appendix Table 5).

4.3.2 On the Biology of A. craccivora

4.3.2.1 Pre-Larviposition Period and Larvipositio Site

Larviposition in A. craccivora started immediately after the last moult (see appendix Table 7), though some adult aphids showed a pre-reproductive delay (the period between the adult

Table 4. Mean duration (in days) of the stages in life cycle of C. lunata.

	S E T S*							
	A		B		C			
+Batches Dev. stages	1	2	3	4	5	6	Mean duration (in days ± SE)	Range
Egg	4.0	4.0	3.0	3.0	3.0	3.0	3.33 ± 0.20	3 - 4
1st Larva	3.7	3.3	2.9	2.8	2.2	2.3	2.86 ± 0.23	2 - 4
2nd Larva	1.4	1.3	1.5	1.6	1.6	1.5	1.48 ± 0.01	1 - 2
3rd Larva	1.5	1.4	1.3	1.3	1.1	1.6	1.36 ± 0.07	1 - 2
4th Larva	2.1	2.4	1.4	1.5	1.7	1.5	1.76 ± 0.16	1 - 3
Pupa	4.1	3.9	3.8	3.9	3.8	3.9	3.90 ± 0.04	3 - 4
Total Dev. period	16.8	16.3	13.9	14.2	13.4	13.8	14.73 ± 1.43	13 - 17

*Period of Development: set A = November, set B = December, set C = January.
+10 replicates/batch
Dev. = Development

moult and the onset of reproduction). This period ranged from 1 to 2 days. Adult aphids larviposited their young ones in clusters along the veins, especially along the midrib of the cowpea leaves (Fig. 13).

4.3.2.2 Larviposition Rate

Though the rate of larviposition per single female varied from 1 to 12 per day (Table 5). The mean number of larvae per day for a single female ranged between 3 to 6 (see appendix Table 7). A. craccivora achieved its highest reproductive rate in early adult life (Fig. 14). A single adult female aphid could produce a maximum number of 99 larvae during its lifetime. However, a low larviposition rate of 11 was also recorded (see appendix Table 7).

4.3.2.3 Post Larviposition Period and Parental Care

Post larviposition period in A. craccivora varied from 1 to 3 days (see appendix Table 7) although, most of the adult females died immediately after larviposition which varied from 3 to 20 days. A. craccivora exhibit some sort of parental care by depositing all the young ones in cluster and attending to them, not moving quite far from the cluster.

Fig. 13 Larviposition site of A. craccivora

cowpea leaf

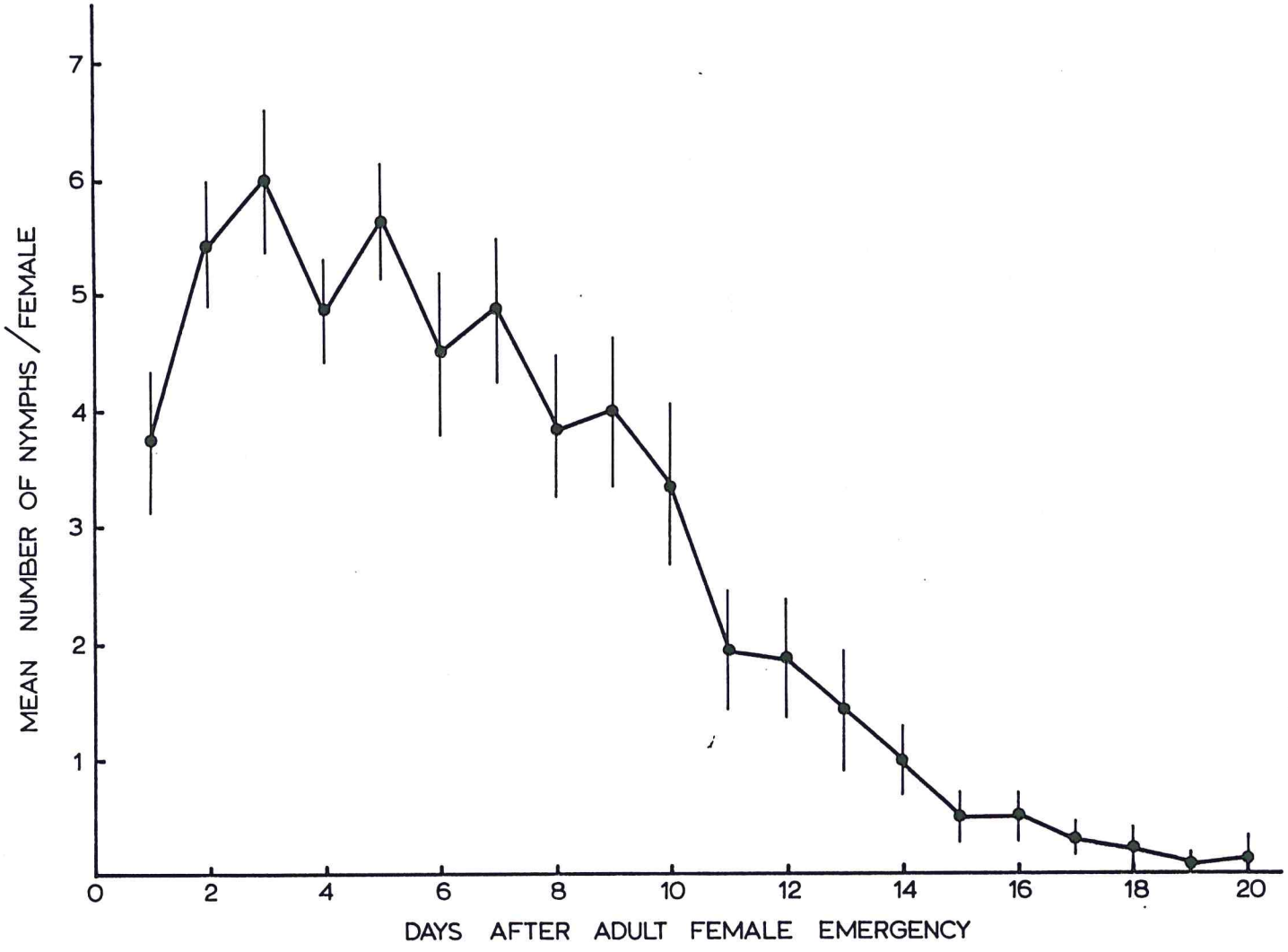

MEAN NUMBER OF NYMPHS / FEMALE
7
6
5
4
3
2
1
0
2
4
6
8
10
12
14
16
18
20
DAYS AFTER ADULT FEMALE EMERGENCY

Table 5. Larviposition rate of A. craccivora during the entire live period in the Laboratory

Larviposition rate	Batch number* 1	2	3	4
Maximum/female	10	12	10	10
Minimum/female	1	1	1	1
Total/batch	304	297	291	196
Mean/female	60.80	59.40	58.20	39.20
Std. Error	11.02	10.79	8.83	7.45
Range	1 - 10	1 - 12	1 - 10	1 - 10

*5 females/batch

4.3.2.4 Growth and Developmental Periods

A. craccivora passes through four larval instars in developing from birth to adult. The life cycle lasted for a period of between 5 to 6 days under mean laboratory temperature of 26.41°C. The duration of instars I, II, and III was between 24 and 28 hours while that of instar IV lasted longer (about 48 hours). The life span of A. craccivora (from birth to death) is varied but in most instances lasts between 10 to 20 days (see appendix Table 7).

4.4 DISCUSSION.

4.4.1 On the Biology of C. lunata

Oviposition occured throughout the life span of the adult coccinellids and the high number of eggs recorded per female within 2 weeks is an indication that C. lunata could be reared in large numbers that could be advantageously used for the biological control of cowpea aphid. The oviposition behaviour of C. lunata is similar to that recorded by Kapur (1942) for A. variegata.

The observation that aphidophagous coccinellids lay their eggs in batches (Hodek, 1967; Kapur, 1942) is in conformity

with the present results. Precopulatory period recorded in the laboratory was 3 days and thereafter copulation occurred several times in a day till death occured. This behaviour is important in ascertaining the fertility of the eggs. This may account for the high percentage of egg hatchability noted earlier.

The mean number of days (± SD) it took C. lunata to complete its life cycle was 14.73 ± 1.43 and the range was 13 to 17 days. Newly hatched larvae remained on their egg case for a period ranging from 18 hrs to 24 hrs before dispersing. The reason for this is not known, though a similar behaviour was reported by Banks (1956) when he studied the searching behaviour of individual neonate coccinellid larvae on cowpea plants.

The differences in developmental period observed between November and January may have resulted from differences in the prevailing temperatures. The effect of temperature on the developmental periods of coccinellids had been reported by Okrouhla et al., (1983) and Kapur (1942). The most interesting aspect of this study was the consistency in the head width, thoracic width and abdominal width. This information could be used to separate the different instars of C. lunata. There are other features which could also be used, these include the number, position and colour of the dorsal spots. The antenna which is three segmented could also be used in separating the

various instars since it was found to vary in length among the different instars.

The high fecundity of adult C. lunata recorded in this experiment (347-713 eggs per single female within two weeks), the short developmental period of the eggs and larval instars (13-17 days) and the long mean life span of the adults (106.21 ± 14.90 days) is an indication of its potential use as an agent for the biological control of A. craccivora.

4.4.2 On the Biology A. craccivora

Larviposition in A. craccivora took place in the early part of the adult life (Fig. 14). The reason for the low number of larvae recorded after 10 days of larviposition by the aphid may be associated with the number of females that survived after day 10 and reduction in ovarial number as the aphid aged. Though, this aspect was not investigated. In similar studies with the aphid, Diuraphis noxia (Mordvilko), Aalbersberg et al., (1987) also recorded high larviposition rate during the first three weeks of their six week study. Most of the larvipositing females died on the 9th and 10th day of the aphids life (see appendix Table 7). The result (Fig. 14) suggests that age affects the larviposition rate of A. craccivora. On developmental periods of aphids, Hughes (1963) and Aalbersberg

et al., (1987) found that the duration of instar I, II, and III of both Brevicoryne brassicae (L.) and D. noxia were approximately equal while that of the fourth instar lasted longer. In this study, the duration of instar I - III were also approximately equal and that of instar four lasted longer. Another important aspect of this result is the fact that adult aphid could live from 3 to 20 days. This result is different from the 0 to 15 days recorded by Singh and Jackai (1985) in Nigeria. But the variation may be ralated to the cowpea variety used as food, the temperature of the study area and the environment in which the experiment was conducted. Singh and Jackai (1985) also recorded a daily progeny of 2 to 20 with A. craccivora. In the present work (Table 5), daily progeny varied from 1 to 12. The longest period it took to complete one generation was 20 days. This showed that A. craccivora could produce up to 18 generations in any given year.

Though most of the larvae were produced within the first 10 days after female emergence, there were instances when low number of larvae were produced within these periods. The short duration of the larval instars (betwwen 5 to 6 days) is an indication that several generations could be produced within a year. Various intrincsic and extrinsic factors such as population density, feeding site, plant growth stage and plant quality has been reported to determine the rate of development,

fecundity and longevity of aphids (Raworth et al., 1984; Jasson and Smilowitz, 1985) Temperature is, however, thought to be the most important factors, and its role has been investigated by several authors (Campbell et al., 1974; Dean, 1974; Aalsberbergs et al., 1987). These authors obtained similar results of decrease in nymphal developmental time with increased temperature. In this study, the short developmental periods recorded may have resulted from the temperature of the study arena (26.41°C). This aspect is very important since large population of aphid may cause a complete failure of cowpea crop in the field (Singh and Jackai, 1985).

Chapter 5

SEARCHING BEHAVIOUR OF CHEILOMENES LUNATA

5.1 INTRODUCTION.

Searching behaviour of predators has received little attention with few notable exceptions (Fleschner, 1950; Banks, 1957; Dixon, 1959 and Firempong and Kumar, 1975). For a predator to be recommended as a good biological control agent, its searching behaviour should be studied in great detail. Although some workers have cited C. lunata as a predator of aphids (e.g. Brown, 1972), they did not examine the searching behaviour. This study was therefore carried out to provide a detailed account of the searching behaviour of C. lunata and to assess its potential as a biological control agent against the cowpea aphid, A. craccivora.

5.2 MATERIALS AND METHODS

This study was made by following the movement of coccinellid predator when they are placed singly at the foot of uninfested cowpea seedling growing singly in plastic pots. The searching behaviour of both fed and unfed adults and first

instar larvae was investigated. The predators were starved for 24 hours prior to the start of the study. The study lasted one hour for each predator during which, the time spent on the various parts of the cowpea seedling was recorded. The same study was repeated with seedlings infested with aphids and either attended or unattended by ants.

5.3 RESULTS

5.3.1 Movement of fed adult coccinellid on aphid infested ant free cowpea seedling.

The fed adult wandered round the stem before climbing to the apical leaflet where it rested for 5 minutes. From its resting position, it moved to the undersurface of the leaflet, followed the main vein strictly to the apex and rested for 2 minutes. It then moved to the leaf petiole and subsequently descended the stem mid way before it changed direction and ascended to the apical leaflet, crossing many aphids as it made its way. At the apical leaflet, it attacked and grabbed an aphid located in the area between veins. After eating the aphid, it rested for 4 minutes before moving to the uppersurface of the leaf where it rested for 16 minutes before the end of the experiment period. Table 6 shows the number of times 12 fed adult coccinellids were observed on the various parts of the cowpea seedling.

5.3.2 Movement of fed adult coccinellid on ant attended aphid colonies on cowpea seedling.

The fed adult coccinellid made its way to the top. It descended the stem and wandered along as it moved, changing directions frequently before finally ascending the apical leaflet where it located an aphid colony. When it attempted to grab an aphid, it was attacked by the ants. It retreated, rested for 45 seconds and launched another attack on the aphids but was again attacked by the attending ants. The coccinellid moved backwards, facing the aphid colony till the end of the experiment. Table 7 shows the number of times 12 coccinellids were observed on the various parts of infested cowpea seedlings attended by ants.

5.3.3 Movement of fed adult coccinellid on aphid-free cowpea seedlings

The fed adult coccinellid ascended the cowpea seedling in a rather slow manner to the first stage leaflet where it rested for 15 minutes. From its resting position, it descended the base of the stem from where it ascended to the first stage leaflet and rested for 11 minutes. It wandered for a while before finally ascending the apical leaflet, moving here and there until the end of the experiment. Table 8 shows the number of times fed adult coccinellids were observed in various parts of aphid free cowpea seedlings.

Table 6. Number of times 12 fed adult C. lunata were observed on parts of infested cowpea seedlings while searching for aphids.

	Parts of cowpea seedlings					
	Between veins	Veins	Rims	Apex	Petiole	Stem
No. of times observed	147	120	104	82	98	86
% distribution of aphids	32	13.6	0	0	15.6	38.8

Table 7. Number of times 12 fed adult C. lunata were observed on parts of infested cowpea seedlings attended by ants while searching for aphids.

	Parts of cowpea seedlings					
	Between veins	Veins	Rims	Apex	Petiole	Stem
No. of times observed	208	164	200	80	108	88
% distribution of aphids	34.09	17.62	0	0	13.64	34.65

5.3.4 Movement of unfed adult coccinellid on ant free aphid infested seedling.

The adult made its way to the top of the cowpea seedling, changed direction and descended the stem. This searching behaviour of moving up and down the seedling were repeated several times before the coccinellid came in contact with an aphid colony located between the veins on the lower surface of the leaflet. After grabbing and eating the first aphid, the movement pattern changed. The coccinellid thereafter, concentrated its search only in the immediate area where the first aphid was captured. Finally, it moved to the uppersurface of the leaflet and rested for 9 minutes before moving back to the undersurface of the leaf where it continued feeding till the end of the experiment. Table 9 shows the number of times 12 unfed adult were observed on different parts of infested seedling.

5.3.5 Movement of unfed adult coccinellid on aphid infested ant-attended cowpea seedling.

The coccinellid ascended the seedling, crossed to a leaflet and followed the main vein to the apex where it rested for a minute before moving round the leaflet, following the rim closely. Thereafter, it moved to the petiole and rested for 23 seconds. From the petiole, it followed the main vein to the

Table 8. Number of times 12 fed adult C. lunata were observed on parts of aphid free cowpea seedlings while searching for aphids.

	Parts of cowpea seedlings					
	Between veins	Veins	Rims	Apex	Petiole	Stem
No. of times observed	156	112	184	80	100	104
% distribution of aphids	0	0	0	0	0	0

Table 9. Number of times 12 unfed adult C. lunata were observed on parts of infested cowpea seedlings but ant free while searching for aphids.

	Parts of cowpea seedlings					
	Between veins	Veins	Rims	Apex	Petiole	Stem
No. of times observed	201	117	201	78	126	84
% distribution of aphids	35.82	14.18	0	0	3.73	46.27

apex, searching for aphids as it made its way. The coccinellid rested for another 17 seconds before moving to the undersurface of the leaflet where a colony of aphid was located. As it attempted to grab an aphid, it was attacked by the attendant ants. Although the coccinellid moved backwards, the presence of the ants did not prevent further attack and seizure of the aphids. Thereafter, the searching pattern of the coccinellid was concentrated within the area where the aphid colony was found. Finally, the coccinellid moved back, cleaned its mandibles with the forelegs and rested for 10 minutes before the end of the experiment. Table 10 shows the number of times the coccinellids were found in different parts of the seedling.

3.3.6 Movement of unfed adult coccinellid on aphid-free cowpea seedling.

The unfed adult coccinellid moved swiftly from the base of the stem where it was placed to the second stage leaflet and climbed onto the upper surface. It went round the leaf three times through the rim, bypassing the apex on each occasion before resting for 34 seconds on the rim. It then crossed to the opposite leaflet, searched along the veins and the areas between veins of both the upper and lower surfaces. The coccinellid recrossed its path on to the former leaflet, following the veins to the apex. During this movement, the

Table 10. Number of times 12 unfed adult C. lunata were observed on parts of infested cowpea seedling attended by ants while searching for aphids.

	Parts of cowpea seedlings					
	Between veins	Veins	Rims	Apex	Petiole	Stem
No. of times observed	144	72	164	72	60	48
% distribution of aphids	30.91	14.55	0	0	16.36	38.18

Table 11. Number of times 12 unfed adult C. lunata were observed on parts of aphid free cowpea seedling while searching for aphids.

	Parts of cowpea seedlings					
	Between veins	Veins	Rims	Apex	Petiole	Stem
No. of times observed	196	72	140	88	100	92
% distribution of aphids	0	0	0	0	0	0

coccinellid changed directions several times. Finally, it descended the stem and rested for 5 minutes before ascending again. This up and down movement continued to the end of the experiment. Table 11 shows the number of times 12 unfed coccinellids were found in different parts of the cowpea seedling.

5.3.7 Movement patterns of unfed first instar coccinellid larva on cowpea leaf

A coccinellid larva was placed at the base of the leaf-stalk. It followed the main vein, branched to a minor vein and rejoined the main vein which it followed midway between the stalk and the apex. It then followed a minor vein towards the margin, but suddenly crossed to another minor vein which it followed across the main vein, changed direction and joined the main vein again, moving toward the stalk (Fig. 15). It followed the first minor vein from the stalk and headed towards the rim, recrossing several minor veins to the rim which it followed to the the apex. On getting close to the apex, it changed direction and moved towards the stalk through the periphery of the rim (Fig. 15). It then changed direction again and moved towards the apex, following the rim closely till the end of the experiment.

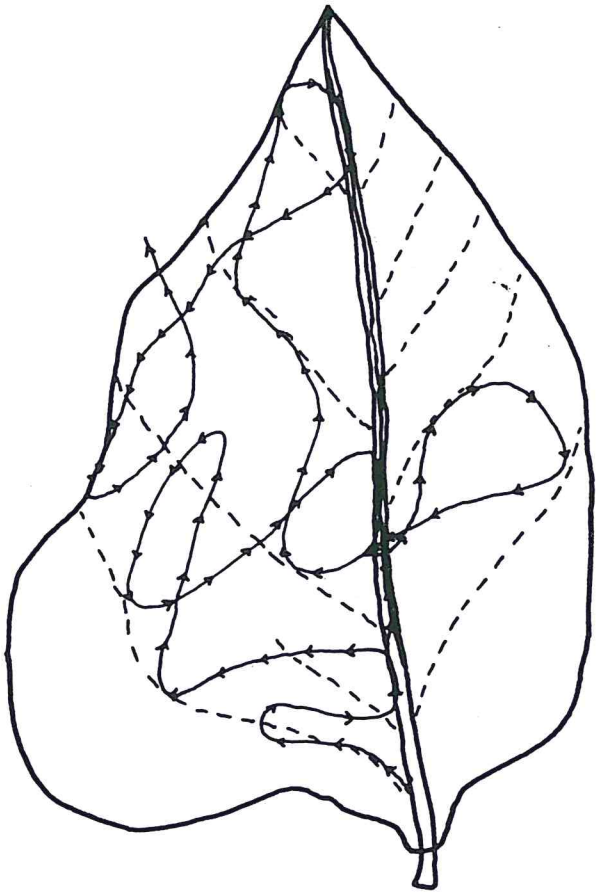


FIG. 15 MOVEMENT PATTERNS OF UNFED FIRST INSTAR LARVA

5.3.8 Movement patterns of fed first instar coccinellid larva on uninfested cowpea leaf

The searching behaviour of C. lunata larvae after feeding is quite distinct from that which has not fed. The fed larvae tend to search an area where it was placed thoroughly in anticipation of finding aphids after which most of the remaining time was spent resting or walking along the margin. Fig. 16 is a typical movement pattern shown by fed first instar larva of C. lunata. After being placed on the leaf stalk, the larvae moved round and round in search of prey. When the search proved fruitless, it went straight to the rim, followed it towards the apex before crossing to the undersurface of the leaf. It re-appeared very close to the apex and crossed to the other side of the rim in a zig-zag manner. The rim was gradually followed until it finally came to the area between veins on the upper surface of the leaf where it spent most of its time resting.

5.3.9 Movement patterns of fed first instar coccinellid larva on aphid infested cowpea seedligs.

The fed larvae was placed at the base of the leaf-stalk, it followed the vein, crossed to the upper-leaf surface passing across minor veins (Fig. 17). It searched the surface and eventually grabbed an aphid. After eating the aphid, its search thereafter was concentrated within the region where the

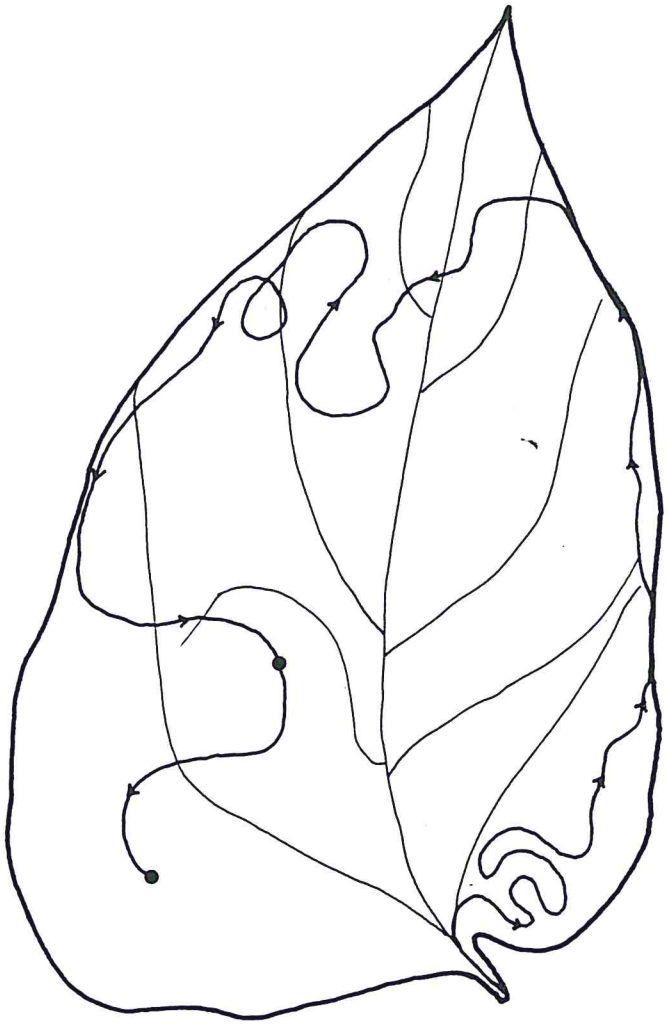


FIG. 16. MOVEMENT PATTERNS OF FED FIRST INSTAR LARVA

FIG. 17. MOVEMENT PATTERNS OF UNFED FIRST INSTAR LARVA WHICH ENCOUNTERED APHID COLONY

aphids was found. This side by side movement continued for a long time, and the coccinellid was mainly crossing and recrossing its tracts (Fig. 17). Finally, it moved to the rim and rested for the remaining period of the experiment.

5.4 DISCUSSION.

The different stages of C. lunata are capable of thorough search for their prey on cowpea plants, factors such as the state of hunger and the presence of attendant ants do influence their ability to search and capture their prey. Ants are commonly found in large numbers wherever there is an aphid colony. The caurse of their presence was not investigated but it well documented that they are attracted to feed on the honey dew secreted by aphids (Dixon, 1959; Firempong and Kumar, 1975). In return, these ants protect the aphids against enemies such as coccinellid predators. This is a symbiotic relationship that ensures constant food supply for the ants and protection for the aphids.

It was also observed that compared to an unfed coccinellid, a fed coccinellid spent most of its time resting in one part of the plant or moving along the rims. The same observations were made by Dixon (1959) and Firempong and Kumar (1975). C. lunata larvae and adults tend to search an immediate area where an aphid has been captured more thoroughly

than an area where no aphid has found found. Moreover, the coccinellid concentrated its search along the cowpea veins, especially the major veins as this is the part of the leaf where most feeding occurs (Firempong, pers. comm.). This also confirmed Banks (1957) statement that rims and prominent veins of leaves often determined the pattern of coccinellid tracks and distribution.

Another observation made on C. lunata was their inability to perceive their prey from long distance. Attack by C. lunata was made only when it came in close contact with aphids. This showed that the sensory perception of C lunata is of range. This factor also affect the searching ability since the major cause of mortality in coccinellid larvae is starvation as a result of their inability to locate aphids (Banks 1957). Some coccinellid larvae and adults spend all their time searching areas where no aphid is found (Banks, 1957). C. lunata is not an exception to this. Most of their time was spent moving along the rim where the chances of locating aphid is very rare (see tables 5-10). Moreover, aphids deposit their young ones on the areas between veins. The side by side turning after feeding by C. lunata increased the chance of meeting another aphid of the colony, hence the frequent recrossing of tracts observed in Figure 15. The random movement of unfed C. lunata first instar larvae and adults is related to their level of hunger. This random movement is reduced once aphids are discovered.

Chapter 6

SYNCHRONISATION OF C. LUNATA POPULATIONS WITH COWPEA APHID, A. CRACCIVORA POPULATIONS

6.1 INTRODUCTION

van Emden (1965) considered synchronisation as the time-relationship of the attack by aphidophagous insects with the aphid population and the life span of the individual aphid. Synchronisation as used here is the time gap between the inception of aphid colonies and the appearance of aphidophagous coccinellids. The aim of this study is to investigate the level of synchronisation between the cowpea aphid, A. crassivora and its coccinellid predator, C. lunata. This information is important since a close synchronisation between a predator and its prey enhances the ability of the predator to control the prey population.

6.2 MATERIALS AND METHODS

This study was conducted in eight differnt sites at Mbita Point Field Station. Sites 1, 2, and 4 were located in a fallow field where sorghium was last planted and site 3 was located in fallow field where cowpea was last planted. Sites 5

and 6 were located very close to maize plot, while sites 7 and 8 were located in a grazing field. At each site were placed 10 two-litres plastic buckets containing 25 days old cowpea plants infested with different stages of A. craccivora.

The experiment (Fig. 18), were observed at two hour intervals (beginning from 0800 to 1800 hours) for 8 days. The coccinellid densities at each site were censused by direct counting. All plant parts were examined and counts made using a tally counter. The coccinellids found on the plants were not removed. The records taken were based on: (1) the time taken for the coccinellids to locate the infested plants; (ii) the population build up of the predators with reference from start of the experiment; and (iii) the time of peak activities (feeding periods) of the coccinellids. Synchronisation here is considered high if aphidophagous coccinellids appear within the first 2 days after the experimental set up, and low if they appear 7 days or more later. In between these two extremes, synchronisation would be considered moderate. Also investigated were the relationship between site of location, aphid infestation, appearance of aphidophagous coccinellids and the time of peak activities of the coccinellids. The data obtained at the end of the experiment was subjected to two-ways ANOVA and the means separated by Duncans Multiple New Range Test.

Fig. 18 Field plot arrangement for studies on synchronisation between A. craccivora infestation on beans and the appearance of C. lunata.

6.3 RESULTS

Generally there were no significant differences between the mean numbers of aphidophagous coccinellids found in the first 3 days $p = 0.05$ at site 1. The coccinellid population rose from day 1 to 2 and the population were found to be highest between day 2 and 4. However, the population peaked generally on the 3rd day (Fig. 19). Decline in population sets in from day 4 to 8. At site 1, the highest number of coccinellids were recorded within the first 3 days. The population decreased gradually from day 4 until day 8 when no coccinellid was found. Site 2 showed no significant difference in the mean number of coccinellid found between day 2 and 6. The population of coccinellid increased rapidly from day 1 to 2, peaked on day 3. Decline in population started first on day 4, and decreased gradually to day 6. On days 7 and 8, the population dropped below 2% of the total (Fig. 20). Site 3 showed no significantly difference in the mean number of coccinellid recorded from day 1 to 5, and 7, however, these are significantly different from the mean coccinellid number recorded in day 6 and 8 ($p = 0.05$). At site 3, the highest number of coccinellids was recorded during the first 3 days. The population peaked on day 3 and was sustained through day 5,

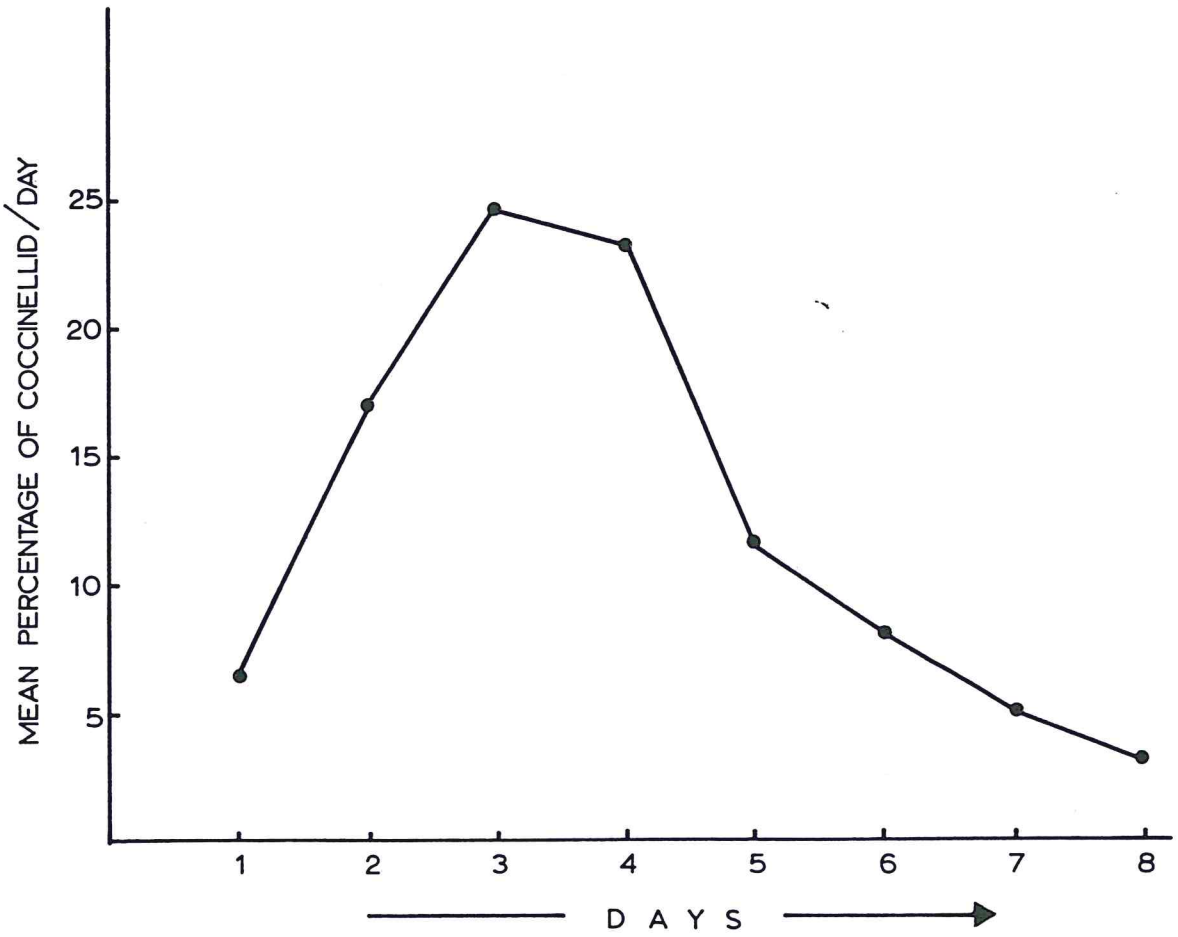


FIG. 19. ACTIVITY PATTERN OF C. LUNATA IN RELATION TO DAY.

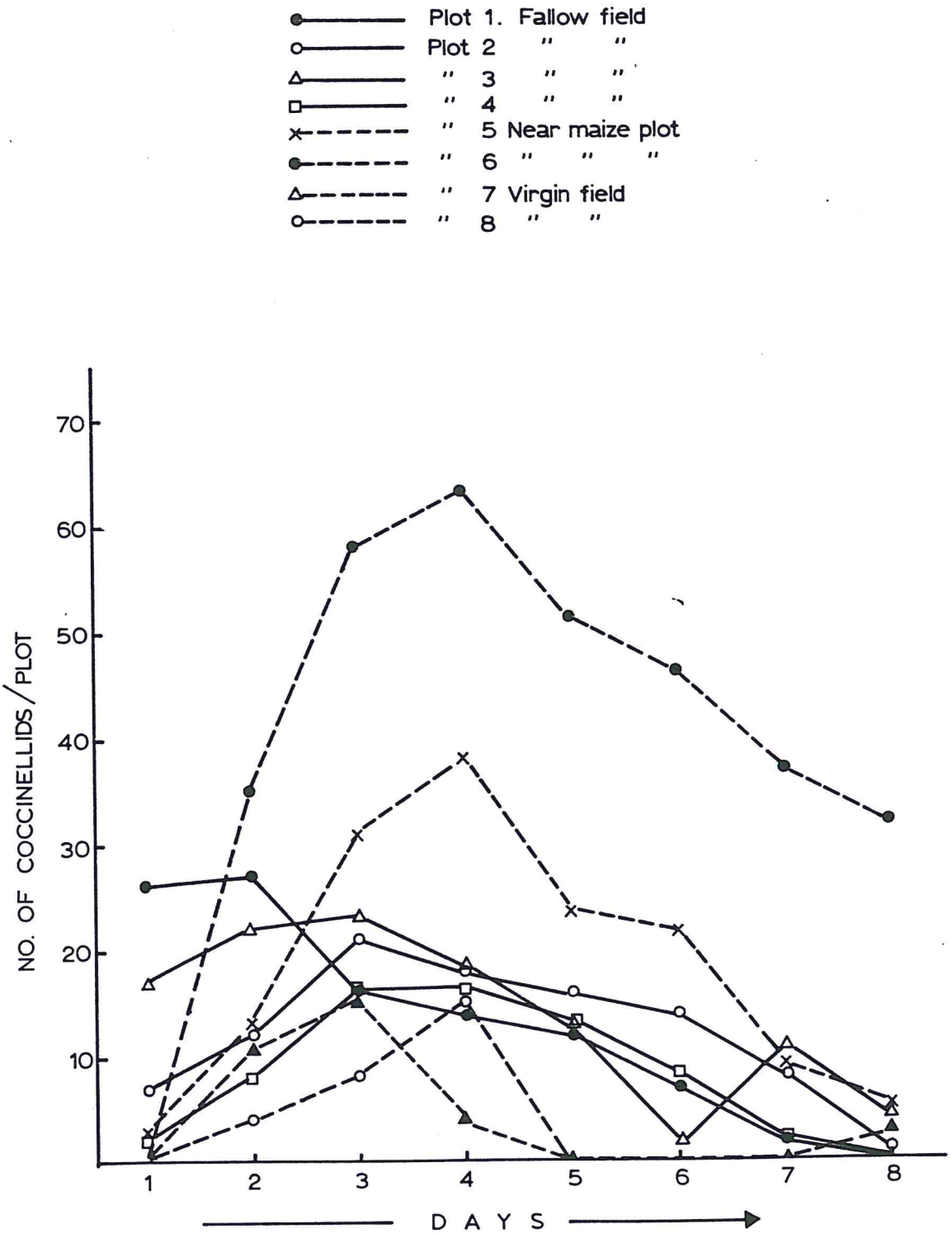


FIG. 20 THE INCIDENCE OF C. LUNATA PER SITE OVER DAY

but dropped on day 6. On day 7 the population rose again and dropped finally on day 8.

The mean number of coccinellid recorded between day 2 and 6 at site 4 did not differ significantly at p=0.05, however, these are significantly different from the mean number of coccinellid recorded in day 1, 7 and 8. At site 4, there was a rapid rise in the coccinellid number from day 1 to 3. The population which peaked on day 3 was maintained to day 4. A gradual decrease started on day 5 and on day 8, no coccinellid was found (Fig. 20). Site 5, there were no significant differences in the mean number of coccinellid recorded between day 3 to 6. However, the former was significantly different from the mean number of coccinellid recorded in day 2, 7 and 8, which in turn was different from that recorded for day 1 (p = 0.05). At site 5, the coccinellid population increased from day 1 to 4 when it peaked. A decline in number occurred on day 5 and on day 8, only 4%(5) of the coccinellids in the site were recored. On site 6, day 3 to 7 showed no significant difference in the coccinellid number recorded. The mean coccinellid number recorded for day 2 and 8 were significantly different from the former. On site 6, the population of coccinellids increased steeply and peaked on day 4. This was followed by gradual decline in coccinellid populations from day 5 to 8 when only 10%(32) of the total population at the site was recorded (Fig. 20).

At site 7, day 2, 3, 4, and 8 showed no significant difference in the mean coccinellid number recorded. However, there were significant differences between the former and day 1, and 5 to 7. On site 7, there was a rapid increase in the coccinellid population from day 1 to 3 (peak day). The coccinellid population dropped on day 4 to zero, rose again on day 8, with 10%(3) of the total coccinellid recorded in that site. On site 8, there were no significant differences in the mean coccinellid number recorded in between day 2 to 4 which in turn was significantly different from the mean number of coccinellids recorded in day 1 and 5 to 8. On site 8, there was a drastic rise in the coccinellid population from day 1 to 4 (peak day). It fell steeply to 0% on day 5 and no coccinellid was observed till the 8^{th} day (Fig. 20).

As regard the activity periods of the coccinellids, it was observed that at sites 1 and 3, the coccinellids were more numerous in the sites between the hours of 1000 and 1600, whilst the lowest number of coccinellids were recorded at 0800 and 1800 hours. At sites 2 and 4, fewer coccinellids were recorded in the early hours of 0800 and 1000. High population were observed between 1200 and 1600 hours and the population dropped at 1800 hours. At sites 5 and 7, high coccinellids population were recorded between 1200 and 1400 hours. The

population was moderate at 1000 and 1600 hours but lowest at 0800 and 1800 hours (Fig. 21).

At site 6, high populations of coccinellids were recorded between 1200 to 1600 hours. The population at 0800, 1000 hours and 1800 hours were low. At site 8, no coccinellid was found at 0800 hours, but between 1000 to 1800 hours the coccinellids population were fairly high. On 1200 hours, the highest number of coccinellids were recorded (peak activity period) (Fig. 21).

6.4 DISCUSSIONS

The high synchronisation between aphidophagous coccinellids and A. craccivora in all the experimental sites gave an indication that these insects could be used advantageously for the biological control of A. craccivora. Although some coccinellids appeared on the first day, most of them appeared on the 2nd day after experimental set up and the population built up rapidly and peaked on the 4th day but most often, on the 3rd day. van Emden (1965) observed that the early appearance of aphidophagous coccinellids in the aphid population will very much improve the control. Concerning time of high activity, it was observed that most of the coccinellids

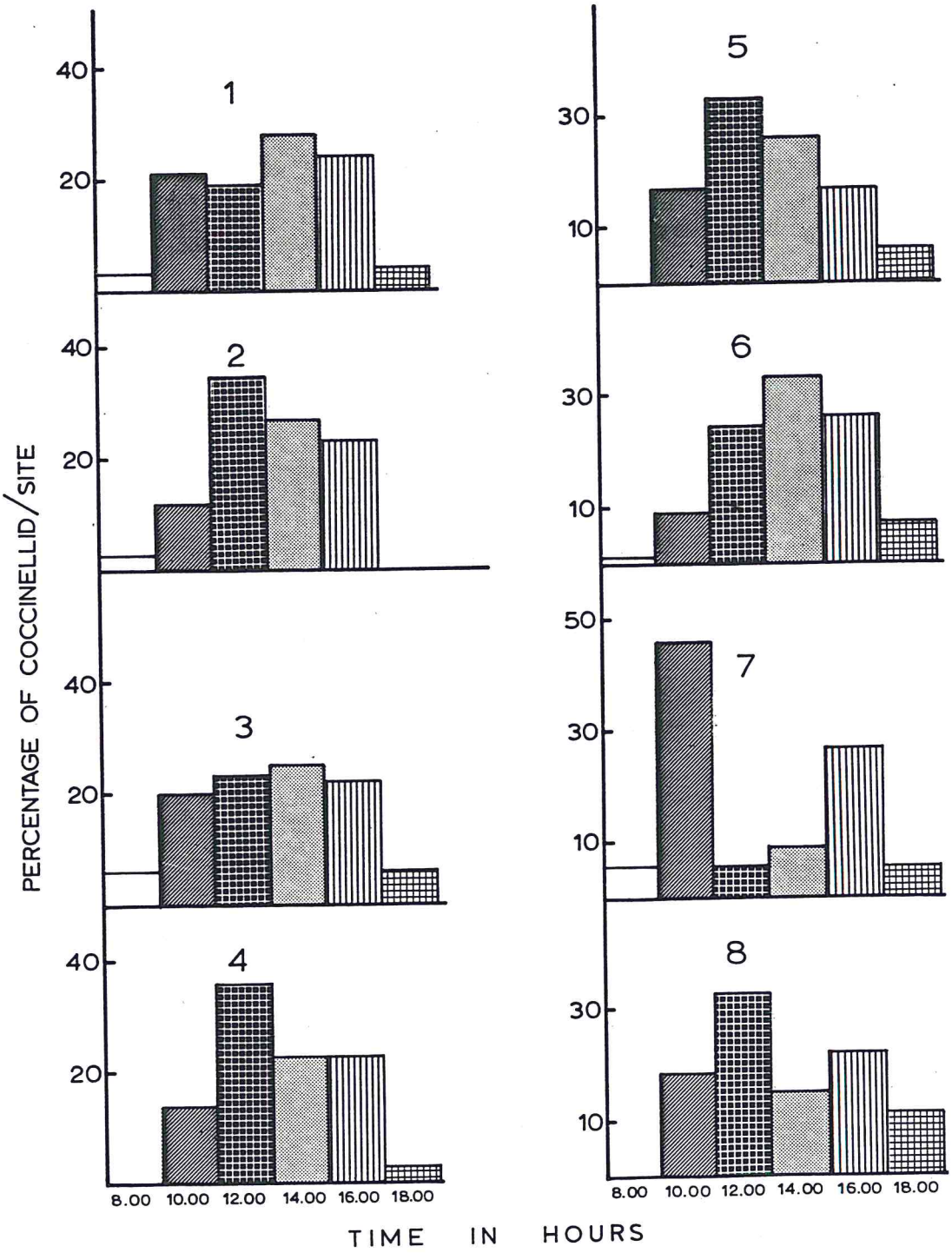


Fig. 21. Percentage incidence of C. lunata per site over time

were present in the field between the hours of 1000 hours and 1600 hours. Very few coccinellids were recorded at 0800 hours and 1800 hours (before sunrise and after sunset). In some cases, no coccinellids were found at all (Fig. 21).

The most interesting aspect of this result is the appearance of the coccinellids late in the morning and their subsequent build up in population, reaching a peak between 1000 and 1600 hours and the finally declining to zero after 1800 hours. This daily activity pattern indicates that the aphidophagous coccinellids have a feeding site which is on aphid infested plots and a resting or retiring site which is away from aphid infested plots. Even though the resting or retiring site was not traced, it is possible that they may have hidden in either the neighbouring grasses or in the soil.

The importance of the above findings is that cowpea fields located close to maize plots are likely to have more aphidophagous coccinellids which may assist in suppressing the aphid population below the level that is injurious to the crop. For a cowpea farmer, it would be advantageous to site the cowpea farms in close proximity to maize plots since maize plants are known to be attacked by the aphids, Rhopalosiphum maidis (Fitch) which is also attacked by aphidophagous coccinellids. This accounts for the high number of coccinellids recorded in plot 6 (see appendix Table 8).

Cowpea plots located in virgin fields are likely to be attacked and seriously damaged by A. craccivora as was the case with plants at site 7 and 8 where only 33 and 27 coccinellids were recorded throughout the duration of the experiment (see appendix Table 8). The reason for the high number of coccinellids recorded in the first 4 days may be connected with the fact that, during these days the population of aphids were observed to be high. As the population of the aphids become reduced due to predation by coccinellids, the population of coccinellids also decreased. This may have resulted from competition among the coccinellids for limited resources (food). This type of relationship between predators and prey was referred to as coupled oscillations by Begon and Mortimer (1981).

Chapter 7

PATTERN OF A. CRACCIVORA DEFENSIVE BEHAVIOUR.

7.1 INTRODUCTION

Although aphids have long been known to vary in their suitability as prey for Coccinellidae, reports in the literature on their ability to avoid predation are scanty (Brown, 1974). The first report of a defensive behaviour employed by aphids was given by Busgen (1891) who stated that some aphids exude an oily liquid from their siphonculi which they smeared on to the head of an attacking predators from which they then escaped. Since then, literature on this subject abound, for example, Dixon (1958); Brown (1974); Firempong and Kumar (1975). In this study, the defensive reaction of A. craccivora to its predator, C. lunata is investigated.

7.2 MATERIALS AND METHODS

Cowpea leaves collected from two weeks old plants growing singly in plastic pots were put in plastic petri-dishes (diameter 9.0 cm) with their undersurface upwards. Ten aphids of a known growth stage were introduced and allowed 30 minutes to settle and feed. A coccinellid predator also of a known growth stage was introduced to the aphids and observation commenced under a binocular microscope. The experiments were

done using all the different combinations of developmental stages of the aphids and their predator. These experiments took place in the laboratory under ambient room temperature and relative humidity conditions.

6.3 RESULTS

Defensive behaviour was observed only in third, fourth and adult aphids. Four types of defensive behaviour were recognised in the laboratory which are described below:

(a) **Leg shedding:** This involves kicking of appendages when the aphids are attacked. This behaviour was observed to be very effective against the first three larval instars of the predator. Leg shedding was observed only in fourth instar larvae and adult aphids. The behaviour accounted for between 50-70% of the escape recorded in adult (Table 12) and 30-50% escape in fourth instar aphids (Table 13) against instar I-III of C. lunata.

(b) **Walking away:** This was the most effective defensive behaviour shown by aphids of third, fourth and adult stages. It usally occurred when an aphid saw a coccinellid coming in its direction. There upon the aphids stops feeding, withdraws its stylets and walks off. The behaviour accounted for between 20-40%, 20-30% and 10-60% of the escape recorded in adult, fourth and third instars aphids respectively (Tables 13-15).

(c) **Dropping down:** This behaviour was observed on cowpea plants growing singly in a plastic pot. It occurs in cases where the predator was unsuccessful at seizing the aphid. The aphids thereafter move to the adge of the leaf and drop down. It was effective against larval instars of the predator which usually required more than one encounter before they were able to capture their prey (Table 15).

(d) **Exudation of secretions:** Forth instar and adult aphids aphids produce a brownish, sticky and viscous secretion from their siphunculi. It was usually directed towards the head of attacking predators. The function of the fluid is not clear as it does not deter the predators from capturing their prey (Tables 12-15).

7.4 DISCUSSION

A. craccivora adults show four tyes of defensive behaviour when they are attacked. These defensive behaviour may involve (1) moving away from the direct paths of the predators (2) shedding of an appendage (3) exudation of fluid from the siphunculi and (4) dropping off the plant.

The above defensive behaviour was found to be effective against the first three instars of C. lunata, but not against fourth larval instars and adults. One of the reason may be

Table 12. The percentage of adult A. craccivora that escaped capture by the different instars of C. lunata.

C. lunata instars	% escape: Leg shedding	Walking away	Fluid exudation	% capture
I	70	30	-	-
II	50	20	-	30
III	50	20	-	30
IV	10	40	-	50
Adult	-	40	-	60

40 replicates/instar

Table 13. The percentage of 4th instar A. craccivora that escaped captureby the different instars of C. lunata.

C. lunata instar	% escape: Leg shedding	Walking away	Fluid exudation	% captured
I	50	20	-	30
II	40	30	-	30
III	30	30	-	40
IV	10	30	-	60
Adult	-	30	-	70

40 replicates/instar

Table 14. The percentage of 3rd instar A. craccivora that escaped captureby the differnt instars of C. lunata.

C. lunata instars	% escape			% captured
	Leg shedding	Walking away	Fluid exudation	
I	-	60	-	40
II	-	40	-	60
III	-	20	-	80
IV	-	10	-	90
Adult	-	20	-	80

40 replicates/instar

Table 15. The percentage of adult A. craccivora that escaped capture by the differnt instars of C. lunata in the field.

C. lunata instars	% escape*			
	Leg shedding	Walking away	Fliud exudation	Dropping down
I	10	30	-	30
II	20	10	-	10
III	10	40	-	20
IV	-	10	-	-
Adult	-	-	-	-

40 replicates/instar

*The unaccounted percentage is for the captured aphids.

that at these growth stages the predators are much larger than their prey and thus can subdue them easily. Another reason may be that the fourth larval instars and adults of C. lunata use their fore-legs to lift the aphids off the substrate. In this situation the kicking and appendage shedding response of the aphids are ineffective. Two tyes of defensive behaviour, that of dropping down and moving away from approaching predators were found to be effective, but only to a limited extent.

The fluid which were released from the siphunculi by the adults were found to have no deterrent effect on the predators. Similar observations were made by Firempong and Kumar (1975) but Dixon (1958) reported that the fluid released from the siphunculi by A. decempunctata assisted the prey to free its self from the predator.

Chapter 8

PREY STAGE PREFERENCE, CAPTURE EFFICIENCY, VORACITY AND HANDLING TIME BY C. LUNATA

8.1 INTRODUCTION

Prey stage preference, capture efficiency, voracity and prey handling time are some of the parameters that have been used to determine the predation efficiency of aphidophagous coccinellidae (van Emden, 1965; Iperti, 1965). Prey stage preference of a few aphidophagous coccinellidae has been reported in Africa (Brown, 1972; Firempong and Kumar, 1975; Ofuya, 1986). According to these authors, all the predators tested showed marked preference for the early larval instars of the prey, and the capture efficiency of the predators decreased as the prey advanced in age.

In addition, a direct relationship exist between the age of the predator/prey and the number of prey consumed (voracity) (Okrouhla et al., 1983; Liao et al., 1985); the older the predator, the higher the consumption rate and the capture efficiency. Regarding prey handling time, Dixon (1959) observed that the handling time of A. decempunctata increased as the prey progressed in age. These field and laboratory studies reported here were therefore undertaken to evaluate the predation efficiency of C. lunata on A. craccivora.

8.2 MATERIALS AND METHODS

8.2.1 Preferred Prey Stage.

9.2.1.1 Laboratory test on preferred prey stage of C. lunata

Ten individuals of each of the aphid stages were introduced into the experimental arena (see counting technique in chapter 3). The aphids were allowed 15 minutes to settle before a single unfed one-day old adult C. lunata was introduced. The duration of the experiment was 2 hours after which the number of aphids consumed were noted. This experiment was done for both sexes of C. lunata and for each sex there were 10 replicates.

8.2.1.2 Field test on preferred prey stage of C. lunata.

These studies were conducted on caged cowpea plants aged 20 Day After Planting (DAP) and growing singly in 9.0 litre plastic buckets in the open field. Ten individuals of each of the aphid stages were placed on the plant. The aphids were allowed 15 minutes to settle, after which a single day old unfed adult C. lunata was introduced into the cage (Fig. 22). This arrangement excluded other natural enemies and disturbance from wind and rain. A sheet of wax paper was spread on the soil in the bucket to facilitate retrieval of any fallen aphid. There were 10 replicates for each sex of the predator.

Fig. 22 Arrangement of equipment for studies on field test of preferred prey stage.

8.2.2 Prey Capture Efficiency.

Ten individuals of a particular A. craccivora instar were placed on the undersurface of a freshly detached cowpea leaf in a 9.0 cm petri-dish and allowed to settle (see counting techniques). An unfed one-day old C. lunata was introduced and observed as it attempted to seize the aphids. The number of times the predator encountered and captured an aphid was recorded. An encounter was assumed when a predator touched an aphid or when the latter moved away from the direct path of the former at a very close range (Dixon, 1959; Dixon and Russel, 1972). Recording was stopped when a predator seized an aphid.

Twenty encounters were allowed for each C. lunata. A recording was rejected if a predator, after 20 encounters, failed to seize an aphid. Furthermore, a predator was removed after a successful capture of an aphid. The captured aphid was replaced and the aphids were allowed 15 minutes to resettle, and another predator introduced for the continuation of the experiment. After three aphids were captured, from a colony of ten, the whole set up was discarded and a new set (as described above) with fresh aphids obtained to exclude the possibility of the aphids learning to avoid the predators. The experiment was conducted with the different larval instars and adults of the predator (C. lunata) and the prey (A. craccivora). Prey

capture efficiency is defined in two ways. "Encounter Efficiency" (EE) which is defined as the percentage of prey captured out of the total number of encounters made and "Percentage Efficiency" (PE), defined as the percentage captured from the number of aphids offered.

8.2.3 Voracity.

Two hundred and fifty aphids of the same instar were introduced into an arena as described before (see counting techniques in chapter 3) and allowed 15 minutes to settle. An unfed one-day old (adult or larva) C. lunata was introduced into the arena and the whole set-up (Fig. 23) was left undisturbed for 24 hours (under normal laboratory conditions) after which the number of dead aphids was recorded. Dead aphids included those whose bodies were not found as well as cadavers with parts of the body eaten, the cause of their death was assumed to be as the result of the predatory action of the coccinellid. This experiment was carried out for all the instars and adults of the predator and prey. Twelve replications were conducted for each predator/prey stage combination.

Fig. 23 Experimental set-up for studies on C. lunata voracity

8.2.4 Handling Time of Prey.

Twenty aphids were released onto the undersurface of a two week old detached cowpea leaf placed in a 9.0 cm petri-dish with the upper surface facing downwards (see counting techniques in chapter 3). Each petri-dish contained aphids of the same instar. A coccinellid of a known age (eg. 3rd instar) was introduced into the petri-dish and observation commenced with a binocular microscope. The time taken to consume the different instars of the aphid by all stages of the predator were recorded with stop-watch. A predator was considered unable to consume its prey if after 8 hours the captured aphid was still alive.

8.3 RESULTS

8.3.1 Preferred Prey Stage

Irrespective of the sex of the predator, the number of aphids consumed in a 2-hour period decreased as the aphid age increased (Table 16). The predator showed a marked preference for the early larval instars of the prey. The fourth instar apterae and alate were relatively more preferred than the adults. For instance, the male C. lunata consumed an average of 7 first instar aphid within 2 hours, while only an average

of 2 adults was consumed (Table 16). The female coccinellid consumed 7 1st instar aphids compared to 4 adult aphid over the same time duration.

The results obtained for male C. lunata in the field are similar to those of the laboratory. While the predators showed preference for first, second, third apterae and alates instar, the adult aphids were the least preferred (Table 16). As was in the laboratory results, the fourth apterae and alate instars were moderately preferred. The mean number of first instar aphid consumed by the male was 8.30 $\pm$ 0.44, while 3.40 $\pm$ 0.06 of the adult aphids were consumed.

On the other hand, the females in the field showed marked difference from what was observed in the laboratory. The mean number of first and second instar aphid consumed were significantly different from third and fourth instar apterae which in turn were different from third and fourth alates when separated by Duncans new multiple range test. The adult aphids were the least preferred (Table 16). This showed a significant preference for I and II instar aphids. The mean number of first instar consumed was 8.90 $\pm$ 0.37, whereas that of the adult was 4.50 $\pm$ 0.70 aphids.

Table 16. Stages of prey preferref by C. lunata adults.

A. craccivora instars	Mean number of prey consumed within 2 hours by C. lunata (Mean ± SE)*.			
	Laboratory test		Field test	
	Adult male	Adult female	Adult male	Adult female
I	7.00 ± 0.64 a	7.30 ± 0.61 a	8.30 ± 0.44 a	8.90 ± 0.37 a
II	5.70 ± 0.59 ab	7.60 ± 0.54 a	7.30 ± 0.53 ab	8.20 ± 0.44 ab
III apterae	5.70 ± 0.42 ab	7.30 ± 0.49 a	7.10 ± 0.27 ab	7.00 ± 0.66 bc
III alate	5.30 ± 0.57 ab	6.90 ± 0.60 a	6.50 ± 0.85 ab	6.10 ± 0.70 cd
IV apterae	4.90 ± 0.68 b	6.70 ± 0.53 a	6.20 ± 0.74 b	6.80 ± 0.69 bc
IV alate	4.40 ± 0.26 b	4.90 ± 0.67 b	6.00 ± 0.51 b	5.70 ± 0.63 cd
Adult	2.30 ± 0.56 c	4.30 ± 0.36 b	3.40 ± 0.60 c	4.50 ± 0.70 d

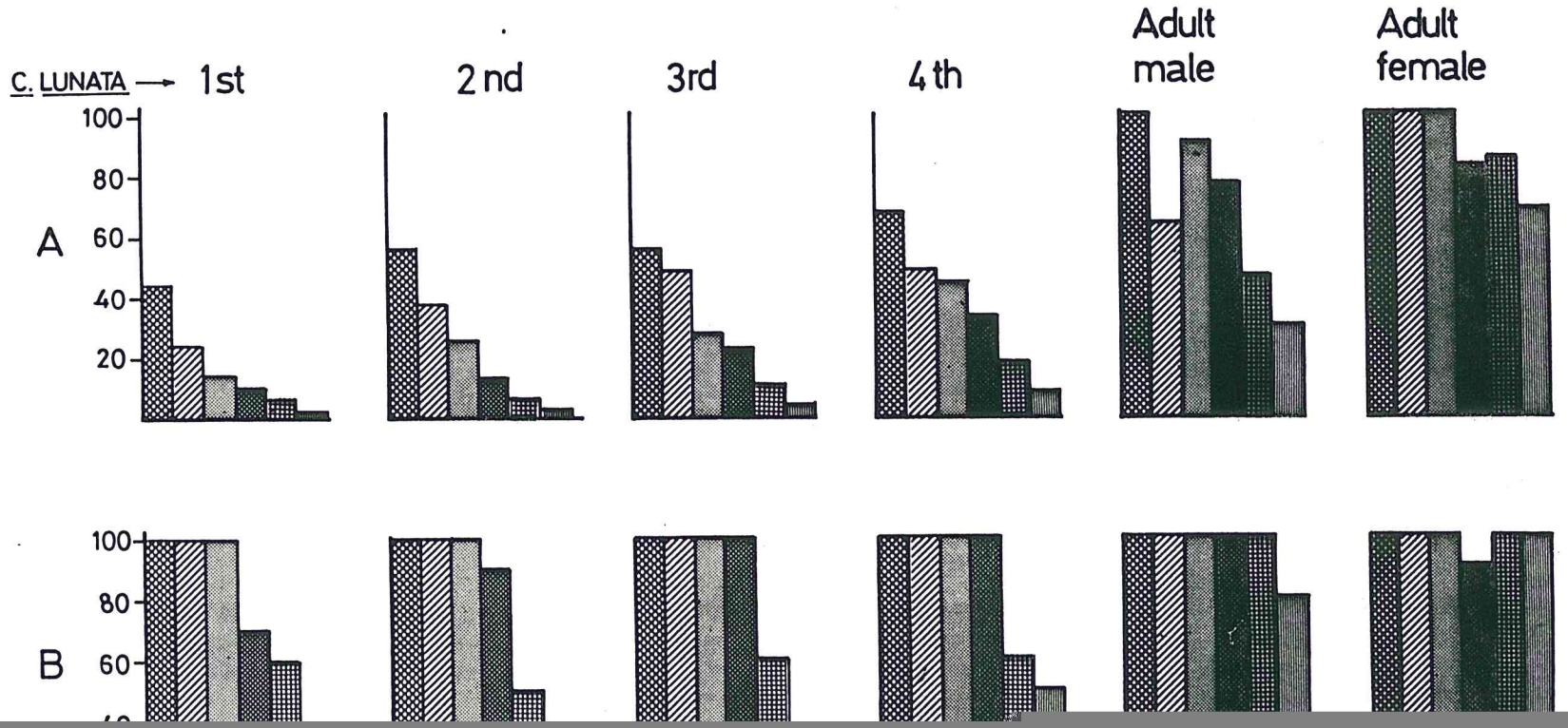
*Means within the same column followed by the letter(s) are not significantly different at p = 0.05 level by Duncan's new multiple range test.

8.3.2 Prey Capture Efficiency.

Figures 24 a and b show the efficiency of the different C. lunata developmental stages in capturing different aphid instars. In Fig. 24 a, prey capture efficiency is illustrated in terms of the number of encounters recorded before a successful capture was made. It is seen that adult females, males and fourth instars of C. lunata were more successful than the early larval instars in capturing aphids. In first instar larvae, the encounter efficiency (EE) decreased as the aged. The EE of capture was 43.5% for first instar aphid larvae, 24.4% for instar two, 15.4% for instar three, 9.6% for fourth apterae, 6.7% in fourth alate and 1.1% in adult aphids.

The second, third and fourth larval instars of C. lunata followed a similar trend of decrease in capture efficiency as the prey stages develop. The EE range for second instar larvae was from 1.9% for adult aphid to 55.6% for first instar aphids. The encounter efficiency was 38.5%, 25.6%, 13.4% and 5.7% for aphid instar II, III and IV (apterae and alates) respectively.

For the third instar larvae, the EE varied from 3.7% for adult aphid to 55.6%,for 1st instar aphids. Encounter efficiencies of 47.6%, 27%, 21.7% and 11.3% were obtained for 2nd, 3rd and 4th (apterae and alates) instars respectively.


C. LUNATA →
1st
2nd
3rd
4th
Adult male
Adult female
A
B
100
80
60
40
20

For the fourth instar C. lunata, the EE varied from 8.2% (adult aphid) to 66.7% (1st instar aphid). Encounter efficiencies of 47.6%, 43.5%,33.3% and 17.2% were recorded for IInd to IVth instar alate aphids respectively.

The encounter efficiency of adults of C. lunata differred from those of the larval instars. In the adult male, the EE varied from 29.6% to 100% while in the females, the EE varied from 66.7% to 100%. The lower EE were recorded in the adult aphids while 100% EE were recorded for first instar aphids. Ecounter efficiencies of 90.9%, 75.9%, 62.5% and 45.5% were recorded for IInd, IIIrd and IVth (apterae and alate) aphids for adult male C. lunata. For adult female, 66.7% EE was recorded for IInd and IIIrd instar aphids, while 81.8% and 83.3% EE were recorded for IVth apterae and alates respectively.

The percentage successful capture made by C. lunata against each larval instar of A. craccivora are given in Fig. 24 b. First and second larval instars were less successful than either third or fourth larval instars which were also less successful than the adult males and females in prey capture. Thus, the first instar showed an efficiency ranging from 20% to 100% against the various larval instars of the prey. The second larval instar of C. lunata was 100% efficient against Ist, IInd and IIIrd instar aphids but only 50% and 20% against

IVth alate and adult aphids respectively. Percentage capture efficiency (PE) of 90% was recorded for IVth apterae aphid.

Third and fourth larval instars of C. lunata had a 100% PE in capturing the first four instars of aphids, but showed 60% PE in capturing IVth alate, 30% and 40% PE for adult aphids respectively. The PE for adult C. lunata varied from 80% to 100%. In the male, 80% was recorded for the adult aphid and 100% for the other larval instars. In the female, 90% was recorded for IVth instar apterae whereas it had 100% PE for the other instars.

8.3.3 Voracity.

Figure 25 shows the mean number of different larval instars and adults of A. craccivora consumed by the different larval instars and adults of C. lunata per day. The number of aphids consumed by adult or larval predator decreased as the aphid aged (Fig. 26 a). It was also observed that as the predator aged, the mean number of aphids consumed increased (Fig. 26 b). Regression analyses of the mean number of aphids consumed by the different larvals instars and adults of C. lunata fitted well with asymptotic and logarithmic linear regression equations (Fig. 25). First and second instars

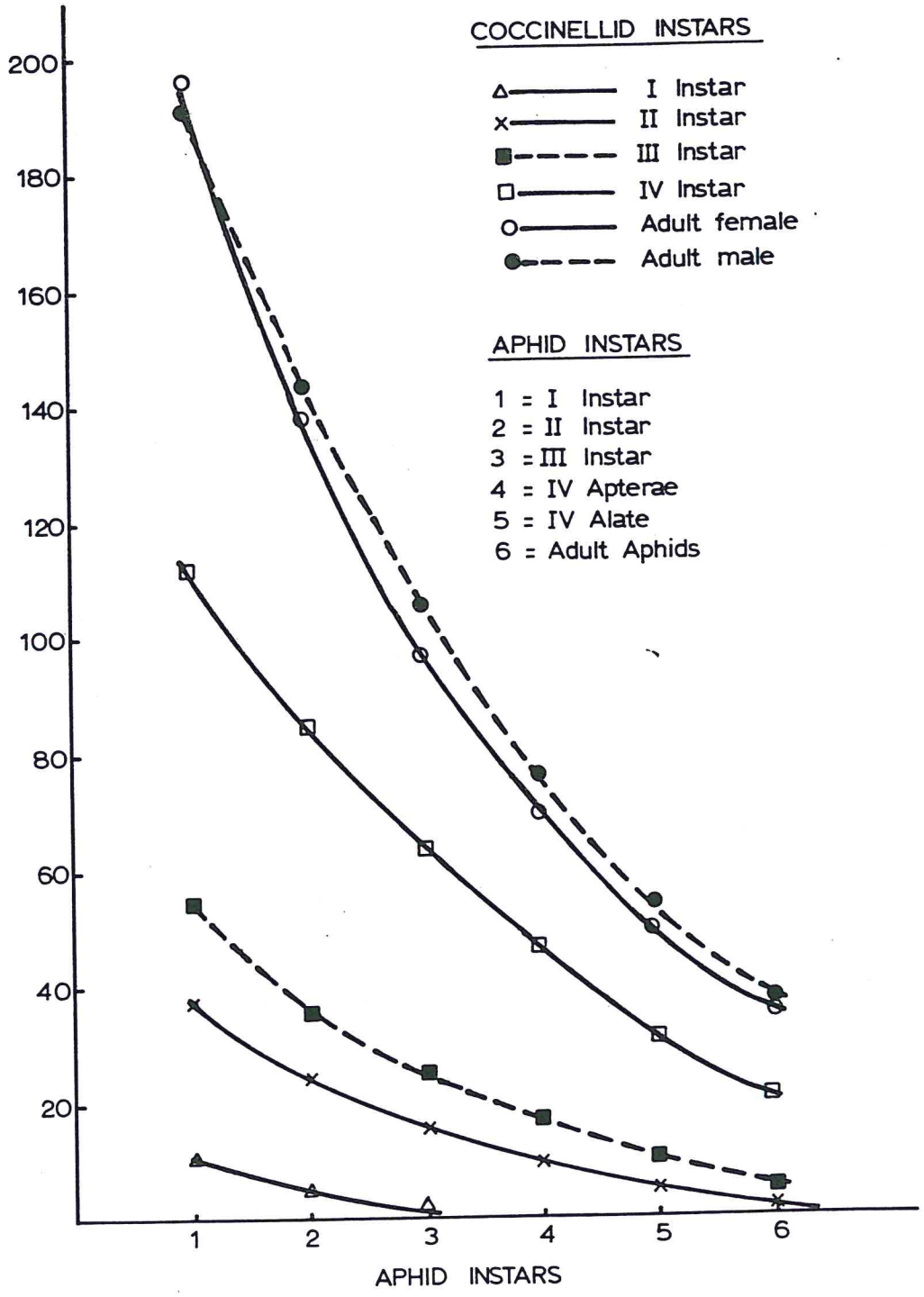


FIG. 24. MEAN NUMBER OF A. CRACCIVORA CONSUMED BY THE DIFFERENT INSTARS AND ADULTS OF C. LUNATA PER DAY.

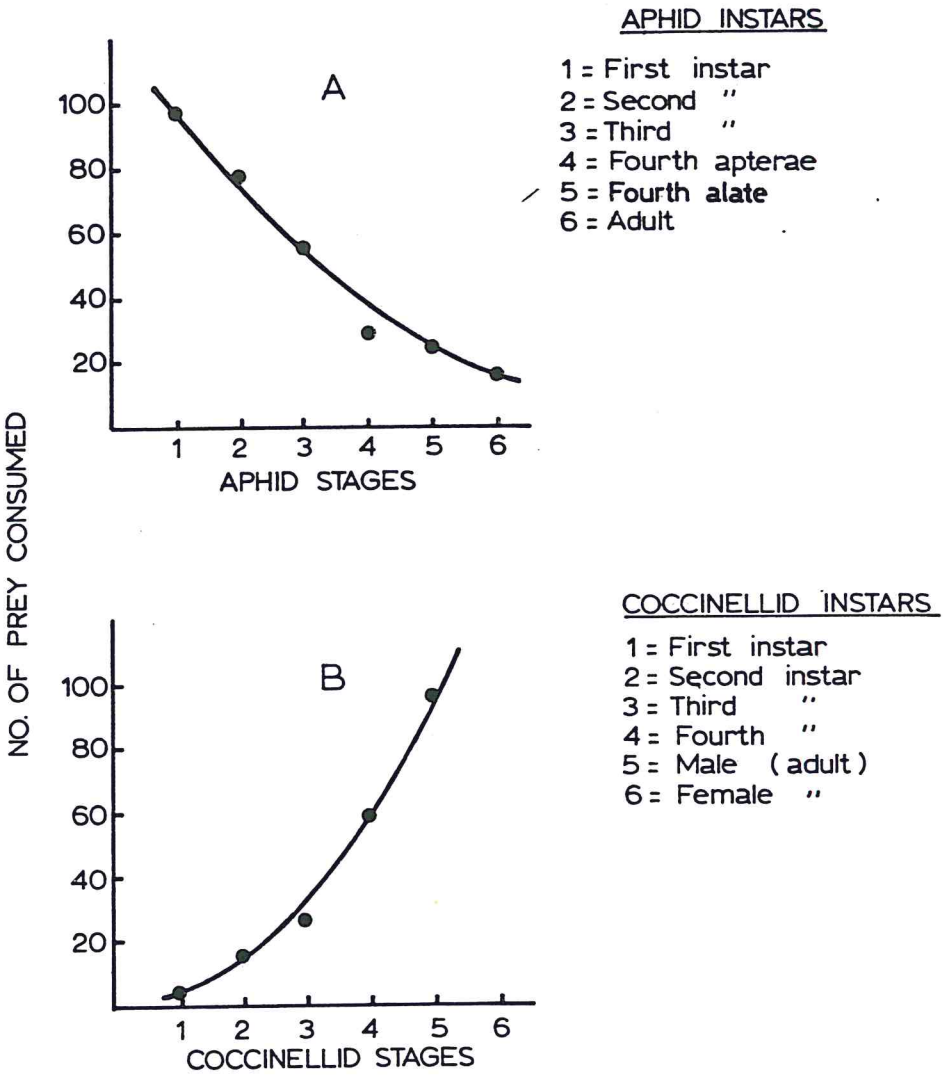


Fig. 26. Relationship between developmental stages of predator/prey and the number of Aphid eaten.
(a) Negative relationship between the number of Aphid consumed and their stages of development.
(b) Positive relationship between the stage of development of C. lunata and the number of Aphids consumed.

of C. lunata fed mainly on the first three larval instars of the aphid, whereas the older larvae fed on all the aphid stages offered. First instars of C. lunata were unable to kill and consume fourth instars and adults of A. craccivora. However, the mean number of the first three aphid instars consumed were not significantly different at p=0.05.

Second instar larvae of C. lunata were able to consume all the aphid larval instars except the adults, however, the number consumed decreased as the aphid aged. There were no significant differences between the number of the Ist and 2nd instar of the aphids consumed but the consumption for these two instars significantly differed (p=0.05) from that for older larvae. Third, fourth, adult male and female C. lunata were able to consume all the aphid stages and like the others, the number consumed decreased significantly as the aphid aged (see appendix table 13).

The low percentage of aphids consumed by the lst two larval instars (Table. 17) was not important in the total consumption of C. lunata. The greatest food consumption was noted in the adult males and females both of which consumed about 33% of the total A. craccivora presented.

8.3.4 Handling Time of Prey.

The time taken for the different stages of the predator to completely consume different stages of aphids is represented in Table 18. There was a direct relationship between the age of the predator and the time taken to consume an aphid of the same instar. This relationship showed that as the aphids aged, the handling time also increased. First instar coccinellids spent a mean time of 19.8, 67.8 and 480.0 (unfinished) minutes to consume first, second and third instar aphids respectively. They were, at times, able to catch aphids of the higher instars (Fourth instars and adults) but unable to kill and consume them.

Second instar larvae of C. lunata spent less time in consuming the different instars of A. craccivora, but were unable to consume the adults. As was in first instar coccinellid, the handling time increased for all other instars as the aphids aged. The time taken by second instars of C. lunata to consume the different instars varied from 18.0 to 214.2 minutes (Table 18).

Third and fourth instars of C. lunata consumed all all stages of the aphid. The handling time for these coccinellid instars also increased as the aphids progressed in age. The time taken to consume the different instars varied from

Table. 17 Proportion of food intake by the individual growth stages of C. lunata.

	Aphid prey		
C. lunata instars	Total consumption	% consumed	Mean consumed /instar
I	193	0.09	2.68 ± 0.41
II	1,092	5.06	5.16 ± 1.60
III	1,778	8.24	24.69 ± 2.24
IV	4,255	19.71	59.05 ± 4.16
Adult male	7,081	32.84	98.37 ± 6.96
Adult female	7,170	33.24	99.54 ± 7.19
12 replicates/instar			

Table 18. The average time taken (minutes) by C. lunata to consume the different A. craccivora instars.

A. craccivora	C. lunata instars					
	I	II	III	IV	Adult Male	Adult Female
	Time taken to consume an aphid (Mean ± SE)*					
Adult	-	-	42.86 ± 2.89 (20)	8.91 ± 0.29a (20)	1.54 ± 0.06a (20)	1.37 ± 0.06a (20)
IV Alate	-	214.20 ± 9.12a (5)	42.29 ± 1.99a (20)	8.16 ± 0.35b (20)	1.01 ± 0.02b (20)	1.45 ± 0.04a (20)
IV Apterae	-	200.00 ± 7.51b (5)	21.46 ± 0.53b (20)	7.39 ± 0.20c (20)	0.84 ± 0.04c (20)	1.11 ± 0.04b (20)
III instar	480 (unfinished)a (2)	97.20 ± 5.52c (10)	12.28 ± 0.41c (20)	6.05 ± 0.24d (20)	0.76 ± 0.03c (20)	1.05 ± 0.01b (20)
II instar	47.80 ± 2.24b (15)	58.85 ± 2.97d (20)	8.49 ± 0.46cd (20)	2.97 ± 0.23e (20)	0.27 ± 0.01d (20)	0.27 ± 0.06c (20)
I instar	19.83 ± 1.03c (15)	18.00 ± 0.70e (20)	7.03 ± 0.30d (20)	1.44 ± 0.13f (20)	0.14 ± 0.00f (20)	0.05 ± 0.01d (20)

*Means within the same column followed by the same letter(s) are not significantly different at p = 0.05. (Values in parentheses indicate the number of replicates).

7.03 to 42.86 and 1.44 to 8.91 minutes for 3rd and 4th instars of C. lunata respectively. The handling time of all aphid by the adult males and females was relatively short compared to that for the larval instars (Table 18). However, for the larval coccinellids, the time taken to consume an aphid increased with the age of the aphid. In all case, adult males of C. lunata, the handling time ranged from 0.14 to 1.54 minutes whereas the time range of 0.05 to 1.42 minutes was recorded for adult female C. lunata .

8.4 DISCUSSIONS

8.4.1 Preferred Prey Stages.

All the stages of C. lunata tested showed preference for early larval instar (especially, the first and second) of the aphid. Similar results were obtained by Firempong and Kumar (1975) for the coccinellid predator (P. ferruginea) of cocoa on the aphid (T. aurantii) in Ghana. These authors observed heavy predation on the first and second aphid instars by all stages of development of their predators whereas the fourth instar and adult aphids are attacked and captured mainly by fourth instar and adult coccinellids. Ofuya (1986) in his studies on the predatory coccinellid C. vicina on cowpea aphid (A. craccivora) in Nigeria also reported similar results. He

noted that all the stages of C. vicina tested consumed more of the first and second instars of the prey than the third and fourth instars which in turn suffered heavier predation than the adult aphids. Fernando and Hassell (1980) showed that Phytoseiulus persimilis (Athias-Henriot) a predatory mite, preferred eggs and larvae than protonymphs and deutonymphs.

The reason for the said preference is not clear, however, Ofuya (1986) suggested that aphids defensive tactics which are more effected in the older instars than in the younger instars may have contributed. Similar defensive behaviour was reported by Dixon (1958), Brown (1974) and Firempong and Kumar (1975). From these study and others quoted above, it is evident that coccinellid predator attacking a young aphid larva is more likely to succeed in capturing and consuming it than if it attacks an older larva. This may explain why the older aphid instars of A. craccivora were hardly attacked by younger predators and few members consumed.

Another probable reason may be the fact that younger aphid instars are tender and probably more succulent than the older aphids which may be relatively tough and hard. This might also explain why adult aphids were mostly sucked up and the younger instars eaten whole (Firempong and Kumar, 1975).

The size of the aphid stages may have played an important role. The number of first and second instar aphids needed to satiate a predatory coccinellid may be more as a result of their smaller size than the number of adult aphids needed for the same purpose. This be the reason why C. lunata adults consumed more of the early larval instars of the prey than the adults. The direct relationship between the developmental stage of the predator and the number of prey consumed is inturn related to the capture efficiency of the predator. Conversely, there is a direct relationship between the developmental stage of the aphid and its vulnerability to capture. This is explained by the defensive behaviour tactic employed by the aphids which is more effective in older aphids than younger ones.

8.4.2 Prey Capture Efficiency

All the stages of C. lunata displayed variable efficiency in their capacity to capture different instars of A. craccivora in the laboratory. The variability observed could be associated with the defensive behaviour of the prey and the relative size of the predator to the prey.

The efficiency of C. lunata also varied with its stage of development as well as with that of its prey. Generally, efficiency improved with each succeeding instar until it

attained its maximum hight in the adult coccinellid (Dixon, 1959; Firempong and Kumar, 1975). It could be that as they grew up, they become more experience in handling their prey. However, the females proved to be more efficient than the males. Moreover, it was observed that the efficiency of any stage of development decreased as the aphids progresed from one stage of development to the next.

On the whole, first instar larvae of C. lunata cannot be considered as inefficient predators since they are able to capture and immobilize high proportion of the early aphid instars. Since an aphid colony comprises individuals in all stages of development, but the majority are always in their early larval instars, it follows that young coccinellid larvae will never die of hunger as a result of their low efficiency in capturing aphids.

8.4.3 Voracity.

The observation that females C. lunata consumed more aphids than the males (Fig. 24), agrees with that of Gowande (1965) and Ofuya (1986). The high number of aphid consumed by females may be explained by their ovipositional requirement (Okrouhla et al., 1983). These results show that there is a

general pattern in the numbers of aphids consumed by coccinellids. The numbers of aphids consumed by the different instars and adults of C. lunata was much higher than that recorded by Ofuya (1986). Although both studies were conducted in different environments and so were the coccinellid species used for the studies, C. lunata seem to be a more promising agent for the biological control of cowpea aphids.

The reason for the low number of aphids consumed by the 1st two larval instars of C. lunata may be related to the defensive behaviour shown by the prey as observed in this studies. Brown (1972); Firempong and Kumar (1975) and Ofuya (1986) reported similar defensive behaviour for other aphid species. The high rate of aphid consumption by successive C. lunata larval instars and adults may be related to their large size and the greater ability to subdue their prey. It is also conceivable that as the predators mature, they become more "experienced" in handling prey.

However, 1st and 2nd larval instars of C. lunata were unable to consume certain stages of their prey (Fig. 25) which showed contrast with early publication by Ofuya (1986). The reason may be related to the attacking behaviour of C. vicina which may be different from that of C. lunata. C. lunata lifts its prey from the substrate during feeding. This feeding behaviour made any defensive tactics by the aphid ineffective.

8.4.4 Handling Time of Prey

The relatively short prey handling time by adults of C. lunata is an indication that this stage is the most important stage of the predator as more aphids were consumed due to less handling time. Dixon (1959) reported that first instar larvae of A. decempunctata took thirty times as long as a fourth instar larva to consume the same stage of prey. This report supports the result obtained in this study with C. lunata.

Chapter 9

FUNCTIONAL RESPONSE OF C. LUNATA TO DIFFERENT PREY DENSITIES.

9.1 INTRODUCTION

Functional response is the change in number of prey eaten per unit time by each predator in relation to a change in prey density (Solomon, 1949). Holling (1959) identified three fundamental types of functional response curves which he named as type I, II and III. Infact, the form of the functional response curves is determined by the behavioural options open to the predator and by the characteristic of the prey to which it is exposed (Murdock and Oaten, 1975). Lately, there has been much interests in many insect predators of aphids (Potts and Vickerman, 1974; Potts, 1977), but little or no attention had been given to the cowpea aphid predator, C. lunata. This study was therefore undertaken to examine the effect of prey density on the amount of cowpea aphids consumed by C. lunata and to determine the functional response curves of adult predators to selected prey stages.

9.2 MATERIALS AND METHODS

The functional responses of adult males, and females of C. lunata were determined in the laboratory using a 9.0 cm petri-dish as the study arena. Different densities of selected prey instars (1st and 3rd larval instars and adults) were counted onto the undersurface of a detached cowpea leaf placed in a 9.0 cm petri-dish with the uppermost surface facing down (see counting procedure in chapter 3). The densities used were 5, 10, 20, 40, 80, and 160. A one day starved (pre-conditioned) C. lunata adult was introduced in each petri-dish and the set up left for a period of two hours. The exposure period of two hours was chosen to minimise larviposition by adult aphids. The second factor being that A. craccivora could change from one instar level to the next if a longer exposure period was used. At the end of the exposure period, the number of aphids consumed was recorded. These included cadavers as the cause of their death was considered to be the effect of predation.

9.3 RESULTS

The functional responses of C. lunata hinges both upon the density of the prey and the ability of the predator to find and capture their prey (searching ability). On the whole, consumption rate increased curvilinearly with increase in prey

density to either exponential growth or sigmoid curves. Thus, at high aphid density the predator effectively spent all its time handling prey, and the predation rate reached a maximum determined by the number of aphids consumed (see Table 19).

There is an upward sweep in the functional response curves (Figs. 27-32) because an increase in density elicits a decreased searching area and thus an increase in the effective encounter and attack rates. The response curves followed a type III functional response. The functional response curve of male C. lunata with first instar aphid (Fig. 27) showed increase in the aphid populations consumed with increase in prey density. For example, at prey densities of 5, 10, 20, 40, 80, and 160, the mean number of prey consumed were 4.2, 6.1, 15.0, 25.4, 37.4, and 72.6 respectively. The results for third instar and adult aphids followed the same trend of increase in the aphid population consumed with increase in aphid density (Figs. 28 and 29), however, Fig. 28 increased in a decreased proportion thereby approaching a sigmoid shape.

For the female predator, the predation rate increased with the increase in prey density. For example, Fig. 30 shows that at prey densities of 5, 10, 20, 40, 80, and 160, the mean number of first instar aphid consumed were 3.8, 8.3, 16.3, 27.6, 57.3, and 116.3 respectively. The data for third instar

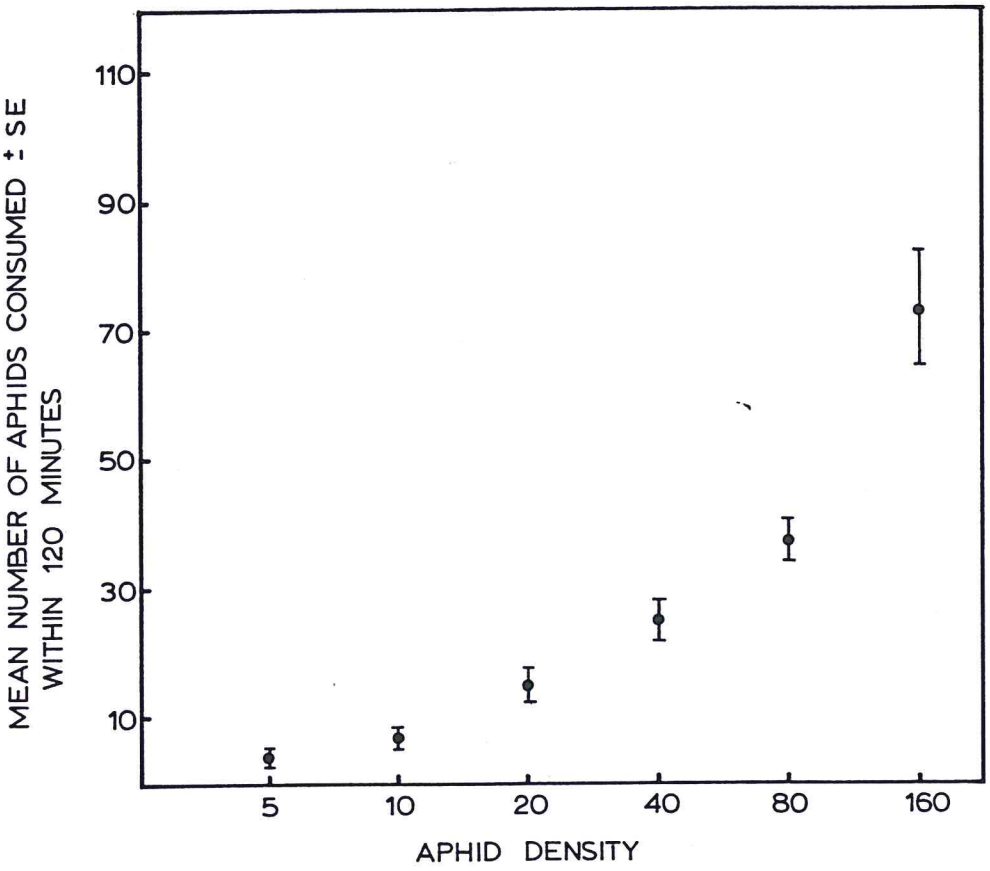


FIG. 27. FUNCTIONAL RESPONSE OF ADULT MALE C. LUNATA WITH INCREASE DENSITY OF FIRST INSTAR A. CRACCIVORA

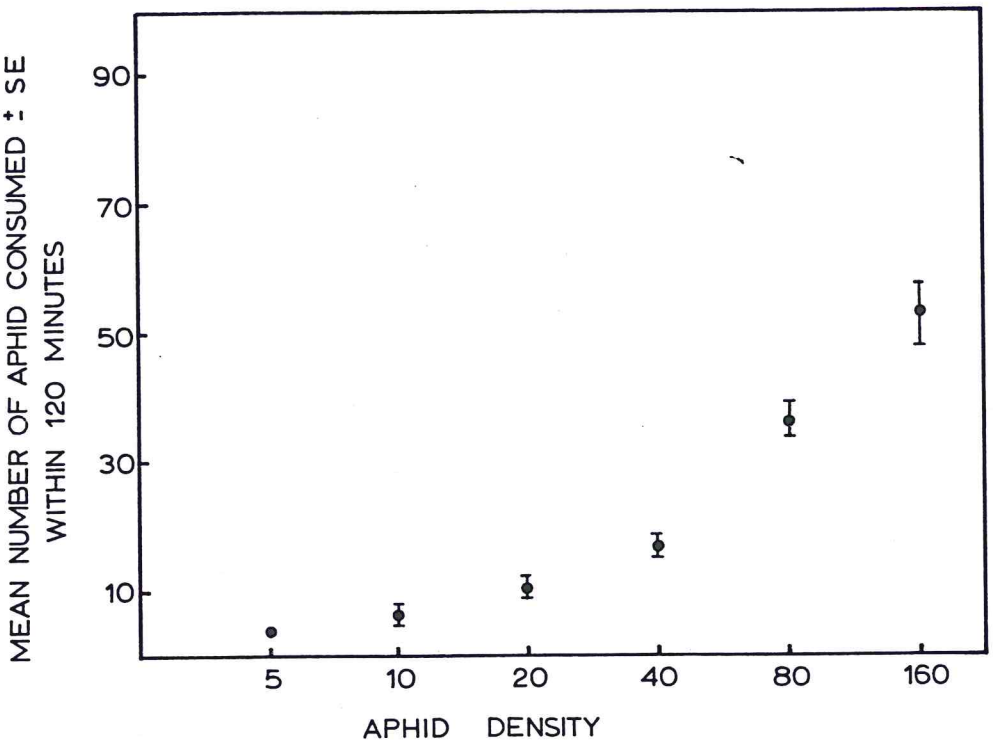


FIG. 28. FUNCTIONAL RESPONSE OF ADULT MALE C. LUNATA WITH INCREASE DENSITY OF THIRD INSTAR A. CRACCIVORA

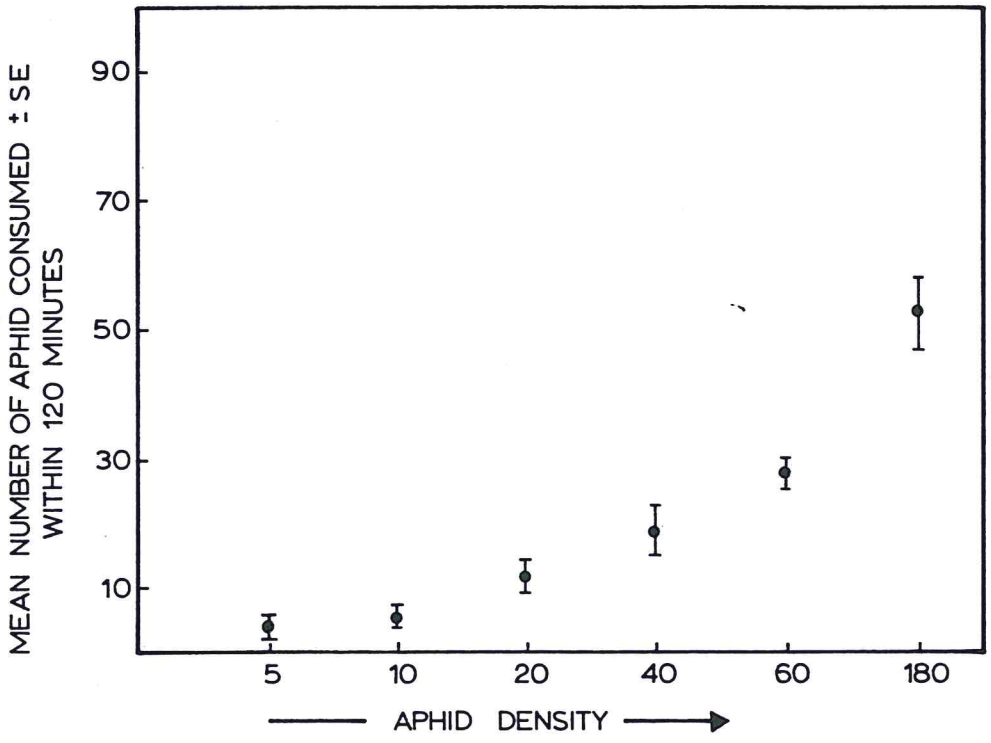


FIG. 29. FUNCTIONAL RESPONSE OF ADULT MALE C. LUNATA WITH INCREASE DENSITY OF ADULT A. CRACCIVORA

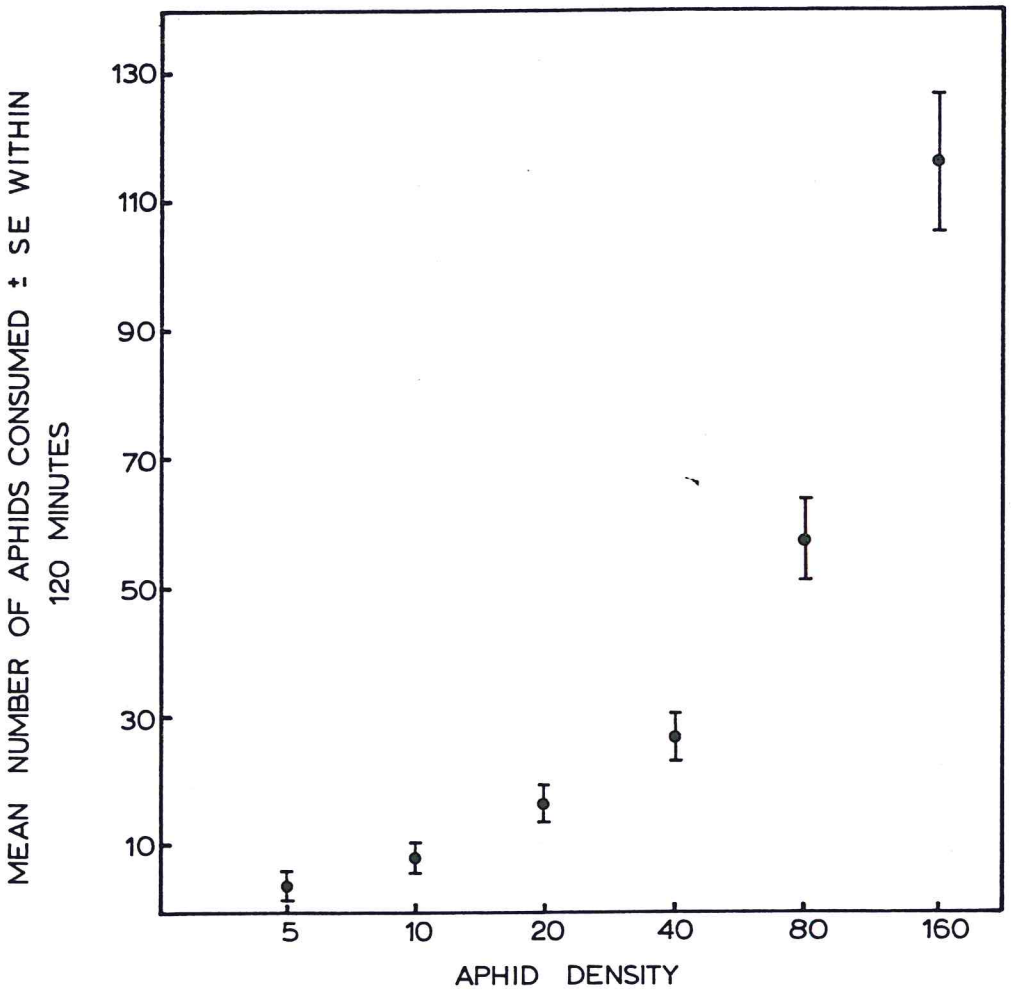


FIG. 30. FUNCTIONAL RESPONSE OF ADULT FEMALE C. LUNATA WITH INCREASE DENSITY OF FIRST INSTAR A. CRACCIVORA

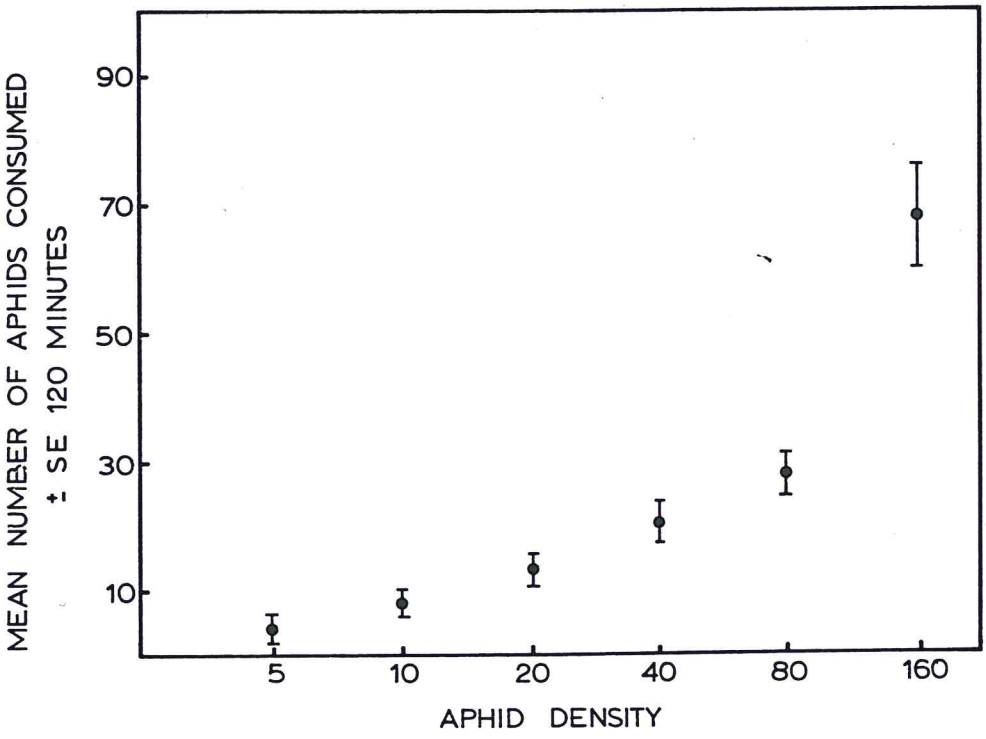


FIG. 31. FUNCTIONAL RESPONSE OF ADULT FEMALE C. LUNATA WITH INCREASE DENSITY OF THIRD INSTAR APHIS CRACCIVORA

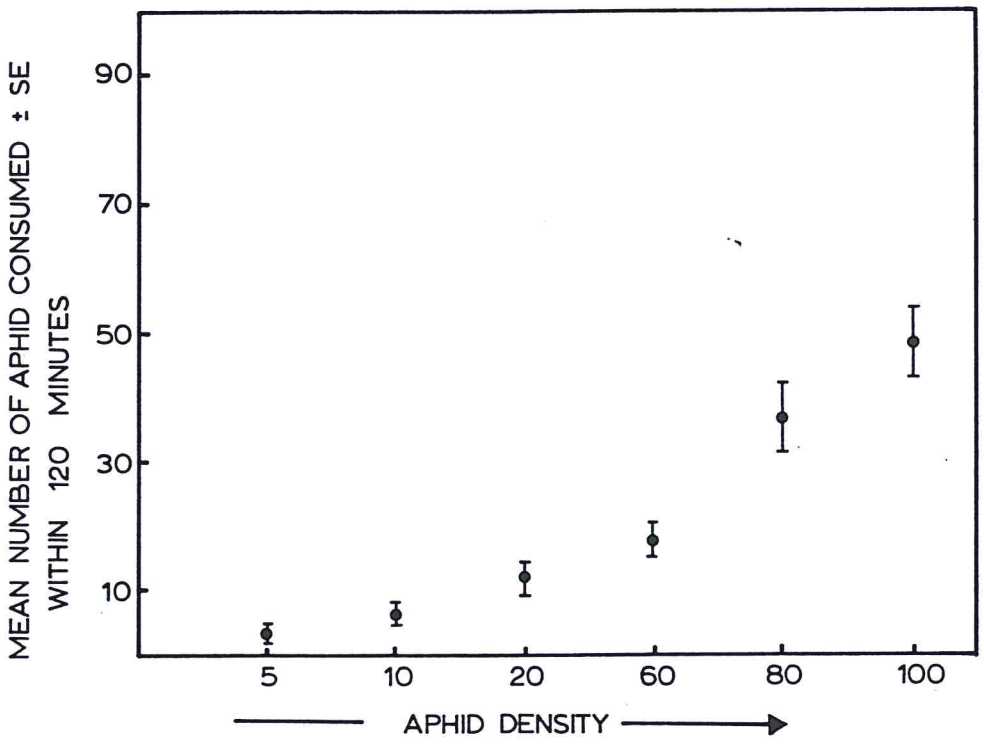


FIG. 32. FUNCTIONAL RESPONSE OF ADULT FEMALE C. LUNATA WITH INCREASE DENSITY OF ADULT A. CRACCIVORA

and adult aphids followed the same trend of increased predation rate with increase in prey density. Although Fig. 32 shows increase in predation rate as the aphid density increased, the rate of increase was rather gradual after the prey density of 80, resulting in a sigmoid or S-shaped curve which is a typical type III functional response curve. Moreover, adult female predators consumed more aphid of all instars than the males. Table 22 showed that while adult females consumed (within 120 minutes) a total of 2296, 1409, and 1227 of first, third and adult aphids respectively, the males consumed only 1607, 1266, and 1169 of the same aphid instars respectively.

9.4 DISCUSSIONS

The level of functional response curves of adult C. lunata depended largely on the stage of the prey supplied, the prey density and the sex of the predator. Other factors that are likely to determine the shape of functional response curves had been reported. For example, Sabelis (1985) observed that the extent of aphid feeding depends on the searching capacity of the predator. However, Solomon (1949) considered prey density as the crucial factor determining the response of predators. Holling (1966) proposed the rate of successful

Table 19 Mean number of prey consumed by 10 adults of *C. lunata* at different prey densities within two hours.

Sex of adult *C. lunata*	*A. craccivora* instars	Mean prey consumetion (+SE) at different densities						Total aphid consumed
		5	10	20	40	80	160	
Male	I	4.2 ± 0.41	6.1 ± 1.19	15.0 ± 1.71	25.4 ± 3.17	37.4 ± 3.29	72.6 ± 10.95	1607
	III	4.3 ± 0.33	5.9 ± 0.88	10.3 ± 0.89	16.2 ± 1.28	36.5 ± 2.00	53.4 ± 5.34	1266
	Adult	3.1 ± 0.40	5.7 ± 1.07	11.2 ± 1.51	18.1 ± 2.55	26.5 ± 2.21	52.3 ± 6.79	1169
Female	I	3.8 ± 0.43	8.3 ± 1.00	16.3 ± 1.50	27.6 ± 2.56	57.3 ± 6.70	116.3 ± 9.73	2296
	III	4.1 ± 0.31	7.5 ± 0.79	13.3 ± 1.63	20.3 ± 1.87	28.0 ± 2.31	67.7 ± 7.68	1409
	Adult	3.9 ± 0.40	6.4 ± 1.03	11.8 ± 2.25	17.5 ± 1.46	36.0 ± 5.06	47.1 ± 4.29	1227
T O T A L		234	399	779	1251	2217	4094	8974

10 replicates for each aphid density/instar

search, the searching time, handling time of prey and the hunger level of the predator as the major factors affecting the functional response of a predator. Murdock and Oaten (1975) noted that the ability to learn by both the predator and prey determines the form of the functional response curve. Similar observations had been made by other workers. For example, Fernando and Hassell (1980) showed that the maximum number of prey consumed by Phytoseiulus persimilis (Athias-Henriot.) decreased in the following order: eggs, larvae, protonymphs and deutonymphs. This showed a preference for early stages of prey development which in turn is in congruity with the current result. Fransz (in Sabelis, 1985) reported that females of Typhlodromus occidentalis (Nesbitt) consumed more eggs of the two-spotted spider mite than males of this species when each of this species were supplied seperately. It may have been possible that reduced searching effort at high prey density may have contributed to the continous rise in the number of prey consumed. Hodek (1973) noted that at high prey density coccinellid may consume considerably more than the maximum required for their development.

Laing and Osborn (1974) found that disturbance of the predator during feeding by another prey can result in killing more individuals than otherwise might be expected; such interruptions would obviously, be more frequent at high prey densities. All these suggestions may have contributed to the high predation rate recorded in this studies.

Chapter 10.

EFFECT OF PREDATION ON FIELD APHID POPULATIONS

INTRODUCTION.

The effect of predators on the populations of prey has been investigated in a number of crops. For example, Richman et al., (1980) evaluated 16 species of predators in field cages to determine their daily consumption levels of eggs and larvae of the soybean looper, Pseudopusia includens (Walker). He recorded the highest predation rates for the nabids Reduviolus roseipennis (Reuter); Tropiconabis capsiformis (Germar), and Hoplistoscelis deceptivus (Harris). Chamber et al., (1983) measured the changes in the number of cereal aphids inside and outside cages designed to exclude aphid predators (certain Coccinellidae, Syrphidae and Chrysopidae). He noted that populations of aphid increased rapidly in the cages without predators while the populations of aphid outside the cages increased at a slower rate or decreased.

Other studies concerning predator/prey relationship are those of Thead et al., (1988) whose studies were on predation on eggs and larvae of Heliothis virescens (F.) by adult predator complex in cage studies on cotton. They noted that

Hemiptera fed more than the Coleoptera on larvae, while Coleoptera was the best egg predator. Frazer et al., (1981) evaluated the role of aphidophagous predators on the population dynamics of the pea aphid, Acyrthosiphon pisum (Harris) on alfalfa. According to them, the pea aphid numbers increased rapidly in the cages (without predators) to as much as 5 times the density in the adjacent fields with a complex of predators. Cambell (1978) studied the population dynamics of damson-hop aphid, Phorodon humuli (Schrank) in sleeve-cages with or without predators. He observed that aphid populations increased on plants from which predators were excluded by sleeve-cages. Luck et al., (1988) evaluated indigenous natural enemies of the cereal aphids, Sitobion avenae (F.), Metopolophium dirhodum (Walker), and Rhopalosiphum padi (L.) in large field cages. From their population samples, they found that the abundance of Coccinella punctata (F.) was negatively correlated with aphid abundance in the uncaged plots, whereas the incidences of parasitism and disease were not.

In east Africa, there exists a complex of natural enemies in cowpea fields (Okeyo-Owuor, unpublished data). Little is known about the effect of these natural enemies on the population dynamics of cowpea crop pests. This study was undertaken to evaluate the effectiveness of C. lunata (the commonest coccinellid predator) on A. craccivora (one of the major pests of cowpea plant) in caged cowpea plants.

MATERIALS AND METHODS.

The population build-up of A. craccivora in the presence or absence of a coccinellid predators was investigated in caged cowpea plants growing in field. The cages used for this studies were constructed with metal rods and covered with nylon netting with sleeve (Fig. 33).

Newly moulted adult aphids were introduced in pairs on one week old experimental plants (50 in all). The plants were inspected to ensure they were present. The plants were grown at a spacing of 70 cm x 70 cm. After introducing the aphids, the plants were caged and allowed one week to settle and establish. A week after the introduction of the aphids, population counts of the aphids were taken. For the cages in which predators were later introduced, the mean aphid population was found to be 45.84, whereas the mean aphid population in the cages where predators were excluded was 35.64. An adult C. lunata was then introduced in each of 25 randomly selected caged plants, care being taken to prevent the predators from escaping. Twenty five control plants had no predators introduced but were also caged to maintain the same environment in both the coccinellids introduced and coccinellid excluded cages.

Fig. 33 Sleeve cage for evaluating the effect of C. lunata on field aphid populations.

A day after the introduction of the predators, 10 randomly selected plants (5 each from the control and predator introduced) were destructively sampled and the number of live aphids taken. Every day thereafter, the number of aphids on 5 caged cowpea plants with coccinellids and 5 without coccinellids were destructively sampled and the number of live aphids counted. The sampling continued untill all the 50 experimental plants were exhausted.

RESULTS.

The results for the field cage tests are presented in Fig. 34. On day zero (a week after the introduction of aphids), the population of aphids in the cages where coccinellids were later introduced (treated) rose from the initial mean number of 2 to 45.84, while that from which coccinellids were excluded (control) rose to 35.64. Generally, the populations of aphids in the coccinellid introduced cages declined, showing a negative relationship between the predator and prey. In the control cages, the population build-up was rapid.

Twenty four hours after the coccinellids were introduced, the aphid population in cages with coccinellids was reduced from the mean number of 45.84 to 35.20, whereas the population

of aphids in the control cages increased from 35.64 to 54.40. There was a drastic decline in aphid population in cages with coccinellids on the second day. The mean population of aphids reduced from 35.20 to 3.80. For the control, it was a period of rapid population growth. The aphid population increased from the mean number of 54.40 to 107.8 which represents 100% rise. A similar pattern of population development was observed throughout the duration of the experiment. In all, there were two periods of sharp rise in aphid population in the control cages. These occurred between days 1 and 2, and 4 and 5. For coccinellid introduced cages, there was only one period of drastic reduction in aphid population. This occurred 48 hours after the coccinellids were introduced. Although, the aphid population rose on the third day, the rise was brought down again by the coccinellids on the fourth day. Thereafter, the population stabilized (Fig. 34).

DISCUSSION.

Cage exclusion techniques for the study of natural enemies were first used by Smith and Debach, (In Chambers et al., 1983) for the study of parasites of black scale and have since been employed for a range of pests and their natural enemies (Ashby, 1974; Cambell, 1978; Richman et al., 1980;

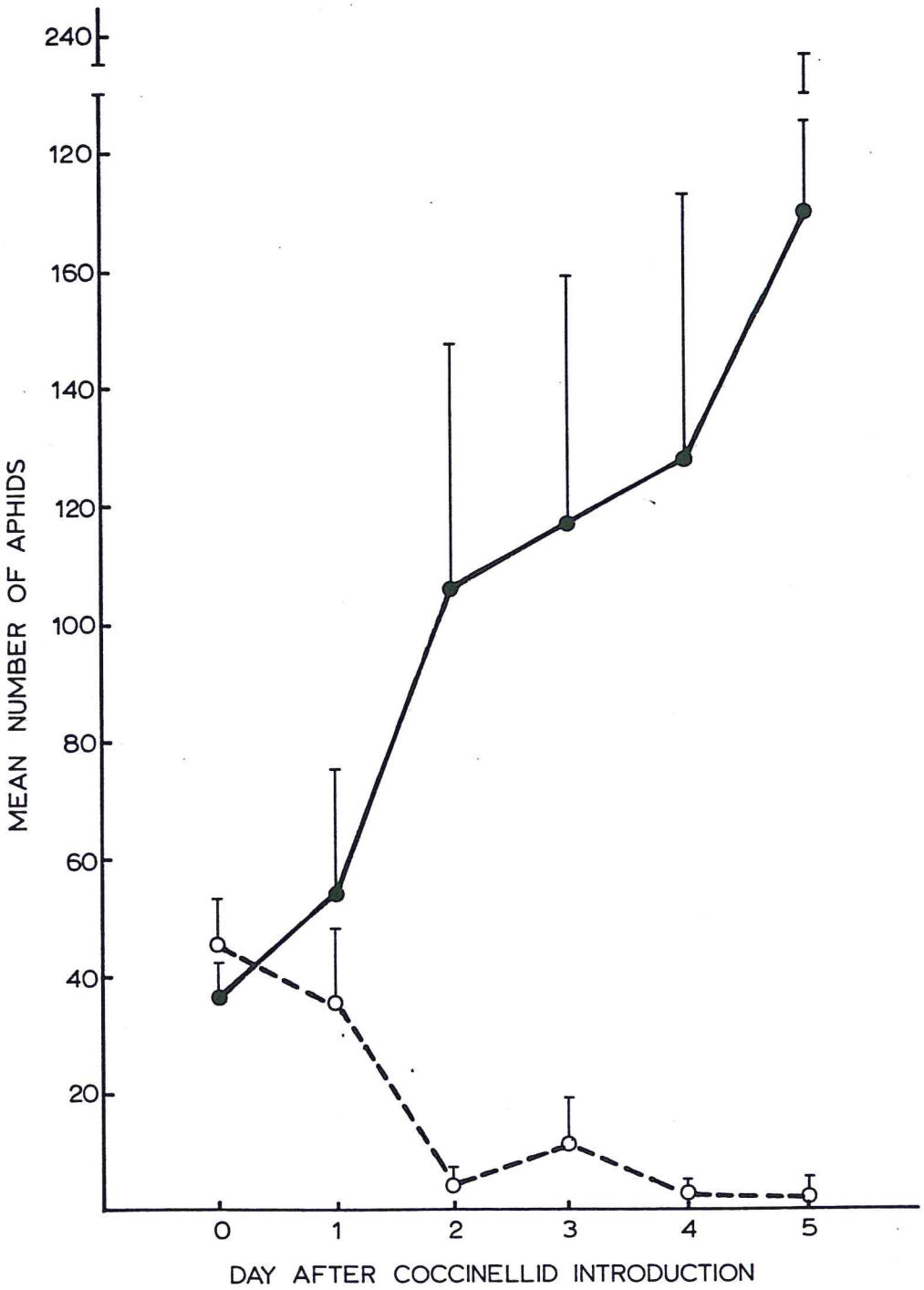


FIG. 34. POPULATION GROWTH RATE OF A. CRACCIVORA IN THE PRESENCE/ABSENCE OF C. LUNATA

Aveling, 1981; Faeth and Simberloff, 1981; Frazer and Gilbert, 1976; Kring et al., 1985).

The rate of population growth of A. craccivora in cages with predators were affected negatively by the presence of C. lunata, while in the cages without predators, aphid population increased five folds before the end of the experiment. Similar results had been reported elsewhere (Frazer et al., 1981; Chamber et al., 1983). The sharp rise in aphid population between days 1 and 2, and 4 and 5 could be attributed to high rate of larviposition. This point is made clear from the number of first instar aphids observed during counting. The slight rise (day 3) in aphid populations in the coccinellid introduced cages may be attributed to the inability of the predators to find their prey at low aphid density. This was also observed in the functional response studies conducted in chapter 6. This type of relationship between predators and prey is what Begon and Mortimer (1981) termed coupled oscillation.

Since C. lunata is the major coccinellid species at Mbita and its environs, it is likely that they were responsible for keeping down the population of A. craccivora to levels that is not harmful to the crops. There is therefore, a need to manipulate the environment to suit their multiplication for an

integrated pest control strategy in cowpea fields. If this is achieved, the recurrent expenditure incurred as a result of chemical control and the side effects associated with chemicals would be minimized (see Kumar, 1984).

Evidence for the effectiveness of C. lunata was published by Brown (1972) when he studied the effectiveness of four predatory beetles in the Orange free state of South Africa. In East Africa, C. lunata was found to be effective as well as abundant (see chapter 5). Since C. lunata possess the means to prevent economically damaging outbreaks of cowpea aphids, methods for improving their abundance and reliability in field crops by modification of habitat or cultural practices would be well worth consideration.

There is therefore, a growing need for an integrated pest control strategy in cowpeas which will take advantage of the naturally occurring control systems, which will in effect, reduce the recurrent expenditure as a result of chemical means of control (Kumar, 1984).

S U M M A R Y.

1. Studies on the biology of C. lunata revealed a range of developmental periods betwwen 13-17 days. This range was determined by the ambient temperature of the months in which the study was carried out; the higher the ambient temperature, the lesser the number of days required to develop from egg to adult.

2. There are 4 stages of development. These are: egg, larval, pupal and adult stages. The two sexes are differentiated in the adult stage; the females are bigger than the males.

3. C. lunata passed through 4 larval instars with a pre-pupal period that lasted between 18-24 hours.

4. The maximum number of eggs laid by a single female within a two week period was 721 while the mean for 6 females within the same period was 554 eggs.

5. C. lunata exhibited multiple copulation which took place at different intervals daily until death occurred.

6. A. craccivora passed through 4 larval instars before the adult stage. There are two morphs in the III and IV larval instars. These are the alate and the apterae.

7. Colonies of A. craccivora comprise of females only. Reproduction occur parthenogenetically.

8. The number of nymphs produced per day by a single female varied between 1 and 12 and the maximum number produced per female during its life time was 99 while the minimum was 11.

9. Fed C. lunata adults spent more time resting on the rims of leaves than searching for aphids and there is little track-crossings while unfed adults search the entire surfaces of the leaves thoroughly, crossing their tracks several times.

10. Unfed first instar larvae and adults concentrate their search in areas where aphid colonies have been found with side to side movements which increase their chances of meeting another aphid of the same colony.

11. Attendant ants in aphid colonies protaect the aphids from coccinellid attack.

12. Both the larvae and adults of C. lunata are unable to perceive their prey from a long distance. Attack is only made when it comes in close contact with an aphid.

13. Defensive behaviour in A. craccivora was recorded only in 4th larval instars and adults and to a lesser extent in 3rd larval instars.

14. Four kinds of defensive behaviour was observed, being 1. walking away from the direct path of the predator when in close contact, 2. shedding off an aprendage, 3. fluid exudation, 4. dropping down from a seedling when an encounter failed.

15. Leg shedding and walking away were found to be most effective defensive behaviour. The defensive fluid secreted upon attack did not deter the coccinellid from attacking.

16. There is a close synchrony between C. lunata and the A. craccivora. The predators were found as early as 4 hours after the inception of aphid colonies.

17. There is a positive relationship between the size of an aphid colony and the number of coccinellids it attracks.

18. C. lunata spend the day feeding on aphid colonies but retire at duck away from thr colonies.

19. C. lunata showed marked preference for early instar aphids.

20. Adults and older nymphs of the predator were more successful in capturing prey than younger ones.

21. Capture by early instars of the predator were few and limited to I and II aphids instars.

22. Prey capture efficiency is highly influenced by the developmental stages of both the predator and that of the prey.

23. For younger nymph predators, the number of encounter required to successfully capture an aphid increased with increased in aphid age. On the other hand the number of encounter required to capture an aphid of the same instar decreased with increase in the coccinellid age.

24. The number of aphid consumed by a particular C. lunata instars is determined by the age of the aphid; the older the aphid, the lesser the predation rate and the more effective the defensive behaviour exhibited.

25. Voracity (number of aphids consumed/day) was found to be highest in adult predators than in larval instars.

26. The age of the predator and prey influenced the handling time of the prey. As the predator progressed in age, the time required to completely devour an aphid decreased. Conversely, the handling time increases with increase in aphid age.

27. The response of C. lunata adults to different aphid densities showed increased in consumption rate with increase in aphid density.

28. C. lunata exhibited a type III functional response curve typified by a sigmoid curve.

29. In field cage trials, aphid populations in coccinellid caged plants declined rapidly to a very low level that could hardly cause any economic damage while in cages without coccinellids, their populations increased five fold.

L I T E R A T U R E C I T E D

Aalbersberg, Y.K, Du Toit F. van Der Westhuizen M.C. and Hewitt P.H (1987). Development rate, fecundity and lifespan of apterae of the Russian wheat aphid, Diuraphis noxia (Mordvilko) Hemiptera. Aphididae), under controlled conditions. Bull. Ent. Res. 77: 629-635.

Aalbersberg Y.K, van Der Westhuizen M.C. and Hewitt P.H. (1988). Natural enemies and their impact on Diuraphis noxia (Mordvilko) (Hemiptera: Aphididae) populations. Bull. Ent. Res. 78: 111-120.

Agyen-Sampong M. (1978). Pests of cowpea and their control in Ghana. In S.R. Singh, T.A. Taylor, and H.F. van Emden (eds) Pests of Grain Legumes; Ecology and Control, pp 85-92. Academic Press, London.

Ashby J.W. (1974). A study of arthropod predator of Pieri rapae L. using serological and exclusion techniques. J. Appl. Ecol. 11: 419-425

Atiri G.I, Ekpo E.J.A. and Thottappilly G. (1984). The effect of Aphid-resistance in cowpea on infestation and development of Aphis craccivora and the transmission of cowpea aphid-borne mosaic virus. Ann. Appl. Biol. 104: 339-346.

Atiri G.I. and Thottappilly G. (1985). Aphis craccivora settling behaviour and acquisition of cowpea aphid-borne mosaic virus in aphid-resistant cowpea lines. Entomologia Experimentalis et applicata 39(3): 241-245.

Aveling C. (1981). The role of Anthrocoris species (Hemiptera: Anthrocoridae) in the integrated control of the damson-hop aphid (Phorodon humuli). Ann. Appl. Biol. 97: 143-153.

Ayanaba, A. (1979). Biological nitrogen fixation in Africa. In Grain Legume Improvement Programe: Information series No.14, IITA. Ibadan, Nigeria. 20pp.

Banks C.J. (1953). The searching Behaviour of coccinellid larvae. Proceedings of the Association for the study of Animal Behaviour. pp. 37-39.

Banks C.J. (1956). Observations on the behaviour and mortality in coccinellidae before dispersal from the egg shells. Proc. R. Ent. Soc. Lond. (A) 31. PTS. 4-6: pp 56-60.

Banks C.J. (1957). The behaviour of individual coccinellid larvae on plants. Brit. J. of Animal Behaviour, 5: 12-24.

Banks C.J (1962). Effects of the ant Lasius niger (L.) on insects preying on small populations of Aphis fabae Scop on bean plants. Ann. Appl. Biol. 50: 669-679.

Bansch R. (1965). On prey-seeking behaviour of aphidophagous insects. In Ecology of Aphidophagous Insects (ed.) Hodek I. pp 123-128, Academia, Prague.

Begon M. and Mortimer M. (1981). Population Ecology Blackwell Scientific Publications. 200pp.

Bernado, E.N. (1969). Effects of six host plants on the biology of black bean aphid, Aphis craccivora Koch. Philippine Entomologist 1: 287-292.

Bishara S.I., Fam E.Z. Attia A.A. and El-Hariry M.A. (1984). Yield losses of Faba bean due to Aphid attack. FABIS Newsletter, 10: 16-18.

Bombasch S. and O. Tokmakoglu (1965). The efficiency of Aphidophagous insects in control of Aphis fabae Scop. In Ecology of Aphidophagous insects (ed.) Hodek I. pp 271-273, Academia, Prague.

Bouchard D., Pilon J.G., Tourneur J.C. (1984). Role of entomophagous insects in controlling the apple aphid, Aphis pomi in southwestern Quebec. In ecology of aphidophaga (ed.) Hodek I. pp 369-374. Academia Praque.

Booker, R.H. (1965). Pests of cowpea and their control in Northern Nigeria. Bull. Ent. Res. 55: 663-672.

Brown H.D. (1972). Predacious behaviour of four species of coccinellidae (Coleoptera) associated with the wheat aphid, Schizaphis graminum (Rondani), in South Africa. Trans. R. Ent. Soc. Lond. 124(1): 21-36.

Brown. H.D. (1974). Defensive behaviour of the wheat aphid, Schizaphis graminum (Rondani) (Hemiptera: Aphididae) against coccinellidae. J. Ent (A) 48(2): 157-165.

Campbell A., Frazer B.D., Gilbert N., Gutierrez A.P. and Mackauer M. (1974). Temperature requirements of some aphids and their parasites. J. Appl. Ecol. 11: 431-438.

Campbell C.A.M. (1978). Regulation of the damson-hop aphid (Phorodon homoli (Schrank) on hops (Homulus lupulus L.) by predators. J. Hort. Sci. 53(3): 235-242.

Chambers R.J.; Sunderland K.D. Wyatt I.J. and Vickerman G.P. (1983). The effect of predator exclusion and caging on cereal aphids in winter wheat. J. Appl. Ecol. 20: 209-224.

Davies J.C. (1969). A study of the chemical control and bionomics of Aphis craccivora Koch and their effects on rosette disease attack and yield of groundnuts Arachis hypogea L. in Uganda. 321 pp, PhD thesis, Univ. E. Afr.

Davies J.C. (1972). Studies on the ecology of Aphis craccivora Koch. (Hemiptera: Aphididae), the vector of rosette disease of groundnuts, in Uganda. Bull. Ent. 62: 169-181.

Dean G.J. (1947). Effect of temperature on the cereal aphids Metopolophium dirhodam (Wlk.), Ropolophum padi (L.) and Macrosiphum avenae (F.) (Hem., Aphididae). Bul. of Ent. Res. 63: 401-409.

DeBach. P. and Bartlett B. (1951). Effects on insecticides on biological control of pests of citrus. J. Econ. Ent. 44: 372-383.

DeBach P. (1975). Biological control by natural enemies. Cambridge University Press. 323pp.

de Pury, J.M.S. (1968). "Crop Pests of East Africa". Oxford University Press, Nairobi, Lusaka, and Addis Ababa. 227pp.

Dixon. A.F.G. (1958). The escape responses shown by certain Aphids to the presence of the coccinellid Adalia decempunctata (L). Trans. R. Ent. Soc. Lond. 110: 319-334.

Dixon A.F.G. (1959). An experimental study of the searching behaviour of the predatory coccinellid Beetle Adalia decempunctata (L). J. Anim. Ecol. 28: 259-281.

Dixon A.F.G. (1987). Parthenogenetic reproduction and the rate of increase in aphids. In World Crop Pests 2A, (eds) Minks A.K. and Harrewijn P. pp 269-287. Elservier, Amsterdam.

Dunn J.A. (1949). The parasites and predators of potato aphids. Bull. Ent. Res. 40: 97-122.

Faeth S.H. and Simberloff D. (1981). Population regulation of a leaf-mining insect, Cameraria sp. Nov., at increased field densities. Ecology, 62(3): 620-624.

Fernado M.H.J.P. and Hassell M.P. (1980). Predator-prey responses in an acarine system. Res. Popul. Ecol. 22: 301-322

Firempong S. and Kumar R. (1975). Natural enemies of Toxoptera aurantii (Boy) (Homoptera: Aphididae) on cocoa in Ghana. Biol. J. Linn. Soc. 7: 261-292.

Fleschner, C.A. (1950). Studies on searching capacity of the larvae of three predators of the citrus red mite. Hilgardia. 20(13): 233-265.

Frazer B.D. and Gilbert N. (1976). A quantitative study of the impact of adult ladybirds (Coleoptera: Coccinellidae) preying on field population of pea aphids (Homoptera: Aphididae). J. Ent. Soc. Brit. Columb. 73: 35-56.

Frazer B.D. and Gilbert N., Nealis V. and Raworth D.A. (1981). Control of aphid density by a complex of predators. Can. Ent. 113: 1035-1041.

Gatecka B. (1965). The effectiveness of predators in control of Aphis nasturtii kalt. and Aphis frangulae kalt. on patatoes. In Ecology of Aphidophagous Insects (ed.) Hodek I. pp 255-258, Academia, Prague.

Gawande R.B. (1965). Effect of constant and alternating temperatures on feeding and development of Cheilomenes sexmaculata. In Ecology of Aphidophagous Insects (ed.) Hodek I. pp 63-67, Academic Prague.

Georghiou G.P. and Taylor C.E. (1977). Pesticides resistance as an evolutionary phenomenon. Proc. XV Int. Congr. Ent. Washington, 759-785.

Hagen K.S. (1962). Biology and ecology of predaceous coccinellidae. Ann. Rev. Ent. 7: 289-326

Hagen K.S and van Den Bosch R. (1968). Impact of pathogens, parasites and predators on aphids. Ann. Rev. Ent. 13: 325-384.

Hammad S.M. (1978). Pest of grainlegumes and their control in Egypt. In: S.R. Singh, H.F. van Emden, and J.A. Taylor (eds). Pests of grain legumes, Ecology and Control. Academia press, London and New York, ppl35-137.

Hodek 1 (1967). Bionomics and ecology of predaceous coccinellidae. Ann. Rev. Ent. 12: 79-104.

Hodek I. (1973). Biology of coccinellidae. Academia, Prague.

Hodek I., Holman J. Novak K. and Skuhravy V. (1965). Influence of predation of Coccinella septempunctata on Aphis fabae. In Ecology of Aphidophaga (ed.) Hodek I. pp 265, Academia Prague.

Hodek I, Hagen K.S and van Emden H.F.(1972). Methods for studyingeffectiveness of natural enemies: In Aphid Technology, with special reference to the study of aphids in the fields. (ed.) van Emden H.F., pp 147-180, Academic press, London.

Hodek I, Chakrabarti S. and Rejmanek M. (1984). The effect of prey density on food intake by adult Cheilomenes sulphurea (Col. Coccinellidae). Entomophaga 29(2): 179-184.

Holling C.S. (1959). Some characteristics of simple types of predation and parasitism. Can. Ent. 91: 385-398.

Holling C.S. (1966). The functional response of invertebrate predators to prey density. Mem. Ent. Soc. Can. 48: 86pp.

Ibrahim M.M. (1955). Studies on Coccinella undecimpunctata aegyptiaca Rche. II Biology and life history. Bull. Soc. Ent. Egypte, 39: 395-423.

Ingram W.R. (1969). A note on the failure to control Aphid infestations on beans with insecticides in Uganda. East Africa Agricultural and Forestry Journal, pp 476-481.

Iperti G. (1965). Some components of efficiency in aphidophagous coccinellids: In Ecology of Aphidophagous Insects (ed.) Hodek I. pp 253, Academia Prague.

Jansson R.K. and Smilowitz Z. (1985). Development and reproduction of the green peach aphid, Myzus persicae (Homoptera: Aphididae) on upper and lower leaves of three potato cultivars. Can. Ent. 117: 247-252.

Kaiser W.J. and Massambi G.H. (1975). Studies with cowpea aphid-borne mosiac virus and its effect on cowpea in Iran. FAO. Plant Protection Bull. 23(2): 33-39.

Kamal M. (1951). The biological control of the cotton leaf-warm, Prodenia litura F., in Egypt. Bull. Soc. Fouad I Ent. 35: 221-270.

Kapur A.P. (1942). Bionomics of some coccinellidae, predaceous on Aphids and coccids in North India. Indian J. Ent. 4(1): 49-66.

Kawauchi S. (1979). Effect of prey density on the rate of prey consumption, development and survival of Propylea. Japonica Thunberg (Coleoptera: coccinellidae). Kontyu. 47: 204-212.

Kayumbo H.Y. (1978). Pests of cowpeas and their control in Tanzania. In S.R. Singh, H.F. van Emden, and J.A. Taylor (eds). Pests of grain legumes Ecology and control. Academia press, London and New York, pp 123-126.

Kring T.J., Gilstrap F.E., and Michels G.J.Jr. (1985). Role of indigenous coccinellids in regulating green-bugs (Homoptera: Aphididae) on Texas grain sorgum. J. Econ. Ent. 78(1): 269-273.

Kumar R. (1984). Insect Pest Control with Special Reference to African Agriculture. Edward Arnold. 298 pp.

Laing, J.E. and Osborn, A.L. (1974). The effect of prey density on the functional and numerical responses of three species of predatory mites. Entomophaga, 19: 267-277.

Le Pelley R.H. (1959). Agricultural insects of East Africa. East Africa High Commission, Nairobi, Kenya. pp 248-259.

Liao H.T., Harris M.K., Gilstrap F.E., and Mansour F. (1985). Impact of natural enemies on the blackmargined pecan aphid, Monellia caryella (Homoptera: Aphidae). Environ. Ent. 14(2): 122-126.

Luck R.F., Shepard B.M. and Kenmore P.E. (1988). Experimental methods for evaluating arthropod natural enemies. Ann. Rev. Ent. 33: 367-391.

Macfoy C.C.A. Dabrowski Z.T. (1984). Preliminary studies on cowpea resistance to Aphis craccivora Koch. (Homoptera: Aphididae). Zeitschrift fur Angewandte Entomologie, 97: 202-209.

Mariga I.K. Giga. D. and Maramba P. (1985). Cowpea production contraints and research in Zimbabwe. Tropical Grain legume Bull. 30: 9-14.

Milne W.M. and Bishop A.L. (1987). The role of predators and parasites in the natural regulation of Lucerne aphids in the Eastern Australia. J. Appl. Ecol., 24: 893-905.

Modawal C.N. (1941). A biological note on Cheilomenes sexmaculata Fabr. Indian J. Ent. 3(1): 139-140.

Mogi. M. (1969). Predation response of the larvae of Harmonia axyridis Pallas (Coccinellidae) to the different prey density. Jap. J. Appl. Ent. Zool. 13: 9-16.

Murdoch W.W. (1971). The developmental response of predators to changes in prey density. Ecology. 52(1): 132-137.

Murdock. W.W. (1973). The functional response of predators. J. Appl. Ecol. 10: 335-341.

Murdock W.W. and Oaten A. (1975). Predation and population stability. Advances in Ecological Research, 9: 1-131.

Nyiira Z.M. (1971). The status of insect pests of cowpeas (Vigna unguiculata (L) Walp), in Ugnada and their control. PANS. 17(2): 194-197.

Ofuya T.I. (1986). Predation by Cheilomenes vicini (Coleoptera:
Coccinellidae) on the cowpea aphid, Aphis craccivora (Homoptera: Aphididae): effect of prey stage and density. Entomophaga, 32(4): 331-335.

Ofuya T.I. (in press). Laboratory observations on the life history of Cheilomenes vicina (Muls.) (Col., Coccinellidae), a predator of the cowpea aphid, Aphis craccivora Koch (Hom., Aphididae).

Okech H.O. (1986). Colonizing, responses of Maruca testulalis (Gayer) (Lepidoptera: Pyralidae) to different cowpea cultivars in relation to their resistance/ susceptibility. PhD. Thesis River State University of Science and Technology, Port Harcourt, Nigeria.

Okrouhla, M. Chakrabarti S. and Hodek I, (1983). Development rate and feeding capacity in Cheilomenes sulphurea (Coleoptera: Coccinellidae) Vest. cs. Spolec. Zool., 47: 105-117.

Owusu-Menu E. (1976). Natural enemies of Battycoelia thalassina (Herrich-Schaeffer) (Hemiptera: Pentatomidae), a pest of cocoa in Ghana. Biol. J. Linn. Soc. 8(3): 217-224.

Pathak, R.S. and Olela J.C. (1986). Registration of 14 cowpea cultivars. Crop Science 26: 647-648.

Potts G.R. (1977). Some effects of increasing the monoculture of cereals. In Origin of Pest. Parasites, Disease and Weed Problems (ed. by Cherrett J.M. and Sagar G.R.) pp 183-202. Blackwell Scientific Publications, Oxford.

Potts G.R. and Vickerman G.P. (1974). Studies on the cereal ecosystem. Adv. in Ecol. Res. 8: 107-197.

Rachilo J.R. and Wataka S.S. (1980). Soils of the ICIPE farm Mbita Point (South Nyanza District). Detail survey report No. D21 of Ministry of Agriculture (Kenya National Agriculture lab).

Radwan Z. and Lovei G.L. (1983). Aphids as prey for the coccinellid Exochomus quadripustulatus. Ent. Exp. & Appl. 34: 283-286.

Raheja A.K. and Leleji O.I. (1974). An aphid-borne virus disease of irrigated cowpea in Northern Nigeria. Plant disease Reporter 58(12): 1080-1084.

Raworth D.A., McFarlane S., Gilbert N. and Frazer B.D. (984). Population dynamics of the cabbage aphid, Brevicoryne brassicae (Homoptera: Aphididae) at Vancouver, British Columbia. III. Development, fecundity, and morph determination vs. aphid density and plant quality. Can. Ent. 116: 879-888.

Richman D.B. Hemenway R.C.Jr. and Whitcomb W. H. (1980). Field cage evaluation of predators of the Soybean Looper, Pseudoplusia includens (Lepidoptera: Noctuidae). Environ. Ent. 9: 315-317.

Ripper W.E. (1956). Effect of pesticides on balance of arthropod populations. Ann. Rev. Ent. 1: 403-436.

Rose. R.I. Chiang, H.S, Harnota, I (1978). Pests of grain legumes and their control in Taiwan. In S.R. Singh T. Ajibola Taylor, H.F. van Emden (eds.) Pests of Grain Legumes: Ecology and Control, pp 67-71. Academic Press, London.

Ruzicka Z. (1980). Regulation of the reproductive activity after hibernation in Coccinella septempunctata L. by photo period. Bull. S.R. Op/W.P.R.S. III /3: 215-220.

Ruzicka Z. Iperti G. and Hodek. I (1981). Reproductive rate and longevity in semiadalia undercemnotata and coccinella septempunctata (Coleoptera: Coccinellidae) Vest. cs. Spolec. Zool. 45: 115-128.

Sabelis M.W. (1985). Predation on spider mites. In World Crop Pests. Spider mites: Their biology, natural enemies and control (eds.) W. Helle and M.W. Sabelis. Elsevier-Amsterdam. Vol. 1B.

Sawicki R.M. (1979). Resistance to pesticides 1. Resistance of insects to insecticides. SPAN, 22(2): 50-52.

Singh S.R. (1977). Grain leguem entomology. IITA. Training booklet, Ibadan Nigeria. 51 pp.

Singh S.R. (1977). Cowpea cultivars resistance to insect pests in world germplasm collection. Trop. Grain Legume Bull. 9: 1-7.

Singh S.R. (1978). Resistance to pests of cowpeas in Nigeria In: S.R Singh, T.A. Taylor, and H.F. van Emden (eds). Pests of grain legumes, Ecology and control, pp 267-279. Academia press, London.

Singh S.R. (1980). Biology of cowpea pests and potential for host plant resistance. In Harris M.K. (ed): Biology and Breeding for Resistances to Arthropods and pathogens in Agricultural plants. College Station, TX., Texas A & M University Bull. MP 1451, 605 pp.

Singh S.R. and van Emden H.F. (1979). Insect pests of grain legumes. Ann. Rev. Ent. 24: 255-278.

Singh S.R. and Allen D.J. (1980). Pests, diseases, resistance and protection in cowpea. In Summerfield R.J. and Bunting A.H. (Eds): Advances in Legume Science Royal Botanic Gardens Kew and Ministry of Agriculture, Fisheries and Food, London. pp 419-443.

Singh S.R. Singh B.B. Jackai L.E.N. and Ntare B.R. (1983). Cowpea reserach at IITA. Grain Legume Improvement Programme. IITA. 14: 20 pp.

Sinha T.B., Pandey R.K., Singh R., Tripathi C.P.M. and Kumar A. (1982). The functional response of Coccinella septempunctata L., a coccinellid predator of mustard aphid, Lipaphis erysimi Kalt. Entomon. 7: 7-10

Singh S.R. and Jackai L.E.N. (1985). Insect pests of cowpea in Africa: Their life cycle, Economic Importance and Potential for Control. In Singh S.R. and Rachie K.O. (eds): Cowpea Research, Production and Utilization. John Wiley & Sons; pp 217-231.

Solomon M.E. (1949). The natural control of animal populations. J. Anim. Ecol. 18: 1-35.

Sundby. R.A. (1966). A comparative study of the efficiency of three predatory insects Coccinella septempunctata L. (Coleoptera: Coccinellidae) - Chrysopa carnea St. (Neuroptera Chrysopidae) and Syrphus mbesii L. (Diptera: Syrphidae) at two different temperatures. Entomophaga 11: 395-404.

Tamaki G. and Weeks R.E. (1972). Efficiency of three predators Geocoris, bullatos, Nabis americoferus, and Coccinella transversgullata, used alone or in combination against three, insect prey species, Myzus persicae, Ceramica picta and Mamestra configurata in a greenhouse study. Environ. Ent. 9: 258-263.

Taylor T.A. (1964). The field pests problems on cowpeas, Vigna sinensis L. in Southern Nigeria. The Nigerian Grower and Producer 3: 17-21.

Thead L.G., Pitre H.N., Kellogg T.F. (1988). predation on eggs and larvae of Heliothis verescens (Lepidoptera: Noctuidae) by an adult predator complex in cage studies on cotton. Publ.N°5936, Mississippi Agric. and Forestory Exp. Sta. Mississippi 39762.

van Emden H.F. (1965). Review of the effectiveness of Aphidophagous insects in reducing aphid populations. In Ecology of Aphidophagous Insects (ed) Hodek I. pp 227-236. Academia Prague.

Way M.J. and Banks C.J. (1962). Significance of competition in the natural control of aphids. XI Int. Congr. Ent. Wien 1960; 746pp.

Way M.J. Murdie G. and Galley D.J. (1969). Experiments on integration of chemical and biological control of Aphids on brussels sprouts. Ann. Appl. Biol. 63: 459-475.

WHO (World Health Organisation) (1972). Resistance of vectors and reservoirs of disease to pesticides. WHO, Geneva 22nd Rpt. of Ser., 585, 88 pp.

Yakchontov V.V. (1965). Coccinellidae and Syrphidae as predators of of Aphids in Uzbekistan: In Ecology of Aphidophagous Insects (ed.) Hodek. I. pp 267-270. Academia Press.

Appendix 1

RESULTS AND OBSERVATIONS

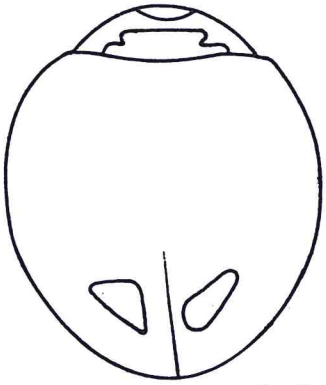
The sampling for aphidophagous coccinellids in cowpea farms in Mbita and its environs revealed that Cheilomenes lunata (Fab.) accounted for 61.91% of the total aphidophagous coccinellids recorded. The remaining 38.09% comprised of Platynaspis sexguttata (Sic.), Cheilomenes vicina (Mulsant) and Cheilomenes posticalis (Fairm) (Appendix Fig. 1). The choice to study C. lunata was undoughtedly due to its abundance.

The distribution of the coccinellid complex on the four sampled plots were as follow: On plot 1, a total of 150 coccinellids comprising of 112 (74.88%) C. lunata, 32 (21.33%) P. sexguttata, 5 (3.33%) C. vicina and 1 (0.66%) C. posticalis were recorded (Appendix Fig. 2). On plot 2, 150 coccinellids comprising of 101 (63.52%) C. lunata, 40 (25.16%) P. sexguttata, 13 (8.18%) C. vicina and 5 (3.14%) C. posticalis were recorded (Appendix Fig. 2).

A total of 227 coccinellids comprising of 121 (53.30%) C. lunata, 67 (29.52%) P. sexguttata, 26 (11.45%) C. vicina and 13 (5.73%) C. posticalis were recorded in plot 3 (see appendix Fig. 2). On plot 4, 162 coccinellids comprising of 91 (56.17%) C. lunata, 46 (28.40%) C. vicina, 18 (11.11%) P. sexguttata and 7 (4.32%) C. posticalis were recorded (Appendix Fig. 2).

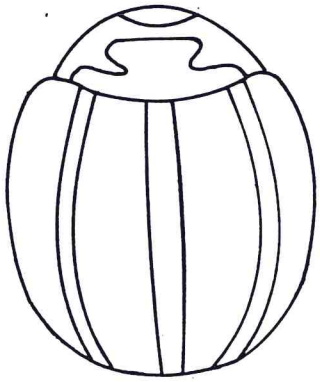
L = 3.31 mm
W = 2.64 mm

Platynaspis sexguttata



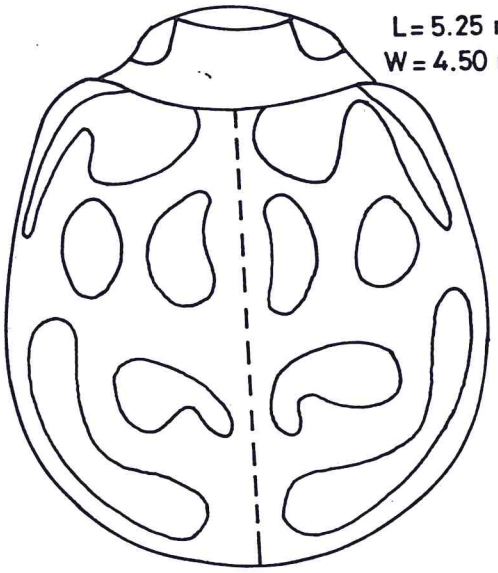
L = 5.00 mm
W = 4.10 mm

Cheilomenes posticalis



L = 5.00 mm
W = 4.18 mm

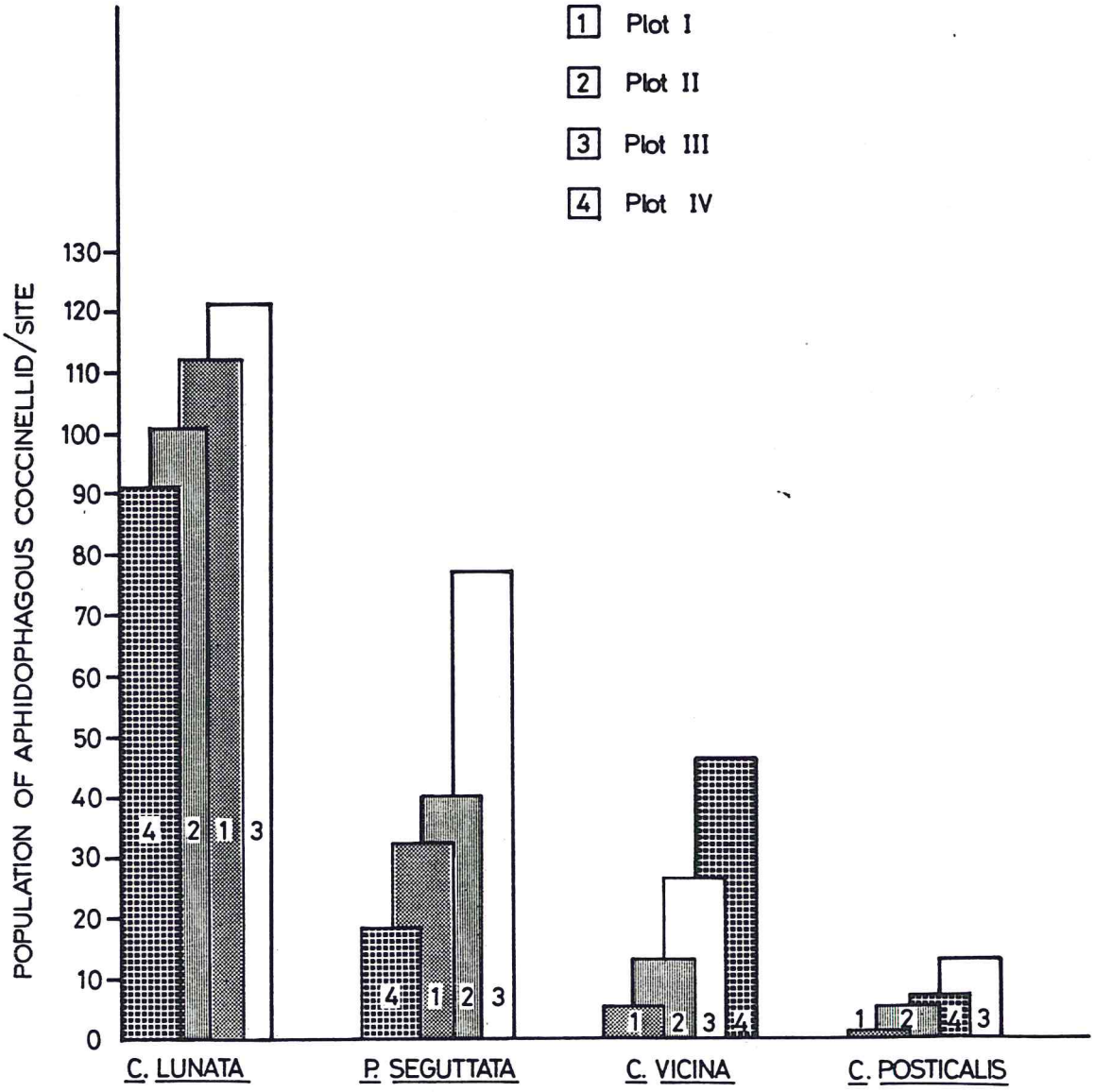
Cheilomenes vicina



L = 5.25 mm
W = 4.50 mm

Cheilomenes lunata

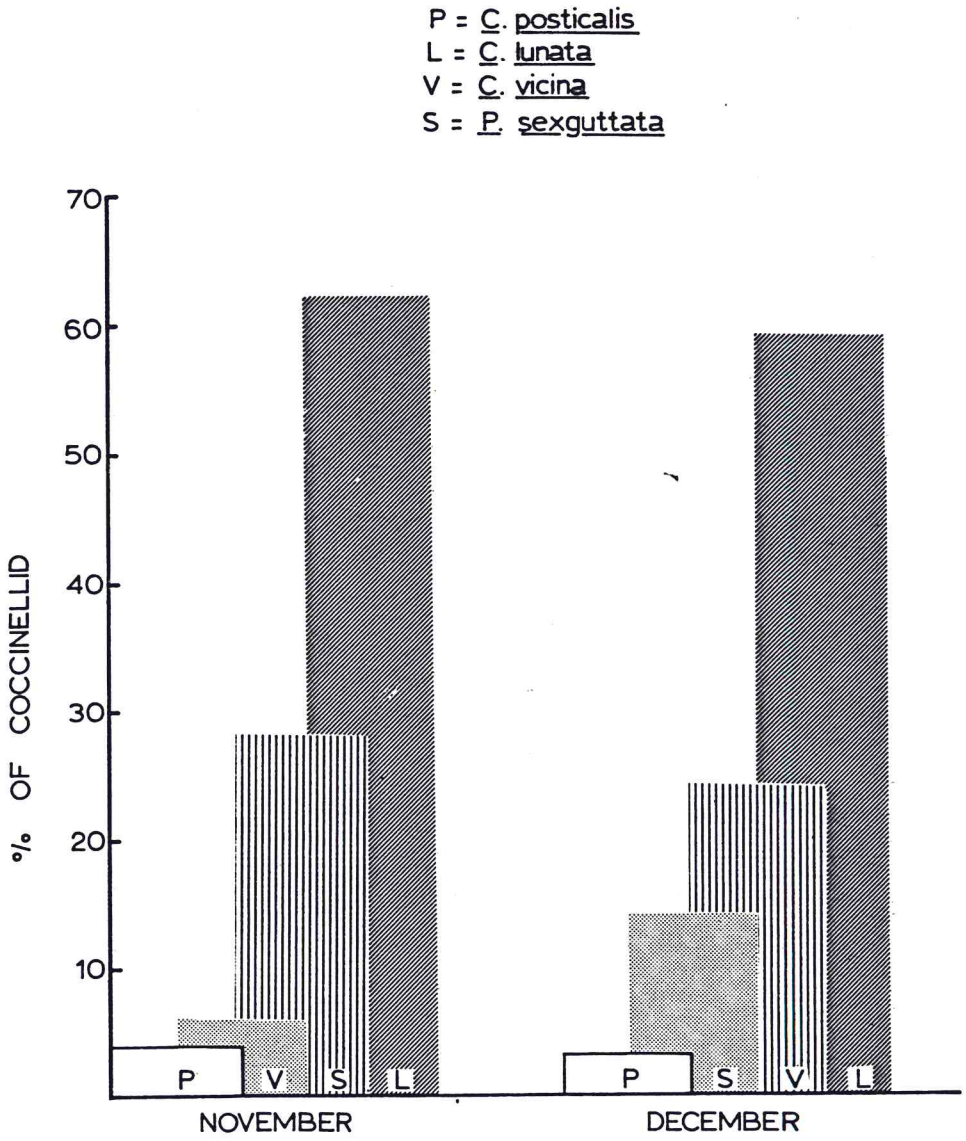
APP. FIG 1. APHIDOPHAGOUS COCCINELLIDS AT MBITA, KENYA.



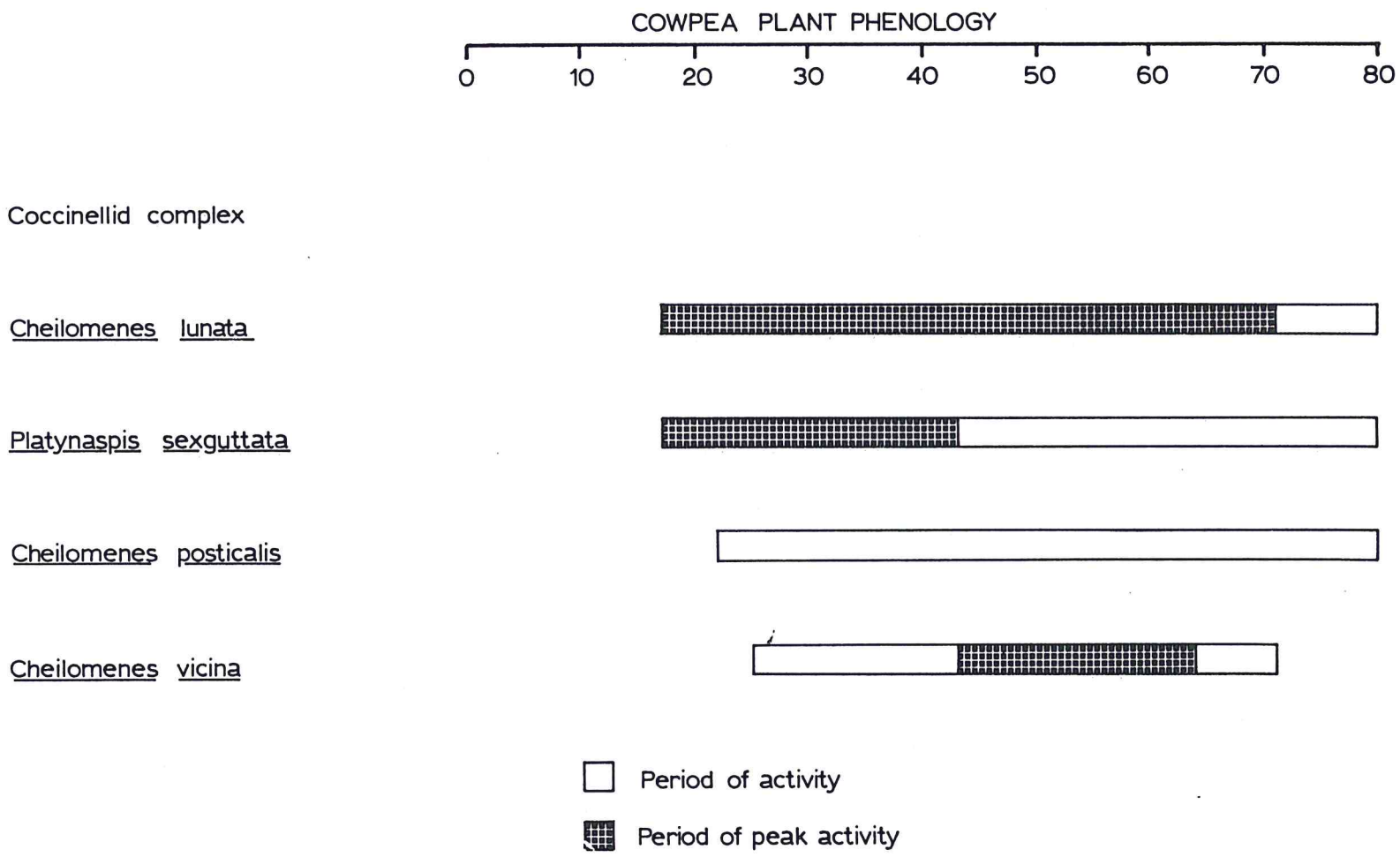
APP. FIG 2. Distribution of Aphidophagous coccinellid beetles found in 4 sampled plots at Mbita.

Apart from C. lunata which ranked first in the sampled months (Appendix Fig. 3), there were temporary differences in the abundance of the predators. For instance, C. vicina was more common in December than in November, but the reverse was the case for P. sexguttata. C. posticalis was the least common coccinellid during the sampled months.

It was also observed that not all the coccinellids appeared im the plots at the same time (Appendix Fig. 4). The first to appear were C. lunata and P. sexguttata, both of which appeared 17 days after planting (DAP). They were present throughout the growth stages of the crop, but the population of P. sexguttata went down on 43rd DAP, whilst C. lunata maintained its population till harvest. C. posticalis first appeared on 22nd DAP, but its population remained low throughout the plant growth cycle. C. vicina which was the last to appear, was first noticed on the 25th DAP. There was a build up in its population on the 43rd DAP and it reached a peak on 64th DAP.



APPENDIX FIG. 3. DISTRIBUTION OF C. LUNATA, C. VICINA, C. POSTICALIS AND P. SEXGUTTATA IN RELATION TO SAMPLED MONTHS



Appendix Fig. 4. Relationship between cowpea growth stage and presence of Aphidophagous coccinellids.

APPENDIX TABLE 1: DURATION OF COPULATION (in min) IN ADULT C. LUNATA UNDER AMBIENT LABORATORY CONDITIONS

No. of observations	REPLICATES			
	1	2	3	4
1	100	30	45	120
2	80	110	90	110
3	65	90	90	160
4	82	65	110	102
5	150	90	120	100
6	180	190	10.3	90
7	130	105	17	18
8	145	165	10	145
9	90	100	155	190
10	95	90	100	45
Total	1117	1035	747.3	1080
Mean	111.7	103.5	74.73	108
S.D.	37.31	45.64	50.99	51.03
S.E.	11.8	14.44	16.13	16.14
Range	65-180	30-190	10-155	18-190

APPENDIX TABLE 2: OVIPOSITION RATE OF C. LUNATA

IN THE LABORATORY OVER A PERIOD OF 2 WEEKS

PETRI DISH 1

DAYS	DATE	BATCH NO.	NO.OF EGGS	TEMPERATURE
1	23/03/88	1	57	26.5
2	24/03/88	1	52	26.0
3	25/03/88	1	39	25.5
4	26/03/88	1	67	26.0
	''	2	30	26.0
5	27/03/88	1	19	25.5
6	28/03/88	1	53	26.0
	''	2	36	26.0
7	29/03/88	1	21	26.5
	''	2	23	26.5
8	30/03/88	1	23	27.0
9	31/03/88	1	29	27.0
10	1/04/88	1	22	28.5
11	2/04/88	1	55	25.5
12	3/04/88	1	73	25.5
13	4/04/88	1	68	28.0
14	5/04/88	1	33	29.0
TOTAL		17	713	372.50
MEAN		1.21	41.94	26.60
S.D.		0.42	17.82	1.16

APPENDIX TABLE 2 CONTD.
PETRI DISH 2

DAYS	DATES	BATCH NO	NO OF EGGS	TEMPERATURE
1	24/3/88	1	21	26.0
2	25/03/88	1	33	25.5
3	26/03/88	1	28	26.0
	''	2	11	26.0
	''	3	26	26.0
4	27/03/88	1	31	25.5
	''	2	8	25.5
	''	3	18	25.5
	''	4	8	25.5
5	28/03/88	1	37	26.0
	''	2	10	26.0
	''	3	20	26.0
	''	4	15	26.0
6	29/03/88	1	42	26.5
	''	2	18	26.5
7	30/03/88	1	34	27.0
	''	2	41	27.0
8	31/03/88	1	12	27.0
	''	2	34	27.0
	''	3	21	27.0
9	1/04/88	1	12	28.5
	''	2	28	28.5
10	2/04/88	1	33	28.5
11	3/04/88	1	38	28.0
	''	2	20	28.0
	''	3	21	28.0
12	4/04/88	1	20	28.0
13	5/04/88	1	32	29.0
	''	2	22	29.0
	''	3	17	29.0
14	6/04/88	1	10	25.5
TOTAL		31	721	377
MEAN		2.21	23.25	26.92
S.D.		1.12	10.18	1.25

APPENDIX TABLE 2 CONTD.

PETRI DISH 3

DAYS	DATE	BATCH NO	NO OF EGGS	TEMPERATURE
1	24/03/88	1	48	26.0
2	25/03/88	1	46	25.5
3	26/03/88	1	10	26.0
4	27/03/88	1	12	25.5
5	28/03/88	1	13	26.0
	''	2	20	26.0
6	30/03/88	1	23	27.0
7	31/03/88	1	5	27.0
	''	2	21	27.0
8	1/04/88	1	28	28.5
9	2/04/88	1	24	28.5
10	4/04/88	1	26	28.0
11	6/04/88	1	10	25.5
	''	2	17	25.5
12	7/04/88	1	22	25.5
13	8/04/88	1	17	26.5
14	9/04/88	1	5	26.5
TOTAL		17	347	372.0
MEAN		1.17	20.41	26.6
S.D.		0.39	12.16	1.1

APPENDIX TABLE 2 CONTD.

PETRI DISH 4

DAYS	DATE	BATCH NO	NO OF EGGS	TEMPERATURE
1	23/03/88	1	32	26.5
2	24/03/88	1	26	26.0
3	25/03/88	1	32	25.5
	''	2	15	25.5
4	26/03/88	1	31	26.0
	''	2	14	26.0
5	27/03/88	1	36	25.5
	''	2	10	25.5
	''	3	15	25.5
6	28/03/88	1	38	26.0
	''	2	22	26.0
	''	3	13	26.0
7	29/03/88	1	8	26.5
	''	2	34	26.5
	''	3	10	26.5
	''	4	18	26.5
8	30/03/88	1	11	27.0
	''	2	10	27.0
	''	3	28	27.0
	''	4	17	27.0
9	31/03/88	1	20	27.0
10	1/04/88	1	12	28.5
	''	2	6	28.5
11	2/04/88	1	5	28.5
12	4/04/88	1	37	28.0
13	5/04/88	1	5	29.0
14	6/04/88	1	6	25.5
TOTAL		27	511	375.5
MEAN		1.77	18.92	26.8
S.D.		0.97	10.96	1.2

APPENDIX TABLE 2 CONTD.

PETRI DISH 5

DAYS	DATE	BATCH NO	NO OF EGGS	TEMPERATURE
1	30/03/88	1	31	27.0
2	31/03/88	1	24	27.0
3	1/04/88	1	28	28.5
4	2/04/88	1	40	28.5
5	3/04/88	1	35	28.0
6	4/04/88	1	25	28.0
	''	2	27	28.0
7	5/04/88	1	47	29.0
8	6/04/88	1	52	25.5
9	7/04/88	1	33	25.5
10	8/04/88	1	10	26.5
11	9/04/88	1	21	26.5
12	10/04/88	1	7	24.5
13	11/04/88	1	20	25.5
14	13/04/88	1	10	27.0
	''	2	5	27.0
TOTAL		16	415	378.50
MEAN		1.12	25.93	27.03
S.D.		0.34	13.79	1.37

APPENDIX TABLE 2 CONTD.

PETRI DISH 6

DAYS	DATE	BATCH NO	NO OF EGGS	TEMPERATURE
1	31/03/88	1	18	27.0
	''	2	26	27.0
2	1/04/88	1	10	28.5
	''	2	23	28.5
3	3/04/88	1	46	28.0
	''	2	43	28.0
4	4/04/88	1	31	28.0
	''	2	20	28.0
5	5/04/88	1	16	29.0
	''	2	45	29.0
	''	3	29	29.0
6	6/04/88	1	45	25.5
	''	2	18	25.5
7	7/04/88	1	11	25.5
	''	2	13	25.5
	''	3	40	25.5
8	8/04/88	1	12	26.5
	''	2	26	26.5
9	9/04/88	1	20	26.5
10	10/04/88	1	18	24.5
	''	2	21	24.5
11	11/04/88	1	40	25.5
12	12/04/88	1	20	26.5
13	13/04/88	1	15	27.0
14	14/04/88	1	8	26.5
TOTAL		25	614	373.50
MEAN		1.52	24.56	26.67
S.D.		0.65	12.09	1.32

APPENDIX TABLE 3: PERCENTAGE EGG HATCHABILITY IN FEMALE C. LUNATA IN THE LABORATORY

Cage No.	Eggs Laid On	No. of Eggs/Batch	Total No. of Eggs	Date Hatched	% Hatchability
1	11/11/87	29	288	15/11/87	100
	13/11/87	22		17/11/87	100
	15/11/87	55		19/11/87	100
	17/11/87	73		20/11/87	100
	20/11/87	68		24/11/87	100
	22/11/87	33		26/11/87	100
	24/11/87	8		28/11/87	100
2	16/11/87	20	64	20/11/87	100
	16/11/87	11		20/11/87	100
	19/11/87	18		23/11/87	100
	20/11/87	15		24/11/87	100
3	14/11/87	22	110	18/11/87	100
	14/11/87	29		18/11/87	100
	14/11/87	20		18/11/87	90
	16/11/87	27		19/11/87	100
	16/11/87	12		20/11/87	100
4	12/11/87	35	153	16/11/87	97.4
	14/11/87	29		18/11/87	96.55
	14/11/87	28		18/11/87	85.71
	16/11/87	29		20/11/87	100
	18/11/87	20		22/11/87	100
	20/11/87	12		24/11/87	100

APPENDIX TABLE 3 CONTD.

Cage No.	Eggs Laid On	No. of Eggs/Batch	Total No. of Eggs	Date Hatched	% Hatchability
	3/12/87	57		6/12/87	
	4/12/87	52		7/12/87	100
	5/12/87	39		8/12/87	90
	6/12/87	67		9/12/87	100
	6/12/87	30		9/12/87	100
5	7/12/87	19	433	10/12/87	100
	8/12/87	53		11/12/87	100
	8/12/87	36		11/12/87	100
	10/12/87	36		13/12/87	81
	10/12/87	21		13/12/87	72
	12/12/87	23		15/12/87	52
	13/01/88	35		16/01/88	100
6	14/01/88	29	60	17/01/88	100
	15/01/88	28		18/01/88	100
7	13/01/88	26	26	16/01/88	100
8	13/01/88	10	10	16/01/88	100
9	13/01/88	11	11	17/01/88	100
10	17/01/88	17	17	20/01/88	100

APPENDIX TABLE 4: LIFE CYCLE OF C. LUNATA

BATCH NO. 1 NOVEMBER '87

	1ST INSTAR			2ND INSTAR		3RD INSTAR		4TH INSTAR		PUPAE		SEX
CAGE	START	STOP	DURATION	STOP	DURATION	STOP	DURATION	STOP	DURATION	STOP	DURATION	
1	15/11	19/11	4	21/11	2	22/11	1	23/11	1	27/11	4	F
2	15/11	19/11	4	21/11	2	22/11	1	23/11	1	27/11	4	M
3	15/11	19/11	4	20/11	1	21/11	1	23/11	2	27/11	4	M
4	15/11	19/11	4	21/11	2	23/11	2	25/11	2	29/11	4	F
5	15/11	18/11	3	19/11	1	21/11	2	24/11	3	28/11	4	F
6	15/11	19/11	4	20/11	1	22/11	2	24/11	2	28/11	4	F
7	17/11	20/11	3	21/11	1	22/11	1	24/11	2	29/11	5	F
8	17/11	21/11	4	23/11	2	24/11	1	27/11	3	30/11	3	F
9	17/11	21/11	4	22/11	1	24/11	2	26/11	2	1/12	5	F
10	17/11	20/11	3	21/11	1	23/11	2	26/11	3	30/11	4	F
TOTAL			37		14		15		21		41	8:2
MEAN			3.7		1.4		1.5		2.1		4.1	

APPENDIX TABLE 4 CONTD.

BATCH NO. 2 NOV/DEC '87

CAGE	1ST INSTAR START	1ST INSTAR STOP	1ST INSTAR DURATION	2ND INSTAR STOP	2ND INSTAR DURATION	3RD INSTAR STOP	3RD INSTAR DURATION	4TH INSTAR STOP	4TH INSTAR DURATION	PUPAE STOP	PUPAE DURATION	SEX
1	16/11	20/11	4	21/11	1	23/11	2	26/11	3	30/11	4	F
2	16/11	19/11	3	20/11	1	21/11	1	23/11	2	26/11	3	F
3	16/11	18/11	2	20/11	2	21/11	1	24/11	3	27/11	3	F
4	16/11	19/11	3	21/11	2	22/11	1	24/11	2	29/11	5	M
5	16/11	19/11	3	20/11	1	22/11	2	24/11	2	29/11	5	F
6	20/11	24/11	4	25/11	1	26/11	1	28/11	2	2/12	4	M
7	20/11	24/11	4	25/11	1	27/11	2	29/11	2	2/12	3	M
8	20/11	24/11	4	26/11	2	27/11	1	30/11	3	4/12	4	M
9	20/11	24/11	4	25/11	1	27/11	2	29/11	2	4/12	5	M
10	20/11	22/11	2	23/11	1	24/11	1	27/11	3	30/11	3	M
TOTAL			33		13		14		24		39	4:6
MEAN			3.3		1.3		1.4		2.4		3.9	

APPENDIX TABLE 4 CONTD.

BATCH NO. 3 DECEMBER '87

CAGE NO.	1ST INSTAR START	1ST INSTAR STOP	1ST INSTAR DURATION	2ND INSTAR STOP	2ND INSTAR DURATION	3RD INSTAR STOP	3RD INSTAR DURATION	4TH INSTAR STOP	4TH INSTAR DURATION	PUPAE STOP	PUPAE DURATION	SEX
1	6/12	9/12	3	10/12	1	11/12	1	12/12	1	15/12	3	F
2	6/12	9/12	3	10/12	1	12/12	2	14/12	2	18/12	4	F
3	6/12	9/12	3	10/12	1	11/12	1	12/12	1	16/12	4	M
4	6/12	10/12	4	12/12	2	13/12	1	14/12	1	19/12	5	F
5	6/12	9/12	3	11/12	2	12/12	1	14/12	2	18/12	4	M
6	6/12	9/12	3	10/12	1	11/12	1	13/12	2	17/12	4	M
7	7/12	10/12	3	11/12	1	13/12	2	14/12	1	17/12	3	F
8	7/12	9/12	2	11/12	2	13/12	2	14/12	1	18/12	4	M
9	7/12	9/12	2	11/12	2	12/12	1	14/12	2	18/12	4	F
10	7/12	10/12	3	12/12	2	13/12	1	14/12	1	17/12	3	F
TOTAL			29		15		13		14		38	6:4
MEAN			2.9		1.5		1.3		1.4		3.8	

APPENDIX TABLE 4 CONTD.

BATCH NO. 4 DECEMBER '87

	1ST INSTAR			2ND INSTAR		3RD INSTAR		4TH INSTAR		PUPAE		SEX
CAGE	START	STOP	DURATION	STOP	DURATION	STOP	DURATION	STOP	DURATION	STOP	DURATION	
1	6/12	9/12	3	11/12	2	13/12	2	15/12	2	20/12	5	F
2	6/12	9/12	3	10/12	1	11/12	1	13/12	2	17/12	4	M
3	6/12	8/12	2	10/12	2	11/12	1	12/12	1	17/12	5	F
4	6/12	9/12	3	11/12	2	12/12	1	14/12	2	18/12	4	F
5	6/12	9/12	3	11/12	2	12/12	1	13/12	1	17/12	4	F
6	11/12	13/12	2	15/12	2	17/12	2	18/12	1	21/12	3	F
7	11/12	14/12	3	15/12	1	16/12	1	18/12	2	22/12	4	F
8	11/12	14/12	3	15/12	1	17/12	2	18/12	1	21/12	3	F
9	11/12	14/12	3	16/12	2	17/12	1	18/12	1	22/12	4	F
10	11/12	14/12	3	15/12	1	16/12	1	18/12	2	21/12	3	F
TOTAL			28		16		13		15		39	9:1
MEAN			2.8		1.6		1.3		1.5		3.9	

APPENDIX TABLE 4 CONTD.

BATCH NO. 5 JANUARY '88

	1ST INSTAR			2ND INSTAR		3RD INSTAR		4TH INSTAR		PUPAE		SEX
CAGE	START	STOP	DURATION	STOP	DURATION	STOP	DURATION	STOP	DURATION	STOP	DURATION	
1	16/01	18/01	2	19/01	1	20/01	1	22/01	2	26/01	4	M
2	16/01	18/01	2	20/01	2	21/01	1	22/01	1	27/01	5	M
3	16/01	19/01	3	21/01	2	22/01	1	24/01	2	28/01	4	M
4	16/01	18/01	2	20/01	2	21/01	1	23/01	2	26/01	3	F
5	16/01	18/01	2	19/01	1	20/01	1	22/01	2	25/01	3	M
6	17/01	19/01	2	21/01	2	22/01	1	23/01	1	26/01	3	F
7	17/01	19/01	2	20/01	1	21/01	1	22/01	1	27/01	5	F
8	17/01	19/01	2	21/01	2	23/01	2	25/01	2	29/01	4	F
9	17/01	19/01	2	21/01	2	22/01	1	24/01	2	27/01	3	F
10	17/01	20/01	3	21/01	1	22/01	1	24/01	2	28/01	4	M
TOTAL			22		16		11		17		38	5:5
MEAN			2.2		1.6		1.1		1.7		3.8	

APPENDIX TABLE 4 CONTD.

BATCH NO. 6 JANUARY '88

	1ST INSTAR			2ND INSTAR		3RD INSTAR		4TH INSTAR		PUPAE		SEX
CAGE	START	STOP	DURATION	STOP	DURATION	STOP	DURATION	STOP	DURATION	STOP	DURATION	
1	16/01	18/01	2	20/01	2	22/01	2	23/01	1	28/01	5	F
2	16/01	19/01	3	21/01	2	23/01	2	24/01	1	28/01	4	F
3	16/01	19/01	3	20/01	1	22/01	2	23/01	1	26/01	3	M
4	16/01	19/01	3	20/01	1	21/01	1	23/01	2	26/01	3	F
5	18/01	20/01	2	21/01	1	23/01	2	24/01	1	29/01	5	F
6	18/01	20/01	2	21/01	1	23/01	2	25/01	2	29/01	4	F
7	18/01	20/01	2	22/01	2	24/01	2	26/01	2	30/01	4	F
8	18/01	20/01	2	21/01	1	22/01	1	24/01	2	28/01	4	F
9	18/01	20/01	2	22/01	2	23/01	1	24/01	1	28/01	4	M
10	18/01	20/01	2	22/01	2	23/01	1	25/01	2	28/01	3	M
TOTAL			23		15		16		15		39	7:3
MEAN			2.3		1.5		1.6		1.5		3.9	

APPENDIX TABLE 5: STUDIES ON LONGEVITY OF ADULT
ADULT C. LUNATA IN THE LABORATORY

Cage	Emerged	Died	Duration	Sex
1	8/12/87	06/02/88	60	M
2	8/12/87	12/02/88	66	F
3	9/12/87	13/02/88	66	F
4	9/12/87	13/02/88	66	M
5	10/12/87	15/02/88	67	M
6	10/12/87	15/02/88	67	M
7	11/12/87	19/01/88	39	M
8	11/12/87	25/02/88	76	F
9	11/12/87	22/03/88	102	F
10	11/12/87	19/05/88	158	F
11	12/12/87	24/05/88	164	M
12	12/12/87	06/06/88	180	M
13	13/12/87	08/06/88	182	F
14	12/12/87	20/06/88	194	F
15	13/12/87	28/06/88	202	F
TOTAL			1689.00	
MEAN			112.60	
S.D.			59.16	
S.E.			15.29	
RANGE			60 - 202	

APPENDIX TABLE 6: MEASUREMENT OF THE LIFE STAGES OF C. LUNATA

EGGS

	LENGTH(mm)	WIDTH(mm)
1	1.30	0.63
2	1.35	0.60
3	1.40	0.60
4	1.35	0.60
5	1.25	0.55
6	1.35	0.60
7	1.30	0.60
8	1.35	0.60
9	1.35	0.60
10	1.35	0.60
11	1.35	0.60
12	1.35	0.60
13	1.35	0.55
14	1.25	0.55
15	1.25	0.55
16	1.30	0.60
17	1.30	0.55
18	1.35	0.60
19	1.30	0.60
20	1.30	0.60
TOTAL	26.45	11.78
MEAN	1.32	0.59
S.D.	0.04	0.02

APPENDIX TABLE 6 CONTD.

SECOND INSTAR

S/No.	HEAD LENGTH	WIDTH	THORAX LENGTH	WIDTH	ABDOMEN LENGTH	WIDTH	ANTENNA LENGTH	TOTAL
1	0.42	0.61	1.82	1.03	1.86	1.03	0.19	4.10
2	0.38	0.61	1.52	1.03	1.63	1.03	0.19	3.53
3	0.30	0.61	1.48	1.03	1.60	1.03	0.19	3.38
4	0.38	0.61	1.33	1.03	1.60	1.03	0.19	3.31
5	0.38	0.61	1.71	1.03	1.71	1.03	0.19	3.80
6	0.38	0.61	1.33	1.03	1.52	1.03	0.19	3.23
7	0.30	0.61	1.33	1.03	1.60	1.03	0.19	3.23
8	0.38	0.61	1.37	1.03	1.67	1.03	0.15	3.42
9	0.42	0.61	1.52	1.03	1.71	1.03	0.15	3.65
10	0.42	0.61	1.33	1.03	1.44	1.03	0.15	3.19
11	0.46	0.61	1.33	1.03	1.90	1.03	0.19	3.69
12	0.46	0.61	1.44	1.03	1.67	1.03	0.19	3.57
13	0.46	0.61	1.33	1.03	1.71	1.03	0.23	3.49
14	0.42	0.61	1.33	1.03	1.52	1.03	0.19	3.27
15	0.46	0.61	1.25	1.03	1.33	1.03	0.15	3.04
16	0.38	0.61	1.33	1.03	1.71	1.03	0.19	3.42
17	0.38	0.61	1.33	1.03	1.71	1.03	0.19	3.12
18	0.46	0.61	1.14	1.03	1.52	1.03	0.19	3.23
19	0.38	0.61	1.14	1.03	1.71	1.03	0.15	3.23
20	0.46	0.61	1.33	1.03	1.44	1.03	0.19	3.42
TOTAL	8.08	12.20	27.69	20.60	32.56	20.60	3.64	68.32
MEAN	0.40	0.61	1.38	1.03	1.62	1.03	0.18	3.41
S.D.	0.04	0.00	0.16	0.00	0.13	0.00	0.02	0.25

APPENDIX TABLE 6 CONTD.

FIRST INSTAR

S/No.	HEAD LENGTH	WIDTH	THORAX LENGTH	WIDTH	ABDOMEN LENGTH	WIDTH	ANTENNA LENGTH	TOTAL
1	0.29	0.41	0.82	0.60	0.91	0.60	0.12	2.02
2	0.36	0.41	0.60	0.60	0.65	0.60	0.17	1.61
3	0.26	0.41	0.88	0.60	0.89	0.60	0.14	2.03
4	0.36	0.41	0.67	0.60	0.60	0.60	0.17	1.63
5	0.29	0.41	0.91	0.60	1.20	0.60	0.12	2.40
6	0.33	0.41	0.60	0.60	0.89	0.60	0.17	1.82
7	0.26	0.41	0.72	0.60	0.79	0.60	0.17	1.77
8	0.29	0.41	0.69	0.60	0.96	0.60	0.16	1.94
9	0.31	0.41	0.81	0.60	0.96	0.60	0.17	2.08
10	0.31	0.41	0.74	0.60	0.79	0.60	0.17	1.84
11	0.31	0.41	0.79	0.60	0.69	0.60	0.17	1.79
12	0.31	0.41	0.79	0.60	0.96	0.60	0.17	2.06
13	0.29	0.41	0.69	0.60	1.08	0.60	0.14	2.06
14	0.29	0.41	0.69	0.60	0.86	0.60	0.14	1.84
15	0.34	0.41	0.94	0.60	0.67	0.60	0.17	1.95
16	0.29	0.41	0.67	0.60	1.08	0.60	0.12	1.63
17	0.29	0.41	0.84	0.60	0.72	0.60	0.14	2.21
18	0.31	0.41	0.69	0.60	0.91	0.60	0.14	1.72
19	0.31	0.41	0.79	0.60	0.79	0.60	0.17	2.01
20	0.29	0.41	0.72	0.60	0.67	0.60	0.14	1.80
TOTAL	6.09	8.20	14.98	12.00	17.07	12.00	3.06	38.21
MEAN	0.31	0.41	0.75	0.60	0.85	0.60	0.15	1.91
S.D.	0.02	0.00	0.10	0.00	0.16	0.00	0.01	0.20

APPENDIX TABLE 6 CONTD.

THIRD INSTAR

S/No.	HEAD LENGTH	WIDTH	THORAX LENGTH	WIDTH	ABDOMEN LENGTH	WIDTH	ANTENNA LENGTH	TOTAL
1	0.60	0.75	2.25	1.50	2.25	1.50	0.30	5.10
2	0.50	0.75	2.10	1.50	2.40	1.50	0.30	5.00
3	0.50	0.75	2.25	1.50	2.25	1.50	0.30	5.00
4	0.60	0.75	2.25	1.50	2.40	1.50	0.35	5.75
5	0.65	0.75	2.20	1.50	2.40	1.50	0.35	4.85
6	0.65	0.75	2.05	1.50	2.15	1.50	0.30	4.65
7	0.55	0.75	2.00	1.50	2.10	1.50	0.35	4.95
8	0.55	0.75	2.25	1.50	2.15	1.50	0.35	5.40
9	0.50	0.75	2.50	1.50	2.40	1.50	0.35	5.25
10	0.50	0.75	2.00	1.50	2.75	1.50	0.35	4.75
11	0.50	0.75	2.00	1.50	2.25	1.50	0.30	5.25
12	0.50	0.75	2.25	1.50	2.10	1.50	0.30	4.50
13	0.60	0.75	1.80	1.50	2.50	1.50	0.35	5.15
14	0.55	0.75	2.35	1.50	2.25	1.50	0.35	5.00
15	0.60	0.75	1.90	1.50	2.50	1.50	0.35	4.95
16	0.55	0.75	2.10	1.50	2.30	1.50	0.30	5.60
17	0.60	0.75	2.25	1.50	2.75	1.50	0.35	5.85
18	0.60	0.75	2.25	1.50	3.00	1.50	0.35	5.60
19	0.55	0.75	2.30	1.50	2.75	1.50	0.35	5.20
20	0.55	0.75	2.25	1.50	2.40	1.50	0.30	5.75
TOTAL	11.20	15.00	43.30	30.00	48.05	30.00	6.60	103.55
MEAN	0.56	0.75	2.16	1.50	2.40	1.50	0.33	5.17
S.D.	0.05	0.00	0.16	0.00	0.24	0.00	0.02	0.38

APPENDIX TABLE 6 CONTD.

FOURTH INSTAR

S/No.	HEAD LENGTH	WIDTH	THORAX LENGTH	WIDTH	ABDOMEN LENGTH	WIDTH		TOTAL
1	0.70	1.00	3.90	2.80	5.00	2.80	0.46	9.60
2	0.60	1.00	3.40	2.80	4.80	2.80	0.42	8.80
3	0.60	1.00	3.30	2.80	4.80	2.80	0.42	8.70
4	0.60	1.00	3.40	2.80	4.70	2.80	0.42	8.70
5	0.70	1.00	3.40	2.80	4.50	2.80	0.42	8.60
6	0.60	1.00	3.40	2.80	4.50	2.80	0.42	8.70
7	0.60	1.00	3.50	2.80	3.50	2.80	0.50	8.00
8	0.60	1.00	3.70	2.80	3.90	2.80	0.50	8.60
9	0.60	1.00	3.30	2.80	4.80	2.80	0.42	8.70
10	0.60	1.00	3.50	2.80	3.50	2.80	0.50	8.60
TOTAL	6.20	10.00	34.80	28.00	44.20	28.00	4.48	87.00
MEAN	0.62	1.00	3.48	2.80	4.42	2.80	0.45	8.70
S.D.	0.04	0.00	0.18	0.00	0.56	0.00	0.63	0.38

APPENDIX TABLE 6 CONTD.

PUPAE

	LENGTH(mm)	WIDTH(mm)
1	6.10	3.75
2	5.00	3.55
3	5.75	3.70
4	6.38	4.13
5	5.25	3.75
6	5.50	4.00
7	6.15	4.10
8	6.75	4.25
9	5.50	4.00
10	5.80	3.75
11	5.90	3.70
12	5.80	3.90
13	6.00	4.00
14	5.90	3.75
15	5.90	3.85
16	5.90	3.70
17	5.85	4.00
18	5.80	3.75
19	5.90	3.70
20	5.80	3.75
21	5.80	3.70
22	6.00	4.25
23	5.70	3.70
24	5.50	3.75
25	5.75	3.75
26	5.50	3.65
27	6.00	4.00
28	5.75	3.80
29	5.50	3.65
30	6.00	4.15
TOTAL	174.43	115.48
MEAN	5.81	3.84
S.D	0.31	0.18
S.E.	0.05	0.03

APPENDIX TABLE 7: LARVIPOSITION RATE OF A. CRACCIVORA

BATCH 1

CAGE NO.	1	2	3	4	5	TOTAL	MEAN	S.D.
DAY								
1	2	2	8	4	2	18	3.6	2.60
2	5	6	3	7	7	28	5.6	1.67
3	6	4	5	6	7	28	5.6	1.14
4	7	2	5	6	6	26	5.2	1.92
5	7	5	5	7	7	31	6.2	1.09
6	2	10	5	9	6	32	6.4	3.20
7	5	2	2	9	8	26	5.2	3.27
8	2	2	1	5	7	17	3.4	2.50
9	3	3	2	3	8	19	3.8	2.38
10	5	3	1	6	8	23	4.6	2.70
11	2	-	2	3	5	12	2.4	1.81
12	7	-	-	1	4	12	2.4	3.04
13	4	-	-	-	6	10	2.0	2.82
14	3	-	-	-	5	8	1.6	2.30
15	1	-	-	-	1	2	0.4	0.54
16	-	-	-	-	3	3	0.6	1.34
17	-	-	-	-	2	2	0.4	0.89
18	-	-	-	-	3	3	0.6	1.34
19	-	-	-	-	1	1	0.2	0.44
20	-	-	-	-	3	3	0.6	1.34
TOTAL	61	39	39	66	99	304	60.80	38.33
MEAN	4.06	3.90	3.54	5.50	4.95	15.20		
S.D.	2.08	2.55	2.21	2.43	2.39	10.94		
RANGE	1-7	2-10	1-8	1-9	1-8			

APPENDIX TABLE 7 CONTD.

BATCH 2

CAGE NO.	1	2	3	4	5	TOTAL	MEAN	S.D.
DAY								
1	2	1	5	9	3	20	4.0	3.16
2	5	4	6	10	6	31	6.2	2.28
3	3	7	10	12	4	36	7.2	3.83
4	6	6	5	2	7	26	5.2	1.92
5	6	6	9	1	4	26	5.2	2.94
6	9	9	1	3	3	25	5.0	3.74
7	8	9	-	6	2	25	5.0	3.87
8	8	3	-	6	2	19	3.8	3.19
9	5	8	-	7	2	22	4.4	3.36
10	5	7	-	8	-	20	4.0	3.80
11	4	7	-	2	-	13	2.6	2.96
12	3	8	-	1	-	12	2.4	3.36
13	1	3	-	-	-	4	0.8	1.30
14	2	3	-	-	-	5	1.0	1.41
15	1	1	-	-	-	2	0.4	0.54
16	2	4	-	-	-	6	1.2	1.78
17	1	2	-	-	-	3	0.6	0.89
18	1	1	-	-	-	2	0.4	0.54
TOTAL	72	89	36	67	33	297	59.4	24.17
MEAN	4	4.94	6	5.58	3.66	16.5		
S.D.	2.63	2.81	3.22	3.75	1.8	10.87		
RANGE.	1-9	1-9	1-10	1-12	2-7			

APPENDIX TABLE 7 CONTD.

BATCH 3

CAGE NO	1	2	3	4	5	TOTAL	MEAN	S.D.
DAY								
1	1	0	0	5	4	10	2.0	2.34
2	4	0	5	6	10	25	5.0	3.60
3	7	4	2	10	4	27	5.4	3.12
4	4	5	6	5	4	24	4.8	0.83
5	7	6	3	9	9	34	6.8	2.48
6	7	10	2	1	8	28	5.6	3.91
7	6	9	6	-	6	27	5.4	3.28
8	7	9	6	-	0	22	4.4	4.15
9	8	8	7	-	4	27	5.4	3.43
10	6	10	3	-	0	19	3.8	4.26
11	7	2	3	-	-	12	2.4	2.88
12	4	5	2	-	-	11	2.2	2.28
13	5	2	1	-	-	8	1.6	2.07
14	3	3	2	-	-	8	1.6	1.15
15	4	2	0	-	-	6	1.2	1.78
16	2	0	0	-	-	2	0.4	0.89
17	-	1	-	-	-	1	0.2	0.44
TOTAL	82	76	48	36	49	291	58.2	19.77
MEAN	5.12	4.47	3.42	6	5.44	17.11		
S.D.	2.06	3.62	2.17	3.22	3.12	10.38		
RANGE	1-8	1-10	1-7	1-10	4-10			

APPENDIX TABLE 7 CONTD.

BATCH 4

CAGE NO.	1	2	3	4	5	TOTAL	MEAN	S.D.
DAY								
1	7	10	2	2	6	27	5.4	3.43
2	3	9	8	2	3	25	5.0	3.24
3	10	9	1	4	7	31	6.2	3.70
4	2	6	-	6	7	21	4.2	3.03
5	6	5	-	4	4	19	3.8	2.28
6	3	1	-	4	0	8	1.6	1.81
7	7	4	-	6	4	21	4.2	2.68
8	7	2	-	7	3	19	3.8	3.11
9	2	2	-	7	2	13	2.6	2.60
10	1	-	-	3	1	5	1.0	1.22
11	0	-	-	2	-	2	0.4	0.89
12	2	-	-	1	-	3	0.6	0.89
13	1	-	-	1	-	2	0.4	0.54
TOTAL	51	48	11	49	37	196	39.2	16.67
MEAN	3.92	5.33	3.66	3.76	3.7	15.07		
S.D.	3.09	3.39	3.78	2.16	2.41	10.16		
RANGE	1-10	1-10	1-8	1-7	1-7			

APPENDIX TABLE 8: SYNCRONISATION BETWEEN C. LUNATA AND A. CRACCIVORA

PLOT 1

DAYS	1	2	3	4	5	6	7	8	TOTAL	MEAN	S.D.
TIME											
8.00	0	3	0	0	0	0	0	0	3	0.38	1.06
10.00	3	5	3	6	2	3	0	0	22	2.75	2.12
12.00	3	5	4	1	4	2	1	0	20	2.38	1.59
14.00	8	7	4	3	6	1	1	0	30	3.75	3.01
16.00	9	6	5	4	0	1	0	0	25	3.13	3.39
18.00	3	1	0	0	0	0	0	0	4	0.50	1.06
TOTAL	26	27	16	14	12	7	2	0	104	13.00	10.01
MEAN	4.33	4.50	2.66	2.33	2.00	1.16	0.33	0	17.33		
S.D.	3.44	2.16	2.16	2.42	2.52	1.16	0.51		11.23		

APPENDIX TABLE 8 CONTD.

PLOT 2

DAYS	1	2	3	4	5	6	7	8	TOTAL	MEAN	S.D.
TIME											
8.00	0	1	2	0	0	0	0	0	3	0.38	0.74
10.00	0	2	2	5	0	1	2	0	12	1.5	1.69
12.00	2	2	8	6	5	7	3	1	34	4.25	2.6
14.00	3	3	5	1	8	4	2	0	26	3.25	2.49
16.00	2	4	4	6	3	2	1	0	22	2.75	1.9
18.00	0	0	0	0	0	0	0	0	0	0.00	0
TOTAL	7	12	21	18	16	14	8	1	97	12.13	6.53
MEAN	1.16	2.00	3.5	3	2.66	2.33	1.33	0.16	16.16		
S.D.	1.32	1.41	2.81	2.96	3.32	2.73	1.21	0.4	13.42		

APPENDIX TABLE 8 CONTD.

PLOT 3

DAYS	1	2	3	4	5	6	7	8	TOTAL	MEAN	S.D.
TIME											
8.00	0	5	1	0	0	0	0	0	6	0.75	1.75
10.00	4	6	7	3	0	1	1	0	22	2.75	2.71
12.00	1	3	5	7	3	1	4	1	25	3.13	2.16
14.00	1	4	8	3	7	0	2	2	27	3.38	2.82
16.00	5	4	2	5	3	0	4	1	24	3	1.85
18.00	6	0	0	0	0	0	0	0	6	0.75	2.12
TOTAL	17	22	23	18	13	2	11	4	110	13.75	7.77
MEAN	2.83	3.66	3.83	3	2.16	0.33	1.83	0.66	18.33		
S.D.	2.48	2.06	3.31	2.75	2.78	0.51	1.83	0.81	9.68		

APPENDIX TABLE 8 CONTD.

PLOT 4

DAYS	1	2	3	4	5	6	7	8	TOTAL	MEAN	S.D.
TIME											
8.00	0	0	0	0	0	0	0	0	0	0	0
10.00	0	2	1	0	4	2	0	0	9	1.13	1.45
12.00	0	3	5	8	4	3	1	0	24	3	2.72
14.00	1	2	4	3	1	3	1	0	15	1.88	1.35
16.00	1	1	5	4	4	0	0	0	15	1.88	2.1
18.00	0	0	1	1	0	0	0	0	2	0.25	0.46
TOTAL	2	8	16	16	13	8	2	0	65	8.13	6.42
MEAN	0.33	1.33	2.66	2.66	2.16	1.33	0.33	0	10.83		
S.D.	0.51	1.21	2.25	3.07	2.04	1.5	0.51	0	9.02		

APPENDIX TABLE 8 CONTD.

PLOT 5

DAYS	1	2	3	4	5	6	7	8	TOTAL	MEAN	S.D.
TIME											
8.00	0	0	0	0	0	0	0	0	0	0	0
10.00	0	0	2	3	6	8	6	0	25	3.13	3.18
12.00	0	0	9	15	10	9	3	2	48	6.00	5.50
14.00	0	2	8	14	7	4	0	3	38	4.75	4.74
16.00	2	8	8	5	1	1	0	0	25	3.13	3.39
18.00	0	3	4	1	0	0	0	0	8	1.00	1.60
TOTAL	2	13	31	38	24	22	9	5	144	18.00	12.82
MEAN	0.33	2.16	5.16	6.33	4.00	3.66	1.5	0.83	24.00		
S.D.	0.81	3.12	3.71	6.56	4.25	4.03	2.5	1.32	17.92		

APPENDIX TABLE 8 CONTD.

PLOT 6

DAYS	1	2	3	4	5	6	7	8	TOTAL	MEAN	S.D.
TIME											
8.00	0	0	0	4	0	0	0	0	4	0.5	1.41
10.00	0	0	6	12	2	1	8	0	29	3.63	4.53
12.00	0	3	9	11	19	11	16	9	78	9.75	6.2
14.00	0	18	17	17	16	14	8	17	107	13.36	6.27
16.00	0	13	20	15	9	16	4	6	83	10.38	6.78
18.00	0	1	6	4	5	4	1	0	21	2.63	2.38
TOTAL	0	35	58	63	51	46	37	32	322	40.25	19.66
MEAN	0	5.83	9.66	10.5	8.50	7.66	6.16	5.33	53.66		
S.D.	0	7.73	7.5	5.46	7.66	6.88	5.87	6.86	41.08		

APENDIX TABLE 8 CONTD.

PLOT 7

DAYS	1	2	3	4	5	6	7	8	TOTAL	MEAN	S.D.
TIME											
8.00	0	0	2	0	0	0	0	0	2	0.25	0.7
10.00	0	0	12	3	0	0	0	0	15	1.88	4.22
12.00	0	0	1	1	0	0	0	0	2	0.25	0.46
14.00	0	0	0	0	0	0	0	3	3	0.38	1.06
16.00	0	9	0	0	0	0	0	0	9	1.13	3.18
18.00	0	2	0	0	0	0	0	0	2	0.25	0.7
TOTAL	0	11	15	4	0	0	0	3	33	4.13	5.79
MEAN	0	1.83	2.5	0.66	0	0	0	0.5	5.5		
S.D.	0	3.6	4.72	1.21	0	0	0	1.22	5.39		

APPENDIX TABLE 8 CONTD.

PLOT 8

DAYS	1	2	3	4	5	6	7	8	TOTAL	MEAN	S.D.
TIME											
8.00	0	0	0	0	0	0	0	0	0	0	0
10.00	0	0	1	4	0	0	0	0	5	0.63	1.4
12.00	0	0	3	6	0	0	0	0	9	1.13	2.23
14.00	0	0	2	2	0	0	0	0	4	0.5	0.92
16.00	0	3	0	3	0	0	0	0	6	0.75	1.38
18.00	0	1	2	0	0	0	0	0	3	0.38	0.74
TOTAL	0	4	8	15	0	0	0	0	27	3.38	5.52
MEAN	0	0.66	1.33	2.5	0	0	0	0	4.5		
S.D.	0	1.21	1.21	2.34	0	0	0	0	3.01		

APPENDIX TABLE 9: NUMBERS OF APHIDOPHAGOUS COCCINELLIDS RECORDED IN EACH SITE IN RELATION TO LOCATION AND DAY

SITE	LOCATION	DAYS 1	2	3	4	5	6	7	8	TOTAL	MEAN ± SD
1	FALLOW FIELD	26	27	16	14	12	7	2	0	104	13.00 ± 10.01
2	"	7	12	21	18	16	14	8	1	97	12.12 ± 6.53
3	"	17	22	23	18	13	2	11	4	110	13.75 ± 7.78
4	"	2	8	16	16	13	8	2	0	65	8.12 ± 6.42
5	NEAR MAIZE PLOT	2	13	31	38	24	22	9	5	144	18.00 ± 12.82
6	"	0	35	58	63	51	46	37	32	322	40.25 ± 19.66
7	VIRGIN FIELD	0	11	15	4	0	0	0	3	33	4.12 ± 5.79
8	"	0	4	8	15	0	0	0	0	27	3.37 ± 5.02
TOTAL		54	132	188	186	129	99	69	45	902	

APPENDIX TABLE 10: PERCENTAGE INCIDENCE OF APHIDOPHAGOUS COCCINELLIDS PER SITE IN RELATION TO LOCATION AND DAY

SITE	LOCATION	DAYS 1	2	3	4	5	6	7	8	TOTAL%
1	FALLOW FIELD	25.00	25.96	15.39	13.46	11.54	6.73	1.92	0.00	100
2	"	7.22	12.37	21.65	18.56	16.49	14.43	8.25	1.03	100
3	"	15.46	20.00	20.90	16.36	11.82	1.82	10.00	3.64	100
4	"	3.08	12.31	24.61	24.61	20.00	12.31	3.08	0.00	100
5	NEAR MAIZE PLOT	1.39	9.03	21.53	26.39	16.66	15.28	6.25	3.47	100
6	"	0.00	10.87	18.01	19.57	15.84	14.28	11.49	9.94	100
7	VIRGIN FIELD	0.00	33.33	45.46	12.12	0.00	0.00	0.00	9.09	100
8	"	0.00	14.81	29.63	55.56	0.00	0.00	0.00	0.00	100

APPENDIX TABLE 11: NUMBERS OF APHIDOPHAGOUS COCCINELLIDS RECORDED IN EACH SITE IN RELATION TO TIME OF DAY

	TIME OF DAY							
SITE	8.00	10.00	12.00	14.00	16.00	18.00	TOTAL	MEAN ± SD
1	3	22	20	30	25	4	104	17.33 ± 11.23
2	3	12	34	26	22	0	97	16.16 ± 13.42
3	6	22	25	27	24	6	110	18.33 ± 9.68
4	0	9	24	15	15	2	65	10.83 ± 9.02
5	0	25	48	38	25	8	144	24.00 ± 17.92
6	4	29	78	107	83	21	322	53.66 ± 41.08
7	2	15	2	3	9	2	33	5.50 ± 5.39
8	0	5	9	4	6	3	27	4.50 ± 3.01
TOTAL	18	139	240	250	209	46	902	150.33 ± 99.94
MEAN	2.25	17.37	30	31.25	26.12	5.75	112.75	
S.D.	2.18	8.39	23.99	33.02	24.14	6.64	93.41	

APPENDIX TABLE 12 : PERCENTAGE INCIDENCE OF APHIDOPHAGOUS COCCINELLIDS PER SITE IN RELATION TO TIME OF DAY

SITE	TIME OF DAY 8.00	10.00	12.00	14.00	16.00	18.00	TOTAL %
1	2.89	21.15	19.23	28.85	24.03	3.85	100
2	3.09	12.37	35.05	26.80	22.68	0.00	100
3	5.45	20.00	22.73	24.55	21.82	5.45	100
4	0.00	13.85	36.92	23.08	23.08	3.07	100
5	0.00	17.36	33.33	26.39	17.36	5.56	100
6	1.24	9.01	24.22	33.23	25.78	6.52	100
7	6.06	45.46	6.06	9.09	27.27	6.06	100
8	0.00	18.52	33.33	14.82	22.22	11.11	100

APPENDIX TABLE 13: STAGES OF PREY PREFFERED BY MALE C. LUNATA UNDER LABORATORY CONDITIONS

APHID STAGE	TOTAL NO OF PREY OFFERED	REPLICATES 1	2	3	4	5	6	7	8	9	10	%APHID CONSUMED	MEAN	S.E.
1st INSTAR	100	7	4	5	10	5	8	6	8	7	10	70	7	0.64
2nd INSTAR	100	6	7	8	6	3	9	7	2	6	5	57	5.7	0.59
3rd INSTAR APTERAE	100	4	3	6	6	6	6	6	6	6	8	57	5.7	0.42
3rd INSTAR ALATE	100	7	6	5	5	7	7	4	5	1	6	53	5.3	0.57
4th INSTAR APTERAE	100	3	4	6	6	4	4	5	1	8	8	49	4.9	0.68
4th INSTAR ALATE	100	5	4	4	4	6	5	5	4	3	4	44	4.4	0.26
ADULT	100	2	3	0	3	2	0	5	2	1	5	23	2.3	0.56
TOTAL	700	34	31	34	40	33	37	38	28	32	46	353	35.3	3.72

APPENDIX TABLE 13 CONTD.: STAGES OF PREY PREFERRED BY FEMALE C. LUNATA UNDER LABORATORY CONDITIONS

APHID STAGE	TOTAL NO OF PREY OFFERED	REPLICATES 1	2	3	4	5	6	7	8	9	10	%APHID CONSUMED	MEAN	S.E.
1st INSTAR	100	7	4	6	8	7	9	6	10	10	6	73	7.3	0.61
2nd INSTAR	100	5	8	8	5	8	10	7	10	8	7	76	7.6	0.54
3rd INSTAR APTERAE	100	7	7	5	9	6	10	7	9	7	6	73	7.3	0.49
3rd INSTAR ALATE	100	8	5	5	7	7	10	10	6	5	6	69	6.9	0.6
4th INSTAR APTERAE	100	6	6	7	8	7	10	4	8	6	5	67	6.7	0.53
4th INSTAR ALATE	100	2	7	5	2	5	3	7	6	8	4	49	4.9	0.69
ADULT	100	4	6	3	3	3	4	5	6	5	4	43	4.3	0.36
TOTAL	700	39	43	39	42	43	56	46	55	49	38	450	45	3.13

APPENDIX TABLE 13 CONTD.: STAGES OF PREY PREFERRED BY MALE C. LUNATA IN THE FIELD

APHID STAGE	TOTAL NO OF PREY OFFERED	REPLICATES 1	2	3	4	5	6	7	8	9	10	%APHID CONSUMED	MEAN	S.E.
1st INSTAR	100	10	9	9	8	9	9	9	7	8	5	83	8.3	0.44
2nd INSTAR	100	6	8	10	7	4	6	9	8	7	8	73	7.3	0.53
3rd INSTAR APTERAE	100	8	6	8	8	6	8	6	7	7	7	71	7.1	0.27
3rd INSTAR ALATE	100	3	10	10	7	7	7	3	4	5	9	65	6.5	0.84
4th INSTAR APTERAE	100	6	4	7	8	3	8	5	8	3	10	62	6.2	0.75
4th INSTAR ALATE	100	5	7	7	5	7	8	5	3	5	8	60	6	0.51
ADULT	100	0	3	2	5	2	4	2	5	5	6	34	3.4	0.6
TOTAL	700	38	47	53	48	38	50	39	42	40	53	448	44.8	3.94

APPENDIX TABLE 13 CONTD.: STAGES OF PREY PREFFERED BY FEMALE C. LUNATA IN THE FIELD

APHID STAGE	TOTAL NO OF PREY OFFERED	REPLICATES 1	2	3	4	5	6	7	8	9	10	%APHID CONSUMED	MEAN	S.E.
1st INSTAR	100	9	9	6	10	8	9	10	10	9	9	89	8.9	0.37
2nd INSTAR	100	6	7	9	6	8	9	9	9	9	10	82	8.2	0.44
3rd INSTAR APTERAE	100	7	8	6	8	8	6	8	7	2	10	70	7	0.66
3rd INSTAR ALATE	100	0	7	7	7	7	7	7	5	7	7	61	6.1	0.7
4th INSTAR APTERAE	100	7	6	8	8	7	1	7	9	8	7	68	6.8	0.69
4th INSTAR ALATE	100	4	3	5	6	3	7	6	6	8	7	57	5.7	0.63
ADULT	100	4	4	1	6	2	3	6	7	4	8	45	4.5	0.7
TOTAL	700	37	44	42	35	43	42	53	53	47	58	472	47.2	4.19

APPENDIX TABLE 14: CAPTURE EFFICIENCY OF C. LUNATA

COCCINELLID STAGES	DESCRIPTION	APHID STAGES I	II	II	IV AP	IV AL	AD
	a	10	10	10	10	10	10
FIRST INSTAR	b	10	10	10	7	6	2
	c	23	41	65	73	90	183
SECOND INSTAR	b	10	10	10	9	5	3
	c	18	26	39	67	88	161
THIRD INSTAR	b	10	10	10	10	6	3
	c	18	21	37	46	53	82
FOURTH INSTAR	b	10	10	10	10	6	5
	c	15	21	23	30	34	61
ADULT MALE	b	10	10	10	10	10	8
	c	10	16	11	13	22	27
ADULT FEMALE	b	10	10	10	9	10	10
	c	10	10	10	11	12	15

a= No. of Aphids Offered
b= No. of Aphids Captured
c= No. of Encounters

APPENDIX TABLE 15: NO. OF PREY CONSUMED PER DAY BY VARIOUS STAGES OF C. LUNATA

REPLICATE 1	C. LUNATA STAGES					
APHID STAGE	1st	2nd	3rd	4th	MALE	FEMALE
1st INSTAR	11	25	49	10	138	184
2nd INSTAR	4	33	47	97	164	177
3rd INSTAR	2	21	39	44	95	97
4th INSTAR AP.	-	8	3	36	55	60
4th INSTAR AL	-	3	4	28	41	60
FEMALE	-	-	2	14	40	49
TOTAL	17	90	144	229	533	627
MEAN	2.83	15	24	38.16	88.83	104.5
S.D.	4.3	13.25	23.25	31.56	52.76	61.11

APPENDIX TABLE 15 CONTD.

REPLICATE 2

APHID STAGE	C. LUNATA STAGES 1st	2nd	3rd	4th	MALE	FEMALE
1st INSTAR	9	36	51	102	172	134
2nd INSTAR	5	31	46	87	154	157
3rd INSTAR	2	25	41	33	87	99
4th INSTAR AP.	-	5	12	23	50	61
4th INSTAR AL	-	4	13	22	51	49
FEMALE	-	-	1	18	43	24
TOTAL	16	101	164	285	557	524
MEAN	2.66	16.83	27.33	47.5	92.83	87.33
S.D.	3.66	15.63	21.11	37.04	56.65	51.65

APPENDIX TABLE 15 CONTD.

REPLICATE 3

APHID STAGE	C. LUNATA STAGES 1st	2nd	3rd	4th	MALE	FEMALE
1st INSTAR	9	29	44	99	127	200
2nd INSTAR	5	32	32	95	122	150
3rd INSTAR	3	20	28	51	97	90
4th INSTAR AP.	-	7	18	44	41	35
4th INSTAR AL	-	2	12	50	49	60
FEMALE	-	-	2	24	36	22
TOTAL	17	90	136	363	472	552
MEAN	2.83	15	22.66	60.5	78.66	92.83
S.D.	4.3	13.91	15.05	29.92	41.63	69.57

APPENDIX TABLE 15 CONTD.

REPLICATE 5	C. LUNATA STAGES					
APHID STAGE	1st	2nd	3rd	4th	MALE	FEMALE
1st INSTAR	7	43	50	107	242	247
2nd INSTAR	5	18	42	89	107	177
3rd INSTAR	2	12	36	37	93	91
4th INSTAR AP.	-	8	6	25	44	50
4th INSTAR AL	-	2	2	25	46	31
FEMALE	-	-	2	20	43	41
TOTAL	14	83	138	303	575	637
MEAN	2.33	13.83	23	50.5	95.83	106.16
S.D.	3.01	15.72	22.04	37.64	76.75	87.33

APPENDIX TABLE 15 CONTD.

REPLICATE 7

	C. LUNATA STAGES					
APHID STAGE	1st	2nd	3rd	4th	MALE	FEMALE
1st INSTAR	12	36	49	108	160	198
2nd INSTAR	6	28	47	86	122	189
3rd INSTAR	2	19	36	60	136	96
4th INSTAR AP.	-	3	7	14	45	84
4th INSTAR AL	-	1	3	24	66	72
FEMALE	-	-	1	22	48	58
TOTAL	20	87	143	314	577	697
MEAN	3.33	14.5	23.83	52.33	96.16	116.16
S.D.	4.84	15.42	22.61	38.68	49.34	61.28

APPENDIX TABLE 15 CONTD.

REPLICATE 9

APHID STAGE	C. LUNATA STAGES 1st	2nd	3rd	4th	MALE	FEMALE
1st INSTAR	12	29	59	126	186	190
2nd INSTAR	5	23	38	88	132	108
3rd INSTAR	2	16	41	43	96	86
4th INSTAR AP.	-	8	28	32	61	61
4th INSTAR AL	-	2	8	29	59	53
FEMALE	-	-	3	18	41	42
TOTAL	19	78	177	336	575	540
MEAN	3.16	13	29.5	56	95.83	90
S.D.	4.75	11.66	21.17	42.05	54.79	54.5

APPENDIX TABLE 15 CONTD.

REPLICATE 11

	C. LUNATA STAGES					
APHID STAGE	1st	2nd	3rd	4th	MALE	FEMAL
1st INSTAR	9	27	48	98	172	190
2nd INSTAR	6	25	27	106	181	194
3rd INSTAR	1	18	50	86	158	94
4th INSTAR AP.	-	7	23	31	60	69
4th INSTAR AL.	-	3	4	31	52	70
FEMALE	-	-	2	15	46	48
TOTAL	16	80	154	367	669	665
MEAN	2.66	13.33	25.66	61.16	111.5	110.8
S.D.	3.88	11.57	20.63	39.83	65.01	64.54

APPENDIX TABLE 16. MEAN NUMBER (±SD)* OF A. CRACCIVORA CONSUMED BY THE DIFFERENT INSTARS AND ADULTS OF C. LUNATA PER DAY.

Aphid stages	C. lunata instars and adults.					
	I	II	III	IV	Adult male	Adult female
I instar	9.42 ± 1.68 a	34.08 ± 6.27 a	49.08 ± 5.33 a	110.33 ± 10.58 a	184.17 ± 33.23 a	193.00 ± 24.92 a
II instar	4.50 ± 1.17 a	28.33 ± 6.18 ab	40.08 ± 6.49 a	90.00 ± 14.53 b	149.75 ± 29.50 b	154.00 ± 33.37 b
III instar	2.17 ± 0.58 a	19.33 ± 3.37 b	37.33 ± 6.69 a	62.67 ± 22.63 c	112.67 ± 25.83 c	93.83 ± 27.51 c
IV apterae	–	6.58 ± 1.68 c	13.25 ± 7.45 b	37.83 ± 12.40 d	55.08 ± 12.45 d	63.17 ± 25.17 d
IV alate	–	2.67 ± 1.07 c	6.58 ± 3.94 b	33.58 ± 11.32 d	47.50 ± 8.32 de	54.42 ± 13.88 d
Adult	–	–	1.83 ± 0.94 b	19.92 ± 6.84 e	41.08 ± 9.12 e	39.08 ± 13.68 e

*Mean within the same colume followed by the same letter are not significantly different at p=0.05 .

APPENDIX TABLE 17: HANDLING TIME OF PREY (TIME IN MINUTES)

1st INSTAR COCCINELLID S/NO.	1st	2nd	3rd	4th AP	4th AL	ADULT
1	14.0	75	480			
2	20.0	57	480			
3	19.0	58				
4	22.0	61				
5	15.0	71				
6	19.0	59				
7	21.0	76				
8	18.5	68				
9	20.0	65				
10	22.0	78				
11	26.0	81				
12	13.0	72				
13	28.0	76				
14	19.0	53				
15	21.0	67				
MEAN	19.83	67.80				
SD	4.00	8.68				
SE	1.03	2.24				

APPENDIX TABLE 17 CONTD.

2nd INSTAR COCCINELLID

S/NO.	1st	2nd	3rd	4th AP	4th AL	ADULT
1	18.0	61	96	215	219	
2	21.0	39	63	196	223	
3	16.0	68	106	173	241	
4	19.0	66	83	204	190	
5	15.0	64	120	212	198	
6	16.0	56	121			
7	16.0	38	101			
8	17.0	71	92			
9	16.0	73	86			
10	18.0	64	104			
11	21.0	68				
12	26.0	29				
13	18.0	36				
14	17.0	51				
15	14.0	61				
16	16.0	63				
17	13.0	67				
18	19.0	76				
19	21.0	65				
20	23.0	61				
MEAN	17.70	58.85	97.20	200.00	213.80	
SD	3.61	13.29	17.47	16.80	20.31	
SE	0.80	2.97	5.53	7.53	9.10	

APPENDIX TABLE 17 CONTD.

3rd INSTAR COCCINELLID

S/NO.	1st	2nd	3rd	4th AP	4th AL	ADULT
1	5.63	8.01	12.17	18.79	36.18	20.00
2	9.10	8.99	12.01	21.68	28.01	29.01
3	6.38	9.06	12.08	26.11	41.00	26.73
4	6.36	6.07	12.23	23.37	46.43	36.64
5	6.72	7.73	12.76	19.18	38.96	31.37
6	6.88	6.15	6.88	20.19	31.17	24.44
7	5.63	8.92	10.09	20.07	29.77	43.04
8	6.76	8.19	12.91	19.00	61.03	32.00
9	9.11	10.90	13.07	21.07	41.48	63.41
10	8.20	5.63	15.00	21.07	33.30	47.11
11	6.31	8.66	12.99	21.08	52.28	59.63
12	6.99	9.09	13.06	21.99	46.09	48.89
13	6.89	9.01	12.01	21.00	45.00	48.44
14	9.91	6.89	12.99	21.98	43.37	41.31
15	9.18	6.02	12.86	16.09	49.00	53.42
16	6.81	7.44	14.16	23.45	47.01	60.55
17	5.55	8.64	12.66	22.18	56.61	36.13
18	5.08	9.42	9.09	21.09	31.52	48.28
19	7.13	15.01	11.99	23.55	41.08	59.48
20	6.09	10.11	14.67	26.40	46.67	47.37
MEAN	7.03	8.49	12.28	21.43	42.29	42.86
SD	1.36	2.09	1.84	2.41	8.93	12.96
SE	0.31	0.47	0.41	0.54	1.99	2.89

APPENDIX TABLE 17 CONTD.

4th INSTAR COCCINELLID

S/NO.	1st	2nd	3rd	4th AP	4th AL	ADULT
1	1.96	2.00	5.58	6.60	11.01	8.12
2	0.90	2.53	6.10	7.18	6.80	6.36
3	1.21	2.80	6.80	6.10	9.44	6.44
4	3.41	1.50	6.34	6.86	7.06	9.06
5	1.06	2.16	6.81	6.13	8.77	8.69
6	1.01	4.02	6.85	6.42	6.48	8.48
7	1.01	2.81	5.90	8.10	6.98	8.70
8	1.03	2.16	4.36	7.86	6.01	9.30
9	1.31	3.49	7.16	7.14	8.47	9.16
10	1.47	2.93	7.11	7.86	9.01	8.89
11	1.71	3.10	6.33	8.80	6.78	10.46
12	2.23	3.66	5.51	8.10	8.00	6.18
13	1.06	4.09	6.60	7.19	8.96	10.00
14	0.98	2.71	7.18	8.32	8.91	9.94
15	1.74	2.86	5.88	8.00	8.67	8.67
16	1.34	2.11	3.67	6.47	6.76	9.90
17	1.09	3.23	6.18	9.01	9.47	9.10
18	1.22	6.41	6.80	8.73	6.83	9.81
19	1.08	3.07	6.58	6.33	6.81	10.11
20	2.10	1.89	5.99	6.76	12.02	10.86
MEAN	1.44	2.97	6.18	7.39	8.16	8.91
SD	0.61	1.06	0.90	0.93	1.59	1.31
SE	0.13	0.23	0.20	0.21	0.35	0.29

APPENDIX TABLE 17 CONTD.

ADULT MALE S/NO.	1st	2nd	3rd	4th AP	4th AL	ADULT
1	0.06	0.27	0.75	0.85	1.08	1.13
2	0.07	0.26	0.90	0.96	1.03	1.58
3	0.07	0.35	0.65	0.98	1.06	1.60
4	0.09	0.30	0.95	0.96	1.07	1.46
5	0.08	0.33	0.75	1.00	1.10	1.53
6	0.23	0.20	0.89	0.73	1.10	1.23
7	0.06	0.18	0.93	0.51	1.06	1.40
8	0.19	0.33	0.64	0.50	0.98	1.63
9	0.14	0.23	0.69	0.73	1.00	1.68
10	0.19	0.40	0.72	0.56	1.01	1.39
11	0.23	0.36	0.78	0.96	0.96	1.66
12	0.10	0.32	0.80	0.95	1.11	1.10
13	0.13	0.19	0.90	0.98	0.83	1.38
14	0.06	0.23	0.58	0.94	0.86	1.32
15	0.11	0.36	0.66	1.13	1.01	1.45
16	0.13	0.25	0.68	0.89	0.98	2.05
17	0.12	0.19	0.49	0.81	0.83	2.00
18	0.26	0.29	0.96	1.01	0.88	1.64
19	0.24	0.28	0.71	1.07	1.21	1.50
20	0.36	0.18	0.96	0.66	1.08	2.17
MEAN	0.14	0.27	0.76	0.85	1.01	1.54
SD	0.08	0.06	0.13	0.18	0.10	0.27
SE	0.01	0.01	0.02	0.04	0.02	0.06

APPENDIX TABLE 17 CONTD.

ADULT FEMALE

S/NO.	1st	2nd	3rd	4th AP	4th AL	ADULT
1	0.02	0.12	1.07	1.09	1.23	1.36
2	0.03	0.10	1.00	1.15	1.50	1.48
3	0.03	0.07	1.03	1.15	1.43	1.61
4	0.05	0.05	0.90	1.78	1.67	1.63
5	0.05	0.13	1.01	1.01	1.81	1.59
6	0.07	0.07	0.93	1.02	1.76	1.09
7	0.07	0.16	1.10	0.96	1.28	1.19
8	0.07	0.13	1.02	1.02	1.44	1.02
9	0.03	0.11	0.96	0.93	1.36	1.38
10	0.03	0.13	1.12	0.87	1.17	1.60
11	0.03	0.15	1.08	1.16	1.73	1.63
12	0.08	0.10	1.10	1.07	1.64	1.62
13	0.05	0.17	1.03	1.04	1.43	1.66
14	0.10	0.15	1.07	1.09	1.67	0.78
15	0.07	0.32	1.16	1.11	1.46	1.64
16	0.07	0.53	1.18	1.00	1.34	1.03
17	0.06	0.61	1.11	1.06	1.32	1.00
18	0.05	1.10	1.01	1.13	1.46	1.60
19	0.04	1.06	1.03	1.17	1.19	1.03
20	0.05	0.23	1.17	1.40	1.25	1.56
MEAN	0.05	0.17	1.05	1.11	1.45	1.42
SD	0.02	0.14	0.07	0.19	0.19	0.26
SE	0.004	0.03	0.01	0.04	0.04	0.05

APPENDIX TABLE 18: FUNCTIONAL RESPONSE OF ADULT C. LUNATA TO DIFFERENT DENSITIES OF A. CRACCIVORA

Adult Male coccinellid Vs First Instar Aphid

	APHID DENSITY					
Replicate Number	5	10	20	40	80	160
1	5	8	17	11	36	31
2	5	6	15	26	14	30
3	5	10	6	9	31	57
4	4	3	19	30	38	79
5	5	9	5	34	40	79
6	1	10	18	21	42	108
7	5	1	13	38	31	83
8	4	1	20	29	45	94
9	3	10	19	20	51	33
10	5	3	18	36	46	132
TOTAL	42	61	150	254	374	726
MEAN	4.2	6.1	15	25.4	37.4	72.6
S.D.	1.31	3.78	5.41	10.02	10.41	34.61
S.E.	0.41	1.19	1.71	3.17	3.29	10.95

APPENDIX TABLE 18 CONTD.

Adult Male coccinellid Vs Third Instar Aphid

	APHID DENSITY					
Replicate Number	5	10	20	40	80	160
1	5	2	7	23	32	90
2	5	10	13	19	34	53
3	5	9	8	20	45	48
4	3	9	14	13	39	63
5	5	5	13	16	43	69
6	5	5	10	14	43	30
7	4	7	9	13	27	43
8	4	3	6	17	39	41
9	2	6	10	9	35	50
10	5	3	13	18	28	47
TOTAL	43	59	103	162	365	534
MEAN	4.3	5.9	10.3	16.2	36.5	53.4
S.D.	1.05	2.8	2.83	4.67	6.32	16.88
S.E.	0.33	0.88	0.89	1.28	2	5.34

APPENDIX TABLE 18 CONTD.

Adult Male coccinellid Vs Adult Aphid

Replicate Number	APHID DENSITY 5	10	20	40	80	160
1	5	7	16	16	37	72
2	2	10	11	25	29	89
3	2	6	2	28	28	68
4	5	10	6	22	31	70
5	1	9	18	32	32	55
6	3	1	14	10	13	30
7	3	1	8	11	27	29
8	4	4	12	10	21	31
9	3	3	14	15	28	36
10	3	6	11	12	19	43
TOTAL	31	57	112	181	265	523
MEAN	3.1	5.7	11.2	18.1	26.5	52.3
S.D.	1.28	3.4	4.8	8.07	6.99	21.46
S.E.	0.4	1.07	1.51	2.55	2.21	6.79

APPENDIX TABLE TABLE 18 CONTD.

Adult Female coccinellid Vs First Instar Aphid

	APHID DENSITY					
Replicate Number	5	10	20	40	80	160
1	3	10	16	34	60	152
2	5	10	18	40	19	153
3	3	0	19	20	80	137
4	5	8	20	10	75	142
5	5	6	7	31	78	140
6	3	10	18	31	34	80
7	1	10	19	26	79	85
8	5	9	19	29	49	91
9	5	10	8	29	42	98
10	3	10	19	26	57	85
TOTAL	38	83	163	276	573	1163
MEAN	3.8	8.3	16.3	27.6	57.3	116.3
S.D.	1.39	3.19	4.76	8.12	21.2	30.77
S.E.	0.43	1	1.5	2.56	6.7	9.73

APPENDIX TABLE 18 CONTD.

Adult Female coccinellid Vs Third Instar Aphid

	APHID DENSITY					
Replicate Number	5	10	20	40	80	160
1	4	8	17	22	28	88
2	3	10	9	29	42	110
3	2	10	19	28	23	95
4	4	10	19	16	37	85
5	4	9	20	26	32	46
6	5	7	7	10	24	52
7	5	4	7	18	17	44
8	5	3	12	19	28	46
9	4	8	14	18	26	58
10	5	6	9	17	23	53
TOTAL	41	75	133	203	280	677
MEAN	4.1	7.5	13.3	20.3	28	67.7
S.D.	0.99	2.5	5.18	5.94	7.33	24.28
S.E.	0.31	0.79	1.63	1.89	2.31	7.68

APPENDIX TABLE 18 CONTD.

Adult Female coccinellid Vs Adult Aphid

	APHID DENSITY					
Replicate Number	5	10	20	40	80	160
1	5	9	17	7	36	37
2	3	10	20	23	62	68
3	5	10	20	17	67	60
4	4	9	18	18	32	64
5	4	1	17	23	30	63
6	5	4	7	19	32	47
7	3	7	6	16	28	31
8	1	2	4	14	30	28
9	4	7	3	20	15	43
10	5	5	6	18	28	30
TOTAL	39	64	118	175	360	471
MEAN	3.9	6.4	11.8	17.5	36	47.1
S.D.	1.28	3.27	7.14	4.64	16.02	15.55
S.E.	0.4	1.03	2.25	1.46	5.06	4.92