A STUDY ON EGG DEVELOPMENT AND SURVIVAL IN *LOCUSTA MIGRATORIA MIGRATORIOIDES* (Reiche and Fairmaire) IN THE CHAD BASIN AREA

BY

JOSEPH B. ACKONOR
(B.Sc, M.Sc.)

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NIGERIA

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DEDICATION

In appreciation of their understanding and sacrifice I dedicate this work to my dear wife Emma, my children: Kofi, Abena, Adwoa, Yaw and Kwasi and to my dear mother, Beatrice Amma Darkoa.

DEPARTMENT OF BIOLOGICAL SCIENCES
AHMADU BELLO UNIVERSITY
ZARIA
NIGERIA

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

JOSEPH BEKAE ACKONOR

CERTIFICATION

This thesis, entitled A Study On Egg Development And Survival In Locusta migratoria migratorioides(Reiche and Fairmaire) In The Chad Basin Area,

By

Joseph Bekae Ackonor

meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, and it is approved for its contribution to knowledge and literary presentation.

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(Name and Signature)
Chairman, Supervisory Committee

Date:.....

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(Name and Signature)
Member, Supervisory Committee

Date:.....

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(Name and Signature)
Member, Supervisory Committee

Date:.....

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(Name and Signature)
Head of Department

Date:.....

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.....
(Name and Signature)
Dean, Postgraduate School

Date:.....

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A B S T R A C T

Field and laboratory studies on egg development, survival and hatchling weight in L. migratoria migratorioides were made at Ngala (12°20'N, 14°10'E) and Maiduguri (11°53'N; 13°16'E) in the Lake Chad Basin locust outbreak area.

During 1981 to 1985 data on eggpods were compiled for four seasons namely, the rainy season (July to September); the harmattan (mid-November to February); the hot-dry season (March to mid-May) and the early rains season (mid-May to June),

In the field locusts were bred in open-bottomed wooden frame cages in three soil habitats classified as sandy, sandy-clay loam and clayey.

In the laboratory breeding occurred in cages provided with predetermined soil/water mixtures for oviposition; incubation temperature ranged from 22 ± 1°C to 40° ±1°C. The laboratory study centred on the age of the female in relation to fecundity and the effects of moisture — including flood and drought—and also of temperature, on egg development, survival and hatchling weight,

A total of 907 eggpods were obtained in the field during the rainy season; these comprised 350 in sand,

298 in clay and **259** in sandy-clay loam. During the harmattan 49 eggpods were obtained, 24 in clay, 16 in sand and nine in sandy-clay loam soils. During the hot-dry season 35 eggpods were obtained; 16 of these occurred in clay, 11 in sand and eight in sandy-clay loam. Sixteen eggpods were obtained for the early rains seasons, eight in clay, seven in sand and one in sandy-clay loam.

Egg development rate was inferred from incubation period; it was fastest in the early rainy season when the mean incubation period in sand was 9.5 days and corresponded to the highest mean air temperature ranging from 29.8 C to 36.2 C. Development rate was slowest during the harmattan; incubation averaged 24 days in clay and coincided with **the** lowest mean air temperature ranging from 19.2°C to 25.6°C. Average development rates for the rainy season were intermediate to those for the seasons mentioned above; the rates coincided with the intermediate air temperature ranging from 24.6°C to 27.3°C;incubation lasted 13.6 days in sand, 16,0 days in sandy-clay loam and 18.1 days in the clayey soil.

Egg survival rate was inferred from the percentage of eggpods that hatched in a given eggpod population. The best survival rates were recorded during the rainy

season when 49.9% of 350 eggpods survived in sand, 25.1$ of 298 eggpods survived in clay and 16.6% of 259 eggpods survived in sandy-clay loam. During the harmattan 11.4$ of 24 eggpods survived in the clayey habitat only and during the early rains 29.2$ of seven eggpods survived in the sandy habitat only; eggs did not survive in any habitat during the hot-dry season.

Egg mortality factors under field conditions were identified as predation, parasitism, desiccation and decay. These factors were seasonally influenced. Predation was the major mortality factor, particularly during the rainy season; the major predatory suspects were larvae of coleoptera while a mite of the genus Allothrombium was a minor predatory agent. The parasites comprised Scelio africanus Remaudiere, S. sudanensis Remaudiere which belong to the family Scelionidae (Hymenoptera) and an unidentified worm of the family Enchytraeidae. The two parasitic groups caused minor mortality in the rainy season only. Desiccation and decay, which were prevalent during the drier and wetter seasons respectively, caused little mortality.

Laboratory observations showed that the female locust laid a maximum of five eggpods, the mean being

2.9. The number of eggs per eggpod declined with the age of the female but development and survival rates, and also hatchling weight, were independent of parental age.

Laboratory observations also indicated that development rate was influenced by soil moisture, including flood and desiccation; wetter soil conditions and drought retarded egg development. Development rate was also influenced by temperature, 34 ±1°C being the optimum at which the average incubation period was 10 days.

Eggs survived at temperatures ranging from 22 ± 1°C to 38° ± 1°C; no egg survived at 40 ± 1 °C. Survival was higher in wetter soils but flood was detrimental. Older eggs survived better in flood but pharates about to hatch were highly susceptible. Drought was also detrimental to survival.

Hatchlings emerging from wetter soils were heavier and had higher survival potentials.

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ABBREVIATIONS AND DEFINITIONS

Abnormal oviposition - Oviposition occurring not in the soil but on floor or walls of breeding cages.

African migratory locust - Locusta migratoria migratorioides (Reiche and Fairmaire (Orthoptera : Acrididae).

ALRC - The Anti-Locust Research Centre, London.

Arrested egg development - A halt in egg development controlled directly by adverse external conditions including drought and high temperature and brought to an end when the conditions improve; it is sometimes termed quiescence.

Clutch size - Number of eggs per eggpod

Congregans - Transient forms of locusts changing from the solitary to the gregarious phase.

COPR - Centre for Overseas Pest Research, London.

Earth plug - Reddish coating of the entire eggpod. It comprises froth and adhering soil particles.

Eggmass - The posterior end of locust eggpod where the clutch of eggs are normally located.

Eggpod - The reproductive unit produced by the female locust at the end of oviposition; it comprises the froth plug, the eggmass and the earth plug.

Flood period (duration) - Number of days during which eggpods are submerged under water.

Froth plug - The foamy anterior-most portion of the locust eggpod. It contains no eggs.

Gregaria - The phase of locust characterized by gregarious and migratory habitats; it is often referred to as the 'true locust.'

Hatchling - The first 24 hours of the hopper life.

Incubation period - Starting from the date of oviposition to the date of mass (or first)hatching.

Locusts - Species of grasshoppers that are capable of phase transformation and long distance migration often leading to plagues.

Mass hatching - Hatching usually involving majority of the eggs in an eggpod. It is, invariably, the first hatching.

Outbreak area - a natural ecological region where complementary spatio-temporal conditions permit the mechanism of phase polymorphism to lead to a generalized locust plague upsurge.

Pharate - The vermiform, larval, stage of egg development in locusts and grasshoppers.

Phases - Individuals of one and the same locust species of which the morphological and behavioural characters differ so much that they may be mistaken for different species.

Preflooding period - The interval between the day of oviposition and the day on which immersion under water commences.

Rate of egg development - Incubation period (duration of incubation)

Rate of egg survival - Percentage egg hatch per eggpod, or percentage of eggpod hatch per a given eggpod population.

Segregans - Transient forms of locusts changing from gregarious to solitary phase.

Solitaria - The phase of locust which behaves as the relatively inactive, solitary grasshopper, exhibiting little reaction to the presence of other members of the population.

Transiens - The intermediate stages which occur during the transformation from one phase of locust to another.

CHAPTER ONE

I N T R O D U C T I O N

Locusts and grasshoppers belong to the order Orthoptera which consists of many taxa some of which are major pests of agriculture and grazing lands in many parts of the world. The most recent account of the classification of the order is given by Kevan (1977) and it has been adopted by the Centre for Overseas Pest Research (COPR), London. COPR recognises the following suborders: Acridodea, Proscopiodea, Tridactylodea and Tetrigodea (Anonymous, 1982).

Locusts, and most of the agriculturally important grasshoppers, belong to the suborder Acridodea (Family: Acrididae), and are recognisable by the big hind legs used for jumping. Unlike grasshoppers, locusts have the habit of changing their behaviour when they occur in large numbers; in other words when in small numbers locusts live solitarily like grasshoppers but when their numbers increase, locusts can become gregarious and stay together in dense groups.

1.1 Historical Background

Locusts, and grasshoppers, might have appeared during the course of evolution, hundreds of millions of years before Homo sapiens (Husain, 1963) and since prehistoric times plagues of locusts have been feared as

the forerunners of famine and human suffering (Lean, 1931, 1936; Bullen, 1970). For instance, in the Bible, Chapter ten of the Book of Exodus presents a vivid description of the locust plague that tormented Egypt in 1491 BC (Bullen, 1970), i.e. some 3,477 years ago.

Another proof of man's ancient familiarity with locusts is provided by the paintings and carvings in the ancient monuments of Iraq, Mexico and also on tombs of the 6th dynasty at Saqqara in Upper Egypt dating from about 2,420 to 2,270BC (Husain, 1963; Hemming, 1974). There is also record of locust plagues from Shantung Province in China as early as 707BC and Rao (1960) has stated that locust menace was mentioned in Sanskrit (India) literature of the third and forth centuries AD as one of the six hazards to which the cultivator was exposed.

Other historical records indicate that locusts have long presented agricultural problems in the Philippines, the Middle East , North Africa as well as South-East Europe (Lean, 1936; Waloff and Conners, 1964; Lieberman, 1970). As agriculture developed locusts, and grasshoppers, became serious pests in the Soviet Union, India, South-East Asia, Australia, South, Central and North America as well as Africa (Husain, 1963). The world-wide spread

of locusts menace led Husain (1963) to declare that "there is no stretch of land which is totally free from the insects." Hemming (1974) has also stated that all continents of the world, except Antartica, are still liable to attack by locusts.

1.2 Modern Knowledge On Locusts

The foundation of knowledge on modern locust problems was laid when Uvarov (1921) first propounded the hypothesis which led to the "fundamental phase theory." According to the theory locust species are extremely plastic in their morphological characters and behaviour; and the extreme forms may be so different that they were once regarded as discrete taxa (Anonymous, (1966).

Two forms are recognised, namely phase solitaria and phase gregaria. Members of the phase solitaria behave as relatively inactive, solitary grasshoppers, exhibiting little reaction to the presence of other members of the population. On the other hand, individuals of the phase gregaria possess highly developed gregarious and migratory habits; thus the immature stages march in massed hopper bands and the adults migrate long distances in dense swarms (Lean, 1936).

The phase of a locust community depends on population density (Uvarov, 1921). Therefore, a large number of solitaria hoppers developing in a restricted environment can become gregarious. Conversely a few hoppers of gregarious individuals developing in an unconfined space may revert to the solitary status. There are also transient forms which occur during the transformation from one phase to the other and are defined as congregans, if the change is from solitaria to gregaria, or as segregans, if the change is moving in the reverse direction (Anonymous, 1966). All acridid species capable of the phase transformation described above are called locusts.

1.3 Species Of Locusts

Through the phase theory the tendency to consider two phases of the same species as two different species was eliminated. Since then subspecies and geographical races have been reliably identified. According to the 1966 publication of the Anti-Locust Research Centre,(ALRC) based in London, there are eleven important taxa of locusts common in Africa and Asia; these are presented below:

i) Schistocerca gregaria (Forskal), the desert locust;

ii) Nomadacris septemfasciata (Serville), the red locust;

The Anacridium species group, commonly called the

tree locusts, consists of:

iii) A. aegyptium (Linnaeus),

iv) A. wernerellum (Karny),

v) A. melanorhodon grabafum (Walker); and

vi) A. melanorhodon melanorhodon (Walker);

The Locusta species group, commonly called the migratory locusts comprises four subspecies, namely:

vii) L. migratoria migratorioides (Reiche and Fairmaire) the African migratory locust,

viii) L. migratoria migratoria (Linnaeus), the Asiatic migratory locust,

ix) L. migratoria manilensis (Meigen), the Oriental migratory locust, and

x) L. migratoria capito Saussure; and

xi) Locustana pardalina (Walker), the brown locust.

A brief account of the areas in Africa and Asia usually invaded by the eleven taxa listed above is given below, beginning with S. gregaria. In the course of this account, mention will be made of a single prominent species in South America.

S. gregaria: Most of the earliest examples of locust menace referred to S. gregaria and its invasion area (Fig.1) is estimated at 28 million square kilometres, an area which is more than 20% of the total land surface of the world: the damage it causes can affect 10% of the world population (Anonymous, 1966; Hemming, 1974). As reported by the ALRC in 1966, the invasion area encompasses a great variety of climatic zones from the sea level up to an altitude of 30,000cm.

Although swarms of S. gregaria have been recorded from the sea level up to an altitude of 30,000cm, breeding has only been known to occur in about half the invasion area and rarely above 15,000cm (Anonymous, 1966). S. gregaria has no well-defined outbreak area to which the genesis of a generalised plague is restricted. This situation mitigates against economic monitoring of its breeding activities and timely forecast of impending population upsurges. Breeding only occurs in the rainy season, but the breeding area is restricted to the relatively drier environments where the annual rainfall is usually between 50mm and 200mm. (Anonymous, 1966). It is known that rainfall in parts of the breeding areas is unpredictable and may fail completely as was the case during the 1983-84 drought in West Africa.

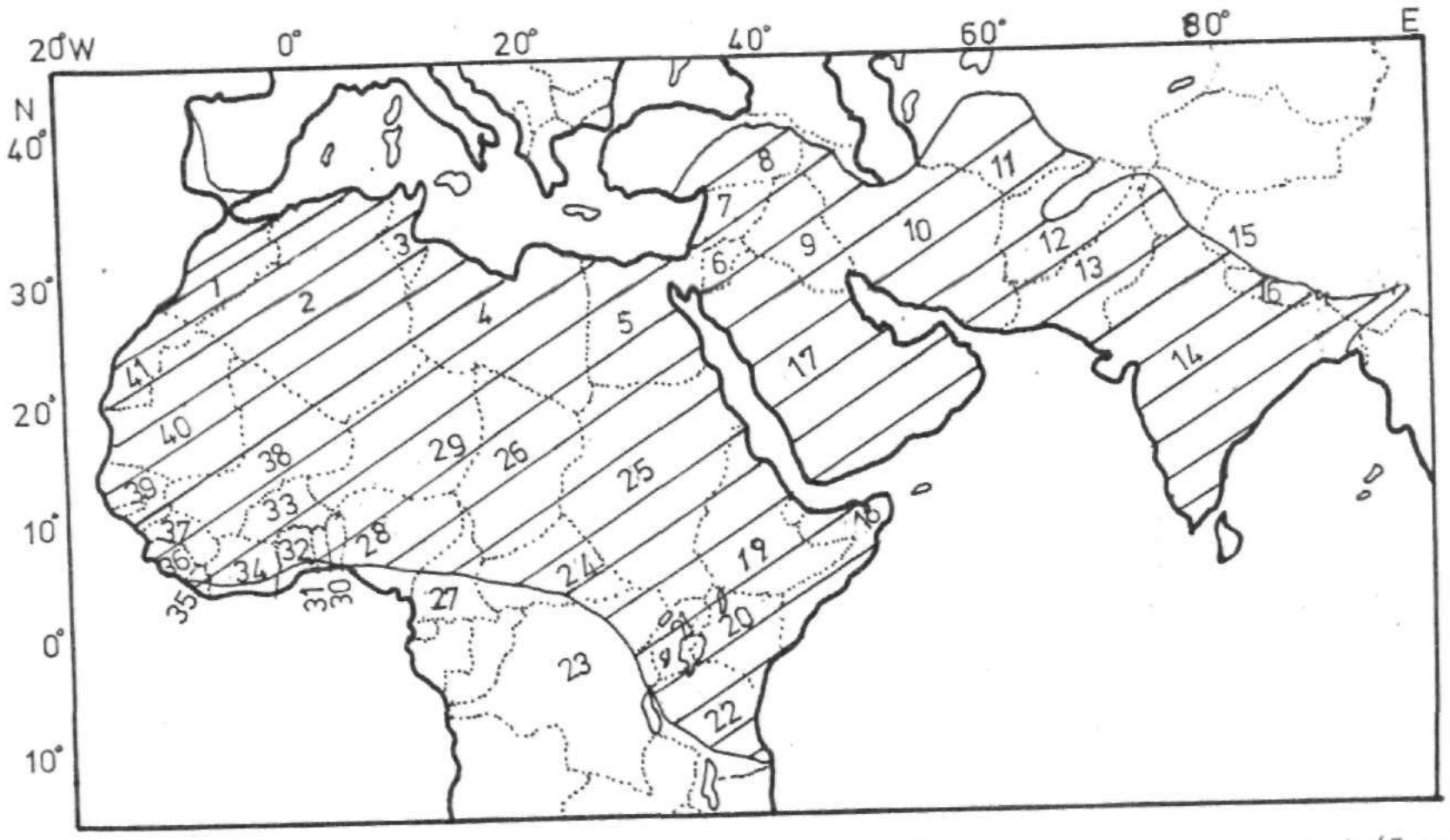


Fig. 1: Maximum Recorded Invasion Area (shaded) Of Schistocerca gregaria (Forskal)

LEGEND TO FIGS. 1 - 5

1. Morocco
2. Algeria
3. Tunisia
4. Libya
5. Egypt
6. Israel
7. Syria
8. Turkey
9. Iraq
10. Iran
11. USSR
12. Afganistan
13. Pakistan
14. India
15. China
16. Nepal
17. S. Arabia
18. Somalia
19. Ethiopia
20. Kenya
21. Uganda
22. Tanzania
23. Zaire
24. Central Africa
25. Sudan
26. Chad
27. Cameroon
28. Nigeria
29. Niger
30. Benin
31. Togo
32. Ghana
33. Burkina Faso
34. Cote D'Ivoire
35. Liberia
36. Sierra Leone
37. Guinea
38. Mali
39. Senegambia
40. Mauritania
41. Saharaoui Republic
42. Gabon
43. Congo
44. Angola
45. Zambia
46. Malawi
47. Mozambique
48. Zimbabwe
49. Botswana
50. Namibia
51. S. Africa
52. Madagascar
53. S, Arabia
54. France
55. Poland
56. Italy
57. Mongolia
58. Korea
59. Japan
60. Philippines
61. Malaysia
62. Indonesia

Another important species of the genus Schistocerca is the South American locust, S. americana, which poses the biggest threat to agriculture in Argentina (Lieberman, 1970). Its main outbreak area is north-west Argentina where it lives with S. gregaria, though the invasion area extends to Paraguay, Bolivia, Brazil, Uruguay and Chile (Lieberman, 1970).

N. septemfasciata:Plagues of this species can cover nearly all of Africa, south of the Sahara; the last one which started in 1930 ended in 1944 and covered the area shown in Figure 2 (Anonymous, 1966). Six outbreak areas of the species have been recognised (Fig.2); three in Tanzania (22), two in Zambia (45) and one in Malawi (46). Swarms have been known to escape from the first five of these, particularly the Rukwa Valley in Tanzania (22). In 1941 an international organisation, the Red Locust Control Organisation, was established to survey and control populations in the outbreak areas and since then there have been no further plagues of the species.

Occasionally this species is also found in considerable numbers in the outbreak area of the African Migratory Locust in Mali (Anonymous, 1966).

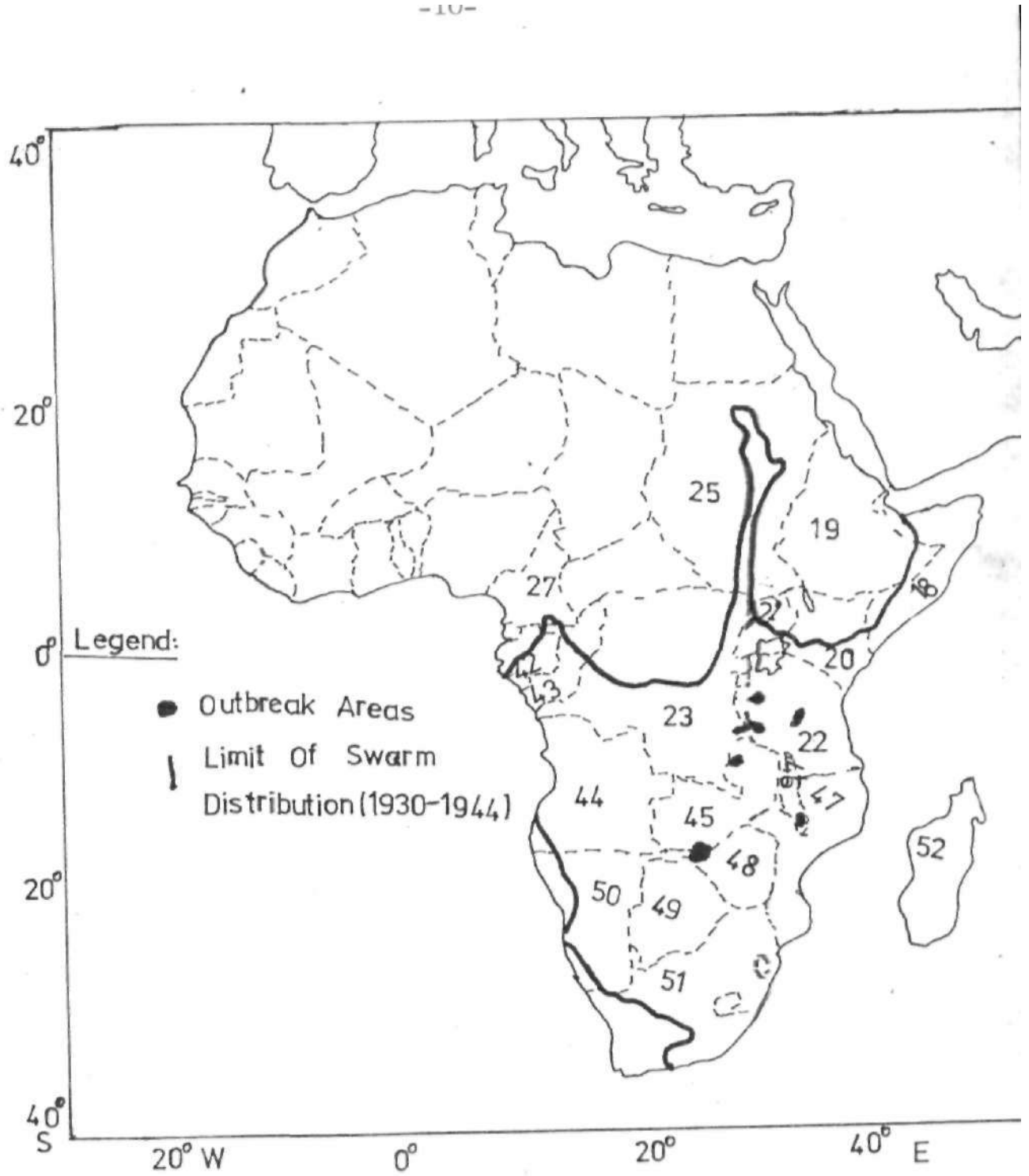


Fig. 2: Invasion Area Of Nomadacris septemfasciata (Serville) During 1930-1944 Plague

Anacridium species group: Data on this group are scanty; the invasion area (Fig. 3) as reported by the ALRC (1966) overlaps those of S. gregaria, N. septemfasciata and L. migratoria migratorioides, though members of the Anacridium species group prefer the short grass country with scattered Acasia trees.

Some members of the group are known outside Africa. A. melanorhodon melanorhodon and A. melanorhodon arabafum have been reported in Saudi Arabia (53) and southern Iran (10), while A. aegyptium has been found in countries around the Mediterranean and the Middle East (Anonymous, 1966). A. wernerellum lives generally to the south of A. melanorhodon melanorhodon though their areas overlap considerably (Anonymous, 1966).

L. migratoria migratorioides: The last major plague of the pest lasted from 1928 to 1941, and the invasion area (Fig.4) stretched from Mauritania (40) in West Africa to Tanzania (22) in the East, and from Sudan (25) in the North to South Africa (51) Anonymous (1966).

Analyses of the data on the genesis of that plague (Lean, 1931, 1936; Coleno, 1932; Zolotarevsky, 1934) led

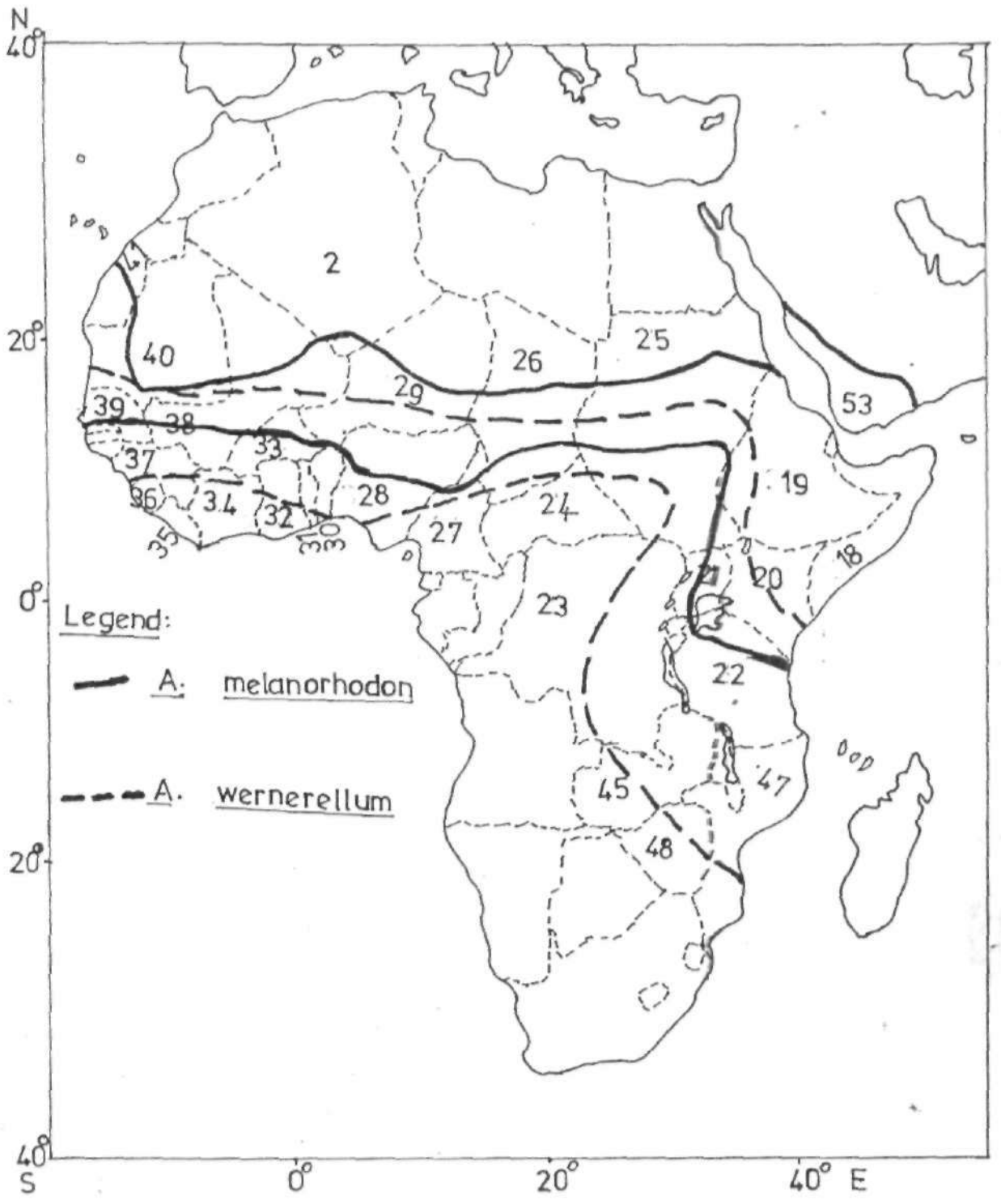


Fig. 3: Distribution Of *Anacridium melanorhodon melanorhodon* (Walker) And *A. wernerellum* (Korny)

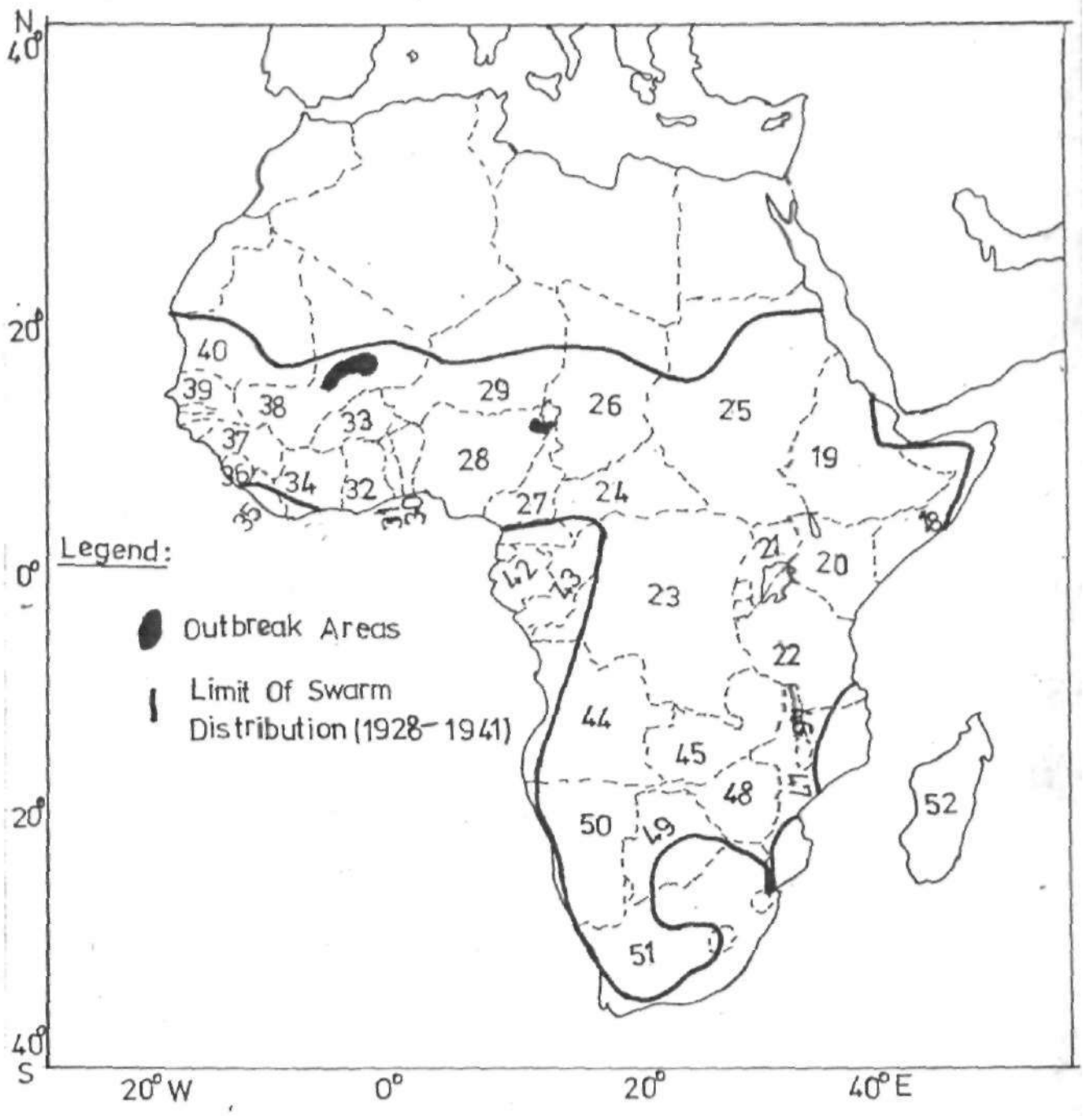


Fig. 4: Invasion Area Of L. migratoria migratorioides During 1928-1941 Plague

to the location of an outbreak area of the subspecies in the rain and river flood plains of the central delta of the Niger River in Mali (38).

There are three main breeding periods each year in the Mali outbreak area; the first on the rain flood plains at the beginning of the rains in May, the second in the surrounding drier Sahelian zone at the end of the rains in August-September, when the plains are normally completely flooded and the third in both the rain and the river flood plains as the land is exposed in the receding floods (Davey, 1953; 1955; Popov, 1959; Anonymous 1966; Farrow, 1975). In 1948 an international organisation, The International African Migratory Locust Organisation (OICMA*) was established in Mali to survey and control populations of the subspecies in that outbreak area.

Until the 1970s, the Mali outbreak area was considered the only important breeding ground for the African Migratory Locust though interest in the Lake Chad region of Nigeria (28), as a possible outbreak area, had existed since the early 1930s (Popov, 1972).

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*Organisation Internationale Contre le Criquet Migrateur Africain.

The most comprehensive investigation of the Lake Chad area is that by Davey and Johnston (1956); they described the locust as indigenous in the Borno State, "where it may be found throughout the year in the lake-shore habitats" (Popov, 1972). Popov (1972) has also given a vivid description of the record of events which eventually led to the declaration of the Lake Chad Basin as a second outbreak area of L. migratoria migratorioides. Analysis of available data by Popov (1980) indicates that from 1969 to 1980 preventive control operations against the pest have been undertaken during eleven years in the Lake Chad Basin.

Apart from the two recognised outbreak areas of Mali (38) and the Lake Chad Basin, unpublished OICMA records also indicate that Angola (44), Eastern Sudan (25) and Madagascar (52) provide very favourable breeding conditions for L. migratoria migratorioides.

Of the three other important subspecies of the migratory locust, L. migratoria capito is found in Madagascar (Fig.4, 52). During plague, four-fifths of the island is invaded, leaving only the humid coast free (Têtefort and Muller, 1972). It is regarded as the most important agricultural pest in Madagascar (52) where it attacks crops such as rice and sugar cane.

The distribution of L. migratoria migratoria is shown in Figure 5. It extends from France (54) through Poland (55), USSR (11), China (15), Mongolia (57) to Japan (59); the subspecies also destroys grain crops, cabbage, cotton and fruit trees in Turkey (8), Iraq (9) Iran (10) and the surrounding countries.

L. migratoria manilensis occurs in the Philippines (60), Malaysia (61), Indonesia (62) and the neighbouring islands (Fig.5). It is regarded as one of the most important agricultural pests in the low-lying grasslands in Eastern Asia where it causes the greatest damage to graminaceous crops including Zea mays, Sorghum species and Oryza sativa (Roffey, 1979).

L. pardalina: This is the only acridid which regularly forms swarms in South Africa (Fig.4, 51), where it constitutes a major threat to agriculture (Faure and Marais, 1937; Lea, 1958; 1962; Botha, 1967). Almost half of every year, that is from May - June to October-November, is spent in the egg state in diapause (Mathe'e, 1951).

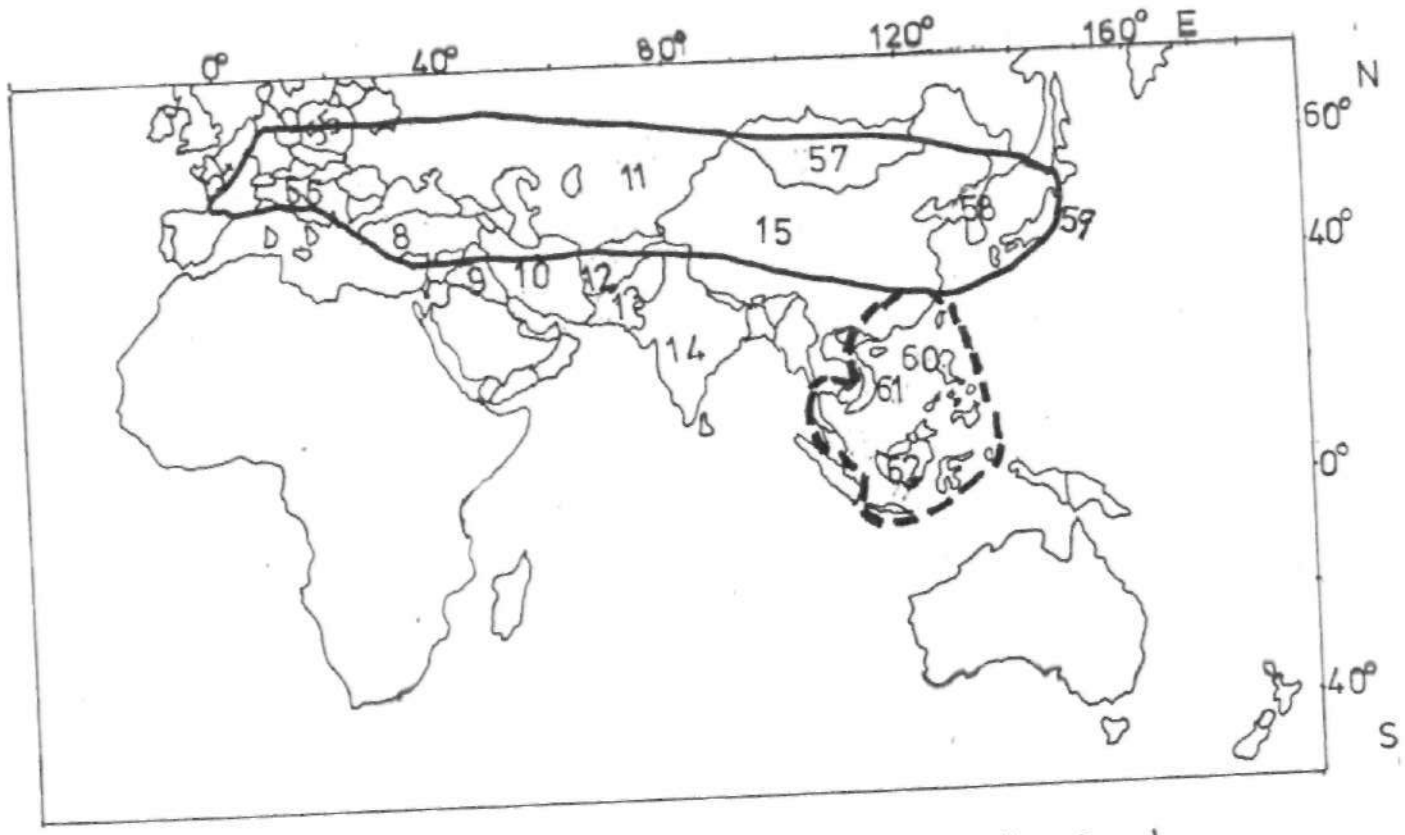


Fig. 5: Distribution Of L. migratoria migratoria (▬)
And L. migratoria manilensis. (▬ ▬)

1.4 Economic Importance of Locusts

As already indicated the three most important locusts in Africa are S. gregaria, N. septemfasciata and L. migratoria migratorioides. These cause damage by eating the leaves, flowers, fruits, seeds, bark and growing points of plants; in addition trees are known to break down as a result of the sheer weight of roosting swarms (Ananymous, 1966).

To quantify the economic status of an insect pest is an extremely difficult task as reported by Husain(1963). It may be easier in the case of stored grain pests, where the pre-storage and post-storage values of a commodity can be worked out and the loss due to pests determined; where grasshoppers attack a germinating crop, seed and labour costs can be calculated and a loss deduced; but where locusts devastate a vast area, covering a variety of plants-wild plants, some of them weeds, pastures, cultivated crops at different stages of growth, forests or orchards - the task of making an accurate calculation of economic loss is not always easy.

Uvarov first treated this intricate problem in 1951, discussed it further in 1960 and estimated the average

crop loss to locusts to be 100 million dollars per year. His estimate was based on the finding that an adult locust eats its own weight (about 2gm.) of food per day and that a swarm of about 15km square contains approximately 1,000 million locusts. A population of this magnitude will weigh approximately two million tons, which represent the weight of vegetation liable to be destroyed daily by the swarm (Hussain, 1963).

To illustrate the economic importance of locusts more or less quantifiably, data presented by the ALRC in 1966 based on damage by S. gregaria in Africa, are shown in Appendices 1 and 2. Emphasis is placed on the value of crops damaged in Appendix 1; the situation is even more alarming if losses are considered in terms of quantities of actual food or other crops destroyed (Appendix 2).

Again it must be emphasised that such calculations provide only rough estimates because it is difficult to distinguish the portion of greenery of economic importance eaten by the locust from that which consists of valueless matter that is best destroyed.

The gravity of locust menace may be further appreciated if cognizance is taken of the pest's ability for long distance migration. During such migrations the

swarms traverse international frontiers, descend at intervals to feed and to breed (Uvarov, 1921; Lean, 1931; 1936; Bullen, 1970; Anonymous, 1984). The international status of the locust problem led to the formation of world-wide regional locust monitoring and research organisations, particularly at the end of the last major plagues in 1944.

Prominent among the organisations are the following:

i) The Grasshopper Research Section of the United States Department of Agriculture;
ii) The Locust Research Section of the Ministry of Agriculture, United Arab Emirate;
iii) The Locust Control Department of Saudi Arabia; and
iv) The COPR of London, United Kingdom (formerly known as the ALRC).

In Africa, the major organisations include:

i) The Desert Locust Control Organisation for Eastern Africa (DLCOEA) based in Addis Ababa in Ethiopia (Fig.4, 19);
ii) The International Red Locust Control Service (IRLCS) at Mbala, Zambia (Fig.4, 45);
iii) The Organisation Commune de Lutte Antiacridienne et de Lutte Antiaviaire (OCLALAV) based at Dakar in Senegambia (Fig.4, 39); and

iv) The Organisation Internationale Contre le Criquet Migrateur Africain (OICMA) which is based at Bamako in Mali (Fig.4, 38).

Inspite of the establishments of the locust control organisations and the regular co-operation among them, locust control operations have not always achieved the expected results. For instance, according to Husain(1963), inspite of well organised control measures, the United States of America lost crops worth 10 million dollars annually to locusts during the period 1937 to 1949.

In the Lake Chad Basin outbreak area (Fig.6), Popov (1980) has reviewed the available information on population upsurges of L. migratoria migratorioides from 1969 to 1979 including the control measures taken to arrest the plagues. A chronological summary of these locust menace and control activities is provided below:

1969, October: Five to six bands of late instar hoppers were controlled at Logomani near Ngala.

1970, October: Several bands of late instar hoppers and concentrations of fledglings were observed in the area around Logomani and Marte. Out of the estimated 50,000 hectares infested only 485 hectares were effectively treated using 600 litres of Gammalin 20 and controlling 100 infestations.

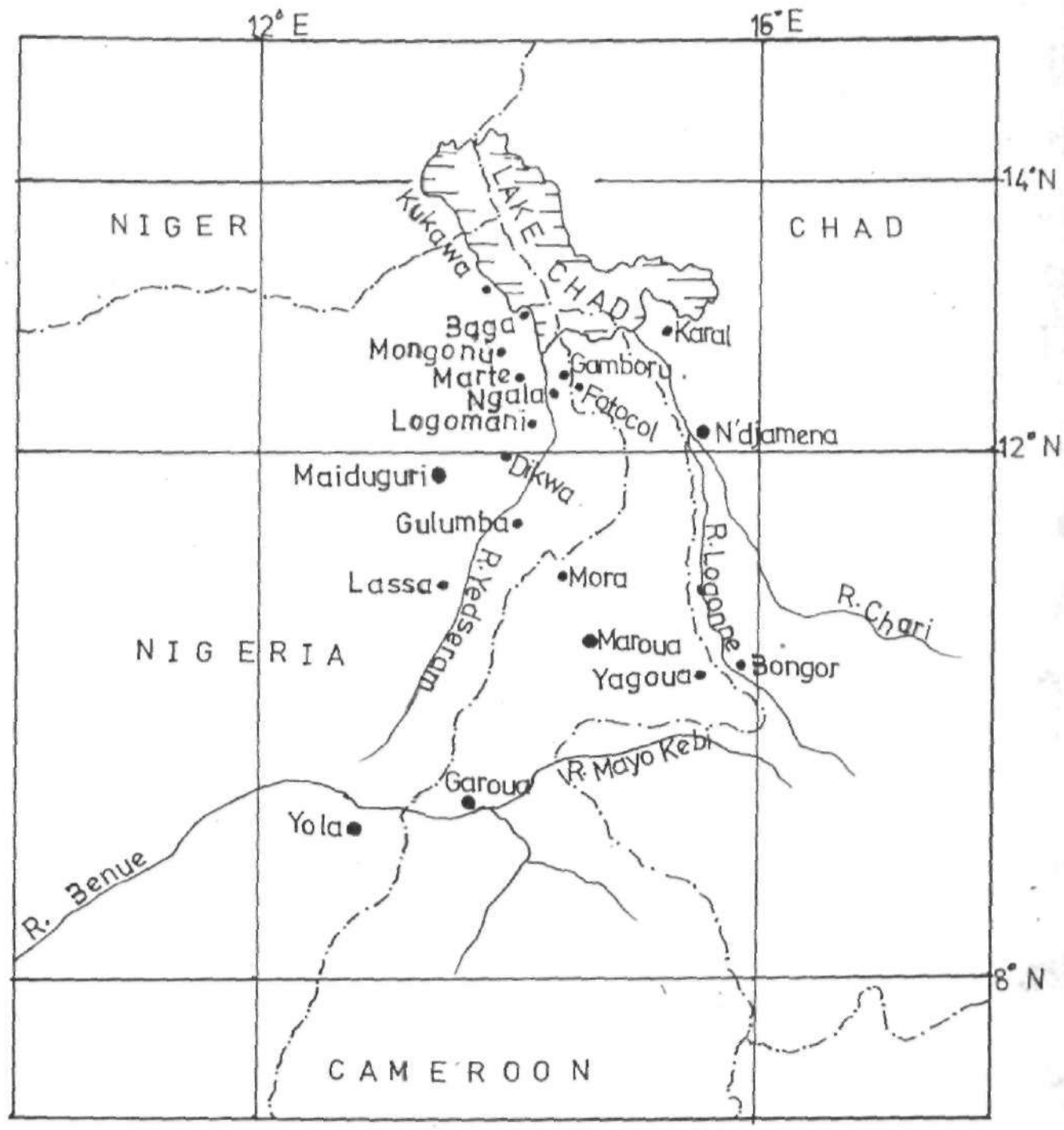


Fig. 6: The Outbreak Area Of Locusta In The Lake Chad Basi

1971:	Apparently calm.
1972:	Bands and concentrations were controlled in Mongonu - Dikwa areas in Nigeria and also near Mora in Cameroon.
1973:	There was a major outbreak as described below:
August:	Bands of second to fifth instars were found and treated in Marte - Lassa areas.
October:	Despite the control measures taken in the previous months infestation spread to the shores of Lake Chad, down the River Yedseram valley and reached the valleys of the Rivers Benue and Mayo Kebbi where breeding occurred in October and November,
November:	Despite control operation, 37,000 hectares by OCLALAV alone, swarms escaped moving downwind to the South. Their fate was not ascertained.
1974, September:	Preventive control was organised against late hopper instars and young adults (fledglings) from South of Baga to Lassa.

November : In Gulumba district infestation of late instar hoppers and fledglings were recorded and controlled in an area of about 7,000km.^{2}

December : Locust population in the river flood plains at Bongor (Chad) rose to a maximum of 3,500/ha over an area estimated to be over 60 hectares.

1975, December: Potentially dangerous hopper and adult concentrations were recorded in Gulumba area and a population density estimated at 3,675/ha was controlled over an area of 34 x 15km.

1976: Calm locust situation.

1977, October to December : Density of 20,000 to 30,000/ha was recorded at Dikwa. A similar density was observed and controlled at Gulumba over an area of 10,000km.^{2} These caused 30% to 60% damage to crops (the dry season Sorghum).

1978, November to December : Outbreak occurred in Gulumba district affecting 38 villages. Control was conducted in December over 26,850 hectares and with 14,025 litres of assorted insecticides using both ground and aerial means of control.

1979, September: Gregarious groups were found at Gulumba and Yagoua (Cameroon) areas. 800 hectares of the Yagoua area were controlled though no control was effected in Gulumba area.

November: Breeding therefore occurred in Gulumba area leading to production of transiti-form individuals in the Amchaka-Amharas-Jilbe areas in Gulumba district.

December: These were controlled by both ground and air teams in December.

In all the years, the major crops damaged were the dry season guinea corn, Sorghum caudata Stapf and S. durra Stapf, irrigated maize, Zea mays Linnaeus, rice, Oryza sativa Linnaeus and wheat, Triticum species (Anonymous, 1984).

Another preventive control operation by OICMA, involving both air and ground teams, was implemented during May to July, 1980 (Alomenu, 1985). The operation area (Fig.7) covered Mayo Selbe, Gashaka, Serti, Mbamnga and Gembu (on the Mambila Plateau), all of the Southern Sardauna area of Gongola State of Nigeria as well as the neighbouring towns and villages in Cameroon, including

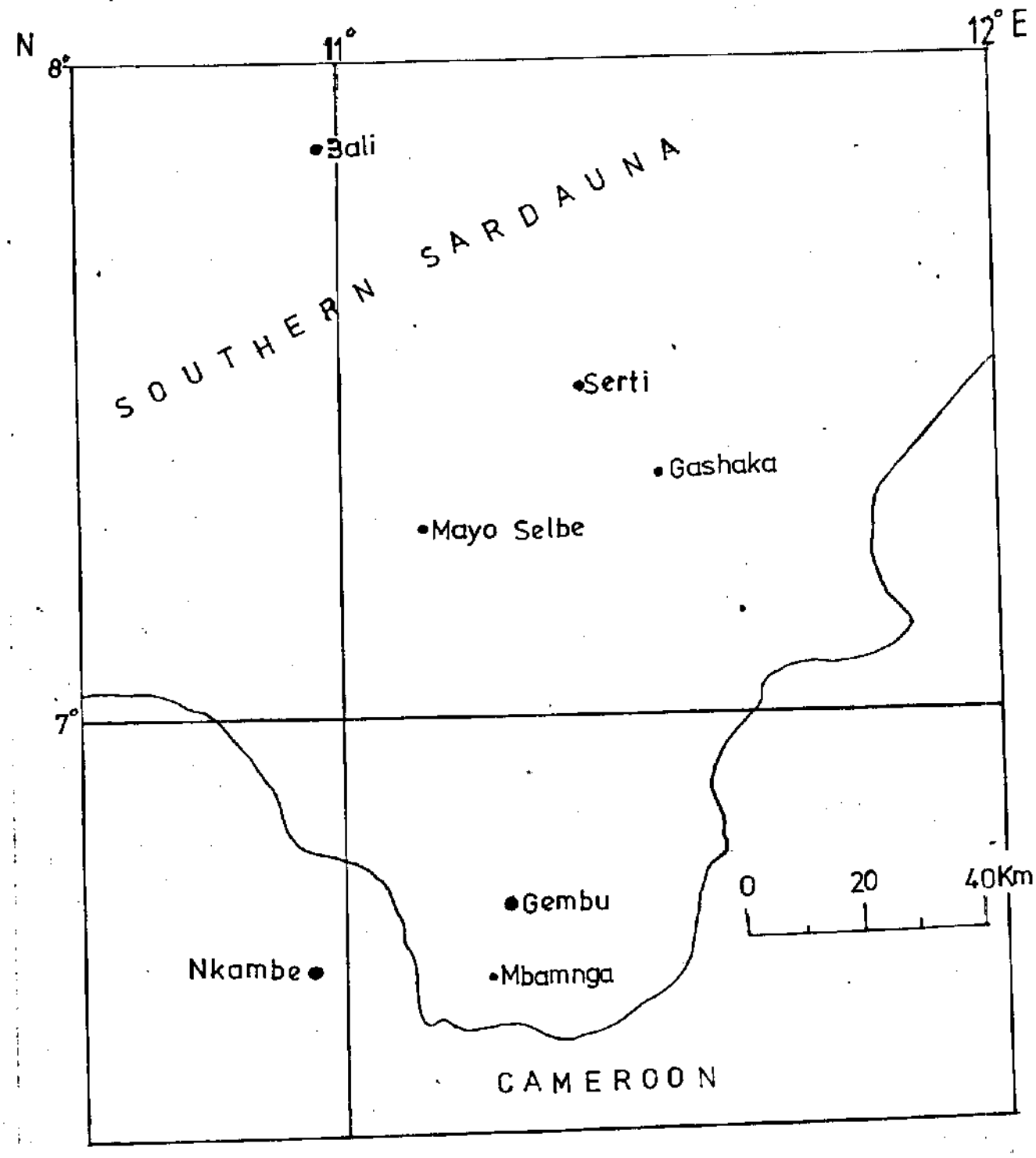


Fig. 7: Areas Of The 1980 Preventive Control Operation.

Nkambe. According to the 1984 report of the Food and Agriculture Organisation (FAO), damage to crops, including Z. mays, O. sativa and Musa species, was also observed in areas of Nigeria and Cameroon lying between latitudes 5°N and 10°N and longitude 5°E to 10°E.

A similar preventive control operation was carried out by OICMA in November, 1982, after five concentrations of third to fifth hopper instars and fledglings were found, again in late October, in the Gulumba district of Bornu State of Nigeria (Fig.6). Their densities ranged from about 6,000/ha to over 600,000/ha over an area estimated to be approximately 400 hectares. Again, the dry season guinea corn, S. caudata and S. durra, were the major crops attacked, damage ranging from about 10% to 80%. About 300 litres of insecticides were applied using the exhaust nossle sprayer (Anonymous, 1982).

That L. migratoria migratorioides poses great threat to agricultural crop and forage production advancements in the Lake Chad Basin is evident from the above account. Despite the efforts made in the past to counter the damaging effects of the activities of the pest in the region, large populations of the insect are observed almost yearly. As stated earlier, in the event of a major plague, which can originate from the Lake Chad Basin, the entire sub-Saharan Africa will be liable to invasion by the locust.

CHAPTER TWO

REVIEW OF LITERATURE

Locusts and grasshoppers are known to oviposit in soil; once oviposition is completed, egg development and survival (hatching) depend on many factors including the following: nature of the soil (Choudhuri, 1954, 1956b; Popov, 1959; Uvarov, 1966; Wardhaugh, 1973, 1977; Farrow, 1975); moisture and temperature (Popov, 1959; Hunter-Jones 1970a, 1970b; Pickford, 1970; Farrow, 1975); predation and parasitism (Greathead, 1958, 1963, 1966; Popov, 1959; Farrow, 1975); and genetic factors(Norris, 1959; Papillon, 1960; Ashall and Ellis, 1962; Bernays, 1971a, 1971b). In addition to the above factors, soil salinity, oxygen supply and the egg's ability to withstand adverse conditions, through the suspension of developmental processes, have also been reported to influence egg development and survival (Achillides, 1970; Hunter-Jones, 1970a).

To understand how the above factors affect egg development and survival, it is important to have some idea of the structure of the locust eggpod.

2.1 Structure Of The Eggpod

Vivid descriptions of the eggpod and the egg of L. migratoria migratorioides have been published (Chapman and Robertson, 1958; Popov, 1959; Farrow, 1975). Each description was based on varied numbers of eggpod samples, most of which were obtained from females which were obliged to lay in open-bottomed field cages. Invariably, the eggpods are cylindrical, inclined at an angle between 10° and 30° from the vertical and reach a depth ranging from 5cm to 9cm. Popov (1959) found majority of the eggpods to be bowshaped.

All the authors agree that the eggpod consists of three component parts, namely: the froth plug, the egg mass and the earth plug (Fig.8). The froth plug is the whitish, anteriormost (uppermost) portion of the eggpod; it is foamy and contains no eggs (Popov, 1959; Farrow, 1975). In the Mali outbreak area, Farrow (1975) has reported that the length of the froth plug ranges from 20mm to 50mm. On the other hand, in the Rukwa Valley of Tanzania, Chapman and Robertson (1958) recorded a range of 14mm to 51mm as the froth plug length in the same subspecies, L. migratoria migratorioides.

Lying posterior to the froth plug is the egg mass, which is the portion of the eggpod containing the eggs

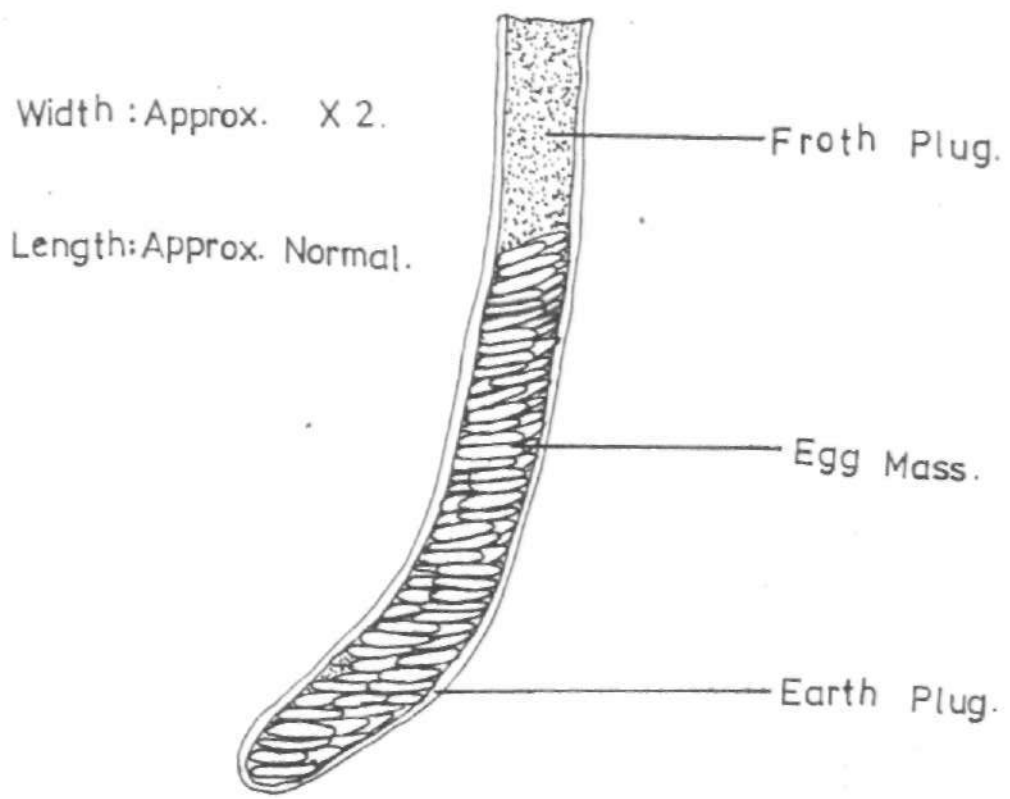


Fig. 8: Diagramatic Representation Of Longitudinal Section Of Eggpod Of L. migratoria migratorioides.

(Popov, 1959). Like that of the froth plug, the length of the eggmass varies considerably. While in Mali Farrow (1975) noted a length range of 20mm to 40mm, in the Rukwa Valley of Tanzania, Chapman and Robertson(1958) recorded a range of 24mm to 36mm for the same subspecies.

The eggs are oval-shaped, with a length range of 5.5mm to 7.1mm (Chapman and Robertson, 1958), and they are aligned in four parallel rows inclined diagonally across the eggpod. In this way the future head of the embryo always points upwards, even in eggpods where the eggmass is virtually horizontal (Chapman and Robertson, 1958; Popov, 1959; Farrow, 1975).

The entire eggpod is clothed in a reddish froth, quite distinct from the white froth forming the froth plug (Popov, 1959). The froth cover does not only bind eggs together but, when coated with the surrounding soil particles at oviposition, forms a tough protective case called the earth plug around the eggpod (Farrow, 1975). The toughness of the earth plug depends on the nature of the soil in which oviposition occurs; it probably offers the best protection to the enclosed eggs in clayey soils (Chapman and Robertson, 1958; Farrow, 1975).

After oviposition, the abdomen is withdrawn and the top 4mm to 5mm of the eggpod cavity is filled with debris compacted by the action of the hind tibiae of the female (Popov, 1959).

2.2 Factors Influencing Egg Development And Survival:

A list of the factors affecting egg development and survival in locusts has been given above and an account of the first five is presented below, beginning with nature of the soil.

2.2.1 Nature of the soil: Zolotarevsky (1934) recorded breeding swarms of L. migratoria capito in a wide range of soils in the Madagascar and reported that no type of soil was noticeably preferred by the subspecies for oviposition. Davey and Johnston (1956) confirmed acridod plasticity in L. migratoria migratorioides when they reported that in northern Nigeria, along the Lake Chad, oviposition by the subspecies is not confined to any well marked sites or even areas.

Despite the apparent wide range of ecological tolerance by the subspecies it has been reported in the Mali outbreak area (Uvarov, 1921; Popov, 1959) that preference is shown for specific sites; majority of females of L. migratoria migratorioides oviposit within a much

more limited range of soil conditions than offered by the environment as a whole. Choudhuri (1954) made similar observation on L. migratoria migratorioides in experiments conducted in the laboratories at the field station of Imperial College. Again, Choudhuri (1956b) reported that in Cyprus the Moroccan locust, Dociostaurus maroccanus (Thunberg) shows preference for hard and firm soil for oviposition. Also in Australia, Wardhaugh (1977) has observed that apart from the mechanical obstructions, such as roots, bulbs, corms and stones, soil compaction also plays important role in the selection of oviposition site by Chortoicetes terminifera (Walker), the Australian plague locust,

Differences exist in the shape of eggpods and depth of oviposition in L. migratoria migratorioides; these variations have been attributed to soil compaction and moisture content (Popov, 1959; Uvarov, 1966; Farrow, 1975). Hafez and Ibrahim (1958), on the other hand, studied the egg and nymphal stages of Acrida pellucida Klug in Egypt and reported that the length of oviposition hole (i.e. the depth of oviposition) is related to the size of the species.

The depth of locust oviposition has been suggested to confer some developmental and survival advantages to

the eggs. For instance, in Queensland, Australia, Clark et al (1969) have reported that while 5mm of rainfall is sufficient to stimulate embryonic development in eggs of C. terminifera laid at 5cm, such rainfall is insufficient to promote the plant growth necessary to sustain the resultant hatchlings. On the other hand, eggs of the species laid at a depth range of 8cm to 10cm require 25mm to 31mm rainfall to satisfy minimum moisture requirements for successful completion of embryonic development; this range of rainfall is also sufficient for plant growth and sustenance which, therefore, enhances hatchling survival (Wardhaugh, 1973, 1977).

Similar relationships between depth of oviposition, moisture requirement and egg development and survival in C. terminifera have been published for Trangie, New South Wales, Australia, (Biddiscombe et al, 1954), and also for Alice Springs area of Melbourne, Australia (Slatyer, 1962).

Popov, (1959) has given an account of the frequency of oviposition by L. migratoria migratorioides in six soil types classified as coarse sand, fine sand, sandy silt, silt, silty clay and heavy clay, in the Mali outbreak area. He reported that more preference is shown for the light clays and silts than for heavy clays and sands; loose sands are completely avoided. His findings confirm Choudhuri's (1954) observations that under laboratory

conditions L. migratoria migratorioides shows marked preference for the more compact soils while particle size is of secondary importance. As noted earlier, Farrow (1975) has noticed that in L. migratoria migratorioides the earth plug and surrounding soil form an integral hardened layer during incubation, particularly in the clayey soils. He therefore postulated that the hardened layer probably offers protection to the eggpod from potential enemies at a later stage of egg development.

Farrow (1975) observed further that the uptake of water by the eggs depends on the availability of water to the eggs but not on the percentage of soil water as usually measured in the field. He emphasized that water available to eggs varies greatly among soils. Clay soils not only have a higher proportion of non-available water, but also retain more water during dry periods; the preference for clay soils by L. migratoria migratorioides for breeding during dry season (Farrow, 1975) underlines this fact.

It has already been stated that in the Mali outbreak area L. migratoria migratorioides prefers lighter soils for breeding during wetter periods (Farrow, 1975). By the end of the (rainy) season, however, embryonic

development is hampered because laying continues to occur in lighter soils which have poor water retentive capacity and ultimately permit egg desiccation (Farrow, 1975).

The relevance of soil type to egg development and survival is further confirmed by the work of Decamps (1962) in which he found that the eggs of L. migratoria migratoroides survive dry conditions in Sahelian Mali when laid in clay soils but that those laid in coarse sand die quickly.

2.2.2 Soil moisture: As regard moisture requirements, Shulov (1952) studied the development of S. gregaria in the Jordan Valley, Israel, and observed that eggs of the species are able to develop and hatch at a temperature ranging from 20°C to 30°C if, during three to five days following oviposition, they absorb sufficient "contact water." Hamilton (1936), 1950) also reported the necessity of contact water in embryonic development of S. gregaria and N. septemfasciata. He reported that in S. gregaria newly deposited eggs and those which have developed for four days under normal conditions, (moist sand and temperature of 32.2°C) fail to hatch when placed in an environment with 100% relative humidity. In contrast, eggs which have developed for 10 days under

the normal conditions mentioned above give a high percentage hatch as do the control (period of incubation spent in moist sand and at temperature of 32°.2C). These observations led Hamilton (1936, 1950) to suggest that it is essential for the eggs, in the early stages of development, to be in contact with moisture and that they are unable to absorb the required amount of moisture from a humid atmosphere. Chapman and Robertson (1958) confirmed the need for contact water to the development of grasshopper eggs; they pointed out that the egg length is proportional to the amount of moisture imbibed from the soil. Eggs that develop in wetter soils also produce heavier hatchlings (Chapman and Robertson, 1958).

Studies on the viability of the eggs of L. pardalina under semi-natural and laboratory conditions have shown that the main cause of egg mortality is progressive desiccation (Botha, 1967). Laboratory investigations on egg development of S. gregaria in relation to moisture also reveal that eggs do not develop either in extreme water-logged or almost dry sand but that the intermediate sand/water mixtures favour development and hatching (Hunter-Jones, 1964). Hunter-Jones (1964) observed further that high moisture levels in the soil are detrimental to egg development, presumably due to restricted supplies of oxygen; the eggs of S. gregaria are not resistant to

desiccation at any stage of development.

Similar observations were made on locusts by Haskell (1960b), who reported that eggs laid by locusts contain far less water than that required for development: infact, much less than the hopper which emerges from the egg. To ensure the viability of its offspring therefore, the female must oviposit in moist soil from which the developing embryo can take up sufficient water to ensure normal growth. In dry soil, the eggs lose water and produce less heavy hatchlings or in extreme cases die altogether.

Exceptions to this generalisation include Salt's (1952) report in Canada that the eggs of Melanoplus bivittatus (Say) appear to be well adapted to withstand desiccation during periods of severe drought.

Arrested development in eggs of L. migratoria migratorioides has been reported by Popov (1959) and also by Decamps (1961) in the locust outbreak area of Mali. Both authors are of the view that this phenomenon is associated with the dry season which renders the soil deficient in water content. This view has been enhanced by the observation that eggs of the subspecies can develop without diapause provided a moist substrate is available (Shulov, 1970). From this observation

Shulov (1970) inferred that arrested egg development in L. migratoria migratorioides under field conditions can be hampered since there is (in the field) "a considerable latitude in moisture availability necessary to ensure that eggs hatch successfully."

Farrow (1975) also investigated factors affecting egg development in L. migratoria migratorioides and observed that during the retreating floods season of the outbreak area in Mali, oviposition takes place in the freely available moist soils near the line of retreating floods. He reported that during the season embryonic development is very slow due to the low soil temperatures. Nevertheless the soils remain damp long enough for sufficient water to be taken up by the eggs for complete development. Moisture is, therefore, never a limiting factor in the retreating floods season and delayed egg development due to lack of moisture is never observed in the field during the season (Farrow, 1975).

On the other hand Farrow (1975) associated the period just before the first rains with the driest soil conditions. Intermittent drizzles at the start of the rainy season provide insufficient soil moisture; consequently Farrow (1975) observed that females confined to cages during this period laid eggpods in semi-dry soil.

Though the females continue to lay at short intervals of three to seven days no hatching occurs, indicating pod accumulation in the ground. Large numbers of small hatchlings were recorded between 30 to 40 days after laying and Farrow (1975) attributed the delayed development and the emergence of small hatchlings to insufficient soil moisture.

Farrow (1975) noted further that at the end of the rainy season there is progressive decrease in the number of hatchlings and concluded that eggpods which are laid by the end of the season do not receive enough moisture to permit normal development. Most of the eggs of L. migratoria migratorioides, therefore, do not survive the dry season; and pods laid late in experimental cages were killed by desiccation (Farrow, 1975).

The dependence of locust egg development and survival on adequate soil moisture is further exemplified by Popov's (1959), report: he reported that in Mali, L. migratoria migratorioides shows preference for soil that is moist on the surface when the insect is exposed to a variety of soil moisture conditions ranging from very moist (but not water-logged) to surface dry (but not completely dry) soils.

2.2.3 Soil temperature: Soil temperature has also been shown to be equally important in the development and survival of the eggs of locusts. The effect of this factor may be direct when its impact on egg incubation is observed, or indirect when observations are made on aspects of the biology of the hopper and the adult in relation to temperature (Hamilton, 1936).

Wardhaugh et al (1969) studied the relationship between incubation period and soil temperature in Saudi Arabia, using over 600 eggpods of S. gregaria. They observed that incubation period varies from 26 days at 24°C to about 12 days at 37°C and concluded that the relationship is approximately linear at low temperatures, up to 30°C, with an increase of about 0.5% in the mean daily development rate for each degree rise in mean soil temperature.

Hamilton (1936, 1950) also investigated the effect of soil temperature on the incubation period of S. gregaria in London while Shulov (1952) and Shulov and Pener (1963) performed similar work in Jerusalem; the results of their respective investigations confirm that in S. gregaria there is a gradual reduction in the period of incubation with rise of soil temperature.

Differences in the shape and in the length of the eggpods of C. terminifera have partly been attributed to different temperatures and photoperiods to which the female adult is subjected (Wardhaugh, 1973, 1977). Popov (1959) made similar observations on L. migratoria migratorioides in Mali and concluded that such differences accord the eggs different degrees of protection from natural enemies. While straighter eggpods are more deeply embeded in the soil and are therefore beyond the reach of some of the natural enemies, curved eggpods are nearer the surface and consequently they are easily accessible to predators (Popov, 1959).

In the Canadian acridid, Camnula pellucida (Scudder), there must exist an optimum set of conditions under which maximum emergence of hatchlings would occur(Pickford 1966). The optimum factors include early oviposition in summer, when there is sufficient heat and moisture, to permit normal embryonic growth prior to "freeze-up" and in winter, when also adequate snow cover is necessary, to protect the eggs from the cold. Finally, during spring, high temperature and maximum sunshine are required to initiate further development and subsequent hatchings (Pickford, 1966a, 1966b).

Again Pickford (1970) investigated the effects of climatic factors on egg survival and hatching in the grasshopper, Melanoplus sanguinipes (Fabricius) in Saskatchewan, Canada, and observed that during mid-summer, sustained high temperatures allow maximum pre-diapause development of the embryos before "freeze-up," and that this in conjunction with a warm early spring ensures early hatch. On the other hand complete reversal of the weather patterns, with constantly low temperatures, does not only drastically reduce the number of eggpods laid but also prolongs incubation period and reduces ability to hatch.

The results of laboratory investigations by Hamilton (1936) at the Biological Department of St. Thomas's Hospital, London, indicate that soil temperature range of 26.7°C to 43.3°C is suitable for embryonic development in L. migratoria migratorioides. Under constant soil temperature conditions the maximum average hoppers hatching per pod (41.9%) occurs at 26.7°C. With a rise in temperature to 32.2°C the average hatch drops drastically to 28.1%; it drops further to 25.2% at 37.8°C and to 14.4% at 43.3°C. Furthermore, approximately 20% of the

eggpods he studied gave no hatch at 43.3°C compared with a mere 2% at both 26.7°C and 32.3°C.

Under alternating temperatures Hamilton (1936) reported that the maximum average hatchling emergence per eggpod is 44.4% and this occurs at a mean temperature of 25.1°C. At mean temperatures of about 23.5°C and 29.8°C the maximum average hatches per eggpod are 25.9% and 29.9% respectively. He did not consider the differences between the results under constant temperature and those under fluctuating temperatures significant and suggested that the reduction in hopper hatch per eggpod at unfavourable soil temperatures might be due to the effect of such temperatures on embryonic development.

In a series of field experiments at the Desert Locust Research Station in Jeddah, Saudi Arabia, Wardhaugh et al (1969) arrived at a similar conclusion on embryonic development of S. gregaria, i.e. "there is no systematic difference between the effect of a steady temperature and that of fluctuating temperature with the same mean value." They reported an incubation period ranging from 26 days at 24°C to 12 days at 37°C.

Similar relationships between soil temperature and embryonic development in S. gregaria and C. terminifera have been reported in India (Rao, 1942, 1960), in Tanzania (Phipps, 1959), and in Australia (Wardhaugh, 1977).

In the Mali outbreak area Farrow (1975) has recorded a maximum incubation period of 46 days (ranging from 22 days) in December/January at a mean air temperature of 19°C and a minimum of 10 days (up to 14 days) in May at a mean air temperature of 32°C for L. migratoria migratorioides. Farrow (1975) suggested that extremes in air temperature do not directly affect the survival of the embryonic stage of the species because maximum soil temperatures (measured at 5cm) are reached in May and June, when air temperature of 45°C is occasionally exceeded for up to four hours per day, whilst minimum air temperatures drop to less than 20°C in January. In both cases no mortality attributable to extremes of temperature was observed (Farrow, 1975). Temperature, however, affects egg survival indirectly because lower temperatures prolong incubation and thereby enhance the chances of such eggpods being found and attacked by natural enemies (Farrow, 1975). Again in Mali Popov (1959) has also reported that incubation in L. migratoria migratorioides varies from 33 to 21 days, the shortest period being registered at higher temperatures in drier soils.

2.2.4 Predation and parasitism: Other factors reported to affect the survival potential of the eggs of locusts and grasshoppers include

egg parasites, egg predators and scavengers (Stower et al, 1958; Popov, 1959; Greathead, 1963; 1966; Farrow, 1975).

All the above-mentioned authors agree that the genus Scelio (Scelionidae: Hymenoptera) is confined to the Acrididae as the only obligate egg parasite. About 95% of the Scelio infestation reported in the Mali outbreak area is caused by S. sudanensis Farriere; the remaining 5% is attributed to S. remaudiere Farriere, which appears to be incidental on L. migratoria migratorioides though it is common on Acrida turrita (Linnaeus) and Paracinema tricolor nigerica Thunberg (Popov, 1959).

In addition, Farrow (1975) has described how the female adult of Scelio burrows down through the froth plug of L. migratoria migratorioides to oviposit in the eggs of the latter; thus the larvae of the parasite develop inside and destroy the affected host eggs. Usually the anterior rows of the locust eggs are the ones parasitised. However, owing to the regular orientation of the host eggs in the eggpod, and also because the embryo of the Scelio sp. takes two to three weeks longer than that of the host to develop, parasitisation of the anterior eggs can block the exit of the emerging hoppers. This results in the death of hatchlings emerging from the non-parasitised posterior eggs (Popov, 1959; Farrow, 1975).

Though they are obligate egg parasites of L. migratoria migratorioides, Scelio never attack more than a small portion of the host eggpods in Mali (Farrow, 1975). Popov (1959), on the other hand, has reported that "parasitisation of L. migratoria migratorioides eggs by Scelio is heavy, about 85%", in that outbreak area. He asserts that in most cases parasitism is complete in L. migratoria migratorioides though he agrees with Farrow that in other acridids, such as P. tricolor nigerica and A. turrita, the attack is only partial.

The remaining assemblage of insects attacking eggpods of the Acridodea are predatory Diptera and Coleoptera (Greathead, 1958, 1963). Among the Colepotera the families Carabidae, Elateridae and Tenebrionidae are the most important egg predators of L. migratoria migratorioides while the Asilidae, Drosophilidae, Phoridae and the Trypetidae are the most important Dipterous predators. Most of the predatory species in the above-mentioned families are facultative (Popov, 1959; Greathead, 1963; Farrow, 1975). The mite, Allothrombium sp. has also been reported preying on eggs of L. migratoria migratorioides and other grasshoppers in Eritrea, Ethiopia (Greathead, 1963); it attacks the anterior eggs only (Farrow, 1975).

Larval stages of the families mentioned above cause greater damage to the host egg; the larger carabid larvae generally consume the entire eggmass before moving into the soil to pupate or to find more food (Farrow, 1975). In contrast, larvae of smaller predatory species consume the posterior tiers of eggs, and leave the anterior ones intact and these subsequently hatch (Popov, 1959; Farrow, 1975).

2.2.5 Genetic factors: In the outbreak area of Mali, Popov (1959) has reported that while some eggs of L. migratoria migratorioides develop and hatch normally, others in the same eggpods, though viable and non-desiccated, fail to develop. These eggs, he observed, undergo arrested development. When Popov placed some of the abnormal eggs in moist sand, the majority hatched after 12 to 20 days; in contrast, those kept in air-dry sand became completely desiccated in 10 to 15 days. Farrow (1975) also made similar observation for eggs of L. migratoria migratorioides in Mali.

Ashall and Ellis (1962) have also reported that there are infertile eggs in every eggpod of S. gregaria collected in Ethiopia, Kenya, Saudi Arabia, Somalia and the Yemen. The above-mentioned reports suggest that the inability for such eggs to hatch could be due to genetic

factors (or lack of fertilisation). There appears, therefore, to be some factors in the eggs themselves which contribute to the survival potential.

Bernays (1971a, 1971b) suggested differential developmental variations in eggs of S. gregaria after observing that in a group of successfully hatched eggs of single female, the dry weight of the serosal cuticle never exceeded 50µg. From the same eggpod he recorded another group of eggs in which the minimum dry weight of the serosal cuticles was 62µg. In the latter group the eggs failed to hatch although they contained healthy larvae which, apparently, were unable to break the serosal cuticle. From these observations Bernays (1971b) postulated that digestion of the serosal cuticles is probably pre-requisite for hatching. In fact it has been suggested (Wigglesworth, 1972) that the serosal cuticle is responsible for the toughness of the grasshopper egg.

Papillon (1960) found the eggs in the anterior and medium sections of eggpods of S. gregaria much more viable than those from the posterior part, containing the earliest laid eggs. In addition Popillon (1960) found that hoppers hatching from the anterior section of the eggpods are heavier than those from the posterior section. In Pretoria, South Africa, Venter and Potgieter (1967) made similar observations on the brown locust, L.

pardalina and reported that there are differences between eggs (and hoppers) from the anterior and the posterior parts of eggpods of this species. There appears, therefore, to be an existence of an inherent genetic or ecological disconcord among eggs of the same eggpod which persists even at the hopper stage of S. gregaria and L. pardalina (Papillon, 1960; Venter and Potgieter, 1967).

In conclusion, the heavier, more viable and earlier-hatching anterior eggs produce larger hoppers which are fitter for survival (Papillon, 1960). The females of the two locusts, therefore, produce a gradient of hoppers, the superior ones coming from the last laid eggs and those of inferior quality coming from the posterior part of the eggpod containing the first laid eggs. These differences may depend on two factors; namely, variations in the amount of yolk in the eggs, a factor which may be dependent on the arrangement of ovarioles in the ovary, and the resorption of yolk from some developing eggs during adverse conditions (Venter and Potgieter, 1967). The examples on S. gregaria (and probably those on L. pardalina) might hold good for L. migratoria migratorioides because the embryonic differentiation of the former has been found to be similar to that of the latter (Roonwal, 1936).

Laboratory studies by Norris (1959) have indicated that in N. septemfasciata the rate of adult maturation and the "sibling" status of the eggpods (whether first or subsequent pods) play important roles in the eventual viability of the eggs. She found that the great majority of the first batch of laid eggpods are sterile, the incidence of sterility being higher in the earliest maturing groups than in the later maturing ones. These observations led Norris (1959) to suggest that, pre-spermatogenesis matings give rise to unfertilised eggs and sterility in females which lay such eggs. In earlier work on S. gregaria Norris (1952) reported that females that mature over a long period lay fewer eggs per eggpod than those that mature rapidly.

It has also been shown by Pickford (1966b) in Saskatchewan, Canada, that in C. pellucida adult age is not a factor in egg viability though Tanaka (1982) has reported in Kyoto, Japan, that egg viability deceases with the age of the female L. migratoria.

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Area

3.1.1 The Lake Chad Basin outbreak area: Figure 6 shows the outbreak area of L. migratoria migratorioides in the Lake Chad basin. The area is situated within longitudes 10°E and 16°E, and latitudes 7°N and 14°N. However, the main centre of the locust's activity is much smaller and it stretches from the Gulumba district in Nigeria to the Logonne - Chari river basin, around Yagoua in Cameroon and Bongor in the Chad Republic (Anonymous, 1984).

Physical features of the outbreak area consist of flat plains broken in places by elevated sandy grounds where villages are sited. The Cameroon mountains and the Adamawa plateau run diagonally south-west and act as the southern limit of the outbreak area (Anonymous, 1984).

Several rivers, including the Yedseram, the Logonne and the Chari, drain into Lake Chad, which is the northern limit of the outbreak area. Besides creating ecologically favourable habitats for the locust during the dry seasons, the river systems also control the flood regimes of the Lake (Davey and

Johnson, 1956; Anonymous, 1984). Since flood is the major factor influencing the migratory and breeding behaviours of the locust in the outbreak area (Davey and Johnston, 1956), the area has been divided into three zones according to the origin of the flood which occurs in the plains. The three plains are the lake flood plains, the rain flood plains and the river flood plains (Iyiola and Diallo, 1974a, 1974b; Anonymous, 1984).

The Lake flood plains: These are flooded annually at the end of the rainy season, from October to January, by waters from Lake Chad. The area stretches from Kukawa-Baga in Nigeria, through the northern tip of Cameroon to Karal in the Chad Republic (Fig.6). In the lake flood plains, sand with shell deposits is found overlying the clayey strata; this makes the plains favourable habitat for the locust during the rainy season when high drainage offered by the overlying sand makes the area preferable for breeding (Davey, 1956; Popov, 1980; Jago, per. comm). According to Ajibola-Taylor (1973), the Lake flood plains favour, at least, three generations of the locust annually, including one dry season generation.

The dominant grass species in the lake flood plains include Echinochloa pyramidalis Stapf, E. obtusiflora Stapf, Vetiveria nigritana Stapf, Cyperus alopercuroides Stapf, Cynodon dactylon (Linnaeus), Paspalidium geminatum

(Forskal) and Dactyloctenium aegyptium Linnaeus (Anonymous, 1984).

The rain flood plains: These form the largest part of the outbreak area, stretching northwards from Lassa, through Gulumba, Maiduguri, Dikwa, Marte and Gamboru-Ngala in Nigeria to Karal in Chad and extending southwards through N'djamena to Yagoua/Bongor areas of the Cameroon/ Chad border (Anonymous, 1984).

The rain flood plains, unlike the lake flood plains, are characterised by black clayey soil with low organic content; the clay retains water for fairly long period after the rains and, therefore, makes the area a favourable breeding ground for the locust during the dry seasons (Davey and Johnston, 1956). In addition, the capacity to retain water makes the clayey soil suitable for growing the dry season sorghum, S. durra and S. caudata, and also for the sprouting of wild grasses including Pennisetum ramosum Schweinf; these grasses form part of the food source for the locust during the dry seasons (Anonymous, 1984).

At the end of the rains, the land dries up, and the clay particles contract progressively. The contraction leads to the formation of numerous lattices of deep cracks which have been found to serve as hiding places

for L. migratoria migratorioides and other grasshoppers during periods of adverse temperatures (Anonymous, 1984). For instance, during the harmattan season, the locusts stay in the cracks at night and during the early mornings when outside temperatures are generally lower than temperatures in the cracks. They only come out to feed later in the mornings and the afternoons when higher temperatures prevail, and retreat into the cracks again when the outside temperatures fall sharply in the evenings.

During the rainy season, on the other hand, the clay absorbs water rapidly, expands and blocks all the cracks and air spaces; the result is that locust eggs and hoppers are trapped and die of asphyxiation (Anonymous, 1984).

Among the most important graminaceous species in the rain flood plains, according to the 1984 FAO report, are Sorghum lanceolatum Stapf, Oryza longistaminata Chevalier, Andropogon pseudopricus Stapf, Eragrostis barteri Hubbard and V. nigritana.

The river flood plains: These are found along the following rivers: the Yedseram in Nigeria, the Logonne, the Chari and the Mayo Kebi in Cameroon/Chad and the Benue in Cameroon/Nigeria. Like the Lake, most of the

rivers normally overflow their banks at the end of the rains and therefore provide suitable breeding grounds for the locust during the dry seasons.

The soil in the river flood plains is sandy and the most important grasses are Eragrostis gangentica Steud, E. bateri, A. pseudopricus, Cyperus species, P. ramosum and Brachiaria ramosa (Linnaeus) Stapf (Anonymous, 1984).

Within the three flood plains lie temporary marshes, locally called fadamas, which are characterized by several species of Echinochloa which serve as the main food source for the locust during the dry seasons (Davey and Johnston, 1956).

Climate: Neither detailed nor up to date meteorological records are available for most of the centres of activity of L. migratoria migratorioides in the outbreak area. Accounts of the general climatic factors in the area have, however, been published (Lecoq, 1974; Darnhofer, 1976; Anonymous, 1977). Davey and Johnston (1956) compiled data on the climatic factors for Maiduguri for 1931 to 1950. The records on Maiduguri, which are summarised below, may be considered representative of the climatic conditions in the outbreak area since "there is little doubt that climate is generally similar throughout the Chad area" (Golding and Gwynn, 1940).

Rainfall: At Maiduguri the rains begin with a few showers in April and heavy rains are abnormal before May; in this month the average rainfall is about 30mm (Davey and Johnston, 1956). The rains increase in both frequency and intensity until August, which is the wettest month, with the average ranging from 100mm to 200mm (Davey and Johnston, 1956; Darnhofer, 1976; Anonymous, 1984). From September onward there is a steady decline until October when the rains normally cease in all areas north of latitude 10°N; from November until the following April rain falls only in exceptional years and only in small amounts (Davey and Johnston, 1956; Popov, 1980; Anonymous, 1984).

Temperature: At Maiduguri the lowest temperatures of the year begin with the advent of the harmattan winds in November and persist until February or early March (Anonymous, 1984). During this period the average monthly maximum temperature is about 32°C (Davey and Johnston, 1956; Anonymous, 1984). After the harmattan the temperature rises steadily until May when the average monthly maximum may be as high as 42°C by mid-May (Golding and Gwynn, 1940). The onset of the rains, in April/May, causes a fall in the maximum temperature until September, when a second rise begins and lasts until November when the harmattan sets in again (Darnhofer, 1976).

There is always a considerable difference between day and night temperatures (Davey and Johnston, 1956; Anonymous, 1984) and Golding and Gwynn (1940) have recorded a difference of 8.9°C at Mongonu (Fig.6) in January. They observed further that temperatures at localities along the lake are often lower than those inland; and that the range is wider in the more northernly parts.

Relative humidity: The average relative humidity at Maiduguri can be as high as 80% during the peak of the rains in August; it falls sharply when the harmattan sets in November and reaches a minimum in either January or February when the average ranges from 20% to 30% (Davey and Johnston, 1956; Anonymous, 1984).

Winds: Records taken at Maiduguri (an altitude of about 34.8m above mean sea level) of wind speed and direction represent the trends throughout the whole region (Davey and Johnston, 1956). During December to March, the wind direction is generally from north and north-east; this is the harmattan, a dry, dust-laden wind. The winds are variable in April, but from May to September the prevailing wind direction is from the south and south-west. October, again, is a month of variable winds until late November, when the harmattan recommences. Thus for five

months in each direction, north and south, the wind may be regarded as almost constant (Davey and Johnston, 1956).

The strongest winds blow at the beginning of the wet season. A normal speed is from one to 10 knots but speeds of 11 to 21 knots are also common; speeds of 22 to 33 knots are rare and occur, usually during or preceding rains, as strong gusts lasting only a few minutes (Davey and Johnston, 1956).

3.1.2 Experimental sites: The field studies were carried out in the operational grounds of the Lake Chad research institute at Ngala (12°20'N, 14°10'E)on the Nigeria-Cameroon border, about 135km north-east of Maiduguri (11°51'N, 13°16'E). Ngala is located on one of the elevated grounds in the transition zone between the lake flood and the rain flood plains. Therefore, two of the three soil habitats described by Davey and Johnston (1956) (i.e. the light sand with silt, normally found along the lake shores, and the heavy black clay, characteristic of the rain flood plains) are available in the area as shown in Figure 9. The area of sand and silt (site A) stretches along the north-east of Ngala village through Gamboru in Nigeria to Fotocol in Cameroon. Greater part of the remaining area around Ngala is covered by the black clay where the Lake Chad research Institute performs most of its research operations. This area was chosen as site C

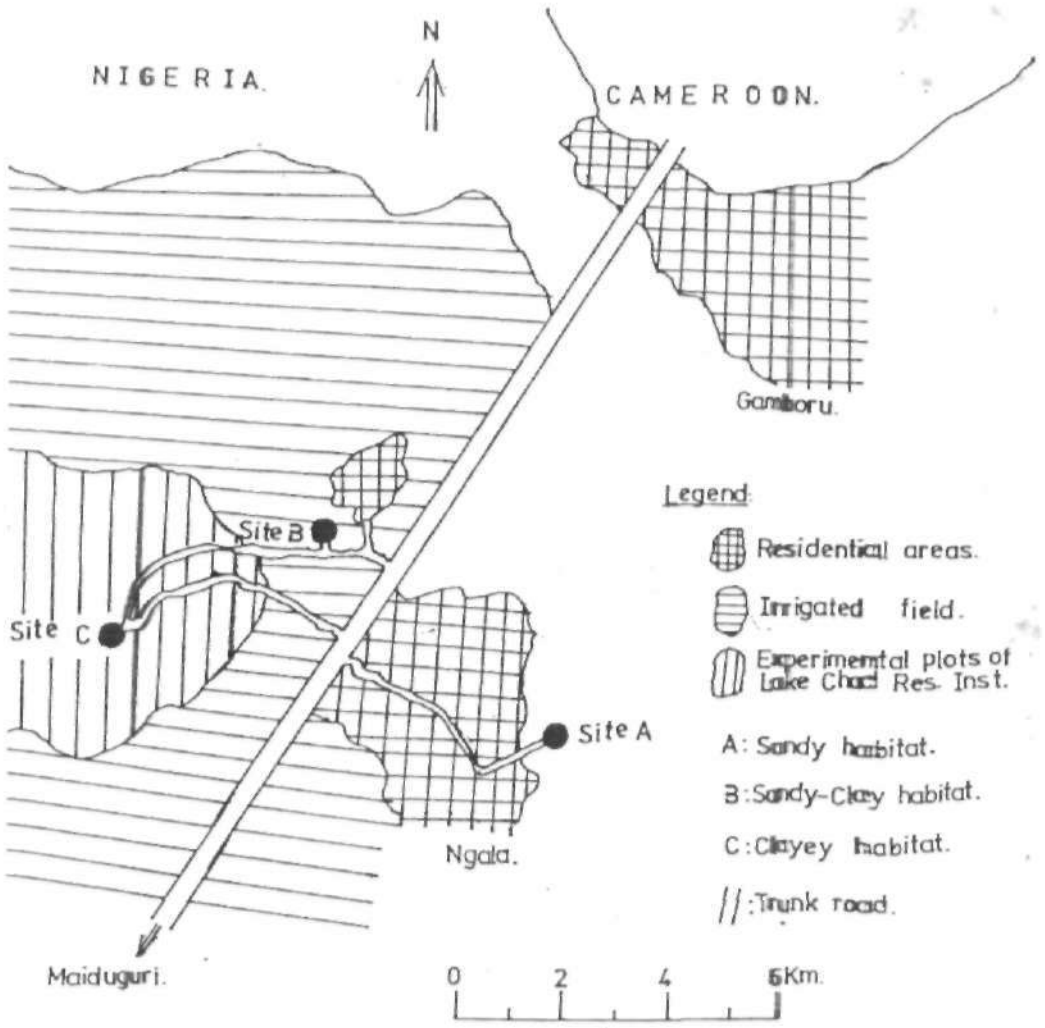


Fig. 9: Locations Of The Experimental Sites.

in the present work; it is an area of irrigated agricultural land for the production of rice, O. sativa, wheat, Triticum sp., barley, Hodeum sp. and varieties of sorghum, Sorghum sp. and cowpeas, Vigna sp. (Anonymous, 1984); in addition experiments on the above crops are carried out in the clayey area (site C).

The third experimental area (site B), was sited in the transition area between the sand/silt and the black clay regimes. In this way the transition area between the two major habitats served as a substitute for the fadamas. This plan ensured that the three experimental sites, the sand (site A), the sandy-clay loam (site B) and the clay (site C) were located within a radius of approximately four kilometers and allowed easy collection of data, using a Land Rover vehicle.

3.2 Field Study

The objectives of the field study were to investigate seasonal egg development and survival for the three soil habitats mentioned above. Therefore, a number of eggpods was studied in each habitat with emphasis on duration of incubation and percentage egg hatch. In addition, egg mortality factors for each habitat were identified and their effectiveness evaluated seasonally.

In order to correlate different climatic regimes and soil types with egg development and survival, data on weather and soil conditions in the study area were obtained for the period 1979 to 1983.

3.2.1 Annual seasons: Monthly means of the data on rainfall and air temperature were compiled for each season namely, the rainy (cool-wet) season, lasting from July till September; the harmattan (cold-dry) seasons, which starts in November and ends in February; the hot-dry season, covering March and mid-May and the early rains (hot-moderately wet) season, which starts in mid-May and ends in June.

3.2.2 Examination of soil properties: Two soil samples, one at a depth of 5cm and the other at a depth of 10cm, were made from each experimental site measuring 100m x 100m. The depth range used is considered normal for oviposition in *L. migratoria migratorioides* in several of its habitats (Popov, 1959; Farrow, 1975). The samples were taken in October, 1981, at the end of the rainy season, and each was replicated thrice.

At each experimental site a one-metre wooden quadrat was randomly placed. By means of a 20cm long iron cylinder with a diameter of approximately 10cm the soil sample was taken in the centre of the quadrat after

carefully removing all the litter from the spot to be sampled. The length of the iron cylinder was subdivided into four 5cm lengths.

The distal end of the cylinder was sharpened to allow easy penetration into the soil as the proximal end was tapped with a piece of iron rod. When the cylinder had penetrated 5cm into the soil it was gradually pulled out and its contents transferred into a polythene bag. After thoroughly cleaning the cylinder, it was sunk again, on the same spot, to the 10cm mark and its contents transferred into another polythene bag. The above procedure was repeated thrice to obtain three random soil collections, at 5cm and 10cm, from each experimental site. All the samples were examined in the laboratory of the Soil Science Department of the University of Maiduguri.

Estimation of soil particle size was done following the procedure of Bouyoucos (1951). It is a sedimentation procedure which uses a special type of hydrometer, the ATMS No.152H, with the Bouyoucos scale in grams per litre (Plate 1b). The instrument makes it possible to directly read the density of soil particles suspended in aqueous solution.

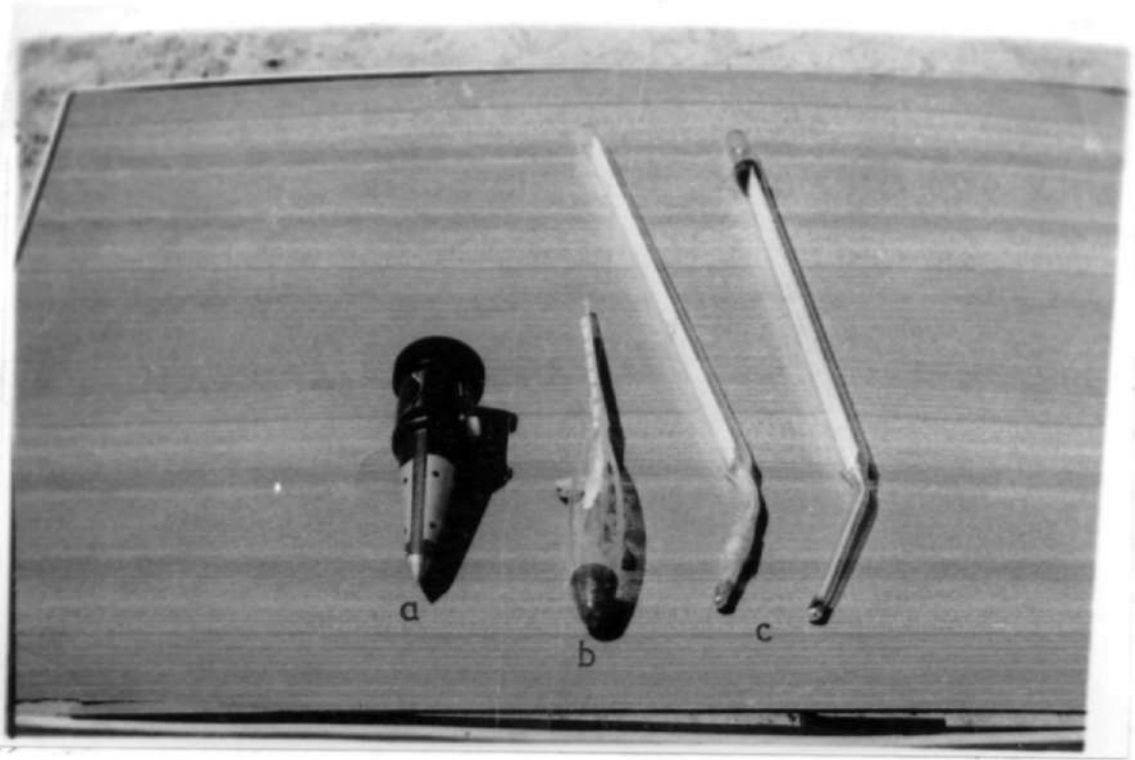


Plate 1: Instruments for collecting data on soil humidity and pH, soil particle size and soil temperature.

a) Demetra pat. 193478EM system soil tester for humidity and pH.

b) ATMS No.152H Bouyoucos hydrometer for soil particle size.

c) Two soil thermometers for temperature at depths of 5cm (left) and 10cm (right).

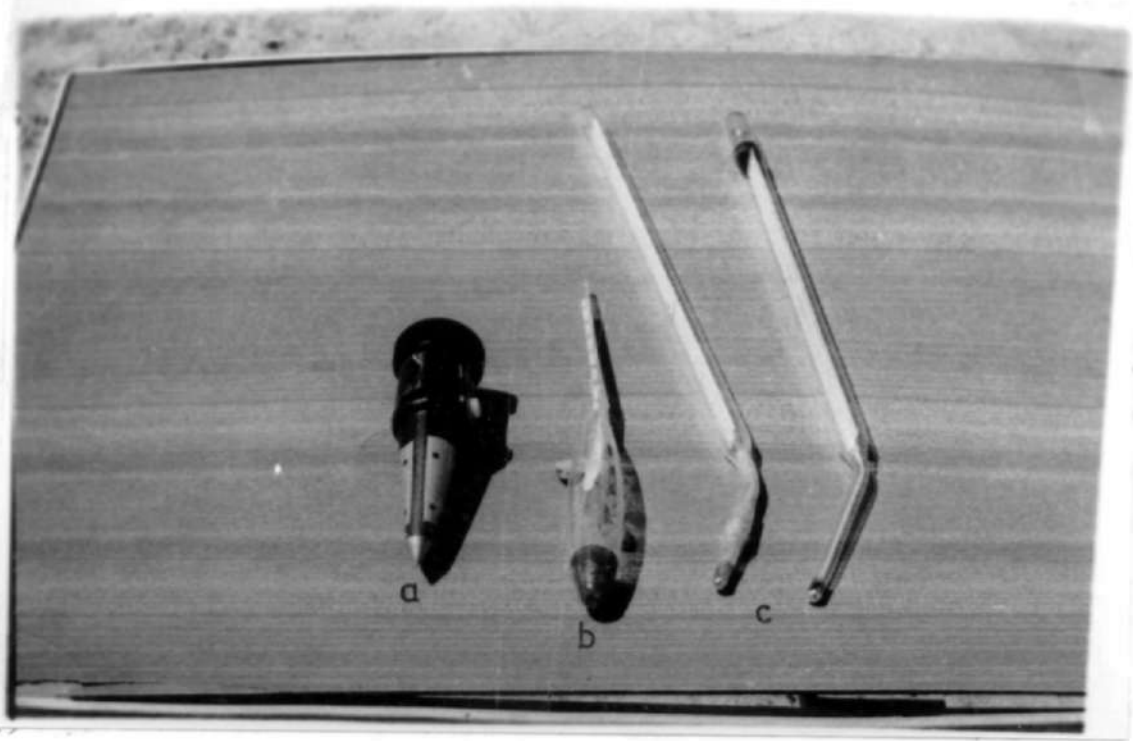


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Soil compaction in the field was examined using a penetrometer, an implement first described by Choudhuri (1956a) and has since been used by other authors (Popov, 1959; Farrow, 1975). By studying the compactness of the soil types an index of the ability of the locust's ovipositor to penetrate each soil habitat was obtained since the female locust penetrates less compact soil more easily than it does in a more compact substrate(Farrow, 1975).

An improvised form of the penetrometer that was used in this work is shown in Plate 2. It consists of a 60cm long iron rod with a diameter of approximately 1cm up to the 15cm mark from the distal end. At the 15cm mark four iron bars, each about 5cm long and with the same diameter as the 60cm rod, are welded perpendicularly. These bars provide a stopper system from which the penetrometric rod tapers gradually to a pointed tip. The tapered end is calibrated in centimeters. Another component of the penetrometer is a 50gm steel weight with a hollow in the centre so that it can be raised to a desired point on the iron rod and allowed to slide onto the stopper system.

To assess the soil compaction, the soil surface was thoroughly cleared of all litter and the pointed (distal) end of the penetrometer placed just on the bare surface.

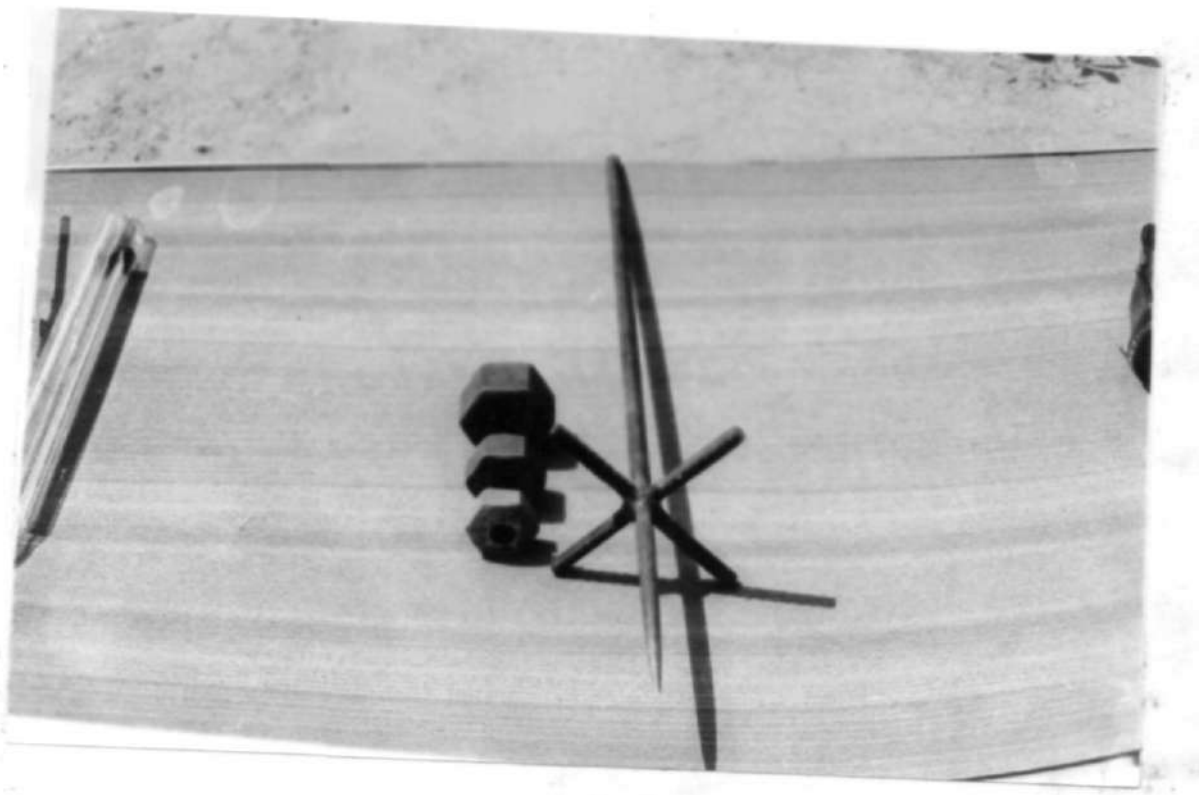


Plate 2 : A penetrometer, comprising a penetrometric rod with a stopper system and three steel weights of 200gm, 100gm and 50gm respectively.

The 50gm weight was raised by hand to the 50cm mark on the rod and allowed to slide downwards; the impact of the weight on the stopper system acted as a hammer, forcing the distal end of the penetrometer into the soil. The 50gm weight was raised repeatedly and allowed to fall on the stopper system until the distal end of the calibrated rod penetrated the soil by 10cm. The number of trials needed to sink the penetrometer by 10cm was considered as an index of the compactness of the soil and therefore an indication of how easy it would be for the locust to oviposit in a particular soil type. Fifty samples were made at each site on each of three occasions towards the end of the rains in 1981 (late August to early September). The results were compared statistically using analysis of variance.

3.2.3 Procedure for obtaining eggpods: The method whereby adult locusts are kept in open-bottomed cages in the field (Popov, 1959; Farrow, 1975) was adopted.

Cages: Open-bottomed wooden frame cages (Plate 3a) were used in each experimental site, each cage measuring 50cm wide and 50cm tall. All the four sides of the cage consist of wiremesh to facilitate ventilation. The roof, which is made of plywood, is provided with a centrally placed window measuring 15cm by 15cm and covered by a wiremesh lid hinged at a point by a nail.

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One could open the window by sliding the lid to a side and in this way food supply and observation of the locusts were accomplished through the window.

Confinement of males and females in same cages: Four to six pairs of the adult L. migratoria migratorioides, freshly captured in the field, were released into the cages. The minimum and maximum numbers of locusts maintained in each cage were eight and twelve respectively.

It is essential, however, to explain that the actual number of locusts kept in a cage depended on the total captured at a time. When more locusts were captured, the number of cages was increased in the sites, the reverse procedure was adopted when few locusts were captured. In this way a maximum of twelve locusts was kept in each cage.

It has been reported in L. migratoria migratorioides and other locusts that crowded adults lay fewer eggs per eggpod than those kept under less crowded conditions, and that their offsprings develop gregarious features if maintained under such crowded conditions (Norris, 1950, 1959, 1968; Hunter-Jones, 1958, 1966a; Popov, 1959). In addition, the author has noticed that when adults of L. migratoria migratorioides are crowded in a confinement they resort to

cannibalism. The maximum of twelve individuals kept in each cage, therefore, was decided on with the above observations in mind.

Efforts were made to always keep some males in each cage even if majority of the females showed signs of prior oviposition, for it has been shown (Norris, 1968; Haskell, 1960a; Pickford, 1970) that in locusts, diminished sexual contact reduces rate of egg production.

Prior to introducing them into the cages, the insects were categorised by age into three groups namely, very young adults, young adults and old adults. This is in line with the system used by OICMA for estimating the age of adult L. migratoria migratorioides in order to forecast oviposition. The very young adult is characterised by a soft cuticle, pale colour and nulliparity; members of this group are the least mobile. The young adult has a harder cuticle, deeper colour and is more mobile; both parous and nulliparous individuals are present in this group. The old adult has the hardest cuticle and the deepest colouration; the margins of the hind wings are usually torn and the insect is definitely parous. The rational for the above grauping was to share the age groups fairly to the three experimental sites in order to ensure timely oviposition at each site.

All cages were normally replenished with newly caught locusts at an interval of five days. In the hot-dry and the cold-dry (harmattan) seasons, however, replenishment was carried out almost daily because mortality rates were high among the insects in captivity.

Feeding the locust in captivity: The insects were fed with a mixture of any of the available grass species in the area though Sorghum lanceolatum and S. aethiopicum featured most prominently as these were the commonest grass species in the study area in all the seasons. During the dry periods these grass species thrived along the irrigation canals in the operational fields of the Lake Chad research station.

Tufts of the grasses were kept in Kilner bottles containing some water and placed in the cages. The cages were secured in position by means of iron rods planted on all sides and also by placing pieces of rock on them. These precautions were essential to ensure the stability of the cages in the event of a strong wind. The water in the bottles served to maintain the succulence of the grass feed and also to provide humidity, particularly during the drier seasons. Precaution was also taken to ensure that too much feed and water were not put in the bottles as such conditions have been found to drown the

conditions in the cages (Hunter-Jones, 1961, 1966a).

Fresh feed was supplied every other day when the bottles were cleaned and the water changed.

Confirmation of oviposition: The tips of the ovipositors of all females were examined each morning for evidence of oviposition (i.e. dirt at the tips of ovipositors), following the procedure of Norris (1959) and Hunter-Jones (1966a). Whenever evidence of oviposition was observed in a cage, all the insects (including the males) were immediately transferred into a small calico sac, the cage shifted to a new spot and the insects released into it.

After shifting the cage to a new spot a thorough search was made for evidence of one or more eggpods. All the litter in the area demarcated by the cage was carefully removed and the soil surface gradually scraped off, using a knife (Popov, 1959; Farrow, 1975). Scraping had to be gradual to avoid damage to the eggpods. In some cases no eggpods but empty oviposition trial holes were found.

3.2.4 Soil factors in relation to incubation: Twenty-four hours after the first oviposition was observed soil temperatures were recorded at depths of 5cm and 10cm using two fixed soil thermometers (Plate 1c). The thermometers

were planted in the centre of each experimental site and the readings made at 08.00hrs, 14.00hrs and 18.00hrs every other day.

Both soil humidity and soil pH were also recorded at a depth of 10cm 24 hours after the first oviposition and repeated every other day at 14.00hrs.

Records were made using a "DEMETRA pat. 193478 EM system Soil Tester" (Plate 1a). It is a 16cm long conical equipment designed to read both soil humidity and soil pH at a maximum depth of 10cm. The tester readily records soil pH when it is pushed into the soil; about one minute was allowed for stabilisation. In order to read the soil humidity, a button on the side of the tester was pressed and again about one minute was allowed for reading to stabilise.

3.2.5 Estimation of incubation period and survival rate: Eggpods detected were serially labelled with emphasis on the date of detection, which was considered as the date of oviposition (Norris, 1950, 1952, 1959, 1968; Hunter-Jones, 1959; Popov, 1959). Plate 4 shows marked eggpods in the sandy and the clayey habitats.

A record sheet was kept for each eggpod which was deliberately left uncovered for five days. The reason for



a) Eggpods in sandy habitat : note absence of pools of water.



b) Eggpods in clayey habitat: note presence of pools of water(white).

Plate 4 : Eggpods covered with wiremesh cages in the sandy and the clayey habitats.

this procedure was to allow sometime for observation on predation and parasitism. The eggpods were not left uncovered for a longer period for fear of early hatching, a situation which would have hampered verification of the number of eggs per eggpod (the clutch size).

After the five-day period, the eggpod was covered with a wirewesh cylinder (about 8cm wide, 20cm long) as recommended by Jago (per. comm.) and observed daily for mass hatching (i.e. the first hatching). The date of mass hatching was recorded as the end of incubation period following the example of Farrow (1975).

The hatchlings were "knocked down" by spraying some aerosol insecticide on them and all collections were taken to the laboratory for counting.

Post-mass-hatching observation was continued for two more days during the early rains and the rainy seasons. During the harmattan season, when low temperatures prolong incubation (Farrow, 1975), the post-mass-hatching observation was extended to four days. The purpose of the post-mass-hatching observations was to verify if there were late hatchings in the eggpods (Jago, per. comm.).

After the end of post-mass-hatching observation, the remains of the eggpods were dug up and examined, using a hand lens. Eggs which failed to hatch, including those which looked viable, that is turgid and yellowish brown, were counted and discarded.

Survival rate was determined by assessing the number of eggpods that produced hatchlings, irrespective of the number, in a given eggpod population. In addition survival was also assessed on the basis of the number of eggs that hatched per individual eggpods.

3.2.6 Assessment of egg mortality factors: To assess the roles played by egg predators and parasites, eggpods which failed to produce any hatchling, after the expected period of incubation, were dug up for examination. During the harmattan period, when the rate of egg development was slow (Farrow, 1975), a period of 30 days, including four days post-mass-hatching period was allowed for incubation after which the eggpod was dug up. Throughout the rainy season a 20-day period was allowed while a 10-day period was allowed during the hot-dry season; all periods included the post-mass-hatching periods.

In several cases the parasites could easily be seen with the naked eye. Such parasites were collected with the remains of the eggpods for counting and identification in the laboratory. Eggpods which could not be traced were assumed to have been removed by predators, for predators are known to remove eggpods of locusts through underground tunnels (Popov, per. comm). Organisms found within or near eggpods were collected and identified either in OICMA laboratory or in the British Museum (Natural History).

Similarly incidences of egg desiccation and decay were recorded and assessed in populations of eggpods and also in individual eggpods.

3.3 Laboratory Study

Laboratory study was necessary for two major reasons: (i) to obtain data for those seasons (the harmattan, the hot-dry season, and the early rains season) when the rate of oviposition was poor in the field, and (ii) to investigate the role of flood in egg development and survival.

The investigations consisted of three main experiments aimed at examining the following:

i) the effects of soil moisture and temperature on egg development, egg survival and hatchling weight,

ii) the influence of flood on egg development, egg survival and hatchling weight, and

iii) the role of drought on egg development, egg survival and hatchling weight.

In order to obtain eggpods of comparable quality for the above experiments, preliminary work to determine the effect of the female age on the quality of eggpod was carried out.

Eggpods used in the experiments mentioned above were obtained as outlined below.

3.3.1 General procedure for obtaining eggpods: Five or six pairs of freshly captured adults of L. migratoria migratorioides were kept in wooden frame mesh cages, which were provided with oviposition aluminium tubes 13cm deep and 4cm wide. The tubes were filled with predetermined soil/water mixture (treatment) to serve as oviposition sites following the example of Hunter-Jones (1966a).

Breeding cage: A picture of the breeding cages used is shown in Plate 3b. The cage is similar to the one described earlier (Plate 3a) except for the following

modifications. The height is 63cm, the additional 13cm representing the depth (height) of the oviposition tubes. It is provided with a main floor which is made of plywood and a false floor made of wiremesh. The false floor which is about 13cm above the main floor has four to six perforations. An oviposition tube was inserted in each perforation in such a way that the tube rested on the main floor while its open top barely protruded the false floor.

In summary the cage consists of two chambers, an upper, larger chamber measuring 50cm x 50cm x 50cm and a lower, smaller chamber measuring 50cm x 50cm x 13cm. The lower chamber contained the oviposition tubes while the locusts were kept in the upper larger chamber. In front of the upper chamber is a mesh door which may be opened by sliding it upwards. The door rests on the edge of the false floor leaving the front of the lower chamber open so as to allow easy replacement of the oviposition tubes. The two side walls of the cage are made of wire-mesh to facilitate ventilation while the back and the roof are made of plywood for support.

Confinement of the insects: A procedure similar to the one described for the field study was adopted. The

insects were fed daily on a mixture of Echinochloa pyramidalis and Cenchrus echinatus two species of grass which have been reported among others to be "correlated with faster rates of growth, maturation and reproduction in L. migratoria migratorioides" (Ohabuike, 1979). The grasses were easily available at the initial stages of the experiments but as the rains diminished they became rare in the field. The two grasses were therefore cultivated in a plot adjacent to a garden of Penisetum sp. and the three provided the mixture for feeding the insects.

At five-day intervals all insects were temporarily removed from the cages and the latter cleaned.

3.3.2 Preliminary study on eggpods laid in relation to the age of the female: The adult female of L. migratoria migratorioides is known to lay eggpods at different stages of its life. The aim of this experiment was to assess the qualitative differences between the first and subsequent eggpods laid by the same female in order to decide which batch of eggpods would be suitable for subseauent experiments.

Two fledglings comprising a male and a nulliparous female were released in a breeding cage supplied with an oviposition tube containing a standard soil/water mixture

procedure of Hunter-Jones (1956, 1966a):

i) 230gm sand to 50ml tap water;

ii) 230gm sand to 20ml tap water (experimental standard soil);

iii) 230gm sand to 10ml tap water;

iv) 230gm sand to 5ml tap water;

v) 230gm sand to 1ml tap water; and

vi) 230gm sand to 0ml tap water(air-dry sand).

The driest soil/water treatments (i.e. v and vi) were rejected by the locust for oviposition, instead oviposition occurred abnormally on the floor or on the walls of the cages which were provided with these soils. Furthermore, eggpods transferred from the standard soil into the two driest soils desiccated completely. As a result of the above observations, the two driest soils were deleted from subsequent experiments.

Five to ten eggpods (replicates) which were obtained in each of the four wetter soils (i.e. treatments, i to iv) were incubated in a cooled incubator (Baird and Tatlock model GA 216 4B000082) at $22^{o} \pm 1^{o}C$, $28^{o} \pm 1^{o}C$, 28^{o} - $34^{o} \pm 1^{o}C$, and $34^{o} \pm 1^{o}C$ in keeping with the procedure of Norris (1959). In addition six to eight eggpods laid in the standard soil (containing 20ml of water) and the wettest soil (containing 50ml of water) were incubated at both $38^{o} \pm 1^{o}C$ and $40^{o} \pm 1^{o}C$.

All the temperatures at which this experiment was conducted are within the range of soil temperatures in the Lake Chad Basin outbreak area (Golding and Gwynn, 1940; Darnhofer, 1976).

It is necessary to make clarification on two irregularities that could not be avoided in this experiment. The 28°–$34^{\circ}\pm 1^{\circ}C$ treatment became necessary for the following reason; at the time the incubation temperature was raised from $28^{\circ}C$ to $34^{\circ}C$ there were four to ten eggpods laid in the various soils which had incubated for two to four days at the lower temperature ($28^{\circ}\pm 1^{\circ}C$). The situation could not be avoided because there was, then, only one incubator available and eggpods were too scarce to be discarded. This batch of eggpods were, therefore, incubated partly at $28^{\circ}\pm 1^{\circ}C$ and partly at $34^{\circ}\pm 1^{\circ}C$. Secondly, only the eggpods laid in the standard and the wettest soils were incubated at $38^{\circ}\pm 1^{\circ}C$ and $40^{\circ}\pm 1^{\circ}C$ because several eggpods laid in the drier soils (iii and v) desiccated even at a lower temperature $34^{\circ}\pm 1^{\circ}C$.

Eggpods which failed to hatch after the expiry of the expected period of incubation (this happened frequently in the soil treatment iv, containing 5ml of water) were further moistened with 20ml of water and kept in the incubator.

The method recommended by Hunter-Jones (1956, 1966a) was adopted to trap the emerging hatchlings; a piece of fine wiremesh was used to cover the top of the oviposition tube containing eggpod. The wiremesh was secured in place by means of a strong rubber band as shown in Plate 5.

Fresh hatchlings from each tube were removed within 24 hours of hatching. A random sample of 10 individuals was made, the hatchlings were killed by aerosol insecticide and weighed. Data collected included incubation period, rate of egg survival and hatchling weight; these were examined statistically by the analysis of variance.

Hatchlings, emerging from eggpods that were incubated at $34^{\circ} \pm 1^{\circ}C$ only, were reared to the second instar in Kilner jars provided with the grass, C. echinatus. At the end of the rearing experiment all hoppers were killed and counted. The aim was to study the relationship between the weight of the hatchling and its survival potential to the second hopper instar.

When the above experiment was completed, an attempt was made to find out how the soil moisture treatments tested in the laboratory compared with the real field conditions. For this purpose the soil tester (Plate 1a) used for the field study was also used to measure the water content in the freshly prepared soil/water mixtures. The measurements were repeated on alternate days for 12 days when eggpods



a) Tubes covered with wiremesh to trap hatchlings.



b) Eggpod deliberately exposed by digging slightly.

Plate 5 : Oviposition tubes containing eggpods.

at 34°±1°C were expected to have hatched. In this way it was possible to determine the changes in water levels that occurred in the various soil/water mixtures during incubation at 34°±1°C.

3.3.4 Experiment on the effects of flood on egg development, egg survival and hatchling weight:

Five to ten eggpods laid in the experimental standard soil (230gm/20ml) were used for this experiment. At the ages of zero, three, six and nine days, during which the eggpods were incubated at 34°±1°C, they were flooded for a period ranging from one to five days. The date of detection of an eggpod was considered the date of oviposition, that is age zero, on which the deduction of the eggpod age was based (Shulov, 1970).

During flood, the oviposition tube containing the eggpod was submerged under water contained in a desiccator constantly kept closed except when eggpods were being put in or being taken out.

At the end of the flood treatment the oviposition tubes (with the eggpods), were removed from the water but retained in the incubator where the excess water evaporated and also drained from the bases and sides of the tubes. The oviposition tubes had their free ends covered with wiremesh to prevent the escape of the hatchlings as earlier shown (Plate 5).

Data compiled were incubation period, rate of egg survival and hatchling weight. The relationship between drought period and the above survival parameters were examined statistically by the analysis of multiple correlation following the example by Bruning and Kintz (1968).

CHAPTER FOUR

R E S U L T S

4.1 Field Study

4.1.1. Annual Seasons: Observations on rainfall and air temperature in the study area revealed four marked annual seasons summarised in Figure 10 and described below.

Rainy (Cool-Wet) Season: This season covered July to September, with the mean air temperature ranging from 24.6°C in August to 27.5°C which normally occurred in September.

The season was characterised by high frequency and intensity of the rains with the peak invariably occurring in August. The total rainfall recorded in September (late rainy season) did not normally differ much from that recorded in June (early rainy season), though September was wetter than June due to the effects of water accumulated from the preceding months (July and August). The average monthly rainfall for the period of study was 139.3mm in July, 166.3mm in August and 49.7mm in September.

Harmattan (Cool-dry) season: The period from mid-November to February was the coldest and the driest with mean air temperature ranging from 19.2°C in January to 25.6°C in November.

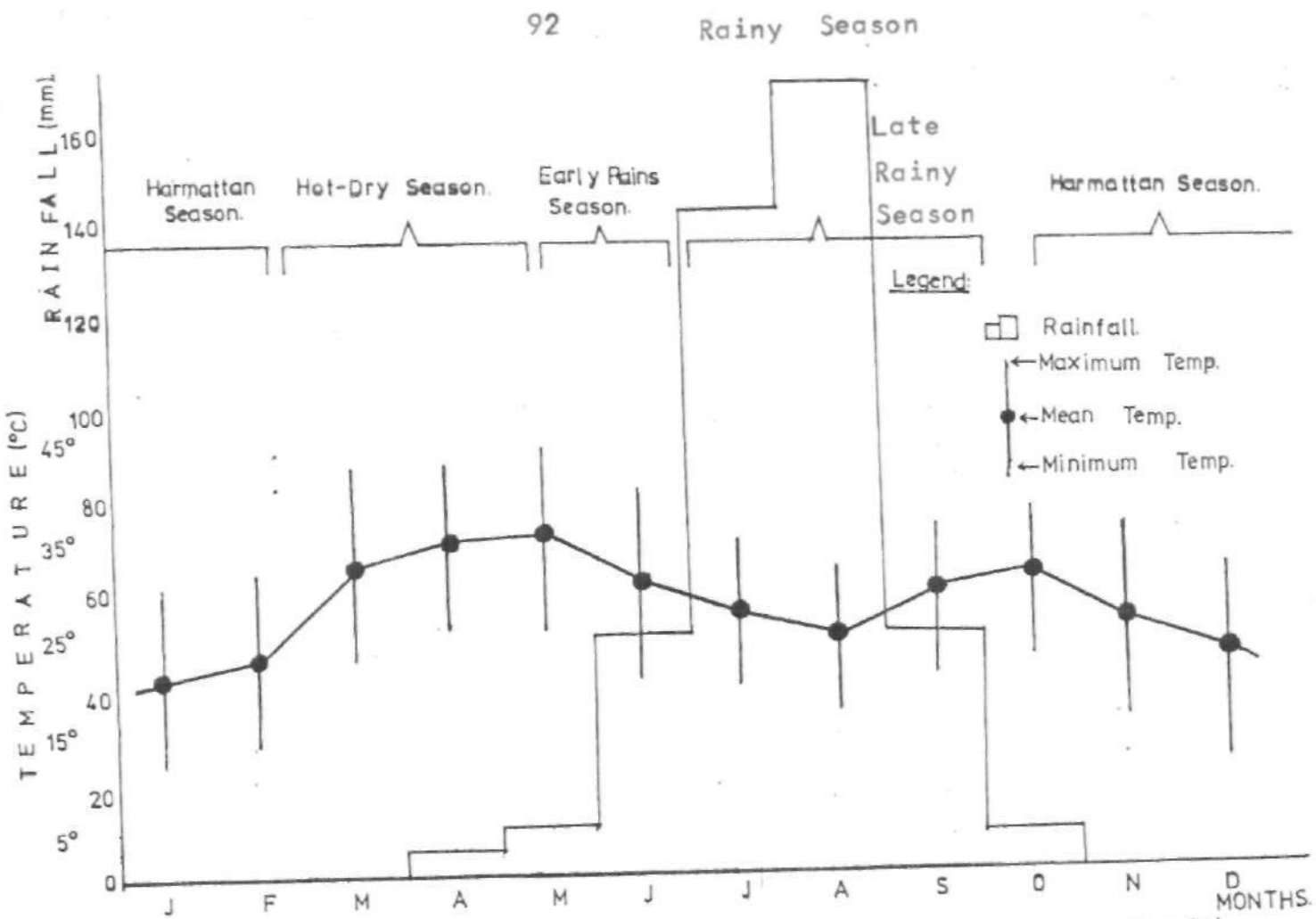


Fig. 10: Monthly Mean Rainfall And Air Temperature At Ngala (1979-1983).

Rainfall was practically nil and any moisture present in the soil depended solely on the water retentive capability of the soil. Also characteristic of the season were the dry, dusty North-Easterlies.

Hot-dry season: Duration of this season was from March to mid-May. The characteristic mean air temperature ranged from 32.5°C to 35.8°C in March and May respectively.

Some rainfall was recorded, particularly in May, but these showers merely wetted the surface of the soil for a few hours only, the water rapidly evaporated by the characteristic scorching sun of the season. During the study period, rainfall recorded averaged 6.3mm in April and 9.8mm in May.

Early rainy (hot-moderately wet) season: This season lasted from mid-May till end of June. The mean air temperature ranged from 29.8°C in June to 36.2°C in the second forthnight of May.

The rains were heavier and also more frequent than in the preceding season, the average for June being 51.4mm.

4.1.2 Soil types: Examination of the physical properties of the soil types in the three habitats gave the results which are presented in Tables 1 and 2.

Table 1: Particle size distribution in soil types at 5cm and 10cm depths.

	Standard Sizes (mm)*	Percentage Type of Soil			Textural Class
		Sand	Silt	Clay	
Site A at 5cm	0.02 to 2.0	94.6	0.0	5.4	Sand
Site A at 10cm	0.02 to 2.0	94.6	0.0	5.4	Sand
Site B at 5cm	0.002 to 0.02	59.0	13.9	27.1	Sandy-Clay Loam
Site B at 10cm	0.002 to 0.02	55.0	12.9	32.1	Sandy-Clay Loam
Site C at 5cm	<.002	22.6	11.8	65.6	Clay
Site C at 10cm	<.002	19.4	13.1	67.5	Clay

*These are the universally accepted limits of the diameter of soil particle size (Black, 1965).

Table 2: Assessment of soil compactness: mean hammerings required to penetrate soil by 10cm depth.

Replicate	Sand	Sandy-Clay Loam	Clay
1	23.9	92.6	13.5
2	21.7	109.0	15.7
3	24.8	97. 8	12.8
Mean	23.5	99.8	14.0

The composition of the soil particles was uniform within a depth of 10cm in each habitat (Table 1). The three soil types were, however, clearly distinct as indicated by the mean percentage sand, silt and clay.

Soil compactness differed significantly ($P \leq .05$) among the habitats as shown in Table 3.

Table 3: Analysis of variance (ANOVA) for soil compaction.

Source	SS	df	MS	F	P
Total	896,975.63	449			
Habitats	663,812.63	2	331,906.31	648.85	.05
Replicate	2,366.41	2	1,183.21	2.31	NS
Habitat x Replicate	5,212.39	4	1,303.10	2.55	NS
Error	225,584.20	441	511.53	-	-

Legend: SS = Sum of squares

df = degrees of freedom

MS = means squares; i.e. $\frac{SS}{df}$

F = the F ratios, i.e. $\frac{\text{MS habitats}}{\text{MS error}}$, $\frac{\text{MS replicates}}{\text{MS error}}$, $\frac{\text{MS habitat x Replicate}}{\text{MS error}}$

P = level of significance

NS = not significant

By applying the t test, it was confirmed that the sandy-clay loam was the most compact soil; it differed significantly from both the sand and the clay. In turn the sandy habitat was more compact than the clayey habitat. ($P \leq 0.05$, $t=1.96$, critical difference between the measures = 8.87; degrees of freedom = 441).

Data on soil humidity (Tables 4a and 4b) show the differences in water retentive capacities of the three soil types during the rainy season. The sandy-clay loam had the highest water retentive capacity (mean humidity, 98.4%), followed by the clay (94.3% humid) and the sand (51.0% humid). The difference was not statistically significant between the sandy-clay loam and the clayey habitats. However, statistically different ($P \leq .05$) soil humidities existed between each of the two soil types and the sand as shown in Table 4c.

It was observed that water seepage, during the rainy season, was most rapid in the sandy habitat followed by the sandy-clay loam habitat; it was least rapid in the clayey habitat. The poor seepage in the sandy-clay loam and the clayey habitats was indicated by the frequent occurrence of pools of water in the two habitats during the rainy season.

As a result of the poor seepage in the sandy-clay loam and the clayey habitats, eggpods in these areas were often flooded during the rainy season as shown in Plate 4b.

Table 4a: Soil humidity, temperature and pH during the rainy season.

	S A N D								SANDY-CLAY LOAM								C L A Y							
	TEMPERATURE (°C)						pH	% HUM	TEMPERATURE (°C)						pH	% HUM	TEMPERATURE (°C)						pH	% HUM
	08HRS		12HRS		18HRS		08HRS	12HRS	08HRS		12HRS		18HRS		08HRS	12HRS	08HRS		12HRS		18HRS		08HRS	12HRS
Year	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm
1981	27.4	27.3	33.1	32.6	29.6	29.7	6.6	48. 3	27.4	27.3	33.3	32.1	30.9	31.2	6.3	95:8	27.7	27.5	31.0	30.3	30.6	31.0	6.2	96.7
1982	28.3	27.8	32.9	32.7	29.4	29.6	6.7	55. 8	28.9	28.1	33.9	32.3	29.1	30.4	6.6	93.4	28.1	28.7	32.1	30.8	30.3	31.7	6.4	99.3
1984	27.8	27.5	32.2	32.8	30.3	29.7	6.5	48. 9	27.9	27.5	33.5	32.2	28.8	30.7	6.6	93.8	28.7	28.6	32.0	31.0	30.7	31.2	6.7	99.2
Mean	27.8	27.6	32.7	32.6	29.8	29.7	6.6	51. 0	27.9	27.6	33.6	32.2	29.6	30.8	6.5	94.3	28.2	28.3	31.7	30.7	30.5	31.3	6.4	98.4
Sd	10.45	0.25	0.47	0.10	0.47	0.06	0.10	4.17	0.84	0.42	0.31	0.10	1.14	0.40	0.17	1.29	0.50	0.67	0.61	0.37	0.21	0.36	0.25	1.48
v	0.14	0.04	0.15	0.00	0.15	0.00	0.00	11.58	0.47	0.12	0.00	0.00	0.86	0.11	0.02	1.10	0.17	0.30	0.25	0.09	0.03	0.09	0.04	1.45

Table 4b: ANOVA for soil humidity

Source	SS	df	MS	F	P
Total	67,084.79	114	-	-	-
Habitats	49,816.29	2	21,908.15	126.78	0.05
Years	1,698.82	2	849.41	4.92	ns
Habitats x Years	3,252.10	4	813.03	4.70	ns
Error	18,317.58	106	172.81	-	-

Table 4c: T test for differences in soil humidity between soil types

Habitat Pairs	t(.05 level) with 106df	Std.error of means	Critical diff. between means	Calculated differences bet. means	Conclusion
Sandy Vs. Sandy-Clay Loam	1.980	3.02	5.98	(94.3-51.0) = 43.3	Significant
Sandy Vs.Clay	1.980	2.98	5.90	(98.4-51.0) = 47.4	Significant
Sandy-Clay Loam Vs. Clay	1.980	3.02	5.98	(98.4-94.3) = 4.1	NS ns

Legend: Sd. = Standard deviation, v = Variance % Hum = Soil humidity

Soil temperature and soil pH were similar for all habitats during all the seasons as may be seen in Table 4a, for the rainy season; and in Appendices 3,4 and 5 for the harmattan, the hot-dry and the early rains seasons respectively.

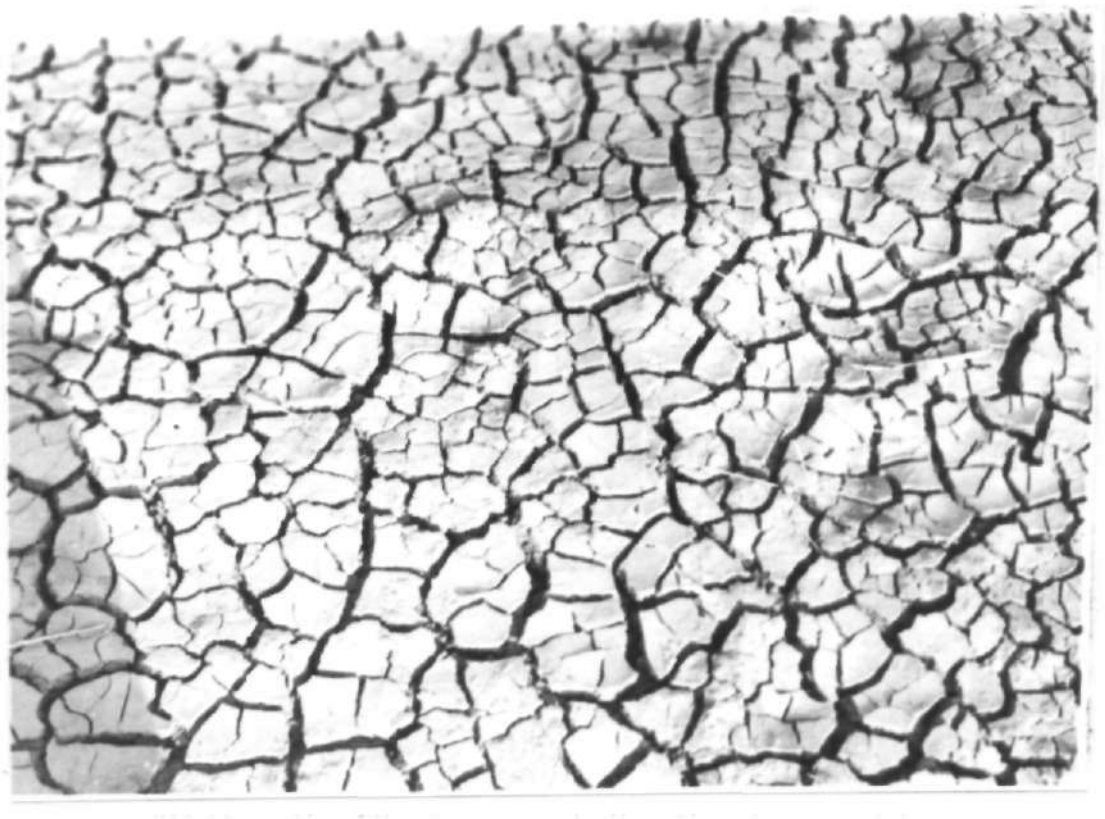
The soil types also behaved differently during the dry periods. The sand (Fig.9, Site A) was normally rendered loose and powdery, at least, on the surface (Plate 6) and sandy-clay loam (Fig,9 Site B) formed a hard pan (Plate 7) which was almost impenetrable to some of the instruments used in the field (e.g. the soil thermometer). The clay (Fig.9, Site C) on the other hand, cracked, the extent of cracking increasing with the duration of the dry season. Characteristically, numerous cracks, some minor others major, appeared on the surface of the clayey habitat (Plate 8a). With the intensification of the dry conditions, particularly during the hot-dry season, most of the minor cracks became obliterated as they were filled by debris blown about by the winds. The major cracks, on the other hand, deepened and widened as the soil lost most of its water and the soil particles shrank. A maximum depth of 1.45m was measured on 17th March, 1981 at site C (Fig.9). At the peak of the cracking, therefore, the



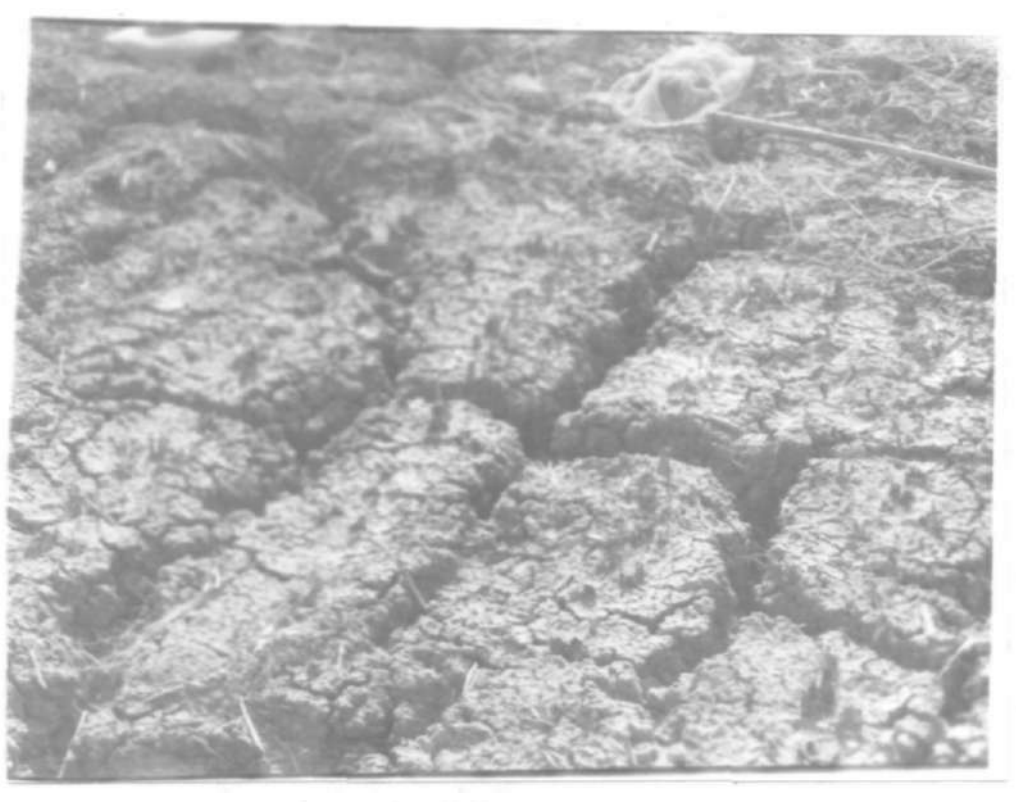
Plate 6 : Powdery surface of sandy habitat during dry seasons.



Plate 7 : Compact surface of sandy-clay loam habitat during the dry seasons.



a) Numerous shallow cracks occurring immediately after the rainy season.



b) Deep cracks during the peak of the dry seasons.

Plate 8 : Cracked surface of the clayey habitat during the dry seasons.

surface of the clay soil appeared to be made of numerous blocks of different shapes and sizes separated from each other by wide gaps (Plate 8b).

4.1.3 Rate of egg development: The rate of egg development was inferred from the duration of incubation.

Although data for the harmattan season (Appendices 6 to 16) and also for the early rains seasons (Appendices 17 to 21) were not sufficient for meaningful statistical analyses, the following indications were evident: (i) Eggs developed fastest during the early rains season, incubation lasting an average of 9.5 days in sandy habitat. (ii) Eggs developed slowest during the harmattan season, the average incubation period being 24.0 days in clayey habitat. (iii) Generally, the rate of egg development, during the rainy season, was intermediate between the rates for the early rains and the harmattan seasons. The mean incubation periods for the rainy season are given in Table 5.

Table 5: Mean incubation periods during the rainy season

Year	Sand	Sandy-Clay Loam	Clay
1981	13.2	15.2	17.6
1982	12.6	15.2	16.4
1984	14.9	17.5	20.4
X	13.6	16.0	18.1
SD	1.19	1.33	2.05
V	0.95	1.18	2.81

Egg development was fastest in the sandy habitat, where it lasted 13.6 days, it lasted 16 days in the sandy-clay loam habitat and 18.1 days in the clayey habitat. As may be seen in Table 6, the inter-habitat and inter-annual differences in incubation periods were statistically different ($P \leq .05$).

Table 6: Analysis of variance for incubation periods during the rainy season.

Source	SS	df	MS	F	P
Total	4,287.57	290	—	—	—
Habitat	1,115.91	2	557.96	54.81	$\leq .05$
Years	354.14	2	177.07	17.39	$\leq .05$
Habitat x Years	-52.06	4	-13.02	-1.28	NS
Error	2,869.58	282	10.16	-	-

Comparison of the rates for the years gave the results shown in Appendix 22. The differences were not significant between 1981 and 1982 in sandy habitat and also in sandy-clay loam habitat; eggs however, developed significantly faster in 1982 than in 1981 in the clayey habitat. In all habitats egg development was faster in 1981 than in 1984. Similarly egg development was faster in 1982 than 1984 in all habitats.

The variances shown in Table 5 (0.95 for sand, 1.18 for sandy-clay and 2.81 for clay) indicate that during the rainy season, incubation periods varied most widely in the clayey habitat; the periods were most uniform in the sandy habitat. In the field it was observed that incubation periods for two eggpods laid on the same day in the clayey habitat sometimes differed by two days (Appendix 23 to 25), at the initial stages of the rainy season (July), and by approximately 15 days (Appendix 23) at the peak of the rains (August). In the sandy-clay loam habitat, the difference between incubation periods of two eggpods laid on the same day ranged from one to four days (Appendix 26-28) while the difference ranged from one to two days in the sandy habitat (Appendices 29 to 31).

In general incubation period was more uniform during the beginning and the final stages of the rains (July and September). Furthermore, incubation period was generally shorter in July, when the rains were yet to attain the peak. Longer incubation periods coincided with the peak of the rains, in August, and as the rains declined, in September, incubation periods were shorter once again (Fig.11).

4.1.4 Rate of egg survival: The criterion for survival was the successful emergence of pharates to the soil surface at the end of incubation; (i.e. the appearance of hatchlings). Egg survival was therefore determined by assessing (i) the number of eggpods that produced hatchlings in the (eggpod) population obtained and (ii) the number of hatchlings from individual eggpods of the same populations mentioned above.

Eggpods in which hatchling occurred in the (eggpod) populations obtained: By this procedure an eggpod was considered to have survived (hatched) irrespective of the number of hatchlings emerging from it. Table 7 summarised the results obtained.

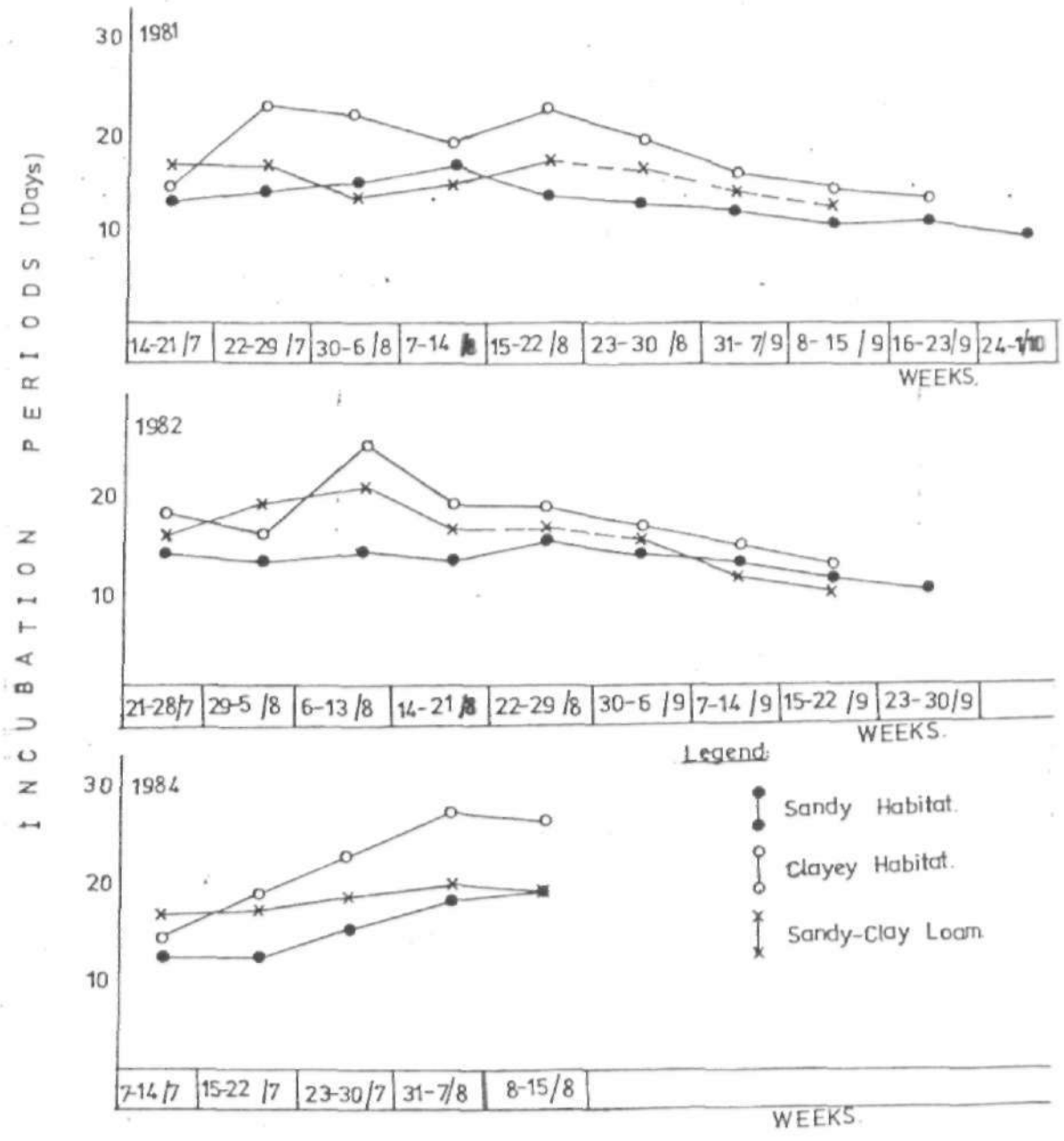


Fig. 11 Weekly Mean Incubation Periods During Rainy Season.

Table 7: Percentage eggpod survival (Producing hatchlings) per given eggpod populations

	RAINY SEASON				HARMATTAN SEASON					HOT-DRY SEASON					EARLY RAINS SEASON		
Habitat	1981	1982	1984	Mean	1981-82	1982-83	1983-84	1984-85	Mean	1981	1982	1983	1984	Mean	1981	1982	Mean
Sand	51.2	53.9	44.6	49.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	33.3	29.2
Sandy-Clay Loam	10.3	16.2	23.4	16.6	0.0	0.0	0.0	0.0	0.0	N.O	0.0	0.0	0.0	0.0	0.0	N.O	0.0
Clay	27.2	21.4	26.7	25.1	14.3	20.0	11.1	0.0	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Legend: N.O. = No oviposition

During the study period, a total of 24 eggpods was obtained in the clayey habitat for the harmattan season (Appendices 13 to 16). Only 8.3% (2) of these survived. Similarly, low survival rate was recorded during the early rains seasons; 29.2% (2) of the seven eggpods obtained (Appendices 17 to 18) did survive in the sandy habitat only. Eggs did not survive during the hot-dry season (Appendices 32 to 42). The rainy season was the most favourable period for egg survival as shown in Appendices 29 to 31.

It is clear from Table 7 that, of the three soil habitats, the best results were obtained in the sandy one. This observation is based on the distribution, by habitat of the 907 eggpods obtained for the rainy season study as well as the rates of survival in each habitat. In a total of 350 eggpods laid in the sandy habitat during the rainy season (Appendices 29 to 31) the survival rate ranged from 44.6% to 53.9%; the average rate was 49.9% (175). A total of 298 eggpods was obtained in the clayey habitat during the rainy season study (Appendices 23 to 25) and of these an average of 25.1% (75) survived, the range being 21.4% to 27.2%. In the sandy-clay loam habitat 259 eggpods were laid (Appendices 26 to 28); an average of 16.6% (43) survived while the range was 10.3% to 23.4%.

Inter-habitat comparisons were made of the mean survival rates mentioned above, by using the z test. The results are presented below. The average survival rate in the sandy habitat (49.9%) was significantly higher ($P \leq .05$, $z = 13.32$) than the average rate in the sandy clay loam habitat (16.6%). Survival rate in the sandy habitat was also significantly higher ($P \leq .05$, $z = 9.54$) than that in the clayey habitat (25.1%), and survival rate in the clayey habitat was significantly higher ($P \leq .05$, $z = 3.54$) than that in the sandy-clay loam habitat.

Survival rate based on the number of hatchlings from individual eggpods: The number of eggpods obtained for each soil habitat during the rainy season has already been stated above (i.e. 350 for sand, 259 for sandy-clay loam and 298 for clay).

The rates of egg survival in the individual eggpods were assessed by two criteria: survival was assessed on the basis of percentage egg hatch per eggpod, alternatively only eggpods producing 100% hatch were considered to have survived.

Table 8 summarises the results based on the first survival criterion. The mean survival rates were 47.8%

Table 8: Percentage egg survival in the soil habitats during rainy season

Habitats	1981	1982	1984	Means
Sand	47.8	51.5	42.0	47.8
Sandy-Clay Loam	4.8	11.8	17.3	11.3
Clay	15.7	18.0	19.5	17.6

in sandy, 17.6% in clayey and 11.3% in sandy-clay loam habitats.

Comparison of the above results, using analysis of variance, showed significant differences ($P \leq .05$) between habitats only (Table 9).

Table 9: Analysis of variance for egg survival during rainy season

Source	SS	df	MS	F	P
Total	1,451,005.60	866			
Habitats	247,462.94	2	123,731.47	88.95	$\leq .05$
Years	326.94	2	163.47	0.12	ns
Habitats x Years	9,668.00	4	2,417.00	1.74	ns
Error	1,193,547.60	858	1,391.08	-	

By means of t test, it was confirmed that the significant differences existed between sandy and sandy-clay loam habitats and also between sandy and clayey habitats; there was no significant difference between sandy-clay loam and clayey habitats (Table 10).

Table 10: Application of t test to confirm differences in egg survival between pairs of habitats.

Habitat Pairs	t (.05 level) with 858d.f	Std.error of means	Critical differences between means	Calculated differences between means	Conclusions
Sand Vs. Sandy-Clay loam	1.960	3.11	6.1	36.5	Significant
Sand Vs. Clay	1.960	3.02	5.9	30.2	Significant
Sandy-Clay loam Vs. Clay	1.960	3.24	6.4	6.3	Not Significant

On the basis of 100% hatch per eggpod, an average of 38.8% (136) of the 350 eggpods survived in the sandy habitat (Appendices 29 to 31), 14.8% (44) of the 298 eggpods survived in the clayey habitat (Appendices 23 to 25) and 9.0% (23) of the 259 eggpods survived in the sandy-clay loam habitat (Appendices 26 to 28). Again the differences were significant ($P \leq .05$) between (i) sandy and sandy-clay loam habitats ($Z = 12.96$), (ii) sandy and clayey habitats ($Z = 10.00$) and also between sandy-clay loam and clayey habitats ($Z = -3.05$).

These results complement those already stated above i.e. egg survival is significantly higher in the sandy habitat than in both sandy-clay loam and clayey habitats.

4.1.5 Relative importance of egg mortality factors: As shown in Table 11, four egg mortality factors were recorded in the field; they are predation, parasitism, desiccation and decay. The relative importance of these factors was assessed on the basis of three parameters, namely seasonal and habitat occurrence, number of eggpods damaged and damage within individual eggpods. Results of the assessments are presented below, beginning with predation.

Predation: Predation was determined by two criteria: the more conspicuous of these was the disappearance of marked eggpods (when dug up for examination) after the expiry of the expected period of incubation; the second criterion was the partial disappearance of individual eggpods.

Predation was the most important egg mortality factor in the field. It occurred in all seasons and in all habitats, except the sandy-clay habitat during the hot-dry season.

It was most frequent during the rainy season when the maximum number of missing eggpods was recorded for each habitat. For instance, 64.3% (167) of the 259 eggpods disappeared from the sandy-clay loam habitat (Appendices 26 to 28), 38.6% (115) of the 298 eggpods were missing from the

Table 11: Percentage eggpod damage due to mortality factors.

	SAND					SANDY-CLAY LOAM					CLAY				
	PARASITISM					PARASITISM					PARASITISM				
	SCE.	ENC.	PRED	DESI	DEC.	SCE	ENC.	PRED	DESI	DEC	SCE	ENC.	PRED	DESI	DEC
Rainy Season	7.3 *(0.4)	7.0 (1.5)	25.9 (9.8)	7.2 (4.4)	13.9 (6.1)	5.0 (1.3)	5.7 (2.5)	64.3 (5.1)	11.2 (6.2)	5.0 (1.3)	2.8 (0.9)	7.2 (4.1)	38.6 (2.9)	8.7 (2.3)	28.4 (4.0)
Harmattan Season	0.0 (0.0)	0.0 (0.0)	37.1 (10.6)	62.9 (10.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.3 (14.4)	91.7 (14.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	67.4 (23.9)	32.6 (23.9)	0.0 (0.0)
Hot-Dry Season	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	93.8 (12.5)	6.3 (12.5)	0.0 (0.0)	0.0 (0.0)	25.0 (25.0)	75.0 (25.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	23.8 (20.6)	76.3 (20.6)	0.0 (0.0)
Early Rains Season	0.0 (0.0)	0.0 (0.0)	25.0 (36.4)	75.0 (36.4)	0.0 (0 0)	0.0 (0.0)	0.0 (0.0)	100.0 (-)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	36.7 (4.7)	63.3 (4.7)	0.0 (0.0)

Legend: SCE = Scelio infestation
ENC. = Enchytraeid infestation
PRED.= Predation
DESI = Desiccation
DEC = Decay

*Figures in brackets represent standard deviations.

clayey habitat (Appendices 23 to 25) and 25.9% (91) of the 350 eggpods were missing from the sandy habitat (Appendices 29 to 31).

During the harmattar, predation was most frequent in the clayey habitat where it accounted for the loss of 62.4% (15) of 24 eggpods (Appendices 13 to 16). It was responsible for the loss of 37.5% (6) of 16 eggpods in the sandy habitat (Appendices 6 to 9) and also for the loss of 11.1% (1) of nine eggpods in the sandy-clay loam habitat (Appendices 10 to 12).

During the hot-dry season predation accounted for the loss of 25% (2) of eight eggpods in the sandy-clay loam habitat (Appendices 36 to 38) and it was responsible for the loss of 25% (4) of 16 eggpods in the clayey habitat (Appendices 39 to 42).

As already stated, predation did not affect any of the 11 eggpods laid in the sandy habitat during the hot-dry season (Appendices 32 to 35).

Predation caused the loss of 37.5% (3) of eight eggpods in the clayey habitat during the early rains season (Appendices 20 to 21), and it was responsible for the disappearance of a single eggpod laid in the sandy-clay loam habitat during the season (Appendix 19). During the same season 28.6% (2) of seven eggpods were lost to predation in the sandy habitat (Appendices 17 to 18).

were frequently found in the vicinity of the eggpods when the latter were dug up for examination. The larvae were suspected to be predatory on the locust's eggpods. Of the larvae of the Carabidae, one genus, resembling Distichus, was most prominent.

Parasitism: Parasitism occurred in the rainy season only; during the season it was registered in all the three soil habitats (Table 11).

Parasitism was easily recognised by two distinguishing features: parasitised eggs contained the developing parasite which changed the characteristic yellowish colour of the normal locust egg to dark brown; alternatively the parasite had emerged leaving an empty egg shell with an exit hole.

Two parasitic groups were observed. Group one comprised two hymenopterous species belonging to the family Scelionidae, i.e. Scelio africanus Farriere and S. sudanensis Farriere. Group two comprised an unidentified worm belonging to the family Enchytraeidae.

Only a small number of eggpods was infested by the parasites. Together the two groups infested a mean of 14.3% (51) of the 350 eggpods in the sandy habitat during the rainy season. They infested 10.7%(28) of the 259 eggpods in the sandy-clay loam habitat and 10.0% (30) of the 298 eggpods in the clayey habitat.

Of the 907 eggpods obtained during the rainy season study, the Scelio species infested an average of 5% (ie 45) while the worm infested 6.6%.(i.e. 60).

The difference in incidence of parasitism was not significant between sandy-clay loam habitat and clayey habitat, but it was sianificant between sandy and clayey habitats ($Z = 2.39$, $P \leq .05$).

Infestation by S. africanus and S. sudanensis caused total or partial mortality as shown in Table 12.

In the sandy habitat partial parasitisation by Scelio caused mortality ranging from 1.1% (Appendix 29, No.169) to 84.1% (Appendix 30, No.71). Similar wide ranges of Scelio infestation also occurred in the other two habitats as shown in Appendices 23 to 28.

Total and partial damage to eggpods was also associated with nematode infestation (Table 12) although the incidence of total mortality caused by the nematode was less frequent than that by Scelio species.

Partial infestation by nematodes sometimes caused as low as 1.4% egg mortality (Appendix 29, No.5). In heavily infested eggpods it was not possible to ascertain the egg survival rate as the remains of such eggpods were intimately mixed up and therefore prevented the identification of individual eggs.

Table 12: Percentage eggpod destruction by parasitism during rainy season

	S A N D				SANDY-CLAY LOAM				C L A Y			
	SCELIO		ENCHYTRAEIDAE		SCELIO		ENCHYTRAEIDAE		SCELIO		ENCHYTRAEIDAE	
	Partial	Total	Partial	Total	Partial	Total	Partial	Total	Partial	Total	Partial	Total
1981	25.0(3)	75.0(9)	46.7(7)	53.3(8)	20.0(1)	80.0(4)	50.0(2)	50.0(2)	50.0(2)	50.0(2)	50.0(7)	50.0(7)
1982	37.5(3)	62.5(5)	28.6(2)	71.4(5)	75.0(3)	25.0(1)	60.0(3)	40.0(2)	50.0(1)	50.0(1)	25.0(1)	75.0(3)
1984	20.0(1)	80.0(4)	50.0(2)	50.0(2)	33.3(1)	66.7(2)	50.0(2)	50.0(2)	0.0(0)	100.0(2)	75.0(3)	25.0(1
Totals	82.5(7)	217.5(18)	125.3(11)	174.7(15)	128.3(5)	171.7(7)	160.0(7)	140.0(6)	100.0(3)	200.0(5)	150.0(11)	150.0(1
% Mean	27.5	72.5	41.8	58.2	42.8	57.2	53.3	46.7	33.3	66.7	50.0	50.0
	(2.3)	(6.0)	(3.7)	(5.0)	(1.7)	(2.3)	(2.3)	(2.0)	(1.0)	(1.7)	(3.7)	(3.7)

Legend: Actual numbers in brackets

Desiccation: In desiccated eggs the yolk retained its characteristic yellowish colour but it was loose in the egg case which peeled off easily. The yolk was oily when touched, brittle and fragmented easily under pressure.

Desiccation occurred in all seasons and in all habitats except one, the sandy-clay loam, where the single eggpod laid was removed by predators (Table 11).

Despite its wide distribution, desiccation cannot be considered a major mortality factor under field conditions since it occurred in a small number of eggpods in each habitat. During the rainy season, 11.2% (29) of the 259 eggpods were desiccated in the sandy-clay loam area (Appendices 26 to 28), 8.7% (26) of the 298 eggpods were desiccated in the clayey habitat (Appendices 23 to 25) while desiccation affected 7.2% (25) of the 350 eggpods in the sandy habitat (Appendices 29 to 31).

Most of the desiccation in the rainy season was registered in mid-July and September, that is before and after the peak of the rains.

During the harmattan, oviposition was generally low and the majority of oviposition in the sandy and the sandy-clay loam habitats were found in abnormal locations. Such eggpods were laid on the soil surface, on the cage walls or in the grass feed (Appendices 6 to 12).

Desiccation in the abnormally laid eggpods was, therefore, the direct result of exposure and may not give a true indication of what actually occurs under natural conditions. However, it was observed that most of the 24 eggpods in the clayey habitat were properly laid (Appendices 13 to 16) and 37.5% (9) of these desiccated.

During the hot-dry season almost all the desiccated eggpods were also laid abnormally (Appendices 32 to 42).

During the early rains season, seven eggpods were laid in the sandy habitat (Appendices 17 to 18). Of the seven eggpods 75% (5) desiccated and one of the desiccated eggpods was laid abnormally.

Eight properly laid eggpods were obtained in the clayey soil during the early rains season (Appendices 20 to 21) and 62.5% (5) of these were desiccated (Table 11).

As shown in Table 13 desiccation sometimes caused partial destruction, particularly during the rainy season, but total egg mortality was also common and occurred mainly in the drier seasons. In the rainy season partial eggpod destruction by desiccation ranged from 10.8% (Appendix 28, No.9) to 96.3% (Appendix 26, No.3).

Table 13: Percentage eggpod destruction by desiccation during rainy season.

	SAND		SANDY-CLAY LOAM		CLAY	
	Partial	Total	Partial	Total	Partial	Total
1981	37.5(3)	62.5(5)	7.1(1)	92.9(13)	10.0(1)	90.0(9)
1982	0.0(0)	100.0(14)	5.9(1)	94.1(16)	7.7(1)	92.3(12)
1984	0.0(0)	100.0(3)	50.0(1)	50.0(1)	0.0(0)	100.0(4)
Total	37.5(3)	262.5(22)	63.0(3)	237.0(30)	17.7(2)	282.3(25)
% Mean	12.5 (1.0)	87.5 (7.3)	21.0 (1)	79.0 (10.0)	5.9 (0.7)	94.1 (8.3)

Legend: Figures in brackets are actual numbers of eggpods; those outside brackets are percentages.

Decay: In decay infested eggpods, the eggs were dark brown or black and the yolk could not be easily separated from the egg shell. Furthermore, decayed eggs stuck to each other.

In terms of distribution, decay was the least important egg mortality factor as shown in Table 11.

Apart from one example in the sandy habitat during the hot-dry season (Appendix 32), all the decay infested eggpods occurred during the rainy season (Appendices 23 to 31), particularly in July/August when the rains were intensive.

Of the 298 eggpods obtained in the clayey habitat during the rainy season, 28.4% (85) were decay infested; 13.9% (49) of the 350 eggpods were decay infested in the sandy habitat and 5.0% (13) of the 259 eggpods were decay infested in the sandy-clay loam habitat.

Decay caused partial or total destruction in infested eggpods as shown in Table 14. Partial eggpod destruction

Table 14: Percentage eggpod destruction by decay during rainy season.

	SAND		SAND-CLAY LOAM		CLAY	
	Partial	Total	Partial	Total	Partial	Total
1981	40.0(14)	60.0(21)	0.0(0)	100.0(5)	21.1(8)	78.9(30)
1982	10.0(1)	90.0(9)	0.0(0)	100.0(4)	7.1(4)	92.9(26)
1984	50.0(4)	50.0(4)	33.3(1)	66.7(2)	16.7(3)	83.3(15)
Total	100.0(19)	200.0(34)	33.3(1)	266.7(11)	45.0(130	255.1(71)
% Mean	33.3(6.3)	66.7(11.3)	11.1(0.3)	88.9(37)	15.0(3.7)	85.0(237)

Legend: Figures in brackets are actual numbers of eggpods, those outside brackets are percentages.

was sometimes as low as 1.1% (Appendix 29, No.8) but it could also be as high as 84.6% (Appendix 25, No.7).

The incidence of total eggpod destruction by decay was most prevalent in the clayey habitat where it occurred in 85% (71) of the 84 decay infested eggpods.

Total destruction of eggpods by decay also occurred in 66.0% (35) of the 53 decay infested eggpods in the sandy habitat, while it occurred in 88.9% (11) of the 12 decay infested eggpods in the sandy-clay loam habitat.

4.2 Laboratory Study

4.2.1 *Preliminary study on eggpods laid in relation to the age of the female:* Results of the preliminary study on eggpod laid in relation to the female age are summarised in Table 15.

Table 15: Quality of eggpods laid in relation to female age.

Eggpod batch	1st	2nd	3rd	4th	5th
Mean intervals between ovipositions (days)	-	5.9	6.6	6.8	10.0
Mean eggs/pod(Clutch size)	66.2	54.8	43.5	29.3	21.0
Mean days of incubation	10.2	10.5	10.3	10.3	10.0
Mean % egg hatch (Survival)	90.6	84.4	89.5	85.7	90.5
Mean hatchling Weight (Mg.)	9.6	9.8	10.0	9.5	10.0

Number of ovipositions per female and interval between successive eggpods: The female L. migratoria migratorioides in captivity laid a maximum of five eggpods, the average being 2.9. Interval between successive ovipositions ranged from an average of 5.9 days, between the first and second ovipositions, 6.6 days, between the second and third, 6.8 days, between third and fourth, and 10 between the fourth and fifth ovipositions.

Duration of incubation in sibling eggpods: The incubation period, signifying rate of egg development, averaged the same (about 10 days) irrespective of the sibling status of the eggpods, the range being nine to 11 days.

Number of eggs in sibling eggpods: The number of eggs per eggpod (the size of egg clutch) declined with the age of the female parent. Generally the largest egg clutch occurred in the first eggpod while the smallest was registered in the last. The size of egg clutch also varied a great deal from one female to another, ranging from 36 to 96 eggs.

Rate of egg survival and weight of hatchlings in sibling eggpods: The rate of egg survival (percentage egg hatch) ranged from 84.4% to 90.6% while the hatchling weight ranged from 9.6mg to 10.0mg. Both parameters were independent of the sibling status of the eggpod.

4.2.2 The effects of soil moisture and temperature on egg development, egg survival and hatchling weight.

The results of the above study are summarised in Table 16. As may be recalled, the two driest soils, containing 1ml and 0ml of water, were eventually deleted since they were rejected by the locust for oviposition, and eggpods transferred into them failed to hatch at $28^{o}\pm1^{o}C$.

In the soil containing 5ml of water, a mean of 37.8% survival rate was registered at $28^{o}\pm1^{o}C$. However, at $22^{o}C$, 28^{o}–$34^{o}C$ and $34^{o}\pm1^{o}C$ eggpods laid in this soil failed to hatch within the expected period of incubation. When such eggpods were moistened with 20ml of water after the expiry of the expected incubation period, some of them eventually hatched. The period of incubation was prolonged, the survival rate reduced and the hatchling weight lowered (Table 16).

Only the eggpods laid in the soils containing 50ml of water and 20ml of water were incubated at both $38^{o}\pm1^{o}C$ and $40^{o}\pm1^{o}C$. The results of incubation in the two wetter soils showed poor eggpod survival and inferior hatchling weight at $38^{o}\pm1^{o}C$. Survival did not occur at $40^{o}\pm1^{o}C$. Invariably, eggpods incubated at $38^{o}\pm1^{o}C$ and $40^{o}\pm1^{o}C$, and failed to hatch, contained well developed pharates which, apparently, were unable to emerge to the soil surface. Such pharates were abnormally small and weighed 20% to 50% less than those in the standard soil. Pharates which managed to emerge from such eggpods were small and were usually found dead on the surface of the soil within 24 hours of emergence.

Table 16: Effects of soil moisture and temperature on egg development, egg survival and hatchling weight.

Temperature (°C)		MEAN % EGG HATCH (Egg Survival)						MEAN INCUBATION PERIOD(DAYS)						MEAN HATCHLING WEIGHT(MG)					
		22	28	28-34	34	38	40	22	28	28-34	34	38	40	22	28	28-34	34	38	40
Soil/Water Mixtures	230gm/50ml	56.4	96.2	98.1	97.9	4.3	0.0	30.3	17.0	13.8	10.5	12.0	-	10.7	9.9	11.0	10.7	5.3	
	230gm/20ml	95.9	99.4	94.7	92.3	5.1	0.0	27.0	14.3	12.0	10.0	11.0	-	12.4	10.9	11.0	10.9	8.9	
	230gm/10ml	36.3	87.8	68.6	69.0			27.6	14.5	12.7	10.2			8.4	9.4	7.9	8.8		
	230gm/ 5ml	6.3 *	37.8	19.5 **	28.4 ***			50.0 *	14.5	28.2 **	21.3 ***			7.6 *	5.8	6.4 **	10.1 ***		
	230gm/1ml		0.0						-						-				
	230gm/0ml		0.0						-						-				

*One eggpod moistened, after incubating for 29 days without hatching, it eventually hatched 21 days after addition of water - i.e. 50 days incubation

** Eggpods were moistened (at 34°C) after they were incubated for at least 15 days without hatching.

*** Eggpods were moistened after they were incubated for 11 days without hatching.

It is also worthy of note that both the wettest and the standard soils remained moist by the 13th day of incubation when the eggpods were examined.

In view of the reasons given above, only eggpods laid in soils containing 50ml, 20ml and 10ml of water and incubated at 22°C, 28°C, 28°C–34°C and 34°C were examined statistically and the results of the analyses are outlined below.

The influence of soil moisture and temperature on rate of egg development: As in the field study, rate of egg development was inferred from the duration of incubation. Table 17 gives a summary of the results obtained, while Table 18 shows that significant differences existed between periods of incubation due to soil moisture, soil temperature and also due to the interactions between the two soil factors ($P \leq .05$).

Table 17: Effects of soil moisture and temperature on rate of egg development(Incubation period)

TREATMENT (Soil/Water Mixture)	INCUBATION TEMPERATURE (±1°C)			
	22°	28°	28°–34°	34°
230gm/50ml	30.3 Days	17.0Days	13.8Days	10.5Days
230gm/20ml	27.0 "	14.3 "	12.0 "	10.0 "
230gm/10ml	27.8 "	14.5 "	12.7 "	10.3 "

Table 18: Analysis of variance for incubation periods in relation to soil moisture and temperature

Source	SS	df	MS	F	P
Total	3,810,99	68	-	-	-
Soil/Water	9.64	2	4.82	8.03	.05
Temperature	3,707.96	3	1,235.99	2,059.98	.05
Soil/Water x Temperature	59.73	6	9.96	16.60	.05
Error	33.66	57	0.60	-	-

As may be seen in Appendix 43, incubation lasted significantly longer ($P \leq .05$) in eggpods in contact with 50ml of water than in those kept in the standard soil which contained 20ml of water. The implication is that rate of egg development was significantly slower in the wetter soil. This result recurred at all tested temperatures.

Similarly, the rate of development was slower ($P \leq .05$) in the soil containing 50ml of water than in the driest soil tested, which contained 10ml of water. Again the result recurred at almost all the temperatures tested.

That egg development is slower in wetter soils, as the above results indicate, was however, contrasted by the results of the comparison between the standard soil and the driest soil tested (Appendix 43). Between the two soils, egg development was significantly faster in the standard soil, which is wetter, at 22°± 1°C and also at 28°-34°± 1°C ($P \leq .05$); the differences were

not significant at the other two temperatures, namely $28^{\circ}\pm 1^{\circ}C$ and $34^{\circ}\pm 1^{\circ}C$.

The effects of incubation temperature on the rate of egg development are also detailed in Appendix 43. Irrespective of the wetness of the soil the eggs developed at a slower rate at lower temperatures.

Tests for the effects of interaction between soil moisture and incubation temperature, using the F test, gave the following indications. (i) The results were significantly higher ($P \leq .001$) in the wettest soil than in the standard soil ($F = 33.67$; $df = 3,57$). This implies that the interactions of the wettest soil and the tested temperatures delayed the rate of egg development more than did similar interactions between the standard soil and the temperatures (ii) A similar result was obtained between the wettest soil and the soil containing 10ml of water; this time the value of F was 15.43 and this was significant ($P \leq .001$, $df = 3,57$). These results complement the earlier one; i.e. rate of egg development is faster in drier soils than in wetter ones.

The effects of the interactions were, however, not significant between the standard soil and the soil containing 10ml of water ($F = -0.55$).

Influence of soil moisture and temperature on rate of egg survival:

Since the two procedures for determining survival gave similar results for the field data, only one of them was adopted for assessing survival rates from the laboratory data; that is rates of egg survival were derived from the percentage egg hatch per eggpod. The results are summarised in Table 19. It is evident in Table 20 that soil moisture, soil temperature and also interaction of the two factors influenced egg survival significantly ($P \leq .05$).

Table 19: Effects of soil moisture and temperature on rate of egg survival (Percentage egg hatch)

TREATMENT (Soil/Water Mix)	INCUBATION TEMPERATURE (± 1°C)			
	22°	28°	28°–34°	34°
230gm/50ml	56.4%	96.2%	98.1%	97.9%
230gm/20ml	95.9%	99.4%	94.7%	92.3%
230gm/10ml	36.3%	87.8%	68.6%	69.0%

Table 20: Analysis of variance for rate of egg survival in relation to soil moisture and soil temperature

Source	SS	df	MS	F	P
Total	46,096.41	70	-	-	-
Soil/Water	11,576.39	2	5,788.20	20.20	$\leq .05$
Temperature	9,453.83	3	3,151.28	11.00	$\leq .05$
Soil/Water x Temperature	8,157.28	6	1,359.55	4.74	$\leq .05$
Error	16,908.91	59	286.59	-	-

As shown in Appendix 44, except at $22^{o}\pm1^{o}C$, the egg survival rates were similar in both the wettest soil, containing 50ml of water, and the standard soil, containing 20ml of water. At $22^{o}\pm1^{o}C$, however, egg survival was significantly lower ($P\leqslant.05$) in the wettest soil.

Between the wettest and the driest soils, egg survival rates were similar at $28^{o}\pm1^{o}C$ only. At the other tested temperatures, survival was significantly better ($P\leqslant.05$) in the wettest soil. The above results were complemented by the results of the comparison between the standard soil and the driest soil tested: rate of egg survival was significantly higher ($P\leqslant.05$) in the wetter(standard)soil.

The influence of temperature on rate of survival is also shown in Appendix 44. Egg survival was lower ($P\leqslant.05$) at lowest temperature, $22^{o}\pm1^{o}C$, than at $28^{o}\pm1^{o}C$, in all soils except the standard one; in this soil the rates were similar at the two temperatures. The comparisons between incubation at $22^{o}\pm1^{o}C$ and $28^{o}-34^{o}\pm1^{o}C$ and also between $22^{o}\pm1^{o}C$ and $34^{o}\pm1^{o}C$ gave results similar to the above.

Survival rates at $28^{o}\pm1^{o}C$ and $28^{o}-34^{o}\pm1^{o}C$ were generally similar except in the driest tested soil, containing 10ml of water. In this soil egg survival was better ($P\leqslant.05$) at the lower temperature, $28^{o}\pm1^{o}C$. Similar results were obtained from the comparison between

$28^{o}\pm1^{o}C$ and $34^{o}\pm1^{o}C$; that is survival rates were similar at the two temperatures in all soils except the driest soil where survival was higher at the lower temperature, $28^{o}\pm1^{o}C$.

The results showed no significant differences between survival rates at 28^{o}-$34^{o}\pm1^{o}C$ and $34^{o}\pm1^{o}C$ (Appendix 44).

With 3 and 59 degrees of freedom, tests for effects of interactions (F test) between soil moisture and the tested temperatures gave the following results. The differences were significant ($P\leqslant.001$) between the wettest soil and the driest soils ($F=7.24$), containing 50ml and 20ml of water respectively. Similarly, the differences were significant ($P\leqslant.001$) between the standard and the driest soils ($F=6.93$). However, the differences were not significant between the wettest and the driest soils, F being 0.89.

Inferred from the results of the F test are: (i) when lower temperatures of $22^{o}C$ or $28^{o}C$ interacted with the wettest soil, egg survival rates were inferior to the rates obtained when such temperatures interacted with the standard soil; (ii) the reverse was true when higher temperature, 28^{o}-$34^{o}\pm1^{o}C$ or $34^{o}\pm1^{o}C$, interacted with the two soil moisture conditions; (iii) interaction between the standard soil and the incubation temperatures produced higher egg survival rates than were produced by the interaction between the driest soil and similar temperatures.

Influence of soil moisture and temperature on hatchling weight:

A summary of the results is given in Table 21, and as indicated in Table 22, hatchling weights were influenced by soil moisture treatments only.

Table 21: Effects of soil moisture and temperature on weight (mg) of hatchlings.

TREATMENT (Soil/Water Mixture)	INCUBATION TEMPERATURES (±1°C)			
	22°	28°	28°–34°	34°
230gm/50ml	10.7	9.9	11.0	10.7
230gm/20ml	12.4	10.9	11.0	10.9
230gm/10ml	8.4	9.4	7.9	8.8

Table 22: Analysis of variance for hatchling weight in relation to soil moisture and temperature

Source	SS	df	MS	F	P
Total	214.41	69	—	—	—
Soil/Water	91.44	2	45.72	25.12	.05
Temperature	13.96	3	4.65	2.55	ns
Soil/Water x Temperature	3.49	6	0.58	0.32	ns
Error	105.52	58	1.82	-	-

Further analysis of the data (Appendix 45) showed that hatchlings weighed significantly less ($P \leq .05$) in the wettest soil than in the standard soil at both 22°±1°C and 28°±1°C; the differences were not significant when the temperature was raised to 28°–34°±1°C and 34°±1°C.

Hatchling weights in the wettest soil were also superior to those in the driest soil at all temperatures except $28^{o}\pm1^{o}C$; at this temperature the weights were similar in the two soil moisture treatments.

Similarly, hatchlings emerging from the standard soil were significantly heavier ($P\leqslant.05$) than those from the driest soil.

Correlation between the weights of hatchlings and their survival potential, to the second hopper instar, gave the following results: the correlation co-efficient (r) was 0.84 and this was significant ($P\leqslant.001$, $t = 6.32$, $d f = 17$). The analysis was based on data given in Appendix 46.

The results imply that under similar rearing conditions heavier hatchlings have significantly higher survival potential than less heavy hatchlings.

The duration of the first hopper instar ranged from five to seven days as shown in Appendix 46.

Comparison of the humidities of the artificially prepared soil moisture treatments and the soil humidities recorded in the field: Humidities of the soil/water mixtures, from the time they were freshly prepared to the expected end of incubation at $34^{o}\pm1^{o}C$, are shown in Figure 12.

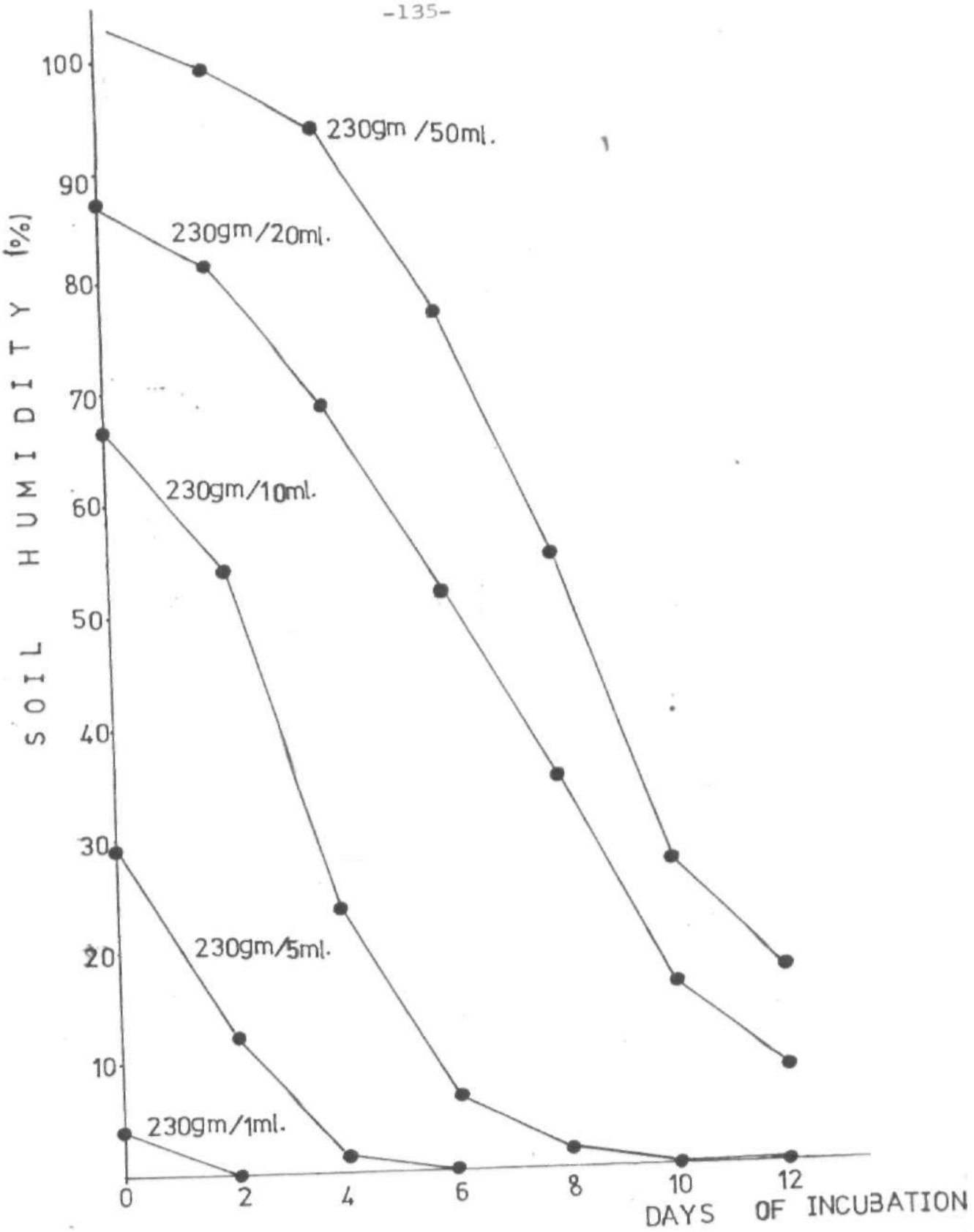


Fig. 12: Changes In Soil (sand) Humidity During Incubation At $34° \pm 1°C$.

The wettest soil, containing 50ml of water, was waterlogged when freshly prepared since the soil tester recorded over 100% humidity. The excess water dripped off gradually as the soil settled down in the oviposition tube. The dripping ceased by the second day although the top soil still appeared moist. By the sixth day of incubation the top 2cm to 3cm was dry and had caked. By day 10, when hatching was expected, the soil was about 29% humid. Two days after hatching might have occurred (day 12), the soil was about 18% humid.

The standard soil (containing 20ml of water) was about 90% humid when freshly prepared. The surface was dry by day two, and the top soil, though firm, was not caked. The standard soil was about 18% humid by day 10 and about 10% humid by day 12.

The soil containing 10ml of water, when freshly prepared, was about 68% humid. The rate of water loss was very rapid up to day six after which the rate declined until by day 10 (when hatching was expected), the soil was practically dry. The top soil was loose and never caked.

Similarly the soils containing either 5ml or 1ml of water remained loose powder, and both were completely dry by day six and two respectively.

4.2.3 The effects of flood on rate of egg development, egg survival and hatchling weight.

The results are summarised in Table 23.

Table 23: Effects of flood on egg development, survival and hatchling weight.

TREATMENTS		No. of Eggpods	Mean % Egg Hatch	Mean Period of Incubation	Mean Hatchling Weight(Mg)
Pre-Flooding Period(Days)	Days of Flooding				
0	1	10	0.6	14.0	9.2
0	2	8	1.4	14.0	7.7
0	3	6	0.0	-	-
3	1	7	75.9	14.3	11.3
3	2	8	60.9	15.4	11.7
3	3	6	8.5	16.5	11.4
6	1	5	96.6	13.2	12.4
6	2	6	69.2	16.8	11.8
6	3	8	15.4	19.0	11.3
6	5	5	-	21.0	7.2
9	1	10	12.9	14.3	11.0
9	2	5	0.0	-	-
9	3	5	0.0	-	-
230gm/20ml (Control)	-	8	92.3	10.0	10.9

Effect of flood on rate of egg development: A summary of the results is given in Table 24. Further analysis of the data, as may be seen in Table 25, show that both the preflooding period and the duration of flood itself influenced egg development rate significantly ($P \leq .05$); interaction

between preflooding and flood durations had no significant effect on rate of the egg development.

Table 24: The effect of flood on rate of egg development (Incubation period: Days)

Pre-Flooding Period(Days)	DURATION OF FLOOD (DAYS)		
	1	2	3
0	14.0	14.0	-
3	14.3	15.4	16.5
6	13.2	16.8	19.0
9	14.3	-	-

Table 25: Analysis of variance for incubation period in relation to flood.

Source	SS	df	MS	F	P
Total	136.4	34	-	-	-
Pre-Flooding Period	20.9	2	10.45	12.74	.05
Duration of Flood	91.6	2	45.78	55.83	.05
Pre-Flood. x Duration of Flood	2.5	4	0.63	0.77	ns
Error	21.4	26	0.82	-	-

Tests for differences between the various means (shown in Table 24) gave the results provided in Appendix 47; these results are presented below.

Effect of preflooding period: The differences were not significant between a zero-day preflooding period and a three-day preflooding period if the flood lasted one day

only. But if the flood lasted two days, incubation was significantly longer in eggpods that were given a three-day preflooding treatment; that is rate of egg development was significantly slower in eggpods treated to a three-day preflooding period. Similar results were obtained in the comparison made between a zero-day pre-flooding period and a six-day pre-flooding period.

Between a three-day preflooding period and a six-day preflooding period, egg development was faster, ($P \leq .05$) in the latter if flood lasted one day only. However, if the flood lasted two or three days, then the rate of development was faster in the shorter preflooding condition.

In general, therefore, younger eggs with shorter preflooding period developed faster than older eggs with longer preflooding period.

Effect of duration of flood: Flood generally prolonged incubation as seen in Table 23 and longer duration of flood prolonged incubation correspondingly longer (Table 24).

If eggpods were flooded immediately after oviposition (i.e. eggpods with zero-day preflooding period) the rate of egg development was the same whether the flood lasted one day or two days (Appendix 47). However, if the preflooding period was three or six days, the rate of

development was faster in the eggpods flooded for only one day. Eggpods experiencing one day flood also developed faster ($P \leq .05$) than eggpods experiencing three days flood irrespective of the length of the pre-flooding period.

Similarly, eggpods flooded for two days developed significantly faster ($P \leq .05$) than those flooded for three days whether the preflooding period was three or six days.

Effect of flood on rate of egg survival: The results are summarised in Table 26. Both preflooding period and duration of flood affected the level of egg survival significantly ($P \leq .05$) as shown in Table 27. In addition, interactions between preflooding period and duration of flood also gave significantly different results.

Table 26: The effect of flood on rate of egg survival (Percentage egg hatch)

Pre-Flooding Period (Days)	DURATION OF FLOOD (DAYS)		
	1	2	3
0	0.6	1.4	0.0
3	75.9	60.9	8.5
6	96.6	69.2	15.4
9	12.9	0.0	0.0

Table 27: Analysis of variance for egg survival rate in relation to flood.

Source	SS	df	MS	F	P
Total	107,132.33	81	-	-	-
Pre-Flooding Period	48,183.18	3	16,061.06	54.97	$\leqslant .05$
Duration of Flood	13,550.43	2	6,775.22	23.19	$\leqslant .05$
Pre-Flood. x Duration of Flood	24,947.22	6	4,157.87	14.23	$\leqslant .05$
Error	20,451.50	70	292.16	-	-

Tests for differences between the means of egg survival gave the results summarised in Appendix 48 and interpreted as follows.

Effect of preflooding period: The rate of egg survival was significantly lower ($P \leqslant .05$) in younger eggpods with shorter preflooding period. For instance, in eggpods with a zero-day preflooding period, flood lasting one day or more produced significantly lower rate of egg survival than in older eggpods with a three-day preflooding period flooded for comparable durations.

Similarly, the rate of egg survival in eggpods with a three-day preflooding period was generally lower than the rate in older eggpods with a six-day preflooding period when treated to similar durations of flood.

It must, however, be noted that despite the generally higher rate of egg survival in older eggpods (with longer preflooding periods) the oldest eggpods in the experiment, with a nine-day preflooding period, registered significantly lower rate of egg survival ($P \leq .05$) than did younger eggpods with either a three-day or a six-day preflooding period. In fact, hatchings did not occur in eggpods with a nine-day preflooding period if the flood lasted two or more days, eventhough eggpods with a six-day preflooding period did hatch after flood lasting five days (Table 23).

Effect of duration of flood: The results(Appendix 48) also indicate that egg survival rate was higher ($P \leq .05$) in eggpods treated to shorter periods of flood irrespective of the age of the eggpod prior to the commencement of the flood (i.e. the preflooding period). For instance, in both the eggpods with a three-day preflooding period and a six-day preflooding period the egg survival rate was higher if the flood lasted one day than if it lasted two days. Similarly, flood lasting three days caused greater egg mortality in eggpods that were three or six days old than did flood lasting two days.

Clearly, all the results of the F test complement the results obtained in earlier analyses. In other words, egg survival is higher in older eggpods, with longer preflooding period, and longer duration of flood causes higher rate of egg mortality.

Effect of flood on hatchling weight (mg): The results are given in Table 28. Indications are that differences in hatchling weight were attributable to preflooding periods only as shown in Table 29.

Table 28: The effect of flood on weight of hatchlings(mg)

	DURATION OF FLOOD (DAYS)		
PRE-FLOODING PERIOD(DAYS)	1	2	3
0	9.2	7.7	-
3	13.3	11.7	11.4
6	12.4	11.8	11.3

Table 29: Analysis of variance for hatchling weight in relation to flood.

Source	SS	df	MS	F	P
Total	108.34	34	—	—	—
Pre-Flooding Period	26.34	2	13.17	4.45	≤0.05
Duration of Flood	0.13	2	0.07	0.03	ns
Pre-Flood Duration of Flood	4.93	4	1.23	0.42	ns
Error	76.94	26	2.96	-	-

Effects of preflooding periods: Eggpods subjected to a zero-day preflooding condition produced significantly less heavy hatchlings than eggpods allowed a three-day preflooding condition if both groups of eggpods were flooded for either one day or two (Appendix 49). Similarly, eggpods that were flooded, either for one or two days, immediately after oviposition, produced lighter hatchlings than eggpods flooded for the same durations after a preflooding period of six days.

The differences in hatchling weights from preflooding periods of three and six days were not significant irrespective of the duration of flood.

It is inferred from the above that hatchlings emerging from eggpods flooded as soon as they were laid weighed significantly less than hatchlings which emerged from older eggpods, experiencing three or six days preflooding treatment.

Comparisons between the survival indicators in the flood treatments and those in the control: A comparison of the results in the flood and the control treatments (Table 23) is presented below.

Rate of egg survival: The rate in the control (92.3%) was not significantly different from that in the eggpods flooded for one day after a six-day preflooding

period 96.6% (t= 0.62, d f = 11). Similarly, the difference was not significant between the control and one day flooding after a three-day preflooding period, 75.9% (t= 1.13, d f 12). Flooding for two days after a six-day preflooding period produced significantly lower rate of egg survival 69.2%, than the control 92.3% (t = 3.62, df = 12, P≤ .05). The inference is that flood regimes lasting two days or more are detrimental to the survival potential of the eggs of the locust even if the flood commenced six days after oviposition.

Hatchling weight: The weights in the flooded eggpods (9.2mg to 12.4mg) were not significantly different from those in the control, 10.9mg. Statistical comparisons were not made for the control and the flood treatments which produced 7.2mg or 7.7mg due to inadequate data.

4.2.4 The effects of drought on egg development, egg survival and hatchling weight.

A summary of the data on the above experiment is given in Table 30. The results of correlation analysis (Table 31), following the example of Bruning and Kintz (1968), indicate strong relationships between the pairs

that between the drought period and hatchling weight was -0.89; all the relationships were highly significant ($P \leq .001$ or $P \leq .01$) as shown in Table 31.

The above results are interpreted as follows:

(i) Incubation prolonged as the drought lasted longer (Table 30), hence the positive correlation co-efficient. In terms of rate of egg development the above statement implies that longer periods of drought retarded the rate of egg development.

(ii) The rate of egg survival decreased as the drought prolonged and this explains the negative correlation co-efficient. Eggpods kept under drought for 21 days produced no hatchling.

(iii) The hatchling weight declined with the prolongation of the drought period, hence the negative correlation co-efficient.

In addition to examining the effects of drought on the rate of egg development, the rate of egg survival and the weight of the resultant hatchlings, the relationships between the three survival parameters were also examined. As shown in Table 31 the relationships were also very strong ($P \leq .01$ or $P \leq .001$).

($P \leq .01$) or $P \leq .001$). The range of hatchling weight, 10.7mg to 10.3mg, produced under drought periods of three to 11 days did not differ significantly from the weight in the control, 10.9mg. Thirteen to 19 days drought, however, produced hatchlings whose weights, 6.8mg to 5.7mg, were significantly less ($P \leq .01$ or $\leq .001$) than those from the control, 10.9mg.

CHAPTER FIVE

D I S C U S S I O N

It is evident in this work that in the Lake Chad Basin outbreak area, egg development, survival and hatchling weight in L. migratoria migratorioides are influenced by environmental factors. The principal ones are soil type, soil moisture – including flood and drought conditions– soil temperature, predation and parasitism. Other factors include decay and desiccation, which will be treated in connection with flood and drought respectively. These factors, particularly the principal ones, are influenced by seasonal regimes in the outbreak area. The discussion examines the impact of these factors on the rate of egg development, survival and hatchling weight in the light of field and laboratory observations.

It would have been ideal to obtain comparative information on the three soil types in the laboratory study. However, certain practical difficulties hampered trials with the sandy-clay loam and the clayey soils: the particles of the two soil types, when in contact with water, quickly absorbed it and prevented seepage. When more water was added the soils formed a thick paste which could not be conveniently used to fill tho

oviposition tubes. In addition, it was impossible to remove the two soil types from the tubes when the need arose. Because of the difficulties outlined above only the sandy soil was found convenient for the laboratory study. Nevertheless most of the inferences made from the laboratory findings are applicable to the other two soil types; this may be seen as the discussion progresses.

Rate of egg development may be inferred from changes in weight of the eggpod during incubation as has been demonstrated by Wardhaugh (1970). This procedure involves regular removal of the eggpod for weighing during the period of incubation and it is more suited for laboratory work involving a few eggpods at a time.

A more generally applied procedure is to deduce the rate of egg development from the duration of incubation (Rao, 1942; Richards, 1953; Popov, 1958, 1959; Decamps, 1961; Pickford, 1966a, 1966b, 1970; Farrow, 1975). This procedure is suitable for both field and laboratory observations as it allows data collection on several eggpods at the same time. Furthermore, the second procedure avoids handling of the eggpods. For these reasons the second method was adopted in this work.

Rate of egg development was fastest in sandy habitat and slowest in clayey habitat (Table 5) during the rainy season when breeding activity was at its peak. The fast rate of egg development in the sandy habitat is attributed to the tendency for that habitat to be less sodden (Table 4a). In other words eggs develop faster in drier soils than in wetter ones.

The fluctuations in rate of egg development, from fast at the beginning of the rains in July, to slow at the peak in August, and again to fast at the end of the rains in September (Fig.11), provide evidence in support of the retarding effect of sodden soil on egg development. In addition, the finding that rate of egg development was most uniform in sandy habitat during the rainy season can also be attributed to the effects of soil moisture. In the clayey and the sandy-clay loam habitats some eggpods were submerged while others laid on the same day in the same habitat were in relatively drier portions of the habitat (Plate 4b). Consequently, these eggpods experienced different soil moisture levels during incubation and therefore developed at different rates as indicated by the variances in Table 5.

That eggs develop faster in relatively drier soils receives further support from the laboratory observations as shown in Appendix 43.

Similar findings on the influence of soil moisture on rate of egg development have been made in Mali by Popov (1959); he observed that the shortest incubation period of 22 to 24 days in L. migratoria migratorioides occurs in the driest soil. Conversely, eggpods in the wettest soil have the longest incubation period, 28 to 30 days. Laboratory observations by Ewer (1977) on the locust further support the present finding.

Observations on the role of flood on egg development also highlight the negative impact of sodden soil as flood generally prolonged incubation (Tabe 23); this was more so in older eggpods (i.e. eggpods with longer preflooding periods).

Delayed hatching under flood condition is attributed to suspension of development during the flood since locust and grasshopper eggs are known to survive adverse conditions, including flood, by this mechanism(Achillides, 1970; Hunter-Jones, 1970a).

The longer delay in emergence observed in the older eggpods suggests that resumption of normal development, after a period of flood, is slower in

older eggpods. In other words, in older eggpods, containing eggs with more advanced embryonic development, the resumption of development is longer. This probably explains the high and low rates of survival in eggpods flooded for six and nine days respectively (Table 26).

Farrow (1975) and Ewer (1979) have observed that oxygen is an important limiting factor in sodden soils and flooded conditions because drier environments enhance oxygen supply and thereby promote faster rate of egg development. On the other hand, flood and sodden soils prevent, or at least retard, rate of oxygen supply to eggs, thereby reducing rate of development (Farrow, 1975).

Ewer (1979) has reported further that during flood the froth plug of the locust eggpod acts as a pathway for oxygen supply to the eggs. In the present study, since egg mortality was high under flood conditions, there is clear indication that this function of the froth plug cannot be reliable in L. migratoria migratorioides under flood lasting 24 hours or more. This is particularly true if the flood commences immediately after oviposition as the high

mortality in the eggpods with zero-day preflooding period indicates (Table 26). Similarly, the froth plug does not appear to effectively act as a pathway for oxygen supply to pharates about to attain the hatchling stage.

There are indications also to show that the rate of egg development is retarded by excessively dry soil conditions. For instance, the laboratory study has shown that incubation period ranges from 12.4 days to 32.5 days under drought period ranging from three to 19 days respectively (Table 30). The longest mean incubation period, 32.5 days, for drought lasting 19 days, is just more than three times the mean incubation period in the control treatment, which is 10 days (Table 30).

Retarded egg development due to drought appears to be a common feature in acridids. Apart from reports of it in L. migratoria migratorioides in Mali (Popov, 1959; Decamps, 1961, 1962; Farrow, 1975), it has also been observed in M. bivittatus in Canada (Salt, 1949, 1952), in S. gregaria (Hunter-Jones, 1964) and in L. pardalina in South Africa (Botha, 1967).

In some orders of insects, retarded development resulting from drought has been reported in larvae of

Tipula oleracea Linnaeus and T. paludosa Linnaeus (Diptera) in Northumberland (Laughlin, 1958; Milne et al, 1965; Meats, 1968).

The reports cited above agree that the prolonged development is due to inadequate supply of moisture.

As regards temperature, there is clear evidence of its dominant role in egg development although few data were obtained for the early rains and the harmattan seasons. The shortest incubation periods, 10 and 9 days (Appendices 17 and 18), were registered during the early rains season; these coincided with the highest range of mean air temperature, 29.2°C to 36.2°C (Fig.10). Conversely, the longest mean incubation period, derived from Appendices 23 to 25, was 24 days and it coincided with the lowest range of mean air temperature, 19.2°C to 25.6°C, of the harmattan season (Fig. 10).

Rates of development recorded in the three habitats (i.e. sand, sandy-clay loam and clay) for the rainy season averaged 13.6 days, 16.0 days and 18.1 days respectively (Table 5). Clearly, the incubation periods for the rainy season are intermediate to those observed during the early rains and the harmattan seasons and they correspond to intermediate temperature of the rainy season which ranged from 24.6°C to 27.5°C. (Fig. 10).

The air temperatures correlate positively with soil, temperatures as shown in Table 4 and also in Appendices 3, 4 and 5. Furthermore, positive correlation between air and soil temperatures has been reliably established and for this reason air temperature, rather than soil temperature, is often used as the basis for forecasting locust egg development in the field (Popov, 1958, 1959; Decamps, 1962; Farrow, 1975).

Hatchlings did not emerge during the hot-dry season, therefore, it was not possible to ascertain incubation period for that season. However, indications from the laboratory study (Table 16) are that the range of average air temperature during the season, 32.5°C to 35.8°C, is within the range tolerated by eggs of the locust. For instance, incubation ranged from 30.3 days at 22°±1°C to 10.0 days at 34°±1°C, which is the optimum for the present study. The temperature range for the hot-dry season also encompasses the temperature reported by Darnhofer (1976) as the optimum (33°C) for egg development in the locust in the same outbreak area. It is possible, therefore, that due to high temperatures, the fastest rate of egg development can occur during the hot-dry season provided other factors, including moisture conditions are favourable.

During the laboratory study, the few hatchlings that survived at $38^{o}\pm1^{o}C$ emerged after slightly longer period of incubation (11 to 12 days) as shown in Table 16. Delayed emergence and complete failure to emerge at temperatures superior to the optimum have also been observed in L. migratoria migratorioides and N. septera-fasciata (Hamilton, 1936, 1950; Waloff, 1963; Pickford, 1970; Hunter-Jones, 1970a). Similarly, delayed emergence at temperatures higher than the optimum has been reported in S. gregaria by Hunter-Jones (1970b); he attributed the phenomenon to incomplete embryonic development dictated by excessive temperature.

In the present study, however, all the eggs which failed to hatch at $38^{o}\pm1^{o}C$ contained apparently well-developed pharates. The failure to emerge, therefore, is not likely to be due to incomplete embryonic development but to other factors such as excessive heat. Thus temperature differences are accountable for variations in seasonal rates of egg development.

The above observation is in agreement with those obtained in Mali on L. migratoria migratorioides (Popov, 1959; Decamps, 1961, 1962; Farrow, 1975). Hamilton (1936) has also made a similar observation on the locust under laboratory conditions and has reported

that incubation period ranges from 23.6 days at 26.6°C to 10.1 days at 43.3°C. Other reports on S. gregaria and N. septemfasciata confirm that incubation period in locusts decreases as the environmental temperature rises (Hamilton, 1936 , 1950; Rao, 1942, 1960; Wardhaugh et al, 1969; Hunter-Jones, 1970b).

What remains to be explained is the factor responsible for the inter-habitat differences in rate of egg development during the rainy season. As shown in Table 4a, differences in the soil temperatures are not significant during the rainy season. The minor discrepancies in the soil temperatures, therefore, cannot account for the variations in rates of egg development recorded in the three habitats during the rainy season. In the writer's opinion soil moisture accounts for such inter-habitat differences in the rate of egg development during the season.

As may be recalled, the criterion for the determination of survival is the emergence of the pharate to the soil surface at the end of incubation (i.e. the appearance of the hatchling). Two procedures were adopted for assessing the survival rate: firstly, survival rate was based on the number of eggpods producing hatchlings, irrespective of the number, in a given

eggpod population; secondly, survival rate was assessed on the basis of the number of hatchlings from individual eggpods of the same populations mentioned above.

Both procedures have been widely applied by acridologists (Davies, 1952; Fortescue-Foulkes, 1953; Popov, 1958, 1959; Hunter-Jones, 1961; Waloff, 1963; Uvarov, 1966; Farrow, 1975); the general consensus is that the two procedures are complementary rather than alternatives.

The rainy season was the most favourable breeding period for L. migratoria migratorioides in the Lake Chad Basin outbreak area as indicated by the number of eggpods obtained during the season. (Appendices 23 to 31). This observation is in agreement with those made in previous reports for the outbreak area (Davey and Johnston, 1956; Popov, 1972, 1980; Iyiola and Diallo, 1974a, 1974b; Darnhofer, 1976; Anonymous, 1984). Similar relationship between oviposition by the locust and rainy season has also been established in the Mali outbreak area (Popov, 1959; Decamps, 1961, 1962; Farrow, 1975).

During the (rainy) season, egg survival rates differed among habitats; the rate was highest in the sandy habitat and lowest in the sandy-clay loam habitat

(Tables 7 to 10).

These observations agree with those of Popov(1959, 1972, 1980), Farrow (1975) and Anonymous (1984), who attribute the variations in survival rates partly to differences in depth of oviposition in the soil types. They explain further that the depth of oviposition is influenced by physical properties of the soil. For instance, Popov (1959) has observed that in Mali eggpods laid in very compact soils are often curved into a bow shape; they slant and are almost horizontal to the soil surface. Such eggpods are greatly affected by fluctuations in climatic factors; in addition they are relatively closer to surface of the soil and are therefore, most accessible to predators and parasites (Popov, 1959). Observations in the present study agree with Popov's since the sandy-clay loam habitat was the most compact (Table 2) and the lowest egg survival rate was registered in that habitat as shown in Tables 7 and 8.

Conversely, the sandy habitat and the clayey habitat were less compact and therefore they permited deeper oviposition, which protects the eggpods from predators and parasites and from fluctuations in climatic factors. Consequently, egg survival rates were higher

in the sandy and the clayey habitats than in the sandy-clay habitat.

Between the sandy habitat and the clayey habitat, rate of survival was higher in the former. This observation is ascribed to differences in soil moisture retentive capacities of the two soil types and predation.

It has been suggested that during oviposition, soil particles adhere to the surface of the eggpod to form a protective coating called the earth plug (Farrow, 1975). During incubation, the earth plug hardens and as a result its protective function to the enclosed eggs against field mortality factors, including predators, improves. The protection offered by the earth plug is believed to be best in clayey and sandy-clay loam habitats because of the capacity for particles of these soil types to stick together (Farrow, 1975; Fwer, 1977).

The protection suggested above does not receive support from observations in the present study since egg mortality was higher in both the sandy-clay loam habitat and in the clayey habitat than in the sandy habitat (Tables 7 and 8).

Another property of the soil is its moisture retentive capacity, which has also been found to influence egg survival in locusts (Norris, 1959; Anonymous, 1984).

Farrow (1975) has also reported that in Mali soils that retain adequate water during the dry seasons enhance survival of eggs of L. migratoria migratorioides.

Observations in the present study agree with the above observations. During the harmattan egg survival occurred in the clayey habitat only, albeit low level of survival, as shown in Appendices 13 to 15. Eggs survive in the clayey soil during the harmattan because despite prolonged incubation, mean of 24.0 days, the soil remains moist for the eggs to imbibe the water required for the completion of development.

Comparable results were obtained under laboratory conditions when, at 22°±1°C, eggpods laid in the soils containing 50ml, 20ml and 10ml of water hatched after 30.3 days, 27.0 days and 27.8 days respectively (Table 16). Despite the prolonged incubation the three soils remained moist for imbibition to occur and the result was successful emergence of hatchlings. On the other hand, eggpods laid in the soil containing 5ml of water failed to produce hatchlings at the same temperature, 22°±1°C, until sufficient water was replenished. For instance, one eggpod moistened after 29 days, at 22°±1°C, hatched 21 days later; incubation therefore lasted 50 days. This observation is similar to that made in the Mali outbreak area by Farrow (1975).

During the early rains season, the occasional light showers may wet the soil sufficiently to promote oviposition as was observed for the sandy and the clayey habitats (Appendices 14 and 15, 17 and 18). However, the soils do not remain moist for long and the eggs have to develop rapidly in order to survive (Farrow, 1975). In the present work the rapid egg development in the sandy habitat is indicated by the shortest incubation periods, 10 days and 9 days (Appendices 17 and 18) recorded during the (early rains) season.

That the rapid development was possible in the sandy habitat during the early rains season presupposes availability of moisture since it has already been shown that lack of moisture retards egg development rate.

In the clayey soil, however, total egg mortality was registered during the early rains season. This is attributed to non-availability of moisture to the eggs leading to retarded development which consequently resulted in mortality. Similar observations were made by Farrow (1975) in the Mali outbreak area.

That total egg mortality occurred in the clayey habitat during the early rains season suggests further that evidence of oviposition in that habitat during the season does not always imply successful breeding.

The discussion, so far, has focused on the role of soil moisture during the drier seasons, when water is generally a limiting factor to egg survival in the field. Indications from the field work are that soil moisture can cause high egg mortality during the rainy season as well. For instance, despite the apparently similar deep ovipositions in both the sandy and the clayey habitats, survival rate was higher in the former (Table 7 to 10). The higher moisture content of the clayey habitat (Table 4) is suggested to have played a dominant role in the higher mortality in that habitat. In the same way the high rate of mortality registered in the sandy-clay loam habitat may also be partly due to moisture content of that soil. The suggestion is supported by the observation that sodden soil and flood are generally detrimental to egg survival.

The role of flood in egg survival is important and intriguing. The ability of eggs to temporarily suspend development under adverse conditions, such as flood, is one of the mechanisms for egg survival (Hunter-Jones, 1970a). Suspension of development implies a non-fatal reduction in dependence on oxygen supply from the environment.

Contrary to the above interpretation, eggs of the locust in the Lake Chad Basin area have been shown to be unable to unduly suspend dependence on oxygen supply as high mortalities were recorded after the apparent critical period (Table 26).

Floods are also known to create insanitary environmental conditions around the eggs (Ewer, 1979). Eggs flooded for long periods are therefore exposed to insanitary conditions which also lead to high mortality. Mortality rate is lower in older eggpods since eggs in such eggpods have better developed protective shell which protects them from the insanitary environment (Jahn, 1935; Hartley, 1961).

In the present study, the high mortality rate in eggpods with nine-day preflooding period (Table 26) apparently contradicts the reports of Jahn (1935), Hartley (1961) and Ewer (1979). The apparent contradiction may be explained as follows. Eggpods incubated at $34^{o}\pm1^{o}C$, at which the flood experiment was also performed, hatched after an average incubation period of 10 days. Therefore, eggpods flooded nine days after oviposition were actually flooded when the hatchling were about to emerge. Thus the egg shells of the nine-day old eggpods no longer contained embryos but fully developed pharates about to emerge.

It appears therefore that in L. migratoria migratorioides the pharate is very susceptible to flood; the pharate appears more susceptible than the embryo, particularly embryo aged six days.

As regards the role of the froth plug in egg survival during flood, Ewer (1979) has reported that it acts as a pathway for oxygen supply to the eggs when submerged. Evidence in the present study does not support the observation by Ewer (1979) since high egg mortality occurred in the flooded eggpods.

The most practical significance of flood, perhaps, is its possible application as a control strategy. Hunter-Jones(1970a) has reported that flooding egg fields with water, such as practised on irrigated farm-lands, has been used for the control of locusts and grasshoppers in China. In the Lake Chad Basin, peasant farmers in the Chad Republic have controlled populations of the cricket, Gryllotalpa spp. by flooding their farms during the 1986 farming season (Ohabuike, per. comm). Flood has also been used to control populations of the lepidopterous bollworm, Heliothis zea Linnaeus in Oklahoma as reported by Young and Price (1968). Similar reports have also been published on H. zea by Barber and Dicke (1939), Blanchard (1942) and Hardwick (1965).

In summary flood in the outbreak area must be an important egg mortality factor in L. migratoria migratorioides and could be exploited as a useful tool in the control of the pest: not only have observed mortality rates been high but there is the additional advantage of the flood plains being submerged at least once a year.

Laboratory observations on the effects of drought point to the need for sufficient soil moisture in egg survival. As may be recalled, the experimental drought comprised oviposition in soil containing 5ml of water and incubation temperature of $34^{\circ}\pm1^{\circ}C$; the soil was approximately 30% humid when freshly prepared and was apparently, totally dry six days thereafter (Fig.12). It implies, therefore, that the drought-treated eggpods had access to soil moisture until six days after oviposition. However, it is not certain if the eggs were able to imbibe water under the drought conditions since water uptake by eggs of the subspecies depends mainly on the water availability to the eggs but not solely on the soil humidity as usually measured in the field (Farrow, 1975). In other words, soil humidity may be reasonably high in the field but the water content may not be necessarily accessible to the eggs.

Furthermore, it is doubtful whether adequate water uptake would have occurred even if water was accessible to the eggs during the first six days following oviposition, when the soil humidity ranged between approximately 30% and 2% (Fig. 12). The doubt expressed above is supported by the findings that, in L. migratoria migratorioides and S. gregaria, water uptake does not occur during the first two days following oviposition; not even in sufficiently moist soil. In both locusts, appreciable water uptake only occurs during the fifth day after oviposition (Shulov and Pener, 1959, 1963; Hunter-Jones, 1964; Bernays, 1970). In addition, Wardhaugh (1970) has observed that although given access to sufficient water, appreciable imbibition does not occur in eggs of S. gregaria until they are five days old. It is possible that the relationship between the eggs of L. migratoria migratorioides and soil moisture is similar to that between eggs of S. gregaria and soil moisture as described above since the embryonic development of the two locusts has been found to be similar (Roonwall, 1936).

It is possible, therefore, that none of the drought-treated eggs absorbed appreciable quantity of moisture until water was replenished. Nevertheless,

the writer is of the opinion that the moisture in the soil (prior to water replenishment) prevented or at least retarded, water loss from the eggs during the first five days following oviposition; from six to eleven days, when the soil was virtually dry (Fig.12), moisture content of the earth plug was the major barrier to excessive evaporation from the eggs. These explain the high survival rates under drought lasting three to eleven days, 98.2% to 78.4% respectively (Table 30), which are statistically the same as the rate in the control treatment (Table 23).

The high survival rates cited above suggest a certain degree of drought tolerance in the eggs of L. migratoria migratorioides. This contrasts the reports that eggs of the locust are highly susceptible to drought (Hamilton,1936; Roonwall, 1936; Popov, 1959; Shulov and Pener, 1959; Shulov, 1970; Farrow, 1975; Anonymous, 1984).

The apparent contradiction between the present finding and those cited above can be attributed to the humidity of the oviposition medium used in the present study (30% when freshly prepared). It is possible that high egg survival rates occurred in drought lasting three to eleven days because such eggs were in contact with humid environment which retarded the rate of evaporation from the eggs.

It is apparent, therefore, that as long as eggs of the sub-species are kept in reasonably moist soil, they will remain viable, even if they are unable to imbibe water, and hatch eventually when adequate moisture is provided. The suggestion receives support from the laboratory observations by Shulov (1970) who kept eggs of the locust in "barely wet" soil for 35 weeks and recorded hatching when they were eventually transferred into wetter soil.

Drought lasting 13 to 21 days was detrimental to egg survival as it produced a survival rate ranging from 21.1% to 0% respectively (Table 30) compared with 92.3% survival in the standard soil as shown in Table 23.

It is inferred from the above observations that as drought intensifies, the earth plug, covering the eggs (Fig.8), dries up progressively and begins absorbing moisture from the enclosed eggs. Under the experimental drought conditions, 13 days appear to be the critical period at which high egg mortality due to desiccation occurs.

The egg of L. migratoria migratorioides, as noted in earlier reports, is therefore not drought resistant. The finding is further supported by the high rate of egg mortality in the abnormally laid egg-pods during the field study (Appendices 6 to 19). It

may be recalled that in abnormal oviposition, the egg-pod was laid on the walls of the breeding cage or on the floor and the eggs were therefore subject to high evaporation.

Drought causes egg mortality directly through desiccation (Ashall and Ellis, 1962; Anonymous, 1984). In desiccated eggs the yolk maintains its characteristic yellowish colour but it shrinks and lies freely in the egg shell.

In this work eggpods were considered desiccated irrespective of the number of eggs affected per eggpod.

That incidence of drought causes egg desiccation in L. migratoria migratorioides is supported by the fact that most of the desiccated eggpods observed in the field during the rainy season occurred before or after the peak of the rains (Appendices 27 to 28). Furthermore, desiccation was the most important mortality factor during the drier seasons; namely, the harmattan, the hot-dry and the early rains seasons (Table 11). It is necessary to emphasize, however, that most of the desiccation recorded during the drier seasons was the direct result of abnormal oviposition.

The exact impact of desiccation under field conditions, even in the present study, is not easy to quantify as some of the eggpods destroyed by predators might have contained some desiccated eggs. During the rainy season only a few eggpods contained desiccated eggs in all habitats; and some of the affected eggpods produced hatchlings (Appendices 23 to 31). In the dry seasons, as noted above, the actual number of eggpods obtained was too small to offer reliable information (Appendices 6 to 20).

It is the opinion of the writer that desiccation is a minor factor of egg mortality judging from the small number of eggpods affected during the rainy season, when breeding was at the peak. The present findings agree with Popov's (1959) in Mali.

The role of decay in egg survival was apparent during the rainy season only (Table 11). In decayed eggs, unlike desiccated ones, the yolk turned brown to black and it was inseparable from the egg shell. In addition decayed eggs often stuck together and it was impossible to ascertain the number. The criterion for determining decayed eggpod did not take into account the number of eggs infected; that is eggpods were considered decayed irrespective of the number of eggs infected.

The incidence of decay appears to be related to soil moisture content. For this reason, the clayey habitat, because of its higher humidity (Table 4), registered more cases of decay infested eggpods than the sandy habitat. The low proportion of decay infested eggpods in the sandy-clay loam habitat contradicts the above suggestion since that habitat was as humid as the clayey habitat (Table 4). The discrepancy is ascribable to the high incidence of predation in the sandy-clay loam habitat. It is possible that most of the eggpods removed by predators in the sandy-clay loam habitat were decay infested but they could not be quantified.

The importance of decay on egg mortality, therefore, cannot be evaluated with certainty. Field observations, however, indicate that decay cannot be an important egg mortality factor as some of the few infested eggpods produced hatchlings (Appendices 23 to 31).

The above conclusion is in line with that made by Popov (1959) for the Mali outbreak area where he has reported that decay and other factors, such as desiccation, are insignificant egg mortality factors.

The role of soil temperature on egg survival rate is complex and intimately linked with availability of soil moisture and incubation period. Laboratory observations in the present study have shown that the rate in the standard soil was unaffected by temperature ranging from $22^{o}\pm1^{o}C$ to the optimum, $34^{o}\pm1^{o}C$ (Table 19). This observation is ascribed to availability of sufficient soil moisture during incubation at all the tested temperatures, including $22^{o}\pm1^{o}C$ at which incubation lasted as long as 27 days (Table 17). It is concluded, therefore, that identical rates of egg survival were possible at the above temperatures because of favourable moisture conditions prevailing in the standard soil at all the temperatures.

However, soil moisture and incubation period become irrelevant to egg survival at temperatures higher than the optimum as increased mortality due to overheating occurred (Table 16). At $38^{o}\pm1^{o}C$, 4.3% and 5.1% egg survival occurred in eggpods incubated in soil with 50ml and 20ml of water respectively. The remaining 95.7% and 94.9% died despite the 15% and 8% humidities recorded in respective soils at the end of incubation (12 and 11 days respectively). In addition to the poor rate of survival at $38^{o}\pm1^{o}C$, most of the hatchlings died shortly after emergence. Also, even though the two soils were

about 12% and 7% humid after 12 days, total egg mortality was registered at 40°±1°C (Table 16).

That hatchlings die shortly after emergence at temperatures exceeding the optimum has also been reported in S. gregaria by Shulov (1970).

Even though excessive temperature is detrimental to egg survival, as shown above, it is doubtful if mortality due to such temperatures is significant under field conditions. This is because extremely high temperatures, such as 42.6°C, which occur during the hot-dry and the early rains seasons in the Lake Chad Basin outbreak area, last a few hours only during the day. This observation is in agreement with that made by Farrow (1975) in Mali: he reported that though maximum soil temperature, at 5cm depth, is about 43.5°C in May and June, it lasts about 4 hours per day and therefore cannot directly cause egg mortality.

Contrary to the situation at temperatures exceeding the optimum, at very low temperatures, such as 22°±1°C inadequate soil moisture facilitates mortality. This explains why mortality was 100% in nine eggpods maintained at 22°±1°C in soil containing 5ml of water after 29 days incubation. Furthermore, high egg mortality(63.7%)

occurred in the soil kept moist with 10ml of water at the same 22°±1°C; the remaining 36.3% produced hatchlings (Table 16). Additional evidence of the role of soil moisture at low temperatures is apparent from the very poor survival rate (6.3%) recorded in the single eggpod kept in contact with 5ml of water at 22°±1°C. This eggpod was further moistened with 20ml of water after incubating for 29 days without producing hatchlings. The eggpod eventually produced the 6.3% survival rate 21 days after the water replenishment, that is after an incubation period of 50 days (Table 16). It is clearly evident that at low temperatures deficient moisture in the soil with 5ml, or even with 10ml, of water can be a critical factor in egg survival.

The above conclusion is supported by the finding in the field, that during the harmattan eggs survived only in the clayey habitat (Appendices 13 to 15), which is the only habitat with reasonable humidity (Davey and Johnson, 1956; Iyiola and Diallo, 1974a, 1974b; Anonymous, 1984).

Although at low temperatures deficient soil moisture causes high egg mortality, too much soil moisture, not only flooded soil, is equally detrimental to egg survival at such temperatures. This inference derives support

from Table 19 where at 22°±1°C eggpods in contact with 50ml of water produced 56.4% survival rate as against 95.9% in eggpods kept in soil with 20ml of water.

Predation, probably, is the most important egg mortality factor in the field; predation was inferred from complete or partial disappearance of eggpods. As shown in Table 11, predation occurred in all seasons and in all habitats; its greatest impact was noticed during the rainy season when it was commonest in sandy-clay loam habitat and least common in sandy habitat.

Popov (1959) has made similar observations for the locust in the Mali outbreak area.

It was not possible to identify most of the predatory agents as such organisms left the spot after removing the eggpods (Popov, 1959). The only agent reliably identified is the mite, Allothrombium, which has also been reported in eggpods of the locust in Eritrea , Ethiopia (Greathead, 1963). However, Allothrombium does not appear to be an important egg mortality factor in the Lake Chad Basin area since it attacked only a few anterior eggs per eggpod.

The major cause of eggpod disappearance in the field has been attributed to subterranian larvae of coleopterous families including Carabidae, Elateridae, and

Tenebrionidae (Popov, per. comm.). According to Popov the larvae reach the eggpods through underground tunnels.

Three families of Coleoptera, that is Carabidae, Elateridae (Pyrophorinae) and Meloidae, were found in the vicinity of several missing eggpods during the course of the present study. Among the Carabidae one prominent genus resembling Disticus was identified. It is possible that the above-named Coleoptera was responsible for the disappearance of most of the eggpods through underground tunnels as suggested by Popov (per comm.).

Predation on eggpods of locusts, including L. migratorioides and S. gregaria, has also been attributed to larvae of dipterous families such as Asilidae, Drosophilidae, Phoridae and Trypedidae (Hynes, 1947; Greathead, 1958, 1963; Stower et al, 1958; Popov, 1959; Ashall and Ellis 1962; Farrow, 1975). In the present study predacious Diptera were not registered.

Two groups of egg parasites, the hymenopterous Scelio group, comprising S. africanus and S. sudanensis, and an unidentified enchytraeid group, were encountered in this work as shown in Table 11.

The genus Scelio is considered the only obligate egg parasite of Acrididae and it has been reported in eggpods of S. gregaria in the Eritrean province of Ethiopia

(Stower et al, 1958; Greathead, 1963, 1966). In the Mali outbreak area, two species of the genus, S. sudanensis and S. remaudiere, have been reported in eggpods of L.migratoria migratorioides (Popov, 1959; Farrow, 1975). Popov (1959) observed that S. sudanensis is more destructive, occuring in 95% of the Scelio infested eggpods while S. remaudiere is responsible for the remaining 5% infestation.

In the Lake Chad Basin outbreak area, the present study has shown that S. africanus is a more important parasite since it was responsible for 75.4% of the Scelio infestation while S. sudanensis accounted for 24.6% of the Scelio infestation.

No report on Scelio infestation in L. migratoria migratorioides in the Lake Chad Basin outbreak area has been published prior to the present one.

Similarly, there is no documented report of enchytraeid infestation on eggpods of L. migratoria migratorioides either for the Mali or for the Lake Chad Basin outbreak area prior to this work.

In general, parasitism was a minor egg mortality factor in the field. In contrast to the large quantity of eggpods damaged by predators (Table 11), parasitic Scelio and enchytraeids infested a small average of 5% and

6.6% respectively of the 907 eggpods obtained during the rainy season. In addition, some of the infested eggpods observed were only partially destroyed as some of the eggs in such eggpods produced hatchlings (Table 12).

At this stage it is essential that the pattern of Scelio infestation be briefly explained. The gravid parasite is carried about under the wings of the female locust and starts depositing its eggs into those of the locust as soon as the latter completes ovipositing (Greathead, 1963, 1966). The parasitic Scelio reaches the host's eggs by penetrating the froth plug of the eggpod with its extended ovipositor, and one parasitic egg is introduced into each egg of the host. The most anterior eggs in the locust's eggpods (Fig.8) are the first, and sometimes the only, to be parasitised by Scelio spp. while the posterior eggs develop normally (Greathead, 1958, 1963).

According to Popov (1959) and Farrow (1975), after normal embryonic development, the resultant hatchlings from the eggs lying posterior to the Scelio infested portion of the host's eggpod are trapped since their normal pathway to the soil surface is occupied by the parasites. Trapping is enhanced since the parasite's eggs take two to three weeks longer than those of the locust to complete

development (Popov, 1959). Stower et al (1958) have also observed similar trapping of hatchlings of S. gregaria in eggpods partially infested by the dipterous Stamorhina lunata Fabricius in Eritrea province of Ethiopia.

The successful hatchling emergence in partially parasitised eggpods observed in the present study contrasts the reports cited above. The apparent contradiction between the present observation and those mentioned above may be explained in terms of soil types prevailing in the respective study areas because soil type has been found to influence hatchling emergence in L. migratoria migratorioides and S. gregaria (Ewer, 1977). Although the above reports do not indicate the soil types in the respective study areas, it is possible that the soil types are not similar to those in the Lake Chad Basin outbreak area. The inference is supported by the fact that the clay in Lake Chad Basin cracks and Ewer (1977) has observed that cracks provide pharates of the subspecies with "escape route" to the soil surface.

As regards hatchling weight, laboratory observations indicate that soil moisture is the major determining factor (Table 22). Heavier hatchlings are produced from wetter soils (Appendix 45). The negative correlation ($r = -0.89$, $t = -5.14$, d.f. = 7, $P \leq 0.01$) between drought

period and hatchling weight (Table 31) confirms the dependence of hatchling weight on soil moisture; an observation which is in line with that published for S. gregaria (Hunter-Jones, 1964).

It is implicit in the above observations that hatchlings emerging from clayey habitat during the harmattan and those from sandy habitat during the early rains season are likely to weigh less than rainy season hatchlings. This interpretation explains the increase in the number of small adults of L. migratoria migratorioides observed in the Lake Chad Basin outbreak area as the dry conditions intensify (Anonymous, 1984) and agrees with similar findings by Farrow (1975) in the Mali outbreak area.

Since bigger adults are commoner in the rainy season (Farrow, 1975; Anonymous, 1984), when both the egg and the hopper stages are spent in wetter conditions, it seems that in this locust the adult size is dependent on the soil moisture in which the egg develops.

There is indication that hatchling weight has survival value. The positive correlation between hatchling weight and survival rate ($r = 0.84$, $t = 6.32$, d.f. = 17, $P \leq .001$, extracted from Appendix 46), to the second hopper instar, attests to this inference; that

is heavier hatchlings stand better chances of reaching the second hopper instar and ultimately to the adult stage.

Cannibalism is a common phenomenon in locusts, including those in the Lake Chad Basin outbreak area; it occurs during both the hopper and adult stages, particularly under crowded conditions (Norris, 1950, 1952). Again, it is reasonable to assume that bigger and heavier individuals are more efficient cannibals than smaller ones; they may therefore survive at the expense of the smaller hatchlings.

In conclusion, L. migratoria migratorioides lives in an ecological system characterised by complex interactions between climatic factors, edaphic factors and other factors such as predators and parasites. Interactions among these factors and their impact on egg development, its survival and hatchling weight in the locust are influenced by seasonal changes. To ensure continual survival in this complex ecosystem, the locust must evolve some adaptive mechanisms.

For instance, eggs of the locust are susceptible to drought, therefore major breeding coincides with the rainy season. The eggs are also susceptible to flood and therefore oviposition and successful development usually

occur in elevated breeding grounds which are sandier and less prone to flooding. Water is not a limiting factor during the rainy season, therefore, hatchlings attain the maximum possible weight, which endows them with high survival potentials.

The locust breeds mainly during the rainy season utilising breeding sites which enhance deep oviposition. Deep oviposition is believed to accord the eggs some protection from mortality factors, including natural enemies, particularly predators, which pose the greatest danger to the locust's eggs during incubation. To further ensure continual survival of the locust in its environment it oviposits more than once in its life time and the eggpod contains several eggs. Moreover, all eggpods, irrespective of the female age, have identical survival potential.

As the rains diminish and the grounds become drier, the locust breeds mainly in the more humid clayey habitat; and with the intensification of the dry conditions, breeding is restricted to the wetter sandy soils along the Lake and the river valleys, following the flooding and receding patterns.

By the above behavioural patterns, L. migratoria migratorioides ensures its perpertual existence in the Lake Chad Basin outbreak area. It is, therefore, imperative that reliable forecasting on its population fluctuations, based on effective and economical survey programmes is made. It is in the light of this need that some parameters crucial to the implementation of campaigns against the pest are highlighted below.

Since breeding occurs mainly during the rainy season, it is important to carry out extensive locust surveys during this season with special emphasis on the elevated sandy areas where optimal soil conditions favour rapid egg development and high survival rate. As the rains decline and the floods recede, the above observations can be extented to the lower clayey areas, and with the intensification of the dry conditions, to the vicinity of the Lake and the river banks where wetter soil conditions prevail.

It is important to stress that the breeding grounds mentioned above have been found to be infested with organisms which serve as predators or parasites of the locust's eggs. Whether these natural enemies can be of use in the control of the pest is beyond the scope of this study. It is suggested that predation and parasitism require further study.

APPENDICES

Appendix 1: Estimates of financial losses caused by S. gregaria.

Year	Country	Value of Crops destroyed(£ Sterling)
1926-1934	India	400,000 per year
1928-1929	Kenya	300,000 per year
1953	Somalia	600,000 per year
1954-1955	Morocco	4,500,000 per year (in 1 season)
1949-1957	FAO estimate for only 12 out of 40 affected countries	1,500,000 per year In 1955 over 5,000,000

Appendix 2: Estimate of economic loss of actual food to S. gregaria

Year	Country	Amount of Crop eaten by locusts
1944	Libya	7 million grape vines
1954	Sudan	55,000 tons of grains
1957	Senegal	16,000 tons of millet
	.....	2,000 tons of other crops
1957	Guinea	6,000 tons of oranges
1958	Ethiopia	167,000 tons of grain
1962	India	10,000 acres of cotton valued at £300,000.

Appendix 4: Soil humidity, temperature and pH in the hot-dry season:

	S A N D								SANDY-CLAY LOAM								C L A Y							
	Temperature (°C)						pH	% HUM	Temperature (°C)						pH	% HUM	Temperature (°C)						pH	% HUM
	08HRS		12HRS		18HRS		08 HRS	12 HRS	08HRS		12HRS		18HRS		08 HRS	12 HRS	08HRS		12HRS		18HRS		08 HRS	12 HRS
Year	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm
1981	31.3	31.5	44.2	43.8	43.0	43.0	7.0	0.0	30.6	30.8	43.7	44.0	42.8	43.0	7.0	0.0	29.8	31.4	41.7	42.0	42.8	43.0	7.0	0.0
1982	30.0	31.2	43.2	44.1	43.7	42.9	7.0	0.0	30.3	31.0	41.5	43.6	41.5	43.0	7.0	0.0	31.3	31.0	41.3	41.0	41.4	41.6	7.0	0.0
1983	30.5	29.9	43.0	43.0	43.3	43.8	7.0	0.0	29.9	31.3	42.2	42.8	39.7	42.3	7.0	0.0	30.3	30.8	43.3	43.7	43.6	43.0	7.0	0.0
1984	30.2	30.5	41.7	44.3	42.8	41.1	7.0	0.0	30.8	31.0	40.9	43.1	41.8	43.6	7.0	0.0	30.3	30.5	42.8	42.5	43.1	43.3	7.0	0.0
$\bar{x}$	30.5	30.8	43.0	43.8	43.2	42.7	7.0	0.0	30.4	31.0	42.1	43.4	41.5	43.0	7.0	0.0	30.4	30.9	42.3	42.3	42.7	42.7	7.0	0.0
Sd	0.57	0.72	1.03	0.57	0.39	1.14	0.00	0.00	0.39	0.21	1.21	0.53	1.29	0.53	0.00	0.00	1.03	0.38	0.93	1.12	0.94	0.76	0.00	0.00
v	0.25	0.39	0.79	0.25	0.12	0.98	0.00	0.00	0.12	0.03	1.09	0.21	1.25	0.21	0.00	0.00	0.80	0.11	0.65	0.95	0.67	0.44	0.00	0.00

Appendix 5: Soil humidity, temperature and pH in early rains season.

	SAND								SANDY-CLAY LOAM								CLAY							
	Temperature (°C)						pH	% HUM	Temperature (°C)						pH	% HUM	Temperature (°C)						pH	% HUM
	08HRS		12HRS		18HRS		08 HRS	12 HRS	08HRS		12HRS		18HRS		08 HRS	12 HRS	08HRS		12HRS		18HRS		08 HRS	12 HRS
Year	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	10 cm	10 cm
1981	29,8	31.4	43.8	41.3	41.1	40.0	6.7	35.3	31.2	30.7	42.0	41.3	39.7	39.7	6.3	42.1	31.0	31.0	35.0	35.7	37.7	38.1	6.7	66.0
1982	31.1	31.1	41.2	40.8	40.3	39,8	6.7	28.6	30.9	30.1	38.7	37.1	40.2	40.1	6.1	57.5	30.5	31.3	36.7	35.3	38.2	37.3	6.7	60.0
$\bar{x}$	30.5	31.3	42.5	41.1	40.7	39.9	6.7	32.0	31.1	30.4	40.4	39.2	40.0	39.9	6.2	49,8	30.8	31.2	35.9	35.5	38.0	37.7	6.7	63.0
Sd	0.92	0.21	1.84	0.35	0,42	0,14	0.00	4.74	0.21	0.42	2,33	2,97	0,35	0,28	0,14	10,89	0.35	0,21	1.20	0.28	0.35	0.57	0.00	4.24
v	0.42	0.02	1.69	0.06	0.09	0.01	0.00	11.22	0.02	0.09	2.72	4.41	0.06	0.04	0.01	59.29	0.06	0.02	0.72	0.04	0.06	0.16	0.00	9.00

Appendix 6: Egg development and survival in sand during 1981-82 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
9-12	1	0	-	-	17	0.0				+		Soil surface
	2	0	-	-	-	0.0			+			
16-1	3	0	-	-	-	0.0			+			
27-1	4	0	-	-	15	0.0				+		Soil surface
18-2	5	0	-	-	6	0.0				+		Among feed
						Totals	0	0	2	3.	0	
						%	0.0	0.0	40.0	60.0	0.0	

Legend:
1) Date = Date of oviposition
2) No. = Serial number of eggpod
3) Mass Hatch. = Mass Hatching
4) Incub. Period = Incubation period
5) 2nd Hat. = Subsequent hatching
6) Eggs/Pod = Eggs per eggpod (Clutch size)
7) % Hatch = % egg survival per eggpod
8) Sce. = Scelio infestation
9) Enc. = Enchytraeid infestation
10) Pred. = Predation
11) Des. = Desiccation
12) Dec. = Decay

Appendix 7: Egg development and survival in sand during 1982-83 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
9-12-82	1	0	-	-	23	0.0				+		In feed
12-12-82	2	0	-	-	-	0.0			+			Normal Laying
16-12-82	3	0	-	-	11	0.0				+		In feed
						Totals	0	0	1	2	0	
						%	0.0	0.0	33.3	66.7	0.0	

Appendix 8: Egg development and survival in sand during 1983-84 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
23-11-83	1	0	-	-	-	0.0			+			In feed
29-11-83	2	0	-	-	17	0.0				+		
	3	0	-	-	-	0.0			+			In feed
12-01-84	4	0	-	-	12	0.0				+		
						Totals	0	0	2	2	0	
						%	0.0	0.0	50.0	50.0	0.0	

Appendix 9: Egg development and survival in sand during 1984-85 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
					-	0.0				+		Eggs broken
4-12-84	1	0	-	-	5	0.0				+		Soil surface
13-12-84	2	0	-	-	18	0.0				+		Soil surface
12-1-85	3	0	-	-	-	0.0			+			
22-1-85	4	0	-	-								
						Totals	0	0	1	3	0	
						%	0.0	0.0	25.0	75.0	0.0	

Appendix 10: Egg development and survival in sandy-clay loam during 1981-82 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
					-	0.0				+		On wall of cage
5-12-81	1	0	-	-	13	0.0				+		Among feed
27-1-82	2	0	-	-	21	0.0				+		
6-2-82	3	0	-	-	-	0.0			+			
18-2-82	4	0	-	-								
						Totals	0	0	1	3	0	
						%	0.0	0.0	25.0	75.0	0.0	

Appendix 11: Egg development and survival in sandy-clay loam during 1982-83 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
21-11-82	1	0	-	-	-	0.0				+		Soil surface
27-11-82	2	0	-	-	-	0.0				+		Soil surface
						Totals	0	0	0	2	0	
						%	0.0	0.0	0.0	100	0.0	

Appendix 12: Egg development and survival in sandy-clay loam during 1983-84 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
29-11-83	1	0	-	-	17	0.0				+		In feed
11-12-83	2	0	-	-	-	0.0				+		On cage wall
13-1-84	3	0	-	-	32	0.0				+		In feed
						Totals	0	0	0	3	0	
						%	0.0	0.0	0.0	100	0.0	

1984-85: No oviposition in sandy-clay loam.

Appendix 13: Egg development and survival in clay during 1981-82 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred	Des.	Dec.	Remarks
						0.0			+			
8-12-81	1	0	-	-	-	-				+		About 55 desiccated
	2	1	20	-	56	0.0				+		Fragmented
10-1-82	3	0	-	-	-	0.0			+			
18-1-82	4	0	-	-	-	0.0				+		Desiccated
2-2-82	5	0	-	-	33	0.0				+		In feed
15-2-82	6	0	-	-	8	0.0			+			
22-2-82	7	0	-	-	-							
						Totals	0	0	3	4	0	
						%	0.0	0.0	42.9	57.1	0.0	

Appendix 14: Egg development and survival in clay during 1982-83 harmattan season:

Date	No.	Mass Hatc	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
						0.0			+			Partial predation
18-11-82	1	4	27	0	-	0.0				+		Desiccated
1-12-82	2	0	-	-	31	0.0			+			
13-12-82	3	0	-	-	-	0.0				+		Soil surface
19-12-82	4	0	-	-	-	0.0			+			
16-1- 83	5	0	-	-	-							
						Totals	0	0	3	2	0	
						%	0.0	0.0	60.0	40.0	0.0	

Appendix: 15: Egg development and survival in clay during 1983-84 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
16-11-83	1	0	-	-	-	0.0			+	+		
17-11-83	2	12	25	0	-	-			+			
21-11-83	3	0	-	-	-	0.0			+	+		In feed
2-12-83	4	0	-	-	-	0.0			+			
21-12-83	5	0	-	-	-	0.0			+	+		On cage wall
11-1-84	6	0	-	-	-	0.0			+			
19-1-84	7	0	-	-	-	0.0			+			
22-1-84	8	0	-	-	-	0.0						
28-1-84	9	0	-	-	-							
						Totals	0	0	6	3	0	
						%	0.0	0.0	66.7	33.3	0.0	

Appendix 16: Egg development and survival in clay during 1984-85 harmattan season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
13-12-84	1	0	-	-	-	0.0			+			
14-1-85	2	0	-	-	-	0.0			+			
23-1-85	3	0	-	-	-	0.0			+			
						Totals	0	0	3	0	0	
						%	0.0	0.0	100	0.0	0.0	

Appendix 17: Egg development and survival in sand during 1981 early rains season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs/ Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
13-6	1	0	-	0	-	0.0			+			Soil surface
16-6	2	0	-	0	-	0.0			+			8 dry
16-6	3	0	-	0	-	0.0				+		
21-6	4	3	9	0	11	27.3				+		
						Totals	0	0	2	2	0	
						%	0.0	0.0	50.0	50.0	0.0	

Appendix 18: Egg development and survival in sand during 1982 early rains season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
21-6	1	0	-	-	24	0.0				+		Dry
26-6	2	7	10	0	19	36.8				+		Rest dry
	3	0	-	0	14	0.0				+		14 dry
						Totals	0	0	0	3	0	
						%	0.0	0.0	0.0	100	0.0	

Appendix 21: Egg development and survival in clay during 1982 early rains season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
14-6	1	0	-	-	-	0.0			+			Normal oviposition
22-6	2	0	-	-	-	0.0			+			Normal oviposition
23-6	3	0	-	-	10	0.0				+		Normal oviposition
26-6	4	0	-	-	-	0.0				+		Normal oviposition
26-6	5	0	-	-	-	0.0				+		Normal oviposition
						Totals	0	0	2	3	0	
						%	0.0	0.0	40.0	60.0	0.0	

Appendix 22: Tests for differences between mean incubation periods in sand, sandy-clay loam and clayey habits.

Between habitats:

1. Sand Vs. Clay(Critical Diff. = 0.44 x 1.96 = 0.86)

   13.6 - 18.1 = -4.5 (Significant)

2. Sand Vs. Sandy-Clay Loam (Critical Diff. =0.57 x 1.96=1.12)

   13.6 - 16.0 = -2.4 (Significant)

3. Sandy-Clay Loam Vs. Clay(Critical Diff.=0.63x1.96 = 1.23)

   16.0 - 18.1 = -1.9 (Significant)

Between years:

1. 1981 Vs. 1982 (Critical Diff. = 0.42 x 1.96 = 0.82)

   Sand : 13.2 - 12.6 = 0.6(not significant)
   Sandy-Clay Loam : 15.2 - 15.2 = 0.0(not significant)
   Clay : 17.6 - 16.4 = 1.7(significant)

2. 1981 Vs. 1984 (Critical Diff. = 0.51 x 1.96 = 1.0)

   Sand : 13.2 - 14.9 =-1.7 (Significant)
   Sandy-Clay Loam : 15.2 - 17.5 =-2.3 (significant)
   Clay : 17.6 - 20.4 =-2.8 (significant)

3. 1982 Vs. 1984 (Critical Diff. = 0.53 x 1.96 = 1.0)

   Sand : 12.6 - 14.9 = -2.3 (Significant)
   Sandy-Clay Loam : 15.2 - 17.5 = -2.3 (Significant)
   Clay : 16.4 - 20.4 = -4.0 (Significant)

Appendix 23: Egg development and survival in Clay during 1981 rainy season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM See	PARASITISM Enc	Pred.	Des	Dec.	Remarks
14-7	1	7	14	0	55	-					+	48 rotten
	2	8	12	0	62	-					+	54 rotten
	3	0	-	-	-	0.0					+	Flooded for 1week
15-7	4	34	16	0	34	100.0						
	5	0	-	-	-	0.0					+	Flooded
16-7	6	0	-	-	-	0.0					+	Flooded
	7	49	21	0	49	100.0						
	8	49	17	3	52	100.0						
	9	0	-	-	-	0.0					+	Flooded
17-7	10	19	12	0	19	100.0						
20-7	11	37	14	0	37	100.0						
	12	63	9	1	64	100.0						
	13	0	-	-	-	0.0			+			
	14	0	-	-	-	0.0			+			
22-7	15	10	20	0	-	-		+				
	16	0	-	-	-	0.0			+			
	17	0	-	-	-	0.0		+				
	18	0	-	-	-	0.0			+			
	19	42	21	0	42	100.0						
24-7	20	0	-	-	-	0.0			+			
	21	0	-	-	-	0.0					+	Flooded
26-7	22	0	-	-	-	0.0			+			
	23	0	-	-	-	0.0			+			
	24	0	-	-	-	0.0			+			
	25	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des	Dec.	Remarks
	51	0	-	-	-	0.0					+	
	52	10	24	-	-	-		+				
	53	0	-	-	-	0.0					+	
5-8	54	0	-	-	-	0.0			+			
	55	0	-	-	-	0.0			+			
	56	0	-	-	-	0.0			+			
	57	0	-	-	-	0.0			+			
	58	13	18	-	65	27.7	+					52 Scelio
	59	42	21	4	46	100.0						
	60	12	17	0	38	31.6	+					26 Scelio
	61	0	-	-	-	0.0			+			
7-8	62	0	-	-	-	0.0			+			
	63	14	12	3	17	88.2					+	2 rotten
	64	0	-	-	-	0.0			+			
	65	28	20	-	-	-					+	
	66	9	14	0	-	-					+	
	67	30	13	1	31	100.0						
11-8	68	0	-	-	-	0.0		+				
	69	15	13	0	-	-		+				
	70	0	-	-	-	0.0					+	
16-8	71	0	-	-	-	0.0					+	
	72	0	-	-	-	0.0					+	
	73	0	-	-	-	0.0					+	
	74	0	-	-	-	0.0					+	
	75	5	14	0	-	-		+				

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
	76	0	-	-	-	0.0					+	
	77	0	-	-	-	0.0					+	Flooded
	78	0	-	-	-	0.0					+	Flooded
	79	0	-	-	-	0.0					+	Flooded
	80	0	-	-	-	0.0					+	Flooded
18-8	81	0	-	-	-	0.0					+	
	82	0	-	-	-	0.0					+	Flooded
20-8	83	0	-	-	-	0.0			+			
21-8	84	0	-	-	-	0.0					+	Flooded
	85	9	35	0	-	-		+				
	86	5	20	0	-	-		+				
	87	0	-	-	-	0.0					+	Flooded
	88	0	-	-	-	0.0					+	Flooded
25-8	89	0	-	-	-	0.0			+			
	90	25	27	0	-	-			+		+	Mites & 4 rotten
26-8	91	14	15	0	-	-			+			Mites found
	92	42	18	0	42	100.0						
29-8	93	0	-	-	-	0.0			+			
	94	0	-	-	-	0.0	+					
	95	0	-	-	-	0.0			+			
1-9	96	0	-	-	59	0.0				+		
3-9	97	0	-	-	-	0.0			+			
	98	0	-	-	-	0.0			+			
6-9	99	53	16	0	53	100.0						
9-9	100	0	-	-	44	0.0				+		
	101	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
10-9	102	0	-	-	-	0.0					+	
	103	0	-	-	-	0.0			+			
12-9	104	0	-	-	-	0.0			+			
13-9	105	0	-	-	-	0.0			+			
17-9	106	0	-	-	-	0.0			+			
	107	31	17	0	64	4.4	+					33 Scelio
18-9	108	0	-	-	-	0.0			+			
	109	0	-	-	-	0.0				+		No. undetermined
	110	33	14	4	39	94.9				+		2 eggs dried up
19-9	111	56	12	0	56	100.0						
	112	0	-	-	-	0.0			+			
22-9	113	0	-	-	-	0.0				+		
	114	0	-	-	-	0.0			+			
	115	0	-	-	-	0.0				+		
	116	0	-	-	21	0.0				+		
	117	0	-	-	46	0.0				+	+	34 dry, 12 rotten
	118	0	-	-	-	0.0			+			
24-9	119	0	-	-	-	0.0			+			
	120	0	-	-	-	0.0		+		+		
	121	0	-	-	-	0.0		+		+		
						Totals	4	14	45	10	38	
						%	3.3	11.6	37.2	8.3	31.4	

Appendix 24: Egg development and survival in clay during 1982 rainy season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
22-7	1	61	17	2	63	100.0						
	2	67	17	0	67	100.0						
	3	42	17	0	56	75.0					+	14 rotten
	4	0	-	-	-	0.0			+			
23-7	5	0	-	-	-	0.0			+			
	6	68	14	0	68	100.0						
	7	0	-	-	-	0.0					+	Flooded
	8	0	-	-	-	0.0			+			
	9	0	-	-	-	0.0					+	Flooded
	10	0	-	-	-	0.0					+	Flooded
	11	0	-	-	-	0.0						
	12	0	-	-	-	0.0			+			
	13	0	-	-	-	0.0			+			
26-7	14	9	21	0	-	0.0					+	Majority rotten
	15	0	-	-	-	0.0			+			
27-7	16	38	22	0	38	100.0						
28-7	17	0	-	-	-	0.0		+				
	18	0	-	-	-	0.0			+			
	19	0	-	-	-	0.0					+	
30-7	20	0	-	-	-	0.0			+			
	21	0	-	-	-	0.0			+			
	22	13	17	0	-	-		+				
	23	0	-	-	-	0.0			+			
1-8	24	55	15	0	55	100.0						
3-8	25	58	17	0	58	100.0						

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
	26	0	-	-	-	0.0					+	
	27	0	-	-	63	0.0	+					63 Scelio
	28	0	-	-	-	0.0			+			
4-8	29	0	-	-	-	0.0			+			
7-8	30	33	24	-	35	100.0						
	31	0	-	2	-	0.0			+			
	32	0	-	-	-	0.0			+			
	33	75	27	1	76	100.0						
8-8	34	0	-	-	-	0.0					+	
	35	0	-	-	-	0.0					+	
	36	0	-	-	-	0.0					+	
11-8	37	0	-	-	-	0.0			+			
13-8	38	0	-	-	-	0.0					+	
17-8	39	0	-	-	-	0.0					+	
	40	0	-	-	-	0.0					+	
	41	88	24	0	88	100.0						
	42	52	13	1	53	100.0						
	43	7	19	0	49	14.3	+					42 Scelio
19-8	44	0	-	-	-	0.0			+			
22-8	45	0	-	-	-	0.0					+	
	46	0	-	-	-	0.0					+	
23-8	47	0	-	-	-	0.0					+	
	48	0	-	-	-	0.0					+	
	49	0	-	-	-	0.0					+	
	50	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce.	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
27-8	51	0	-	-	-	0.0					+	
	52	0	-	-	-	0.0					+	
	53	0	-	-	-	0.0					+	
	54	0	-	-	-	0.0					+	
28-8	55	0	-	-	-	0.0					+	
	56	43	18	0	43	100.0						
	57	0	-	-	-	0.0					+	
	58	0	-	-	19	0.0					+	
	59	0	-	-	-	0.0			+			
2-9	60	0	-	-	-	0.0			+			
	61	58	16	0	58	100.0						
	62	0	-	-	-	0.0			+			
	63	0	-	-	-	0.0			+			
	64	0	-	-	-	0.0			+			
	65	0	-	-	-	0.0			+			
6-9	66	0	-	-	-	0.0					+	
	67	0	-	-	53	0.0					+	
	68	0	-	-	-	0.0			+			
8-9	69	0	-	-	19	0.0				+		
	70	0	-	-	4	0.0						
	71	0	-	-	-	0.0			+		+	
	72	0	-	-	-	0.0			+			
	73	0	-	-	-	0.0			+			
11-9	74	60	14	12	72	100.0						
	75	0	-	0	-	0.0			+			
12-9	76	37	14	0	37	100.0						
	77	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
	78	0	-	-	-	0.0			+			
	79	0	-	-	17	0.0			+			
	80	0	-	-	-	0.0			+			
	81	23	12	0	23	100.0						
14-9	82	0	-	-	-	0.0			+			
	83	0	-	-	-	0.0			+			
	84	0	-	-	-	0.0			+			
	85	0	-	-	-	0.0			+			
	86	0	-	-	-	0.0				+		
	87	0	-	-	-	0.0			+			
	88	0	-	-	-	0.0			+			
	89	73	13	1	74	100.0						
18-9	90	0	-	-	23	0.0			+			
	91	55	12	0	55	100.0						
	92	0	-	-	-	0.0		+				
	93	0	-	-	-	0.0			+			
	94	0	-	-	19	0.0		+				
	95	42	11	0	-	-				+		
19-9	96	0	-	-	63	0.0				+		
	97	60	12	0	60	100.0						
	98	0	-	-	-	0.0			+			
	99	0	-	-	-	0.0			+			
	100	0	-	-	-	0.0						
	101	68	12	0	68	100.0						
	102	0	-	-	-	0.0			+			
	103	0	-	-	-	0.0			+			
	104	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
21-5	105	48	12	0	60	80.0				+		12 Dried up
	106	0	-	-	-	0.0			+			
	107	0	-	-	53	0.0				+		
22-9	108	0	-	-	-	0.0				+		
	109	0	-	-	17	0.0						
	110	0	-	-	-	0.0			+			
	111	0	-	-	-	0.0				+		
	112	0	-	-	23	0.0				+		
23-9	113	0	-	-	-	0.0			+			
	114	0	-	-	-	0.0			+			
25-9	115	0	-	-	-	0.0				+		
	116	0	-	-	-	0.0				+		
	117	0	-	-	-	0.0				+		
						Totals	2	4	49	13	28	
						%	1.7	3.4	41.9	11.1	23.9	

Appendix 25: Egg development and survival in clay during 1984 rainy season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
9-7	1	45	16	3	48	100.0						
10-7	2	0	-	-	-	0.0			+			
	3	73	14	0	73	100.0						
11-7	4	0	-	-	-	0.0			+			
	5	0	-	-	-	0.0				+		
	6	0	-	-	-	0.0			+			
14-7	7	8	14	0	52	15.4					+	Flooded, 44 rotten
	8	0	-	-	-	0.0		+				
	9	0	-	-	-	0.0			+			
	10	48	15	2	50	100.0						
15-7	11	23	18	0	-	-		+				
	12	40	17	0	40	100.0						
16-7	13	7	15	0	53	-					+	Flooded, 46 rotten
17-7	14	0	-	-	-	0.0			+			
	15	0	-	-	-	0.0					+	
	16	50	23	0	50	100.0						
	17	0	-	-	-	0.0			+			
18-7	18	0	-	-	-	0.0			+			
	19	0	-	-	-	0.0					+	Flooded
23-7	20	0	-	-	-	0.0					+	Flooded
24-7	21	63	23	1	64	100.0						
	22	0	-	-	-	0.0					+	Flooded
	23	0	-	-	-	0.0			+			
	24	0	-	-	-	0.0				+		
	25	0	-	-	-	0.0			+			
25-7	26	28	19	3	42	73.8					+	11 rotten
	27	0	-	-	-	0.0					+	
26-7	28	0	-	-	-	0.0					+	

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pad	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
	29	55	26	0	55	100.0						
	30	3	22	0	-	-		+				
29-7	31	0	-	-	-	0.0			+			
	32	0	-	-	-	0.0			+			
30-7	33	0	-	-	-	0.0				+		
	34	0	-	-	-	0.0			+			
	35	0	-	-	-	0.0					+	
	36	0	-	-	-	0.0			+			
2-8	37	19	26	3	22	100.0						
	38	0	-	-	-	0.0	+					52 Scelio
4-8	39	0	-	-	-	0.0			+			
5-8	40	3	27	0	-	-		+				
	41	0	-	-	-	0.0			+			
	42	0	-	-	-	0.0					+	
	43	0	-	-	-	0.0			+			
8-8	44	0	-	-	-	0.0				+		
	45	0	-	-	-	0.0			+		+	
10-8	46	0	-	-	-	0.0						
	47	0	-	-	-	0.0					+	
	48	0	-	-	-	0.0					+	
	49	88	25	1	89	100.0						
11-8	50	0	-	-	-	0.0						

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
	51	0	-	-	-	0.0					+	19 Scelio
	52	0	-	-	-	0.0			+			
	53	0	-	-	-	0.0	+				+	
	54	0	-	-	-	0.0						
12-8	55	0	-	-	-	0.0			+		+	
	56	0	-	-	-	0.0					+	
	57	0	-	-	-	0.0						
15-8	58	40	26	3	43	100.0						
	59	0	-	-	-	0.0			+			
	60	0	-	-	-	0.0			+			
						Totals	2	4	22	4	18	
						%	3.3	6.7	36.7	6.7	30.0	

Appendix 26: Egg development and survival in sandy-clay loam during 1981 rainy season

Date	No.	Mass Hat	Incub. period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
14-7	1	0	-	-	-	0.0			+			
	2	0	-	-	-	0.0			+			
	3	2	17	0	54	3.7				+		52 dried up
	4	56	20	0	56	100.0						
	5	5	16	0	-	-		+				
	6	0	-	-	-	0.0			+			
15-7	7	0	-	-	-	0.0			+			
	8	0	-	-	-	0.0			+			
	9	0	-	-	-	0.0					+	
	10	0	-	-	71	0.0	+					
	11	0	-	-	-	0.0			+			
16-7	12	0	-	-	-	0.0			+			
	13	35	15	1	36	100.0						
	14	0	-	-	-	0.0			+			
17-7	15	0	-	-	-	0.0			+			
20-7	16	0	-	-	-	0.0			+			
	17	0	-	-	-	0.0			+			
21-7	18	0	-	-	-	0.0			+			
	19	0	-	-	-	0.0			+			
	20	0	-	-	-	0.0			+			
	21	0	-	-	-	0.0		+				
25-7	22	79	16	0	79	100.0						
	23	0	-	-	-	0.0			+			
	24	0	-	-	-	0.0			+			
	25	0	-	-	57	0.0	+					
	26	0	-	-	-	0.0			+			
	27	0	-	-	61	0.0				+		
	28	0	-	-	-	0.0			+			

Date	No.	Mass Hat	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
	29	0	-	-	-	0.0					+	
	30	0	-	-	-	0.0					+	
	31	0	-	-	-	0.0			+			
26-7	32	0	-	-	-	0.0			+			
27-7	33	0	-	-	-	0.0			+			
	34	0	-	-	-	0.0			+			
31-7	35	0	-	-	-	0.0		+				
	36	0	-	-	-	0.0			+			
	37	0	-	-	-	0.0			+			
	38	43	13	0	43	100.0						
	39	0	-	-	-	0.0			+			
	40	10	14	0	-	-		+				
	41	0	-	-	-	0.0				+		
	42	0	-	-	-	0.0			+			
1-8	43	0	-	-	-	0.0			+			
	44	0	-	-	-	0.0			+			
	45	0	-	-	-	0.0			+			
	46	0	-	-	-	0.0			+			
	47	0	-	-	-	0.0			+			
	48	16	15	0	71	22.5	+					56 Scelio
	49	0	-	-	-	0.0			+			
	50	0	-	-	-	0.0			+			
	51	0	-	-	-	0.0			+			
	52	0	-	-	-	0.0			+			
3-8	53	0	-	-	-	0.0			+			
	54	0	-	-	-	0.0			+			
	55	0	-	-	-	0.0			+			
	56	0	-	-	-	0.0			+			
	57	0	-	-	-	0.0			+			
6-8	58	0	-	-	-	0.0			+			
	59	0	-	-	-	0.0			+			
	60	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
	61	0	-	-	-	0.0			+			
	62	0	-	-	-	0.0			+			
	63	0	-	-	-	0.0					+	
	64	0	-	-	-	0.0			+			
	65	0	-	-	-	0.0			+			
7-8	66	0	-	-	-	0.0			+			
	67	0	-	-	-	0.0			+			
16-8	68	0	-	-	-	0.0			+			
	69	0	-	-	-	0.0					+	
	70	0	-	-	-	0.0			+			
17-8	71	0	-	-	-	0.0			+			
	72	0	-	-	-	0.0			+			
	73	0	-	-	-	0.0			+			
	74	0	-	-	-	0.0			+			
	75	0	-	-	-	0.0			+			
	76	0	-	-	-	0.0			+			
	77	0	-	-	-	0.0			+			
	78	0	-	-	55	0.0				+		
	79	6	12	-	-	-			+			
20-8	80	0	-	-	-	0.0			+			
	81	0	-	-	-	0.0			+			
	82	0	-	-	49	0.0	+					
	83	0	-	-	-	0.0			+			
	84	0	-	-	-	0.0			+			
	85	0	-	-	-	0.0			+			
	86	0	-	-	-	0.0			+			
	87	0	-	-	-	0.0			+			
30-8	88	0	-	-	-	0.0			+			
	89	0	-	-	-	0.0			+			
	90	0	-	-	70	0.0				+		
1-9	91	0	-	-	83	0.0				+		
4-9	92	0	-	-	32	0.0				+		
9-9	93	0	-	-	58	0.0				+		

Date	No.	Nest Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
	94	0	-	-	25	0.0	+					
10-9	95	34	14	0	51	66.7				+		17 dried up
	96	0	-	-	-	0.0			+			
	97	0	-	-	68	0.0				+		
12-9	98	0	-	-	-	0.0			+			
	99	0	-	-	-	0.0				+		
	100	3	11	0	-	-				+		
	101	0	-	-	-	0.0				+		
	102	0	-	-	-	0.0			+			
	103	0	-	-	-	0.0			+			
	104	0	-	-	43	0.0				+		
	105	0	-	-	-	0.0			+			
	106	0	-	-	-	0.0			+			
	107	0	-	-	-	0.0			+			
						Totals	5	4	75	14	5	
						%	4.7	3.7	70.1	13.1	4.7	

Appendix 27: Egg development and survival in sandy-clay loam during 1982 rainy season.

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
22-7	1	0	-	-	-	0,0			+			
	2	86	16	0	86	100,0						
	3	59	16	0	59	100,0						
23-7	4	0	-	-	-	0·0			+			
	5	0	-	-	57	0,0				+		
	6	0	-	-	-	0,0			+			
	7	0	-	-	-	0,0			+			
25-8	8	0	-	-	-	0,0			+			
26-7	9	0	-	-	-	0,0			+			
	10	0	-	-	-	0,0			+			
	11	0	-	-	61	0,0	+					61 Scelio
	12	0	-	-	-	0.0			+			
	13	37	13	-	53	69.8	+					16 Scelio
28-7	14	0	-	-	-	0.0			+			
	15	0	-	-	-	0,0			+			
	16	0	-	-	-	0.0		+				
	17	0	-	-	-	0.0			+			
29-7	18	0	-	-	-	0.0					+	
	19	59	17	3	62	100.0						
31-7	20	0	-	-	-	0.0			+			
	21	67	18	0	67	100·0						
	22	0	-	-	-	0·0			+			
1-8	23	0	-	-	-	0.0			+			
	24	0	-	-	-	0.0			+			
2-8	25	0	-	-	-	0.0			+			
3-8	26	0	-	-	-	0.0			+			
	27	0	-	-	-	0.0			+			
	28	29	19	-	-	-		+				
	29	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
6-8	30	0	-	-	43	0.0				+		
	31	0	-	-	-	0.0			+			
	32	0	-	-	-	0.0			+			
8-8	33	0	-	-	-	0.0			+			
	34	0	-	-	-	0.0			+			
	35	17	19	0	-	-		+				
9-8	36	0	-	-	-	0.0			+			
	37	0	-	-	-	0.0			+			
	38	0	-	-	-	0.0			+			
	39	0	-	-	-	0.0			+			
	40	0	-	-	-	0.0			+			
12-8	41	0	-	-	-	0.0			+			
	42	0	-	-	-	0.0					+	
13-8	43	0	-	-	-	0.0			+			
	44	0	-	-	-	0.0			+			
14-8	45	12	18	-	78	15.4	+					66 Scelio
	46	0	-	-	-	0.0		+				
	47	0	-	-	-	0.0			+			
16-8	48	0	-	-	-	0.0			+			
17-8	49	0	-	-	-	0.0			+			
	50	0	-	-	-	0.0			+			
19-8	51	68	19	0	68	100.0						
21-8	52	63	13	0	63	100.0						
	53	0	-	-	-	0.0			+			
22-8	54	0	-	-	-	0.0			+			
25-8	55	0	-	-	-	0.0			+			
	56	0	-	-	-	0.0					+	
	57	0	-	-	-	0.0			+			
	58	0	-	-	-	0.0			+			
	59	0	-	-	-	0.0		+				

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
27-8	60	0	-	-	-	0.0			+			
	61	0	-	-	-	0.0			+			
28-8	62	0	-	-	-	0.0			+			
30-8	63	0	-	-	-	0.0			+			
31-8	64	0	-	-	-	0.0				+		
	65	0	-	-	-	0.0			+			
	66	62	13	-	62	100.0						
2-9	67	0	-	-	-	0.0			+			
	68	0	-	-	-	0.0			+			
4-9	69	58	13	0	58	100.0						
	70	0	-	-	-	0.0					+	
6-9	71	59	13	0	59	100.0						
	72	0	-	-	-	0.0			+			
	73	12	17	-	66	18.2	+					54 Scelio
10-9	74	0	-	-	-	0.0				+		
13-9	75	0	-	-	78	0.0				+		
	76	0	-	-	47	0.0				+		
	77	0	-	-	-	0.0				+		
14-9	78	0	-	-	-	0.0			+			
	79	68	12	1	69	100.0						
	80	0	-	-	-	0.0				+		
16-9	81	0	-	-	-	0.0			+			
17-9	82	0	-	-	46	0.0				+		
	83	0	-	-	-	0.0				+		
	84	0	-	-	69	0.0				+		
18-9	85	0	-	-	-	0.0				+		
	86	11	11	-	-	-				+		

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
19-9	87	0	-	-	-	0.0			+			
	88	0	-	-	-	0.0			+			
	89	0	-	-	-	0.0			+			
	90	39	11	2	41	100.0						
	91	0	-	-	-	0.0			+			
22-9	92	0	-	-	-	0.0			+			
	93	0	-	-	7	0.0				+		
	94	0	-	-	-	0.0			+			
23-9	95	0	-	-	-	0.0				+		
	96	0	-	-	-	0.0				+		
	97	0	-	-	-	0.0			+			
25-9	98	0	-	-	-	0.0			+			
	99	0	-	-	-	0.0			+			
26-9	100	0	-	-	-	0.0			+			
	101	0	-	-	-	0.0				+		
	102	0	-	-	-	0.0			+			
28-9	103	0	-	-	-	0.0			+			
	104	0	-	-	-	0.0			+			
	105	0	-	-	-	0.0			+			
						Totals	4	5	64	17	4	
						%	3.8	4.8	61.0	16.2	3.8	

Appendix 28: Egg development and survival in sandy-clay loam during 1984 rainy season.

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
7-7	1	0	-	-	-	0.0			+			
	2	0	-	-	-	0.0			+			
8-7	3	0	-	-	-	0.0			+			
11-7	4	0	-	-	39	0.0				+		
	5	0	-	-	-	0.0			+			
12-7	6	44	15	3	47	100.0						
	7	0	-	-	-	0.0			+			
	8	23	18	0	23	100.0						
13-7	9	58	16	0	65	89.2				+		
16-7	10	0	-	-	-	0.0			+			
	11	0	-	-	-	0.0			+			
	12	0	-	-	-	0.0			+			
19-7	13	0	-	0	42	0.0	+					42 Scelio
	14	55	17	0	55	100.0						
20-7	15	0	-	-	-	0.0			+			
	16	0	-	-	-	0.0			+			
	17	0	-	-	-	0.0			+			
22-7	18	0	-	-	-	0.0			+			
23-7	19	0	-	-	-	0.0		+				
25-7	20	0	-	-	-	0.0			+			
	21	0	-	-	-	0.0			+			
28-7	22	16	19	0	67	23.9	+					51 Scelio
	23	0	-	-	-	0.0			+			
	24	0	-	-	-	0.0			+			
29-7	25	0	-	-	-	0.0			+			
30-7	26	51	16	0	63	81.0					+	12 rotten
	27	0	-	-	-	0.0			+			
3-8	28	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
	29	62	18	0	62	100.0						
4-8	30	0	-	-	-	0.0		+				
	31	0	-	-	-	0.0			+			
	32	0	-	-	-	0.0			+			
	33	0	-	-	24	0.0	+					
7-8	34	38	19	0	38	100.0						
9-8	35	10	18	0	-	0.0		+				
11-8	36	0	-	-	-	0.0			+			
	37	0	-	-	-	0.0			+			
	38	0	-	-	-	0.0			+			
13-8	39	70	18	0	70	100.0						
15-8	40	0	-	-	-	0.0			+			
	41	0	-	-	-	0.0			+			
	42	0	-	-	-	0.0			+			
17-8	43	0	-	-	-	0.0					+	
	44	13	18	-	-	-		+				
	45	0	-	-	-	0.0					+	
	46	0	-	-	-	0.0			+			
	47	0	-	-	-	0.0			+			
						Totals	3	4	29	2	3	
						%	6.4	8.5	61.7	4.3	6.4	

Appendix 29: Egg development and survival in sand during 1981 rainy season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
14-7	1	0	-	-	-	0.0			+			
	2	0	-	-	-	0.0		+				
	3	68	12	0	68	100.0						
	4	84	14	0	84	100.0						
	5	44	13	0	44	100.0						
	6	70	12	0	71	98.6		+				1 egg infested
	7	42	12	0	69	69.9					+	27 rotten
	8	87	12	0	88	98.9					+	1 rotten
	9	72	14	0	76	94.7		+				4 infested
15-7	10	0	-	-	-	0.0					+	
19-7	11	41	12	0	41	100.0						
	12	0	-	-	-	0.0					+	
20-7	13	78	13	0	78	100.0						
	14	0	-	-	-	0.0					+	
	15	0	-	-	-	0.0					+	
21-7	16	62	12	0	62	100.0						
	17	0	-	-	-	0.0					+	
22-7	18	0	-	-	79	0.0	+					
	19	24	12	0	30	80.0					+	6 rotten
	20	65	12	0	65	100.0						
	21	37	12	2	41	90.2					+	2 rotten
	22	0	-	-	-	0.0					+	
24-7	23	0	-	-	-	0.0					+	
	24	31	13	2	33	100.0						
	25	0	-	-	82	0.0	+					
	26	24	12	1	25	100.0						
25-7	27	45	12	1	46	100.0						
	28	0	-	-	-	0.0			+			
	29	70	14	0	70	100.0						
	30	70	18	1	71	100.0						

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
7-8	66	42	12	2	44	100.0						
8-8	67	0	-	-	65	0.0	+					
10-8	68	51	16	1	53	98.1					+	1 rotten
	69	18	14	9	27	100.0						
	70	59	17	0	59	100.0						
	71	49	14	0	49	100.0						
	72	21	14	0	25	84.0	+					4 Scelio
	73	0	-	-	-	0.0			+			
	74	8	15	5	-	-		+				
12-8	75	68	15	10	78	100.0						
	76	64	15	0	64	100.0						
	77*	0	-	-	75	0.0	+				+	48 Scelio, rest rotten
16-8	78	0	-	-	-	0.0					+	
	79	0	-	-	-	0.0					+	
	80	0	-	-	-	0.0					+	
	81	54	14	0	54	100.0						
	82	0	-	-	-	0.0			+			
17-8	83	0	-	-	-	0.0					+	
18-8	84	10	15	0	-	-		+				
	85	21	15	0	21	100.0						
19-8	86	0	-	0	-	-		+				
20-8	87	20	14	11	52	59.6	+					
	88	0	-	-	-	0.0					+	
21-8	89	0	-	-	-	0.0					+	
	90	0	-	-	-	0.0					+	
	91	83	14	0	83	100.0						
	92	14	14	0	-	-					+	Some rotten
22-8	93	53	13	0	53	100.0						
	94	63	14	0	63	100.0						
	95	0	-	-	-	0.0			+			
23-8	96	74	14	1	75	100.0						
	97	0	-	-	-	0.0			+			
24-8	98	0	-	-	-	0.0			+			
	99	0	-	-	-	0.0			+			
25-8	100	80	14	0	80	100.0						

(*) Infested by 2 factors.

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
10-9	135	32	11	8	40	100.0						
11-9	136	0	-	-	-	0.0			+			
	137	34	12	6	40	100.0						
	138	0	-	-	49	0.0				+		
	139	0	-	-	-	0.0			+			
12-9	140	46	17	0	46	100.0						
	141	43	11	0	43	100.0						
13-9	142	0	-	-	-	0.0			+			
	143	17	13	0	-	-		+				
14-9	144	28	12	0	28	100.0						
15-9	145	16	13	7	23	100.0						
	146	61	13	0	61	100.0						
16-9	147	39	12	0	39	100.0						
	148	48	11	0	48	100.0						
	149	50	11	0	50	100.0						
	150	56	12	0	56	100.0						
17-9	151	45	13	4	49	100.0						
	152	0	-	-	-	0.0			+			
	153	40	13	4	44	100.0						
	154	0	-	-	-	0.0			+			
	155	55	13	0	55	100.0						
22-9	156	74	11	0	74	100.0						
	157	0	-	-	53	0.0				+		
	158	69	11	0	74	93.2				+		
	159	0	-	-	-	0.0		+				
	160	69	10	0	73	94.5				+		

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
	161	55	11	1	56	100.0						
	162	0	-	-	-	0.0			+			
	163	51	10	0	51	100.0						
	164	0	-	-	-	0.0			+			
27-9	165	67	10	0	81	82.7				+		
	166	0	-	-	-	0.0			+			
	167	0	-	-	36	0.0				+		
	168	0	-	-	51	0.0				+		
	169	85	9	1	87	98.9	+					
	170	54	10	2	56	100.0						
						Totals	12	15	40	8	35	
						%	7.1	8.8	23.5	4.7	20.6	

Appendix 30: Egg development and survival in sand during 1982 rainy season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
21-7	1	59	14	1	60	100.0						
	2	56	16	0	56	100.0						
	3	56	13	3	59	100.0						
22-7	4	0	-	-	-	0.0					+	
	5	77	17	0	77	100.0						
	6	36	13	0	36	100.0						
	7	0	-	-	-	0.0					+	
	8	0	-	-	-	0.0		+				
	9	48	17	3	51	100.0						
24-7	10	0	-	-	-	0.0					+	
	11	60	12	0	60	100.0						
	12	64	15	0	65	98.5					+	1 rotten
25-7	13	0	-	-	-	0.0			+			
26-7	14	43	14	5	48	100.0						
	15	0	-	-	-	0.0					+	
28-7	16	75	11	0	75	100.0						
	17	37	13	0	51	72.5	+					14 Scelio
	18	0	-	-	81	0.0	+					81 Scelio
	19	45	13	1	46	100.0						
30-7	20	0	-	-	-	0.0					+	
1-8	21	0	-	-	-	0.0			+			
	22	56	13	2	58	100.0						
	23	0	-	-	-	0.0			+			
	24	29	14	0	29	100.0						
2-8	25	0	-	-	-	0.0		+				
	26	67	13	0	67	100.0						
4-8	27	33	12	1	34	100.0						
	28	0	-	-	-	0.0					+	
	29	50	13	0	50	100.0						
	30	0	-	-	-	0.0			+			
	31	38	12	7	45	100.0						
6-8	32	0	-	-	-	0.0					+	
9-8	33	0	-	-	62	0.0	+					62 Scelio
	34	56	13	0	56	100.0						

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
11-8	35	42	14	0	42	100.0						
	36	0	-	-	-	0.0			+			
15-8	37	0	-	-	-	0.0			+			
15-8	38	66	13	0	66	100.0						
16-8	39	24	14	0	24	100.0						
	40	0	-	-	-	0.0		+				
	41	92	13	0	92	100.0						
17-8	42	0	-	-	-	0.0			+			
20-8	43	83	12	2	85	100.0						
22-8	44	50	13	0	50	100.0						
	45	0	-	-	-	0.0					+	
25-8	46	50	15	1	51	100.0						
	47	20	18	0	70	28.6	+					50 Scelio
26-8	48	0	-	-	-	0.0			+			
28-8	49	31	17	3	34	100.0						
29-8	50	55	12	1	56	100.0						
	51	0	-	-	-	0.0			+			
	52	40	16	0	40	100.0						
	53	0	-	-	-	0.0			+			
30-8	54	69	16	0	69	100.0						
31-8	55	66	13	0	66	100.0						
2-9	56	52	12	0	52	100.0						
	57	44	13	3	47	100.0						
	58	0	-	-	-	0.0			+			
3-9	59	68	14	1	69	100.0						
	60	0	-	-	-	0.0					+	
4-9	61	57	13	0	57	100.0						
6-9	62	0	-	-	-	0.0			+			
	63	0	-	-	45	0.0	+					45 Scelio
9-9	64	55	17	2	57	100.0						
11-9	65	0	-	-	-	0.0		+				
	66	55	12	0	55	100.0						
12-9	67	0	-	-	-	0.0			+			
	68	52	12	0	52	100.0						
	69	47	11	7	54	100.0						
14-9	70	47	12	0	47	100.0						
	71	10	15	0	63	15.9	+					

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
16-9	72	65	14	0	65	100.0						
17-9	73	37	10	3	40	100.0						
	74	89	10	3	92	100.0						
	75	40	12	7	47	100.0						
	76	0	-	-	-	0.0				+		
	77	0	-	-	-	0.0			+			
18-9	78	65	11	0	65	100.0						
	79	81	10	0	81	100.0						
	80	0	-	-	59	0.0				+		
	81	64	10	0	64	100.0						
19-9	82	0	-	-	58	0.0	+					58 Scelio
	83	57	10	0	57	100.0						
	84	0	-	-	-	0.0				+		
21-9	85	0	-	-	-	0.0				+		
	86	39	13	0	-	-		+				
	87	0	-	-	-	0.0						
	88	65	10	1	66	100.0			+			
	89	0	-	-	-	0.0			+			
22-9	90	50	9	0	50	100.0						
	91	0	-	-	48	0.0				+		
	92	0	-	-	-	0.0			+			
	93	0	-	-	-	0.0			+			
	94	0	-	-	48	0.0				+		
	95	68	10	3	71	100.0						
	96	51	10	0	51	100.0						
	97	0	-	-	-	0.0		+				
	98	37	11	0	37	100.0						
24-9	99	54	9	1	55	100.0						
	100	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
24-9	101	0	-	-	-	0.0			+			
	102	60	10	0	60	100.0						
	103	0	-	-	-	0.0				+		
	104	0	-	-	23	0.0				+		
25-9	105	10	11	-	-	-		+				
	106	56	10	0	56	100.0						
	107	0	-	-	-	0.0				+		
	108	0	-	-	-	0.0				+		
	109	0	-	-	39	0.0				+		
26-9	110	67	9	0	67	100.0						
	111	33	10	4	37	100.0						
	112	0	-	-	52	0.0				+		
	113	0	-	-	41	0.0	+					
	114	0	-	-	47	0.0				+		
	115	0	-	-	63	0.0				+		
						Totals	8	7	20	14	10	
						%	7.0	6.1	17.4	12.2	8.7	

Appendix 31: Egg development and survival in sand during 1984 rainy season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
9-7	1	42	11	1	43	100,0						
11-7	2	39	11	12	51	100,0						
	3	66	12	0	66	100,0						
	4	0	-	-	-	0,0			+			
14-7	5	55	14	0	55	100,0						
	6	0	-	-	38	0,0				+		
15-7	7	0	-	-	60	0,0				+		
	8	0	-	-	-	0,0			+			
	9	0	-	-	53	0,0				+		
17-7	10	58	13	8	66	100,0						
18-7	11	0	-	-	-	0.0		+				
	12	33	12	0	33	100,0						
	13	37	15	0	37	100,0						
	14	71	12	0	71	100,0						
	15	0	-	-	-	0.0			+			
	16	28	12	13	41	100.0						
	17	0	-	-	-	0.0		+				
19-7	18	0	-	-	-	0.0			+			
	19	0	-	-	54	0.0	+					54 Scelio
	20	46	11	0	46	100.0						
22-7	21	51	11	2	53	100.0						
	22	0	-	-	-	0.0			+			
23-7	23	60	14	0	60	100.0						
	24	0	-	-	-	0.0			+			
	25	17	12	0	49	34.7	+					32 Scelio
	26	62	17	0	62	100.0						
	27	57	14	2	59	100.0						
26-7	28	0	-	-	-	0.0					+	
	29	23	17	-	54	42.6					+	31 rotten
	30	0	-	-	-	0.0			+			
	31	0	-	-	-	0.0			+			

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
	32	20	15	0	22	90.9		+				
	33	0	-	-	-	0.0			+			
	34	83	12	1	84	100.0						
	35	0	-	-	-	0.0			+			
27-7	36	47	14	0	47	100.0						
	37	0	-	-	-	0.0			+			
	38	0	-	-	29	0.0	+					29 Scelio
	39	0	-	-	-	0.0			+			
	40	0	-	-	-	0.0			+			
	41	0	-	-	-	0.0			+			
29-7	42	0	-	-	-	0.0					+	
	43	58	18	1	59	100.0						
30-7	44	55	15	0	57	96.5					+	2 rotten
	45	0	-	-	-	0.0			+			
	46	78	17	1	79	100.0						
	47	0	-	-	61	0.0	+					61 Scelio
31-7	48	0	-	-	-	0.0			+			
	49	0	-	-	-	0.0			+			
	50	0	-	-	-	0.0			+			
	51	0	-	-	-	0.0	+					Scelio
2-8	52	0	-	-	-	0.0			+			
	53	0	-	-	-	0.0			+			
4-8	54	37	18	0	42	88.1					+	5 rotten
5-8	55	56	19	0	56	100.0						
	56	0	-	-	0	0.0			+			
	57	0	-	-	-	0.0					+	
	58	0	-	-	-	0.0			+			
	59	0	-	-	-	0.0			+			
7-8	60	88	20	0	91	96.7					+	
10-8	61	61	19	0	61	100.0						
	62	0	-	-	-	0.0			+			
11-8	63	38	20	3	43	95.3					+	2 rotten
	64	63	19	0	72	87.5		+				
12-8	65	52	19	0	52	100.0						
						Totals	5	4	24	3	8	
						%	7.7	6.2	36.9	4.6	12.3	

Appendix 32: Egg development and survival in sand during 1981 hot-dry season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
23-3	1	0	-	-	5	0.0				+		Under bottle
2-4	2	0	-	-	22	0.0				+		Under bottle
21-4	3	0	-	-	-	0.0				+		In feed
5-5	4	0	-	-	14	0.0					+	Soil surface
						Totals	0	0	0	3	1	
						%	0.0	0.0	0.0	75.0	25.0	

Appendix 33: Egg development and survival in sand during 1982 hot-dry season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
8-5	1	0	-	-	18	0.0				+		Near bottle
						Totals	0	0	0	1	0	
						%	0.0	0.0	0.0	100	0.0	

Appendix 34: Egg development and survival in sand during 1983 hot-dry season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS					Remarks
							PARASITISM		Pred.	Des.	Dec.	
							Sce	Enc				
15-3	1	0	-	-	23	0.0				+		Soil surface
17-3	2	0	-	-	8	0.0				+		Soil surface
10-4	3	0	-	-	-	0.0				+		In feed
						Totals	0	0	0	3	0	
						%	0.0	0.0	0.0	100	0.0	

Appendix 35: Egg development and survival in sand during 1984 hot-dry season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS					Remarks
							PARASITISM		Pred.	Des.	Dec.	
							Sce	Enc				
27-4	1	0	-	-	-	0.0				+		In feed
9-5	2	0	-	-	-	0.0				+		In feed
15-5	3	0	-	-	-	0.0				+		In feed
						Totals	0	0	0	3	0	
						%	0.0	0.0	0.0	100	0.0	

Appendix 36: Egg development and survival in sandy-clay loam during 1981 hot-dry season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
5-5	1	0	-	-	19	0.0				+		Soil surface
14-5	2	0	-	-	16	0.0				+		Normal ovipositio
						Totals	0	0	0	2	0	
						%	0.0	0.0	0.0	100	0.0	

Appendix 37: Egg development and survival in sandy-clay loam during 1982 hot-dry season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
17-4	1	0	-	-	-	0.0			+			
29-4	2	0	-	-	10	0.0				+		Under bottle
10-5	3	0	-	-	19	0.0				+		Under bottle
13-5	4	0	-	-	-	0.0				+		Under bottle
						Totals	0	0	1	3	0	
						%	0.0	0.0	25.0	75.0	0.0	

Appendix 38: Egg development and survival in sandy-clay loam during 1983 hot-dry season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
17-4	1	0	-	-	-	0.0			+			Normal oviposition
7-5	2	0	-	-	27	0.0				+		In feed
						Totals	0	0	1	1	0	
						%	0.0	0.0	50.0	50.0	0.0	

Appendix 39: Egg development and survival in clay during 1981 hot-dry season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
25-3	1	0	-	-	-	0.0				+		Fragmented
9-4	2	0	-	-	-	0.0				+		Soil surface
11-4	3	0	-	-	22	0.0				+		Normal oviposition
						Totals	0	0	0	3	0	
						%	0.0	0.0	0.0	100	0.0	

1984: No oviposition in sandy- clay loam

Appendix 40: Egg development and survival in clay during 1982 hot-dry season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat	Eggs/ Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des	Dec.	Remarks
17-4	1	0	-	-	-	0.0				+		Fragmented
26-4	2	0	-	-	13	0.0				+		Soil surface
2-5	3	0	-	-	22	0.0				+		Normal oviposition
2-5	4	0	-	-	8	0.0				+		Soil surface
13-5	5	0	-	-	-	0.0			+			
						Totals	0	0	1	4	0	
						%	0.0	0.0	20.0	80.0	0.0	

Appendix 41: Egg development and survival in clay during 1983 hot-dry season:

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc.	Pred.	Des.	Dec.	Remarks
21-3	1	0	-	-	-	0.0			+			
	2	0	-	-	-	0.0				+		Fragmented
15-4	3	0	-	-	-	0.0				+		Fragmented
23-4	4	0	-	-	-	0.0				+		In Feed
						Totals	0	0	1	3	0	
						%	0.0	0.0	25.0	75.0	0.0	

Appendix 42: Egg development and survival in clay during 1984 hot-dry season

Date	No.	Mass Hat.	Incub. Period (Days)	2nd Hat.	Eggs /Pod	% Hatch	MORTALITY FACTORS: PARASITISM Sce	PARASITISM Enc	Pred.	Des.	Dec.	Remarks
27-3	1	0	-	-	29	0.0			+			Normal oviposition
5-4	2	0	-	-	-	0.0				+		Normal oviposition
11-4	3	0	-	-	58	0.0			+			Normal oviposition
12-4	4	0	-	-	33	0.0				+		Soil surface
						Totals	0	0	2	2	0	
						%	0.0	0.0	50.0	50.0	0.0	

Between temperatures:

1. 22°C Vs. 28°C (Critical Diff.= .27 x 2.00 = 0.54)

230gm/50ml : 30.3 - 17.0 = 13.3 (significant)
230gm/20ml : 27.0 - 14.3 = 12.7 (significant)
230gm/10ml : 27.8 - 14.5 = 13.9 (significant)

2. 22°C Vs. 28°/34°C(Critical Diff. = .27 x 2.00 = 0.54)

230gm/50ml : 30.3 - 13.8 = 16.5 (Significant)
230gm/20ml : 27.0 - 12.0 = 15.0 (significant)
230gm/10ml : 27.8 - 12.7 = 15.1 (significant)

3. 22°C Vs. 34°C (Critical Diff. = .24 x 2.00 = 0.48)

230gm/50ml : 30.3 - 10.5 = 19.8 (significant)
230gm/20ml : 27.0 - 10.0 = 17.0 (significant)
230gm/10ml : 27.8 - 10.3 = 17.5 (significant)

4. 28°C Vs. 28°/34°C (Critical Diff. = .30x2.00 = 0.60)

230gm/50ml : 17.0 - 13.8 = 3.2 (significant)
230gm/20ml : 14.3 - 12.0 = 2.3 (significant)
230gm/10ml : 14.5 - 12.7 = 1.8 (significant)

5. 28°C Vs. 34°C (Critical Diff. = .27x2.00 = 0.54)

230gm/50ml : 17.0 - 10.5 = 6.5 (significant)
230gm/20ml : 14.3 - 10.0 = 4.3 (significant)
230gm/10ml : 14.5 - 10.3 = 4.2 (significant)

6. 28°/34°C Vs. 34°C(Critical Diff.= 26x2.00 = 0.52

230gm/50ml : 13.8 - 10.5 = 3.3 (significant)
230gm/20ml : 12.0 - 10.0 = 2.0 (significant)
230gm/10ml : 12.7 - 10.3 = 2.4 (significant)

Appendix 44: The role of soil moisture and temperature on rate of egg survival.

t ($P \leq .05$ at 59 degrees of freedom) = 2.00

Between soil moistures

1. 230gm/50ml Vs. 230gm/20ml(Critical Diff.=4.71x2.00=9.42)

At 22°C : 56.4 - 95.9 = -39.5 (significant)
At 28°C : 96.2 - 99.4 = -3.2 (not significant)
At 28°/34°C : 98.1 - 94.7 = 3.4 (not significant)
At 34°C : 97.9 - 92.3 = 5.6 (not significant)

2. 230gm/50ml Vs. 230gm/10ml(Critical Diff.=5.03x2.00=10.06)

At 22°C : 56.4 - 36.3 = 20.1 (significant)
At 28°C : 96.2 - 87.8 = 8.4 (not significant)
At 28°/34°C : 98.1 - 68.6 = 29.5 (significant)
At 34°C : 97.9 - 69.0 = 28.9 (significant)

3. 230gm/20ml Vs. 230gm/10ml(Critical Diff. =5.20x2.00=10.40)

At 22°C : 95.9 - 36.3 = 59.6 (significant)
At 28°C : 99.4 - 87.8 = 11.6 (significant)
At 28°/34°C : 94.7 - 68.6 = 26.1(significant)
At 34°C : 92.3 - 69.0 = 23.1 (significant)

Between temperatures

1. 22°C Vs. 28°C (Critical Diff.=5.87 x 2.00 = 11.74)

230gm/50ml : 56.4 - 96.2 = -39.8 (significant)
230gm/20ml : 95.9 - 99.4 = - 3.5 (not significant)
230gm/10ml : 36.3 - 87.8 = -51.5 (significant)

2. 22°C Vs. 28°/34°C(Critical Diff. =6.03 x 2.00=12.06)

230gm/50ml : 56.4 - 98.1 = -41.7 (significant)
230gm/20ml : 95.9 - 94.7 = 1.2 (not significant)
230gm/10ml : 36.3 = 68.6 = -32.3 (significant)

3. 22°C Vs. 34°C(Critical Diff. = 4.99 x 2.00=9.98)

230gm/50ml : 56.4 - 97.9 = -41.5 (Significant)
230gm/20ml : 95.9 - 92.3 = 3.6 (not significant)
230gm/10ml : 36.3 - 69.0 = -32.7 (significant)

4. 28°C Vs. 28°/34°C (Critical Diff.=6.77 x 2.00=13.56)

230gm/50ml : 96.2 - 98.1 = -1.9 (not significant)
230gm/20ml : 99.4 - 94.7 = 4.7 (not significant)
230gm/10ml : 87.8 - 68.6 = 19.2 (significant)

5. 28°C Vs. 34°C (Critical Diff.=5.87 x 2.00 = 11.74)

230gm/50ml : 96.2 - 97.9 = - 1.7 (not significant)
230gm/20ml : 99.4 - 92.3 = 7.1 (not significant)
230gm/10ml : 87.8 - 69.0 = 18.8 (significant)

6. 28°/34°C Vs. 34°C (Critical Diff.=6.03 x 2.00=12.06)

230gm/50ml : 98.1 - 97.9 = 0.2 (not significant)
230gm/20ml : 94.7 - 92.3 = 2.4 (not significant)
230gm/10ml : 68.6 - 69.0 = -0.4 (not significant)

Appendix 45: The role of soil moisture and temperature on hatchling weight.

t (P≤.05 at 58 degrees of Freedom) = 2.00

Between soil moistures

1. 230gm/50ml Vs. 230gm/20ml(Critical Diff.=0.38x2.00=0.76)

At 22°C : 10.7 - 12.4 = -1.7 (significant)
At 28°C : 9.9 - 10.9 = -1.0 (significant)
At 28°/34°C : 11.0 - 11.0 = 0.0 (not significant)
At 34°C : 10.7 - 10.9 = -0.2 (not significant)

2. 230gm/50ml Vs. 230gm/10ml(Critical Diff.=0.40x2.00=0.80)

At 22°C : 10.7 - 8.4 = 2.3 (Significant)
At 28°C : 9.9 - 9.4 = 0.5 (not significant)
At 28°/34°C : 11.0 - 7.9 = 3.1 (Significant)
At 34°C : 10.7 - 8.8 = 1.9 (significant)

3. 230gm/20ml Vs. 230gm/10ml(Critical Diff.=0.41x2.00=0.82)

At 22°C : 12.4 - 8.4 = 4.0 (significant)
At 28°C : 10.9 - 9.4 = 1.5 (significant)
At 28°/34°C : 11.0 - 7.9 = 3.1 (significant)
At 34°C : 10.9 - 8.8 = 2.1 (significant)

Appendix 46: Survival of hatchling (incubation of 34°±1°C) to second hopper instar

Treatments	230gm/50ml			230gm/20ml			230gm/10ml			230gm/5ml		
	Hatchling WT (Mg)	% 2nd Instar	1st Inst. Duration	Hatchling WT (Mg)	% 2nd Instar	1st Inst. Duration	Hatchling WT (Mg)	% 2nd Instar	1st Inst. Duration	Hatch. WT (Mg)	% 2nd Instar	1st Insta Durat
	13.7	78.7	6 days	11.7	80.0	5 days	9.5	40.0	6 days	11.7	75.0	6days
	9.4	79.2	7 days	11.0	60.0	7 days	10.4	26.7	7 days	10.0	65.0	6 day
	11.5	62.5	6 days	14.7	92.3	7 days	6.6	23.3	6 days	10.2	54.5	6 day
	11.7	56.3	6 days	9.8	64.1	7 days	4.4	14.3	6 days			
	8.1	33.3	7 days	11.4	75.0	6 days	6.9	31.3	6 days			
				7.5	40.0	7 days						
$\bar{x}$	10.9	62.0	6.4	11.0	68.6	6.5	7.6	27.1	6.2	10.6	64.8	6.0
Sd	2.18	18.92	0.55	2.37	18.14	0.84	2.41	9.52	0.45	0.93	10.25	0.0
v	3.79	286.23	0.24	4.67	274.13	0.58	4.63	72.50	0.16	0.58	70.06	0.0

Legend: 1st Inst. = 1st instar

Appendix 47: The effect of flood on rate of egg development.

t ($P \leq .05$ at 26 degrees of freedom) = 2.06

Between preflooding periods.

1. 0-Day Vs. 3-days (Critical Diff.=2.06 x 0.57 = 1.17)

   1-day flood : 14.0 - 14.3 = -0.3 (not significant)
   2-day flood : 14.0 - 15.4 = -1.4 (significant)
   3-day flood : - - -

2. 0-Day Vs. 6-days (Critical Diff.=2.06 x 0.57=1.17)

   1-day flood : 14.0 - 13.2 = 0.8 (not significant)
   2-day flood : 14.0 - 16.8 = -2.8 (significant)
   3-day flood : - - -

3. 3-days Vs. 6-days(Critical Diff.=2.06 x 0.32 = 0.66)

   1-day flood : 14.3 - 13.2 = 1.1 (significant)
   2-day flood : 15.4 - 16.8 = -1.4 (significant)
   3-day flood : 16.5 - 19.0 = -2.5 (significant)

Between durations of flood

1. 1-day Vs. 2-days(Critical Diff.=2.06 x 0.33=0.68)

   0-day Pre-flooding : 14.0 - 14.0 = 0.0 (not significant)
   3-day Pre-flooding : 14.3 - 15.4 =-1.1 (significant)
   6-day Pre-flooding : 13.2 - 16.8 = -3.6(significant)

2. 1-day Vs. 3-days(Critical Diff.=2.06 x 0.42 = 0.87)

   0-day Pre-flooding : - - -
   3-day Pre-flooding : 14.3 - 16.5 = -2.2 (significant)
   6-day Pre-flooding : 13.2 - 19.0 = -5.8 (significant)

3. 2-days Vs. 3-days(Critical Diff.=2.06 x 0.41 = 0.84)

   0-day Pre-flooding : - - -
   3-day Pre-flooding : 15.4 - 16.5 = -1.1 (significant)
   6-day Pre-flooding : 16.8 - 19.9 = -3.1 (significant)

Appendix 48: The effect of flood on rate of egg survival

t ($P \leq .05$ at 70 degrees of freedom) = 2.00

Between preflooding periods

1. 0-day Vs. 3-days(Critical Diff.=2.00x5.23 = 10.45)

1 day flood : 0.6 - 75.9 = -75.3 (significant)
2 days flood : 1.4 - 60.9 = -59.5 (significant)
3 days flood : 0.0 - 8.5 = - 8.5 (not significant)

2. 0-day Vs. 6-days(Critical Diff. =2.00 x 5.30=10.60)

1 day flood : 0.6 - 96.6 = -96.0 (significant)
2 days flood : 1.4 - 69.2 = -67.8 (significant)
3 days flood : 0.0 - 15.4 = -15.4 (significant)

3. 0-day Vs. 9-days (Critical Diff. =2.00x5.23 = 10.45)

1 day flood : 0.6 - 12.9 = -12.3 (significant)
2 days flood : 1.4 - 0.0 = 1.4 (not significant)
3 days flood : 0.0 - 0.0 = 0.0 (not significant)

4. 3-days Vs. 6-days (Critical Diff.=2.00 x 5.48 = 11.0)

1 day flood : 75.9 - 96.6 = -20.7 (significant)
2 days flood : 60.9 - 69.2 = - 8.3 (not significant)
3 days flood : 8.5 - 15.4 = - 6.9 (not significant)

5. 3-days Vs. 9-days(Critical Diff.=2.00x5.41 = 10.81)

1 day flood : 75.9 - 12.9 = 63.0 (significant)
2 days flood : 60.9 - 0.0 = 69.9 (significant)
3 days flood : 8.5 - 0.0 = 8.5 (not significant)

6. 6-days Vs. 9-days (Critical Diff.=2.00x5.48 = 11.00)

1 day flood : 96.6 - 12.9 = 83.7 (significant)
2 days flood : 60.9 - 0.0 = 69.9 (significant)
3 days flood : 15.4 - 0.0 = 15.4 (significant)

Between durations of flood:

1. 1-day Vs. 2-days(Critical Diff.=2.00 x 4.53 = 9.07)

0-day Pre-flooding : 0.6 - 1.4 = -0.8 (not significant)
3-day Pre-flooding : 75.9 - 60.9 = 15.0 (significant)
6-day Pre-flooding : 96.6 - 69.2 = 27.4 (significant)
9-day Pre-flooding : 12.9 - 0.0 = 12.9 (significant)

2. 1-day Vs. 3-days (Critical Diff. = 2.00x4.63 = 9.26)

0-day Pre-flooding : 0.6 - 0.0 = 0.6 (not significant)
3-day Pre-flooding : 75.9 - 8.5 = 67.4 (significant)
6-day Pre-flooding : 96.6 - 15.4 = 81.2 (significant)
9-day Pre-flooding : 12.9 - 0.0 = 12.9 (significant)

3. 2-days Vs. 3-days (Critical Diff.=2.00 x 4.74 = 9.49)

0-day Pre-flooding : 1.4 - 0.0 = 1.4 (not significant)
3-day Pre-flooding : 60.9 - 8.5 = 52.4 (significant)
6-day Pre-flooding : 69.2 - 15.4 = 53.8 (significant)
9-day Pre-flooding : 0.0 - 0.0 = 0.0 (not significant)

Appendix 49: The effect of flood on hatchling weight(mg).

t($P \leq .05$ at 26 degrees of Freedom) = 2.06

Between preflooding period

1. 0-day Vs. 3-days (Critical Diff.=2.06x 1.1 = 2.24)

1-day flood : 9.2 - 13.3 = -4.1 (Significant)
2-day flood : 7.7 - 11.7 = -4.0 (significant)
3-day flood: -

2. 0-day Vs. 6-days (Critical Diff.=2.06 x 1.1 =2.24)

1-day flood : 9.2 - 12.4 = -3.2 (significant)
2-day flood : 7.7 - 11.8 = -4.1 (significant)
3-day flood : -

3. 3-days Vs. 6-days(Critical Diff. =2.06 x 0.61 = 1.26)

1-day flood : 13.3 - 12.4 = 0.9 (not significant)
2-day flood : 11.7 - 11.8 = 0.1 (not significant)
3-day flood : 11.4 - 11.3 = 0.1 (not significant)

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