Factors Affecting the Transfer of Surface Spray Deposit to the Desert Locust *Schistocerca gregaria*

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DEDICATION

To my wife, brother, sisters and children Ahmad, Mohammad, Hamsa, Abdulrahman, Sara and my mother-in-law.

ABSTRACT

The purpose of this research was to determine the influence of factors affecting the transfer of the insecticide Malathion from different surfaces to the Desert Locust Schistocerca gregaria and subsequent mortality.

A flat-bed wind tunnel, and an improvised spray track and tunnel apparatus using a turbair 12V for spraying the insecticide were used to carry out experiments on walking speed of adults and nymphs of S. gregaria on different surfaces and temperature regimes, estimation of mortality rate, estimation of insecticide deposition and of amount of insecticide picked up by insects.

Four types of surfaces were used; grass, glass, soil and sand.

Results suggest that; the optimum temperature for maximum walking activity was around 29°C; the age of insects and walking speed were directly related; the amount of insecticide picked up and age of insects were inversely proportional; insect mortality was higher on grass and glass than on soil and sand; the density of droplets of Malathion sprayed increased with application rate.

The implication of this work is discussed in relation to the needs for control of S. gregaria in Saudi Arabia.

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INTRODUCTION

1.1 GENERAL INTRODUCTION

Locusts belong to a large group of insects belonging to the order Orthoptera, and grasshoppers. The main distinguishing characteristic being the presence of big hind legs used for jumping. All grasshoppers are classified within the super family Acridoidea, and the most important locusts belong to the family Acrididae.

Locusts look just like large grasshoppers which are capable of changing their habitats and behaviour when they occur in large numbers (Steedman, 1988). Morphologically locusts are not distinguishable from grasshoppers but they differ in their behaviour. According to Chapman (1976), this can be simply shown experimentally. When locusts, reared in a crowd, are introduced into an arena which is effectively featureless and in which heating and lighting conditions are uniform, the insect would group together within 30 minutes. If disturbed and became separated they soon aggregate. When this experiment is repeated with a grasshopper, the insects remained scattered around the arena and no more grouping occurs than would be expected in a random distribution. However, the distinction is not

clear cut. The second major distinguishing feature of locusts is that they migrate during the daytime in swarms containing many millions of individuals, although migration is not restricted to locusts among the Acridoidea. There is evidence that grasshoppers also migrate but only as isolated individuals and at night (Chapman, 1976). Locusts however, do not always occur in these vast migrating aggregations, they also exist as solitary individuals. In this solitary phase they show no tendency to aggregate when put together in a crowd and with these solitary individuals the distinction between locusts and grasshoppers breaks down completely (Uvarov, 1966). When adult locusts aggregate the resulting group is known as a swarm, whereas when wingless younger stages, commonly known as hoppers, do so, the group is then called a band.

Neither the tendency to aggregate nor the tendency to migrate would be important if the locusts did not also occur in vast numbers at least for some of the time. Young locusts may occur in bands, commonly at densities of 100 m^{-2} and sometimes exceeding 1,000 m^{-2}, while the bands often exceed 10,000 m^2 in area. Adult swarms may extend over tens of square kilometres and a single swarm may contain more than 1×10^9 insects weighing around 1.5×10^6 kg. Since these insects eat approximately their own weight of

vegetation daily it is obvious that they may do an immense amount of damage to pasture or crops (Chapman, 1976).

Locusts have been a serious pest to mankind since prehistoric times because of their ability to form vast swarms and cause much damage, particularly to agricultural crops. Reference to the locusts has been mentioned in Assyrian tablets during the ninth century BC from information accumulated much earlier in Sumeris (Chapman, 1976).

Since the phase theory was put forward (see Uvarov, 1921, & 1928 and reviews by Key, 1950 and Kennedy, 1956), intensive research has done much to relieve the situation although the problem as a whole is by no means solved. Perhaps the most difficult locust species to control is the Desert locust, Schistocerca gregaria (Farskal), for it has a wide geographical distribution and, unlike the Red locust, Nomadacris septempaseiata (Serville), and the migratory locust, Locusta migratoria migratorioidea (Reiche and Farimaire) it appears to have relatively unrestricted breeding sites (Uvarov, 1951). This locust is therefore, subjected to widely different climatic conditions, and it would clearly be desirable to gain a better understanding of the effect that environmental factors have on this species.

1.2 REVIEW OF FACTORS AFFECTING THE DURATION OF EGG AND HOPPER DEVELOPMENT

1.2.1 Egg Development

Fully developed eggs of the Desert locust are about 9mm in length and 2mm in width (Hunter-Jones and Chapman, 1964) and are laid in batches (pods) containing 10-140 eggs (Norris, 1952). In laying, the female thrusts its ovipositor into the moist ground, expresses the eggs and fills up the hole left as the ovipositor is withdrawn with a frothy secretion which hardens to form a froth plug. The top of the pod is usually about 70mm below the soil surface (Karandikar, 1933). At the end of the incubation period the hatching insects work their way up the froth plug to the surface. Thereafter, the hoppers (nymphs) pass through five or six instars and at the final moult fully developed wings appear: this final moult to adult stage is called fledging.

S. gregaria unlike some other Acrididae, do not diapause when provided with appropriate environmental conditions. Embryonic development is a continuous process (Shulov & Pener, 1961, Uvarov, 1966), although, under certain conditions development can be suspended.

Moisture, temperature, and salinity are the principal environmental factors controlling egg development. At the time of oviposition, the eggs contain sufficient moisture to enable the embryo to complete about half its development. Further development is dependent upon the absorption of additional moisture from the surrounding soil (Shulov, 1952). When such a supplementary supply of moisture is lacking, development is suspended and the eggs enter a state of quiescence. Eggs have been observed though rarely, to remain in a state of quiescence in the field. Under laboratory conditions, with evaporation effects excluded, eggs have been held in a quiescent state for periods up to 98 days, and have resumed development on being moistened (Husain et al, 1941, Shulov & Pener, 1963, Popov, 1965). It was found that quiescent eggs remain viable for as long as six weeks under conditions when they suffer continuous loss of moisture to the surrounding soil, provided that the loss of water does not exceed 30 to 35% of their initial weight (Hunter-Jones, 1966). Popov (1965) concluded that in sandy soils, a moisture content of more than 1-9% is essential for normal egg development. This was augmented by Hunter-Jones (1964) under laboratory conditions using pure sand for laying when he obtained a value of about 2% moisture to sustain development. Embryonic development is also known to be suspended in saline soil (Shulov and Pener, 1963).

The duration of embryonic development becomes a function of temperature when moisture and salinity are not the limiting factors. Rao (1942) reported that incubation time varies from 13 days at an average soil temperature of 34°C to over 70 days at 19°C. These results agree closely with those obtained from laboratory experiments where eggs were kept at constant temperature (Hunter-Jones, 1966).

Hunter-Jones (1966) illustrated that the period of incubation decreased with the rise in temperature up to 35°C but no further reduction was noted above this temperature. He also showed that temperature above 39.0°C was progressively lethal, and no hatching at all was possible above 42.0°C, and at temperatures below 35.1°C there is a curvilinear relation between the duration of incubation and temperature.

The relation between the reciprocal of the period of incubation and mean temperature during the incubation is approximately a straight line. This relationship provides a way of estimating the growth rate of the embryo at any given temperature. From this Hunter-Jones (1966) has inferred that the minimum temperature for continued embryonic development is about 15°C (Fig. 1.1).

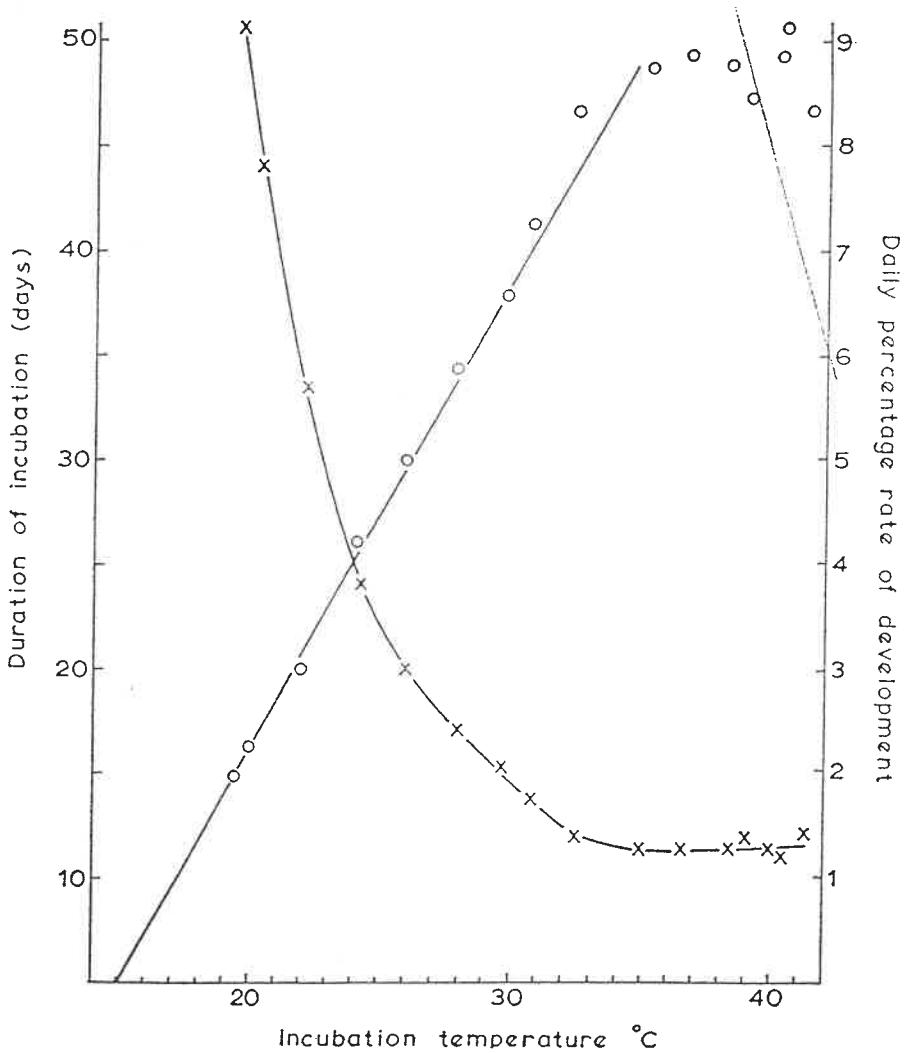


Fig 1.1 Temperature and duration of incubation (after Hunter-Jones, 1966) (o indicates rate of development; x indicates duration). Source Wardhaugh et al (1969) 6pp.

1.2.2 Hopper Development

Studies of the factors affecting the duration of the hopper stage have been concerned largely with the effects of relative humidity and temperature (Wardhaugh et al, 1969). Atmospheric humidity was claimed to have no effect on the duration of hopper development (Husain et al, 1941). However, since large supplies of fresh food were always available during laboratory experiments, it is not obvious whether humidity was under strict control. This problem was solved when Dudley (1961) maintained hoppers on a dry diet and allowed them access to water for a limited period each day. Thus, humidity was regulated. Dudley's results gave no suggestion to whether humidity affected the period of development, though when hoppers were starved of water, development appeared to be retarded. Dudley concluded that, since this effect was noted at all humidities, the critical factor in hopper development is the total amount of moisture available, rather than the relative humidity of the air. This finding contradicts that of Hamilton (1936, 1950) who found that the optimum humidity for development ranged from around 60 to 70 according to temperature. Below and above this optimum both mortality and development time increased. Hoppers were unable to survive at relative humidities below 35.0%. These results may be attributed to the partially dried diet used by Hamilton which have caused

progressive dessication and eventually death (Wardhaugh et al 1969). The extension of development time noted by Hamilton at low humidities was due to starvation caused by the food becoming dehydrated at these humidities , therefore food became unpalatable to the hoppers.

The available information on the effects of the food supply on the length of the hopper period is extremely fragmentary. Studies have been confined almost exclusively to an examination of the differential effects of individual food plants on the length of the hopper stage. Telenga (1930), for example, recorded that hoppers fed on lucerne took 37 days to reach the adult stage, in contrast to 28 to 30 days for those reared on cotton or sorghum. Some of the hoppers fed on lucerne passed through only 4 instars instead of 5, and reached adult stage within 29 days.

1.3 SEASONAL BREEDING AND MOVEMENTS OF SWARMS DURING PLAGUES

The invasion area of swarms of S. gregaria is very extensive (Fig. 1.2), extending over 113 degrees of longitude from the Canary Islands off West Africa to Assam (from 18°W to 95°E), and 51 degrees of latitude, from Turkey to Tanzania (41°N to 10°S). This area about 29

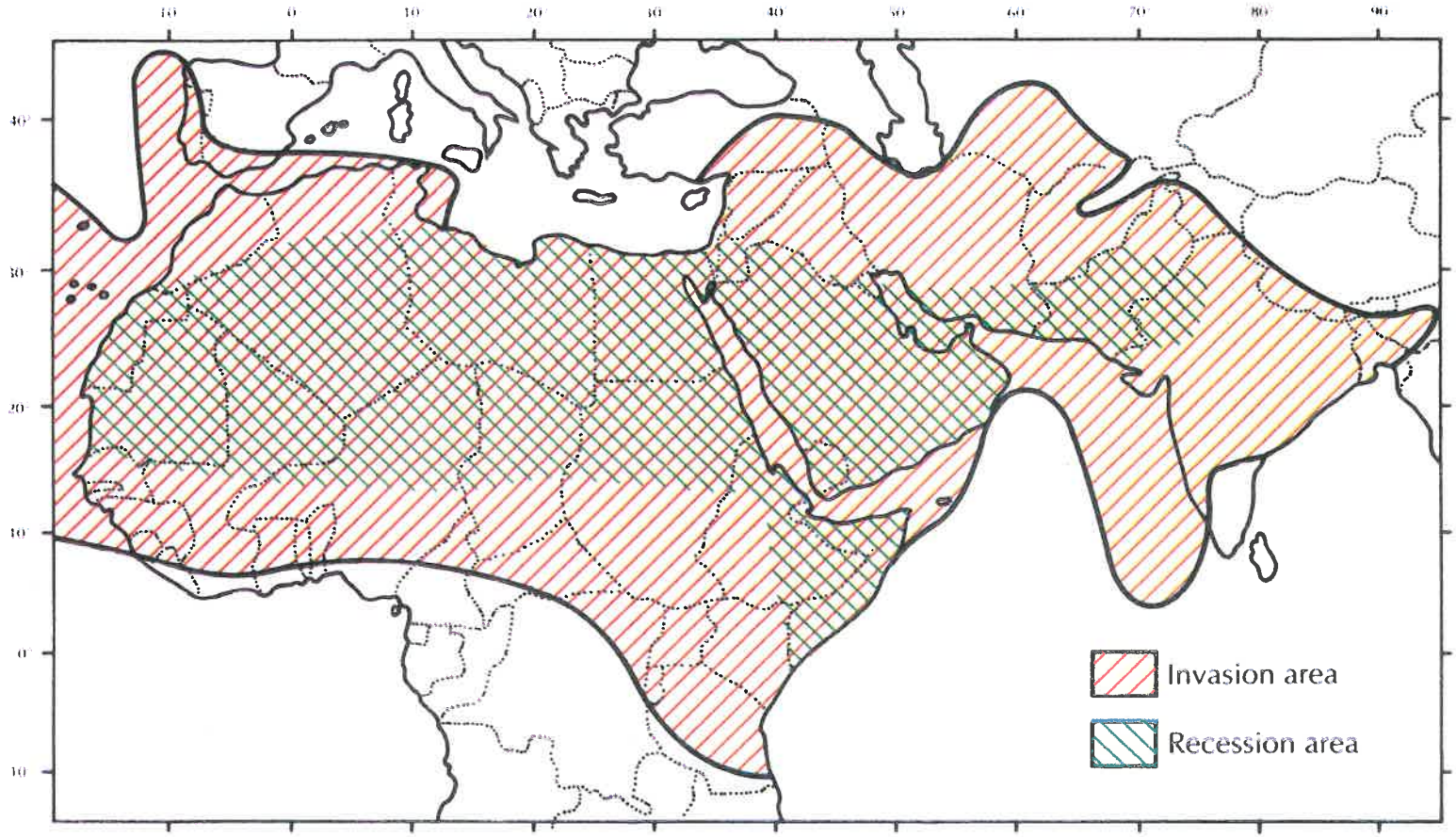


Fig. 1.2 This map shows the maximum area which can be invaded by swarms during a Desert Locust plague, and the smaller more central area where non-swarming scattered locusts are normally found during recessions. Source The Desert Locust Pocket Book (1990) 8pp.

million km², and comprises the whole or parts of 57 countries as well as a considerable range of climatic regimes (Waloff, 1960).

Most of the climates in the Desert locust area have, however, a common characteristic. They are dry, with low average rainfall that falls either sporadically or, more commonly seasonally. As mentioned earlier, Desert locusts need moist soil for egg laying and incubation, and fresh vegetation for hopper development, and in their generally arid environment they are able to reproduce only during periods of rainfall. There are two major seasonal belts in which rains fall and in which locusts breed (respectively, the northern hemisphere summer and spring) run from west to east through the desert locust invasion area (Fig. 1.3 and 1.5). Between the two belts, and partly overlapping with each, lies a third belt, of winter breeding the latter belt is particularly important on the Somali Peninsula and around the Red Sea (Fig. 1.4). The distribution and extent of breeding seasonal belts, within these varies from year to year, and their different frequencies in different parts can be shown by means of frequency maps, (Pedgley, 1981). Pedgley (1981) reports that young swarms as a rule leave their source areas at the end of the rains, and the greater parts of the seasonal breeding belts become free of swarms during their dry seasons. The emigrating swarms move

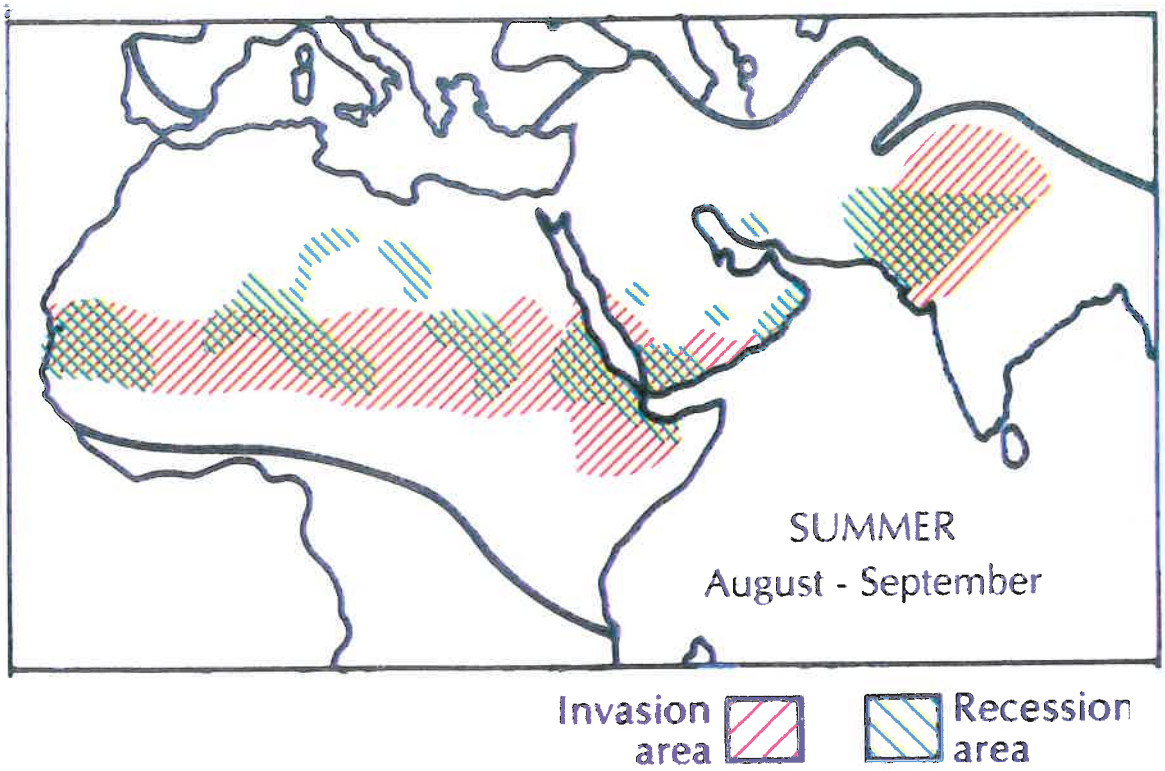


Fig. 1.3
This map shows the major seasonal breeding areas of the Desert Locust during plagues and recessions in summer, August-September. Source The Desert Locust Pocket Book (1990) 10pp.

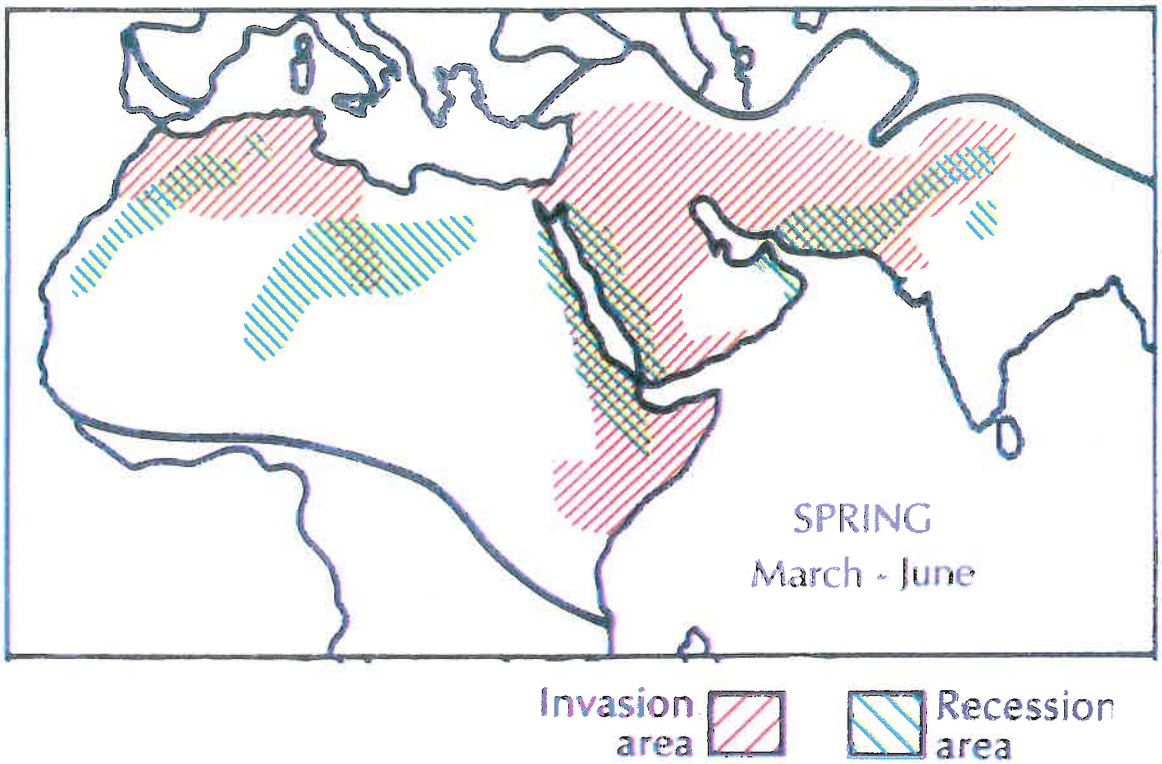


Fig.
1.4 This map shows the major seasonal breeding areas of the Desert Locust during plagues and recessions in spring, March-June. Source The Dësert Locust Pocket Book (1990) 10pp.

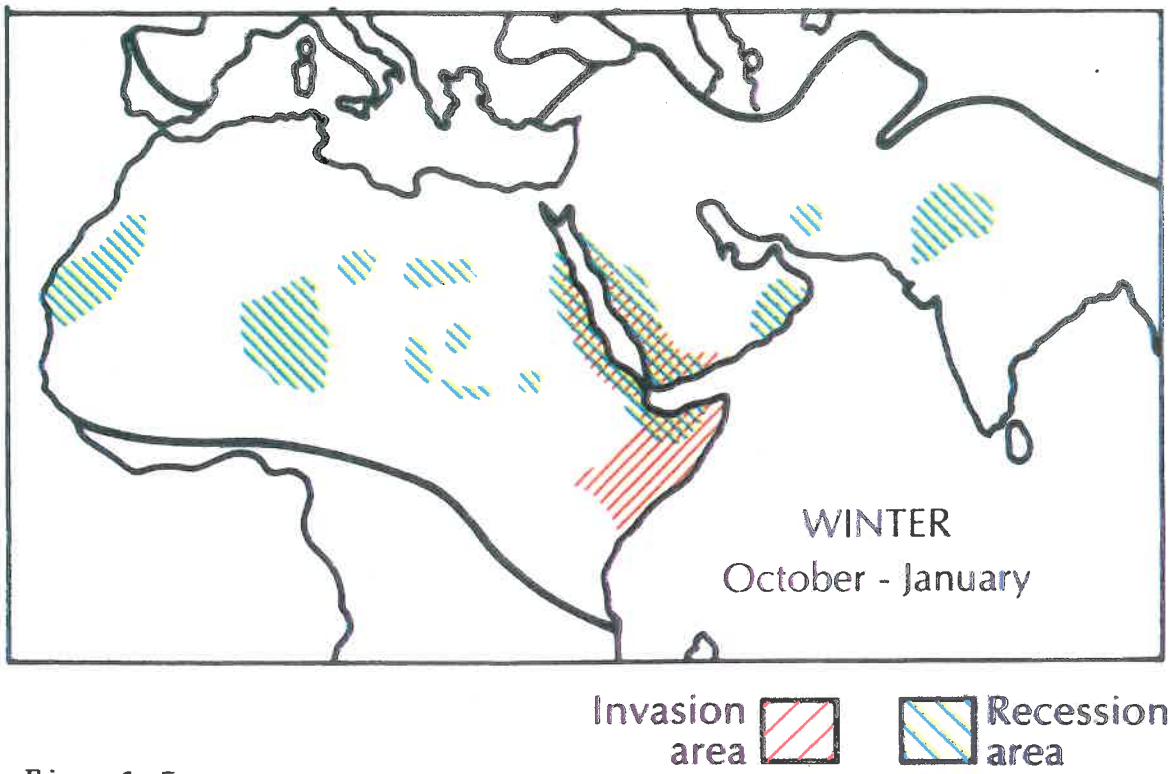


Fig. 1.5
This map shows the major seasonal breeding areas of the Desert Locust during plagues and recessions in winter, October–January. Source The Desert Locust Pocket Book (1990) 10pp.

downwind to the next or next but one breeding belt, and these imigrations usually result in seasonal translocation of entire swarming populations between complementary seasonal area, often thousands of kilometres apart.

1.4 SAUDI ARABIA

1.4.1 Desert Locust Plagues in Saudi Arabia

In examining the Desert locust plague in Saudi Arabia it becomes evident that winter breeding and spring breeding (Fig. 1.4 and 1.5) are very important for the insect multiplication.

Saudi Arabia is one of the countries included in the winter breeding grounds (Husni, 1965). Breeding depends on the winter rainfall of the Red Sea or the rainfall resulting from the Mediterranean Sea depressions. Swarms of locuts resulting from this breeding appear from late November to early April. They migrate to the north, north east or to the south to invade the spring breeding grounds. Therefore, swarms of this breeding season play a significant role in Saudi Arabia, as will be discussed later.

Spring breeding grounds include several countries most of which are near Saudi Arabia, such as north Africa and the Middle Eastern countries. This breeding depends on the winter rainfall of the Mediterranean Sea in the northern part of these grounds and on the rainfall of the Red Sea in the southern parts of these grounds; Saudi Arabia is located in the latter parts. Therefore, swarms of this breeding also play an important role in Saudi Arabia. There are certain ecological requirements for Desert locusts to breed and multiply, such as rainfall, temperature and humidity. According to Roffey and Pedgley (1981) rainfall is the most important requirement for breeding, because it creates, directly or indirectly, an environment suitable for all processes which together constitute breeding; these are maturation, egg laying, egg development and hopper development.

Rainfall provides moisture in soil for egg development. It was found that under laboratory conditions eggs of Desert locusts need to absorb approximately their own weight of water to complete their development (Shulov, 1952; Roonwal, 1954; Henler-Jones, 1964). In the field, eggs normally absorb sufficient water from the soil within a few days of laying, so that about 20mm of rain in a short period, or its equivalent in run-off, will provide adequate moisture for eggs to complete development (Roffey & Pedgley, 1981).

Such amount of rainfall is expected in the coastal and mountainous areas of Saudi Arabia during winter and spring; summer being the dry, hot season. Rainfall distribution in Saudi Arabia during 1988 is given in Figure 1.6.

Temperature is another important ecological requirement; it determines the rate of egg development as well as being the most important factor in determining the rate of hopper development (Roffey and Pedgley, 1981).

Duration of egg development, both in laboratory and field, is said to decrease with the rise in temperature (Rao, 1942, 1960; Hunter-Jones, 1966; Wardhough et al, 1969). Roffey and Pedgley (1981) concluded that the rate of egg development increases as temperature increases and Hunter-Jones (1966) also reported that under controlled laboratory conditions the increase is from 2.0% at 20°C to about 9.0% a day at 35-40°C. In summer, temperatures in some parts of Saudi Arabia exceed this latter range and may lead to desiccation and destruction of the eggs, if any laid during this season. Duration of hopper development, on the other hand was found to be 66 days and 20 days at 24°C and 38°C respectively (Roffey and Pedgley, 1981). The temperature range in Saudi Arabia during winter and spring is within 24-38°C, thus this is further evidence for the importance of winter and spring breeding seasons in locust

multiplication in Saudi Arabia. Figure 1.7 illustrates the temporal fluctuation of temperature in five regions in Saudi Arabia during 1988.

Other requirements for breeding and multiplication of Desert locust, which are of a great signficance in Saudi Arabia, are topography, soil type and vegetation.

Roffey and Pedgley (1981) reported that topography influences the grounds and time of breeding since upland areas often receive more rain than the surrounding lowlands and run-off can result in suitable breeding sites in wadi (valley) beds tens of kilometres downstream of areas where rain has fallen. This situation is similar to the coastal area of the Red Sea where the coastal mountain range receive higher rainfall than the lowland coastal plains, the latter usually flood during winter and spring by run-off from the mountains. According to Nakhlah (1965), breeding usually takes place in mountainous areas, where eggs are laid down in the sand pockets of the mountainous areas, and the hatched nymphs stay there until they reach an advanced stage of their life-cycle when they start marching and descending down to the lowlands and valleys. It is often the case that after workers having controlled and treated lowlands and valleys, they are faced with large groups of older nymphs marching down the mountains.

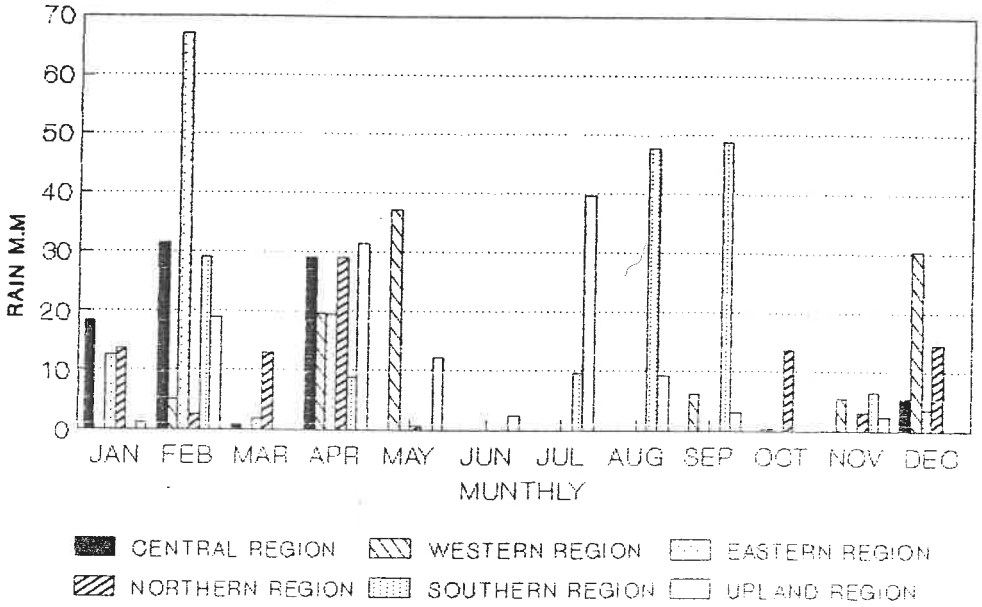


Fig. 1.6 Monthly maximum rainfall at different regions in Saudi Arabia during 1988 (data obtained from Ministry of Defence & Aviation, Meteorological & Environment Protection Department).

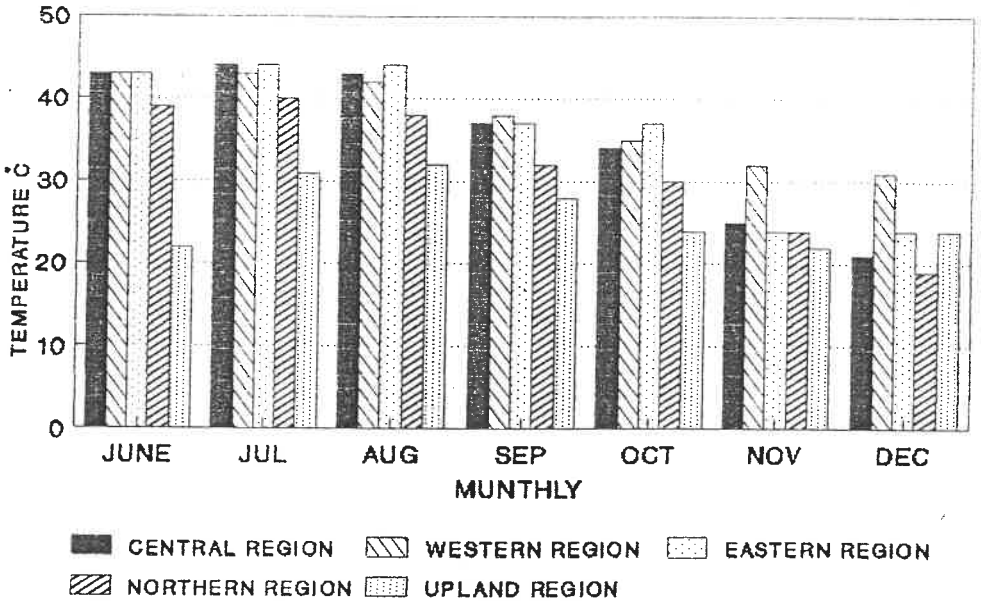


Fig. 1.7 Monthly maximum temperature at different regions in Saudi Arabia during 1988 (data obtained from Ministry of Defence & Aviation, Meteorological & Environment Protection Department).

The type of soil in Saudi Arabia, where locusts are found, is sandy to silty loam, accumulated from the run-off from the mountainous areas. These types of soil are the most favoured by females for oviposition. According to Nakhlah (1965), locusts need relatively loose humid soil to oviposit, and females never oviposit eggs in dry or compact soil. He also added that soils need not necessarily be sandy, since locusts can lay eggs in yellow or silty soils, such as flood areas or agricultural land adjacent to the desert.

The vegetation cover of an area also influences the settlement of the swarms before egg laying, the distribution and density of egg foods, and the behaviour of hopper bands (Roffey and Pedgley, 1981). Since vegetation flourishes in Saudi Arabia during winter and spring, due to rainfall during these two seasons, winter and spring breedings are the most important seasons for locust outbreaks.

1.4.2 Economic Importance

One of the earliest reports of locust outbreaks in Saudi Arabia mentions the 1914 plague, in which several thousand date palm were damaged by the Desert locust (Husain, 1965)

However, during the last twenty eight years there has been no Desert locust plagues in Saudi Arabia.

During these past three decades control of locusts using chemical insecticides has been carried out at alarmingly excessive rates, without paying much attention to the effect, or without knowing or realising the effects, of insecticides on human beings and the environment. Therefore, control of swarms of locusts has been rather successful in this context. However, recently the application of insecticides has been approached more scientifically and in a more environmentally friendly manner.

1.4.3 Desert Locust Invasion in 1988

(This section has been compiled from data published in Arabic by Agricultural Research Center, Jeddah, Saudi Arabia Bulletins No. 231, 232, 234, 235, 236, 237).

Due to the effect of the Indian Monsoon depression on the weather conditions of Saudi Arabia during July and August 1988 persistent rainfall had been recorded in several south-western areas of Saudi Arabia, such as Juzan, Al-Qunfudhah and Hijaz and Asir Highlands. In September, however, the country was under the influence of the Sudan

depression. All these favourable weather conditions helped to attract solitary locusts to the Al-Qunfudhah area and the north Yemen. The density of these solitary locust invasions were estimated at about 500 locust per hectare, and all invaded areas were identified and control operations launched immediately. These operations were successful in controlling this invasion, and the Kingdom was declared free from both solitary and swarm invasion of the Desert locust during August 1988.

During August air temperatures were high all over the country, the mean maximum temperature ranged between 32°C in the highlands to 44°C in the Eastern Region and the mean minimum temperature ranged between 16°C, also in the highlands, and 28°C in both Eastern and Western Regions. Rainfall was also heavy and frequent, as mentioned, above. Vegetation cover in Jizan areas was high and the weather conditions were appropriate for the development of swarms of Desert locusts, compared to the more inland areas of the country which remained very dry.

It is worth mentioning that many countries in Africa have reported having massive swarms of hoppers and adult locuts. These countries included the Sudan, Ethiopia, Chad, The Niger, Mali and Mauritania. Other regions affected by swarms of locust were the Yemen and India. It was then

anticipated that large swarms of Desert locust would invade Saudi Arabia during September/October and that Jizan and the Al-Qunfudhah had both become excellent environments for accomodating outbreak swarms. The Agricultural Research Centre (1988) demanded that all Directorate and divisions along the Red Sea Coast and inland ones to be alert and ready to control defined places of concentration. It was also anticipated that some swarms might be driven deep inland by atmospheric currents.

In early September 1988 the Kingdom was still free from the swarms of the migrating Desert locust. However, due to the effect of the monsoon depression on the country, which had brought about heavy rainfall, different instars of hopper were spotted on 21st September 1988, in the Al-Qunfudhah in an area of about 200 km^2 and a density of one locust per square metre. Control procedures were then undertaken and infested area was sprayed with Summithion and these insolated swarms were completely controlled by the end of September.

With regard to neighbouring countries, weather conditions were optimal for the reproduction of the locust population in the Yemen. The Gulf Cooperation Council (GCC) Countries, on the other hand, were reported free from both adult locusts and hoppers . In the Sudan, the situation

was very alarming due to the presence of a large number of massive swarms as a result of the emergence of the new instars, as well as the availability of suitable egg laying sites. About 281 thousand hectares were controlled in the Sudan in September 1988.

In Ethiopia, there existed hoppers in their last stages of moulting whereby huge losses resulted from these swarms; swarms had however, been controlled in several areas. Iraq was free from locust by the end of August 1988, and in India and Pakistan few scattered solitary swarms were spotted in the monsoon affected areas. The Western Coast of Saudi Arabia was invaded by massive swarms of the Desert locust migrating from east Africa on 13th October 1988. Swarms of Red Desert Locust were found covering Jeddah City and continued invading the country in substantially higher densities and numbers, than the country had witnessed for the past three decades. More than 350 swarms of Red and mixed locusts had been counted. Control procedures were undertaken, but some of these swarms escaped control and continued their migration towards the highlands of Asir and Hijaz. In the latter areas, control was only carried out in accessible areas, whereas in more rugged inaccessible areas, control procedures could not be undertaken. This resulted in some of the swarms migrating to more ecologically suitable areas for their reproduction, such as

the Al-Qunfudha and Jizan region where suitable grounds for egg laying were available. Newly hatched early instars were spotted on 1st November 1988, but were totally controlled and all egg laying grounds and hoppers were totally eliminated so that the country was declared free from egg fields and hopper by the end of November 1988, except for the swarms of locusts which continued their migration inland to other regions of the Kingdom. Controlled areas were estimated to have required about one million litres of various insecticides were sprayed, both aerially and by ground controlled teams.

Weather conditions, especially in Jeddah areas during November 1988 were suitable for growth and breeding of the Desert locust where the mean maximum and minimum temperatures were 21°C - 34°C and the highest and lowest relative humidities were 50% and 89% respectively. Repeated heavy rainfall was recorded in the regions of the Al-Qunfudhah, Taif, Jizan, Asir, Bader, Medinea, Amloj and Tabuk during November 1988.

The vegetation cover during October and November 1988 of the area between the Al-Qunfudhah to the north and the Saudi-Yemen border to the south is one of the best localities for the maximum growth and breeding of the Desert locust. This area includes a strip 500 km long and

50 km wide; that is 25,000 km^2. However, after the heavy rainfall on the areas between Jeddah to the south and Tubuk and the Al-Jauf to the north, these areas also become suitable for the development and reproduction of the locusts.

The situation of the Desert locust swarms invasion to Saudi Arabia during October to November 1988 can be summarised as follows:

1. Jeddah Region. Swarms of Red Desert Locust started reaching Jeddah City by 13th October 1988 and continued until the end of November 1988. Twenty swarms had been controlled in an area of 19,900 ha, that is an average area coverage of more than 1,000 ha per swarm. A total of 9, 950 litres of various insecticides, that is a rate of 0.5 l per hectare, were used.

   The area around Rabigh was also invaded by fifteen swarms of locust in October and November 1988. Covering an area of 14,000 ha. Also, a rate of 0.5 l per hectare of insecticides was sprayed as a control measure.

2. Makkah Region. Fifteen swarms had been recorded over an area of 81, 600 ha and were controlled by spraying 40,800 litres of various insecticides.

3. Khuhaisa Region. This area had been invaded by some swarms which were controlled in an area of 500 ha using 250 litres of insecticides.

4. Al-Qunfudhah Region. This region had been invaded by swarms of Desert locust from South Africa as well as to swarms from the highland areas. Some of these swarms laid their eggs in the following locations (Table 1.1):-

   Egg laying grounds were identified and the emergence of the hoppers at the Al-Burak were spotted 1st November 1988, and hoppers continued emerging in the above mentioned locations, whereby they were controlled with different types of insecticides and all egg laying grounds and hopper spots were completely eliminated on 1st December 1988. The Al-Qunfudha region become free from egg laying ground and hoppers.

   The total controlled area was 110,000 ha using 55,000 litres of various insecticides.

   A total of 104 swarms of the mature adult Red locusts reached this area, that is a rate of 2,000 ha per swarm over an area of 204,050 ha, which were controlled by using 102,025 litres of various insecticides.

5. Taif Region. This region was invaded during October and November 1988 by thirty swarms of locusts.

Covering an area of 46,750 ha. Area mass sprayed at a rate of 0.5 l of different types of insecticides per hectare.

6. Jizan Region. Jizan Region was invaded by returning swarms of locusts from Asir Highlands and some of the swarms managed to lay eggs in the following locations (Table 1.2):-

   This area was controlled by spraying 75,000 l of various insecticides. Also controlled were 58 swarms of mixed locusts in an area of 107,300 ha using 53,650 l of various insecticides.

7. Madinah Region. Madinah regions were invaded by swarms of the Red locust during October and November 1988, where 30 swarms were recorded covering an area of 71,750 ha, with an average of more than 2,000 ha per swarm.

8. Al-Baha Region. Al-Baha regions were invaded by twenty swarms of Red locusts during October and November 1988 at an area of 1,500 ha per swarm.

9. Asir Region. This region was invaded by a total of 20 swarms covering an area of 33,500 ha whereby 16,750 l of various insecticides were used to control these swarms.

10. Tabuk Region. A total of 10 swarms of Red Desert locusts invaded this region during November 1988 over

an area of 17,500 ha and were controlled by spraying 0.5 l of various insecticides per hectare.

11. Ar'ar Region. A swarm of Red Desert locust invaded this region during November 1988 covering an area of 2,000 ha. A thousand litres of insecticides were used to control this swarm. A total of 517,125 litres of eight kinds of insecticide were used to control the Desert Locust swarms during October and November 1988 (Table 1.3).

Table 1.1 Areas of Egg Laying within Al-Qunfudhah Region

Location	Area (ha)
1. Bilad Bani Dheeb	40,000
2. Wadi Shafiga	20,000
3. Jabal Lani	10,000
4. Al-Bink	30,000
Sabt Al-Jarah	10,000
Total	110,000

Table 1.2 Areas of egg laying within Jizan Region

Locations	Area (ha)
1. Al Shaqiq	25,000
2. Al-Darb	15,000
3. Baish	35,000
4. Al-Darb-Abha triangle	10,000
5. Abu Arish	60,000
Total	145,000

Table 1.3 Insecticides used and their quantities during October and November 1988

	Type			Quantity (litres)
1	Sumithion Super	100%	ULV	124,550
2.	Fenitrathion	96%	ULV	50,000
3.	Volaton UN	300	ULV	46,225
4.	Volaton	930	ULV	38,525
5.	Decis	12.5	ULV	127,600
6.	Karate	40	ULV	50,000
7.	Dursban	240	ULV	35,200
8.	Ficam	200	ULV	45,025

Desert locust were still breeding and multiplying in the winter breeding grounds in Mauritania, Senegal, Mali, Sudan, Chad, Morocco, Algeria, Libya, Egypt and the Yemen. In the light of this there still existed the possibility of the arrival of Desert locust swarms to Saudi Arabia until the end of May 1989. Bulletin No. 234, Published by the Agricultural Research Centre in the Western Region (1988) obliged all branches and Directorates of the Ministry of Agriculture and Water to place their areas especially the interior under strict surveillance to control any invasion in the future.

During December 1988 the Red Sea coasts of Saudi Arabia was also subjected to further invasion by swarms coming from east Africa region, some of such continued their migration to the interior. Some areas were invaded by young swarms coming from the breeding grounds in Ethiopia control procedures were promptly carried out in all areas invaded by these swarms. A total of 112,790 hectares were controlled using 78,260 litres of various insecticides.

Several neighbouring countries in east and west Africa and the Middle East were also reported as infested to heavily infested with locust swarms.

The possibility of invasion of the Saudi Arabia and interior regions still existed by swarms from east Africa during January and February 1989 therefore, surveillance and control procedures were continued to eliminate swarms as soon as they arrived in the country.

By the end of January 1989 Desert locust swarms were considered to have been totally destroyed. Egg laying grounds and hoppers were also controlled whereby the nymphs had no chance to reach the adult stages and to produce further generations. More than one million hectares had been sprayed

Some of the interior areas of the Kingdom were reported to have solitary locust infestation in low densities. It was still anticipated that Saudi Arabia would be invaded by swarms resulting from the winter breeding generation in east African countries.

In February the Kingdom of Saudi Arabia was declared free from Desert locust and hopper swarms.

1.5 ECONOMIC IMPORTANCE

Swarms of the Desert locust have plagued as mentioned earlier agriculture from the earliest recorded times.

Desert locust tend to consume about their own weight of fresh vegetation each day. The amount increases from about 20mg at the beginning of the first instar to about 1.5g in the middle of the fifth instar (Delassus, 1931). According to Wies-Fogh (1952), actively migrating immature adults need to eat at least their own weight (2-3g) of fresh vegetation each day, and possibly three times as much as mature adults, but then their food consumption declines. Females consume less than males (Davey, 1954). Since swarms contain about 50 million individuals per square kilometre, even a moderate sized swarm measuring 10 Km^2

would consume about 1,000 tonnes of fresh green vegetation per day on migration.

Desert locust feed on a very wide range of plants and inflict considerable damage to vegetation by cutting through the stems and leaves that are not actually eaten, as well as breaking branches with their weight when densely settled.

Because swarms are so mobile there is great variation in the amount of damage caused seasonally, from one country to another and from region to region. The greatest recorded crop losses occur when young migrating swarms of immature adults reach cultivated areas. Examples of crop losses caused by Desert locusts are shown in Table 1.4.

Table 1.4 Crop losses due to S. gregaria

Source, The Locust and Grasshopper Agricultural Manual, (1982) 311 pp.

YEAR	COUNTRY	CROP OR ESTIMATED VALUE OF CROPS LOST (£ STERLING)
1926-34	India	£400,000 annually (Uvarov & Bowman, 1938)
1928-29	Kenya	£300,000 annually (Uvarov & Bowman, 1938)
1944	Libya	700,000 vines (ALRC 1966)
	Sudan	£390,000 (Maxwell-Darling, 1948)
1950	India	£2,000,000 (FAO 1958)
1952	Pakistan	£3,850,000 (FAO 1958)
1953	Somalia	£600,000 (ALRC 1966)
1954	Sudan	55,000 tons grain (ALRC 1966)
1955	Morocco	£4,780,000 (FAO 1958)
1957	Senegal	16,600 tons millet (Mallamaire & Roy, 1959)
	Guinea	6,000 tons oranges (Mallamaire & Roy, 1959)
	Tunisia	£900,000 (FAO 1958)
1958	Ethiopia	167,000 tons grain (Vayssiere, 1959)
1962	India	4,000 ha (10,000 acres) cotton (ALRC 1966)

For the nine year period 1949-57 the FAO estimate of the total value of crop damage in 12 countries out of 40 subject to invasion, was £15 million (FAO 1958); the rest (28) suffered no appreciable damage in these years. Due to the fact that much agriculture within the Desert Locust

area is subsistence farming or grazing, for which very few damage statistics are available, the total damage caused by S. gregaria was undoubtedly greater than indicated above. This is particularly reflected in an analysis of damage reports: these show that only 8% referred to hoppers, which occur mainly in the less intensively cultivated and under-reported areas (Bullen, 1966).

Little damage has occurred since the end of the last major plague in 1963, largely due to the efforts of national and regional organisations established to prevent plagues. (Locust and grasshopper agricultural manual 1982).

1.6 DESERT LOCUST CONTROL

1.6.1 Introduction

Control of pests is achieved through applying different techniques using a variety of chemical, physical or biological agents.

Effective control for locusts and other pests are of recent origin; having started with the development of synthetic insecticides which helped with the need to spray vast areas, even remote, inaccessible ones, in a very short

time. The latter ensures the destruction and elimination of these pests and their breeding and egg-laying grounds. In other words control of locusts has become a practical proposition (Chapman, 1976).

1.6.2 Traditional or Old Methods of Control

Farmers had been using very primitive methods of controlling locusts until the beginning of the twentieth century. One of these methods, that of controlling locusts by mechanical means, was only applicable to the relatively immobile nymphal stages. Nymphs were beaten to death by gangs of people using sticks and branches. Only when the situation permitted were nymphs destroyed by burning. To achieve this, barriers were erected in the path of advancing nymphal bands, thus directing them into pits where they could be burnt. However, although such methods achieved some success on a very local scale, they were rather expensive in terms of labour and resources. Adult locusts were only controlled by trying to frighten them away by setting fires or making as much noise as possible (Chapman, 1976).

Other primitive approaches, but far less practical, were to call on the gods for help. This was due to the belief then that locusts, and other pests, were commonly regarded as a

divine punishment meted out on the sinful (Chapman, 1976). Control was thought to be achieved by hanging charms in the field or by performing rather more sophisticated and complicated rituals.

1.6.3 Modern Methods of Chemical Control

Control of locusts only became a more effective and practical proposition with the advent of appropriate poisons. The earliest chemical poison ever used was sodium arsenite. Such poisons were only effective when they had to be mixed with bait material palatable by the locusts or attractant to them, such as wheat bran. Baits were either used dry or wetted with water. The arsenite was then replaced by benzene hexachloride (BHC), followed by other synthetic insecticides. The high cost of the bait material and its transport in bulk quantities to remote areas for its use, were the main reasons why the use of bait was abandoned and cheaper direct application of the poison was adopted.

Modern insecticides are now widely applied to control locusts, however, their efficacy varies considerably with some of them many folds more effective than others in destroying locusts (Ahmed, 1968; Chapman, 1976; MacCauig, 1983; Akhtat et al, 1987; Steedman, 1988; Symmons et al,

1989; Dent, 1991). Some of the insecticides and their efficacy are given in Table 1.5.

Table 1.5 Efficacy of different insecticides against locusts and their toxicity to mammals

Class of	Name	Toxicity to locusts (LD_{50}* in mg/g) Schistocerca locusta	Toxicity to rats (LD_{50}* in mg/g) oral	dermal
Organochlorine	Y-BHC	92- 7	90	900
	dieldrin	5 2	46	10-102
	DDT	100 100	115	2500
Organophosphate	Fenitrothion	5 2	250	200
	malathion	31 24- 48	2800	4100
	parathion	2 1	4- 13	9- 21
Carbamate	carbaryl	25-37 --	850	4000

*LD_{50} = The dose which when applied to a group of animals kills 50% of them. Source Chapman (1976)

In practice, the use of an insecticide depends on its other properties, particularly its persistence, its mammalian toxicity and on its cost (Chapman, 1976). Parathion, for example, though highly effective in killing locusts, is highly toxic to man, therefore it is not a safe insecticide to use in locust control.

There are two modes of action of insecticides in killing locusts, namely by direct contact with the outer surface and subsequent absorption through the cuticle or by injection with the food and adsorption through the gut. For direct contact the insecticide should be highly toxic, but not necessarily persistent. For direct ingestion, persistence of the insecticide is of prime importance, as it should persist longer on the plant so that more locusts are likely to be killed. This method is effective against relatively static locust populations flying swarms should be treated with a contact knock-down poison (Chapman, 1976). The insecticide most commonly used to control locusts are BHC and dieldrin, however, others such as malathion and other insecticides mentioned earlier are used in Saudi Arabia.

1.6.4 Mode of Pesticide Application

Insecticides are applied in different ways, for instance, they are applied as dust, or more usually as solutions or emulsion in water or oil using mechanical pumps or sprayers. Spraying can be applied using two different techniques. These are: target spraying whereby the spray is aimed directly at the locusts, or drift spraying in which wind is used to drift the insecticide over the general area occupied by the locusts. In the past a wide

range of insecticides have been used successfully in baiting, dusting and spraying (Ahmed, 1968). The merits and demerits of each technique have been reviewed and discussed by Rainey (1958). Target spraying can be employed at any time and the dispersal of poison can be limited or minimised; however, its great disadvantage is that a thorough search locust is necessary in order to locate all bands of locusts, and this is almost impossible to carry-out effectively in difficult terrains, especially in inaccessible ones. Chapman (1976) reported that an average of 4.7 ha per day could be sprayed to control Red Locusts nymphs.

The drift technique, using spraying machines, on the other hand, is more effective and rapid procedures whereby 12.5 hectares could be sprayed per hour. However, the blanket spraying of large areas is only justified if the locust populations are dense and fairly continuous.

With drift spraying methods from ground as well as from aircraft, the size of droplet produced by the sprayer is critically important. Too large a drop falls to the ground rapidly where too small a drop can be carried up by rising air currents and lost entirely. So the size of the drop has to be regulated by using an appropriate spray nozzle. This has been solved with the development of 'Ultra low

volume (ULV) spraying' techniques for 'vegetation baiting' both by air and ground equipment (Sayer, 1959). Concentrated oil solutions of insecticide (dieldrin) were used as an outstanding insecticide for the control of hopper bands in their breeding areas using the ULV spraying techniques (Sayer, 1959; Courshee, 1959, 1963; Rainey, 1963a; Ahmed et al, 1964). However, according to Ahmed (1968), dieldrin is a slow active poison, highly persistent to mammals and, therefore, not very safe.

Recently, Symmons et. al. (1989) controlled Desert locusts with bendiocarb. For this purpose they sprayed the locusticide from vehicle-mounted spinning sprayers. This procedure also utilised the principle of ULV spray techniques. Chapman (1976) reported that a potentially more efficient means of controlling locust nymphs, but one that has been little tried, is by barriers or lattice spraying. The principle is to spray a series of strips of vegetation with a persistent poison which is eaten by the locusts as they move through them.

Biological control of locusts can also be used since locusts have many natural enemies. However, their practical use in locust control is unlikely for three reasons (Chapman, 1976):

1. Locusts occur in vast numbers
2. They are highly mobile
3. Their occurrences are irregular

Hence, for parasites or predators to be effective they must either be released into the locust population in vast numbers matching those of the locusts themselves or that their populations must build up rapidly so that they can combat the huge locust population. The proposition is not practical since it is not possible to mass rear the numbers of parasites and predators in large numbers or keeping them alive until locusts appear. (Chapman, 1976)

The use of micro-organisms in biological control of locusts seems a more practical proposition. Fungi such as Mettarrhizium can be mass produced and stored and then applied in the same way as insecticides. However, fungal spores only germinate under specific conditions of high humidities and moderate temperatures. As these conditions cannot be controlled, therefore the use of fungi as controlling agents seems unlikely. Protozoa are also known to kill locusts and their development is less dependent on environmental conditions. An example is the outbreak of Malameba locustae which prevented an expected outbreak of the Brown locust in South Africa (Chapman, 1976).

1.7 Aims of the Study

The aim of the present study is to develop an effective economic method to control swarms of the Desert locusts, especially the nymphal instars with the use of conventional insecticide techniques by study of insecticide spray droplet deposition and deposit transfer to walking locusts. The research will determine the effect of age of locusts, the temperature and surface characteristics on the effectiveness of deposit transfer and subsequent locust mortality. This information will identify the most appropriate age of the nymphs at which to target the control measures, such that these measures be more economic and cost effective requiring much less effort to control the large numbers of insects in a swarm ie. between 90.0 and 100% of the swarms. The adoption of improved application rates derived from the study will preserve the environment where control measures have taken place, since current procedures involve using large quantities of insecticides that not only destroy large swarms, but have adverse negative effects on the environment, such as destroying vegetation cover and subsequent effects on livestock and wild life.

In other words, the study aims to establish the most appropriate or 'ideal' method for controlling the swarms of locusts after reaching the breeding areas, as well as knowing the best age of the locusts and air temperatures to start the control operations by using insecticides, such as ULV Malathion in control operations against locusts.

CHAPTER 2

TERMINOLOGY AND BREEDING METHODS

2.1 TERMINOLOGY AND LIFECYCLE STAGES OF SCHISTOCERCA GREGARIA (FORSK)

Having mentioned in chapter one the different instars of locust development, it is worth describing the normal life cycle of the Desert Locust with reference to terminology to avoid confusion over the different terms used.

Eggs tend to be laid in moist sand in groups, with 50 to 80 eggs in each group. Such groups of eggs, also called pods, hatch after about a fortnight's incubation producing hoppers. Hoppers that emerged are known as 'hatchings' for the first 24 hours after occlusion under normal conditions. There are five moults during this stage (the hopper stage) and consequently, there are five nymphal instars. It takes more than a month, depending on the temperature after hatching, for the nymphs to undergo their fifth and last moult to become adults. This last moult is referred to as an 'emergence'.

After their emergence the adults start increasing in weight and undergo a change in colour from pink to pale brown, males firstly becoming bright yellow rather than pale

brown. Adult locusts reach their sexual maturity after about two weeks. Whereby they start reproducing. Females at this stage, lay a clutch of eggs, three times approximately each seven days for the remainder of their life which normally lasts another four or five months. A small proportion of adult females may survive even longer. Fig. 2.1 illustrates the stages of life-cycly of S. gregaria.

2.2 MAINTENANCE OF STOCK CULTURE

A stock of fifty insects of both sexes of Schistocerca gregaria were obtained from a culture at Queen Mary College, University of London in April 1990.

The culture, from which this stock was derived was obtained from the wild type about 15 years ago. The culture was maintained at a temperature regime of 28° to 34°C, which varies during the day due to the light within the cage but the base temperature is constant at 28°C when the lights are off; humidity is maintained at 55 to 60% RH and daylight regime of 12 hours light and 12 hour dark (Dr L J Goodman, pers. com.).

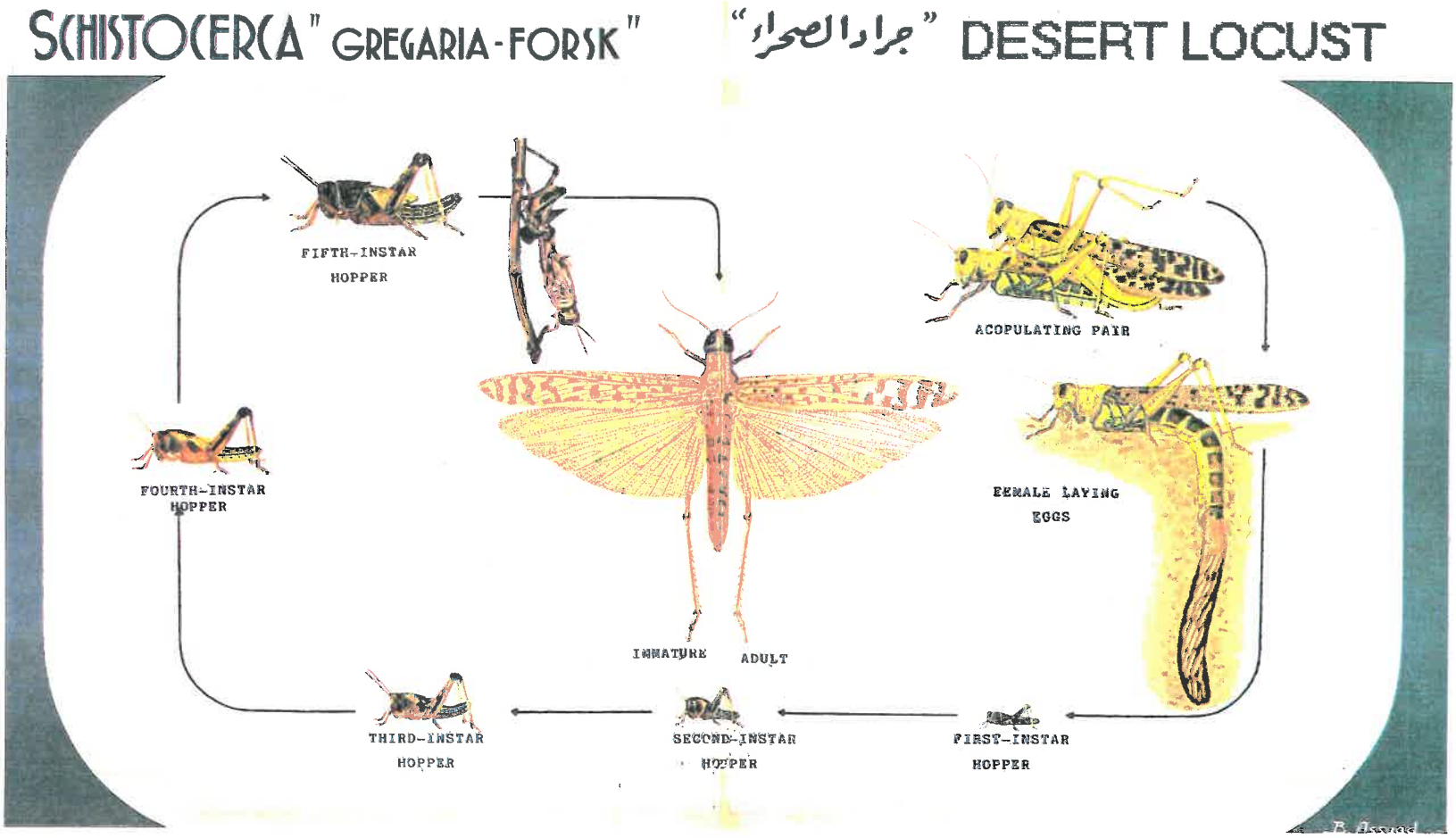


Fig. 2.1 Illustrates the stages of life-cycle of S. gregaria. Source Lectures of the Fourth Desert Locust Training Course, UAR, (1965). 27,28pp.

2.3 BREEDING AND MAINTENANCE OF EXPERIMENTAL STOCK

The stock of insects were kept at Cleppa Park Field Research Station, in cages of dimension 38 x 38 x 51 cm (Section 2.4). The locusts were fed daily on a diet consisting of cabbage, grass and Quaker Oats. The temperature inside the cage was maintained between 22°C to 36°C on a daily cycle. The first batch of eggs were obtained four days after placing the adult stock inside the cage. These eggs were incubated at 28° to 33°C and they hatched after 16 to 18 days of incubation.

The hatched nymphs were then put in a cage and the cage transferred to culture room also maintained at 22° - 36°C. Nymphs were also fed on the above diet. The average development time for hoppers to reach sexually maturity is approximately 52 days.

Once the culture had become established experimental work started.

2.4 DESCRIPTION OF CAGES

Four cages were prepared (see Figure 2.2) and were kept in a culture room measuring 250 x 200 x 200 cm (see Figure 2.3) A diagram of the cages used is given in Figure 2.4.

Each cage had an accommodation capacity of 300 locusts.

Each cage measured 38 x 38 x 51 cm of aluminium angle strips lined with hardboard sides, back and roof of the cage. The floor was false, made of perforated zinc, in order to promote ventilation of the cage. Extending from the false floor to the roof, was a glass observation window. A trap door was cut into the roof, 18 cm diameter, to permit the introduction of food, removal of waste or the handling of the locusts. A light bulb (60w) was fixed on the inside back of the cage to maintain the temperature inside the cage at between 22° to 36°C. These bulbs were controlled and operated by an automatic switch timer, whereby day to night regime was maintained at 18:6 h in winter and autumn, 16:8 in spring and 14:10 in summer. This light regime was found efficient to maintain temperature inside the cage within the range given above throughout the year. However, although varying the light regime controlled temperature there was obviously some

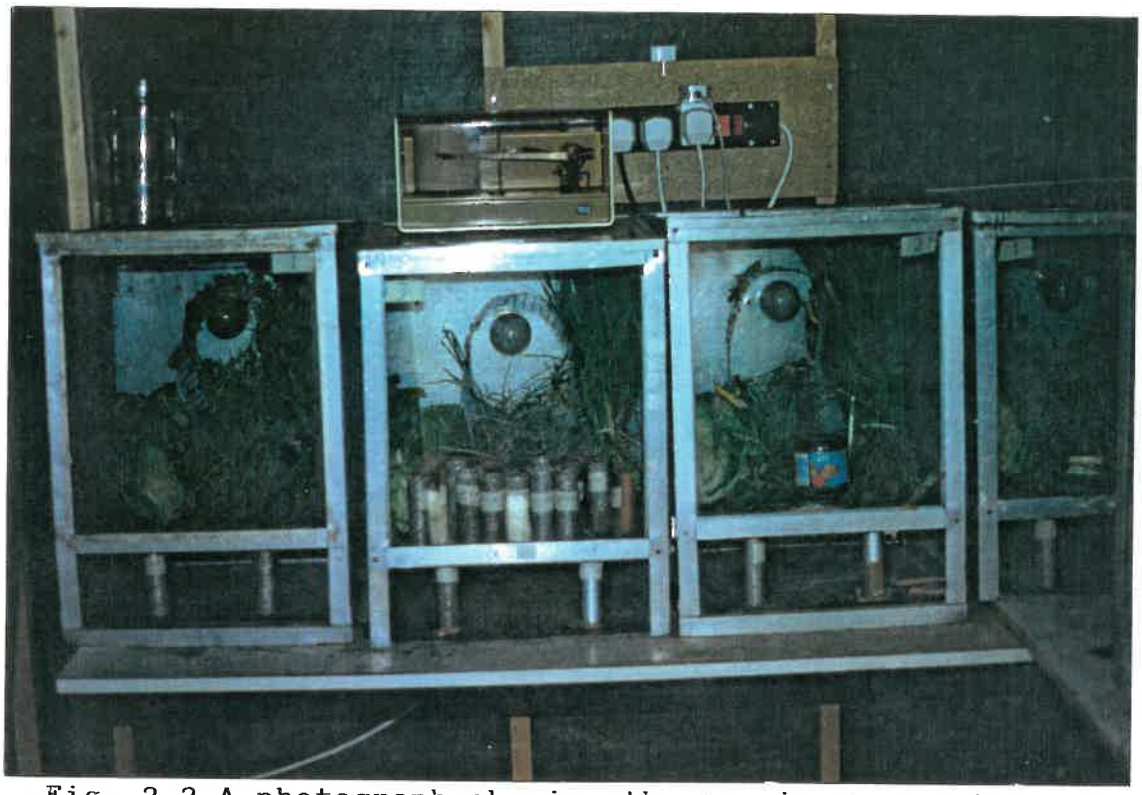


Fig. 2.2 A photograph showing the rearing cages in a culture room.

Fig. 2.3 A photograph showing the culture room at Cleppa Park Field Research Station.

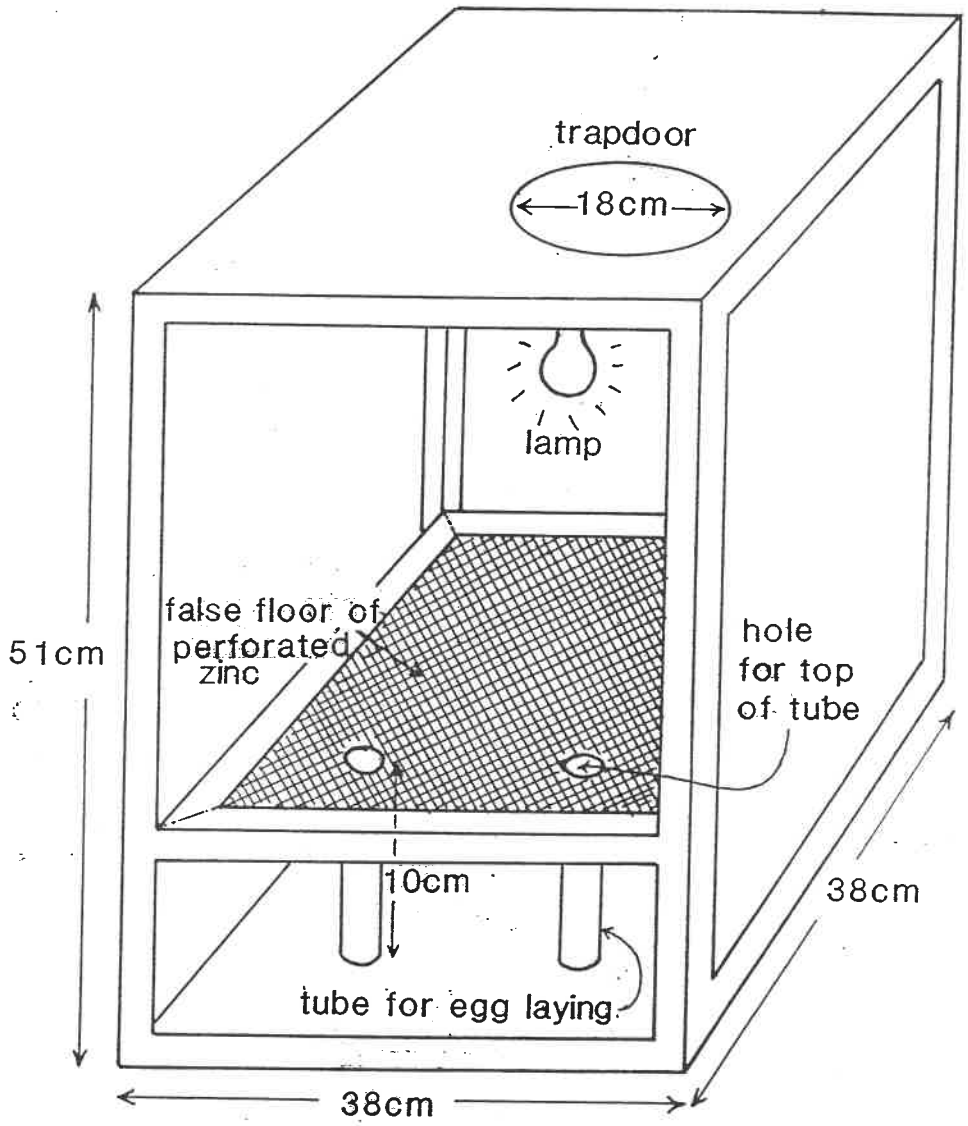


Fig. 2.4 A diagram of the cages used for breeding/rearing.

concern over whether changing photoperiod influenced insect behaviour.

Each cage was filled with two tubes on the false floor for locusts to lay their eggs. Sand was left inside the cage and changed daily. Food consisted of about 500g of cabbage and grass with some Quaker Oats placed in a petri dish. Humidity inside the culture room was maintained at 60 to 85%.

2.5 DISCUSSION

Diurnal activities of locusts seem to be directly stimulated by light and inhibited in darkness. A similar observation was given in the literature by Edney (1937) quoted in Uvarov (1966). Uvarov (1966) maintained that the general activity of adult locusts kept in alternating 12 hour periods of light and darkness was high during the light periods, and very low or none at all in the dark. This was so irrespective of whether of this artificial periods coincided with the day and the night when a locust conditioned to the 12 hour alternation of periods of light and darkness was kept continuously in darkness, its induced activity rhythm continued for a few days but the activity became gradually distributed more equally over 24 hours.

Odhiambo (1966), confirmed the association of high levels of activity with light periods adult male of Schistocerca. Similar information was given by Chapman (1954) for hoppers of locusts. Cassier's (1965) (quoted in Uvarov, 1977) experiments on light reactions of locusts of all stages and phases of development confirmed previous views that photokinetic responses are due to stimulation of the ocelli. When all the ocelli were blackened the insects were immobilised, and partial covering of the ocelli reduced the responses. According to Bayramoglu-Ergene (1966) (quoted in Uvarov, 1977), photokinesis is reduced also by amputation of the antenna. Cassier has shown further more that responses to light depend on variations in neuro secretory activities (Uvarov, 1977) showed that the periods when sensitivity is higher correspond to greater activity of the corpora allata. Uvarov (1967) concluded that responses are greatest during the first half of each inter-moult period, during the maturation of successive cycles and in old females. Uvarov also reported that a very significant finding by Cassier was that solitarious locusta, which fly by night, were much more sensitive than gregarious ones, which might be related to the higher neurosecretory activity of the Corpora allata producing juvenile hormone in the solitarious form. Uvarov also maintained that the effect of ecdysone produced by the thoracic glands is, apparently, the opposite reducing the

activity level; the general hormonal balance is thus finally responsible for the behaviour reactions. Cassier (1965) (quoted in Uvarov, 1977) found that covering the compound eyes of locusta with paint produced evidence that they play no part in stimulating locomotion, but are responsible for photostatic orientation, that is movements towards a source of light which are well know in acridoids (Fraenkel, 1929; Grasse, 1922; Uvarov, 1967). Cassier maintained that the precision of the orientation depends on the number, length and pigmentation of ommatidia; all of which change during hopper and adult life; precision improves with the growth of hoppers and also with the age of adult females, but deteriorates in adult males, due to the greater pigmentation of the males' eyes. The difference in the degree of pigmentation in the eyes of locusta in the extreme phases is very little, whereas there are striking phase differences of eye pigmentation in Schistocerca (Uvarov, 1966). There is also evidence that locomotory activity is increased by starvation (Uvarov, 1977). Ellis (1951) showed that there is a marked increase in marching activities of caged locusta hoppers which corresponded to a decrease of food in the alimentary canal. Aziz (1961) also showed that Schistocerca hoppers spent longer time in locomotion after being starved for 24 to 39 hours than did normally fed hoppers. Moorehouse (1969) reported that locomotory response of Schistocerca hoppers

to airborne grass odour was temporarily abolished by feeding. Kennedy and Moorehouse (1970) found that grass odour had a strong kinetic effect, however, the observed movement towards the source of the odour was due to positive anemotaxis.

The researcher found out that due to the fact that the garden shed, where breeding cages were kept, was not tightly sealed, thus the external temperature affected that inside the shed. Therefore, it was decided to increase the photoperiod inside the cages to maintain the temperature within a range of not lower than 22°C and not exceeding 38°C throughout the year. The following photoperiod regimes were adapted: in autumn and winter, 18l and 6d; in spring, 16l and 8d and in summer, 14l and 10d. These photoperiod regimes did not seem to affect the development of the insects. Evidence for this is i) the external morphology of the locusts was of the gregarious phase, ii) the number of moulting instars were five and iii) the period between final moulting to the sexually mature adults was more than two weeks.

However, some variation in the colour of the fourth and fifth instar hopper was noticed. In this case, hoppers acquired a light yellow colour in winter when the photoperiod was long. This colour deepened during spring

and summer when photoperiod was shorter than in winter. This was the only morphological effect noticed by the researcher; other behaviours appeared normal.

CHAPTER 3

WALKING SPEED OF ADULTS AND NYMPHS OF S. GREGARIA, ON DIFFERENT SURFACES AND TEMPERATURE REGIMES

3.1 INTRODUCTION

Adults and nymphs of the Desert Locusts are known to orientate themselves while marching in a specific direction. According to Uvarov (1977), there has been much controversy on the subject of the factors which determine the direction of marching, but wind and sun has been favoured by most authors though opinions as to their actual role in determining orientation differ greatly.

Experiments on the different factors, such as wind, light and odour, affecting the movements of the locust population have been carried out for several decades and results are well documented in the literature (Clark, 1949; Davies, 1969; Haskell et al, 1962; Kennedy, 1945; Kennedy & Moorehouse, 1969; Moorehouse et al, 1978, 1990).

Norris (1968) and Moorehouse (1971) reported that the behavioural response of the Desert Locust to an olfactory stimulus from host plants alters with different physiological states. They showed that hungry nymphs react by walking quickly upwind to the odour source whereas

replete basking nymphs, at low wind speeds, show no behavioural changes and a female about to oviposit will move away from the scent of the host plants to lay eggs. Moorehouse (1971) showed that hungry nymphs responded nearly every time they were stimulated by rapid movements which brought them quickly to the odour source. Replete nymphs, on the other hand, remained under experimental conditions, in basking groups, but they suddenly switched to reacting like hungry nymphs after one to four hours of food, and continued to react in that way for anything up to 18 hours or more. Moorehouse (1971) also tested the effects of changing potassium content of food and of endocrine gland on nymphs feeding patterns. He concluded that potassium, within normal limits, did not influence feeding behaviour pattern and that the effects of the endocrine glands could not alone account for the observed changes in behaviour associated with feeding. He maintained that increasing blood volume affected the response of the nymphs.

Also, from the researcher's experience and observations in the field, locusts were found to walk in the direction of sun ie. light when they were hungry. Direction and speed of walking were also found to be maintained and increased when there was light wind blowing in the direction of the sun. It is for these reasons that the researcher applied

his experience and field observations in this work using a wind tunnel for this purpose. Subsequently, this experiment has been designed and was carried out to study, the significance of walking speed of the Desert Locust at five temperature regimes on four different kinds of surfaces, sand, arable soil, grass and glass, while utilizing their natural response behaviour to light and air movement.

3.2 MATERIALS AND METHODS

3.2.1 Experimental Animals

Immature locusts and second-, third-, fourth- and fifth-instar hoppers were used in this experiment. The experiment was carried out using a wind tunnel (section 3.2.3).

Ten sexually immature adults of both male and female locusts, and ten hoppers of each of the above mentioned instars were removed from the cages at 10.00 am. ie. two hours after the daylight period started, and these individuals had ceased feeding. They were kept for one hour in an incubator maintained at 28 - 33°C and a relative humidity of 60 - 70%, to adapt and acclimatize to the

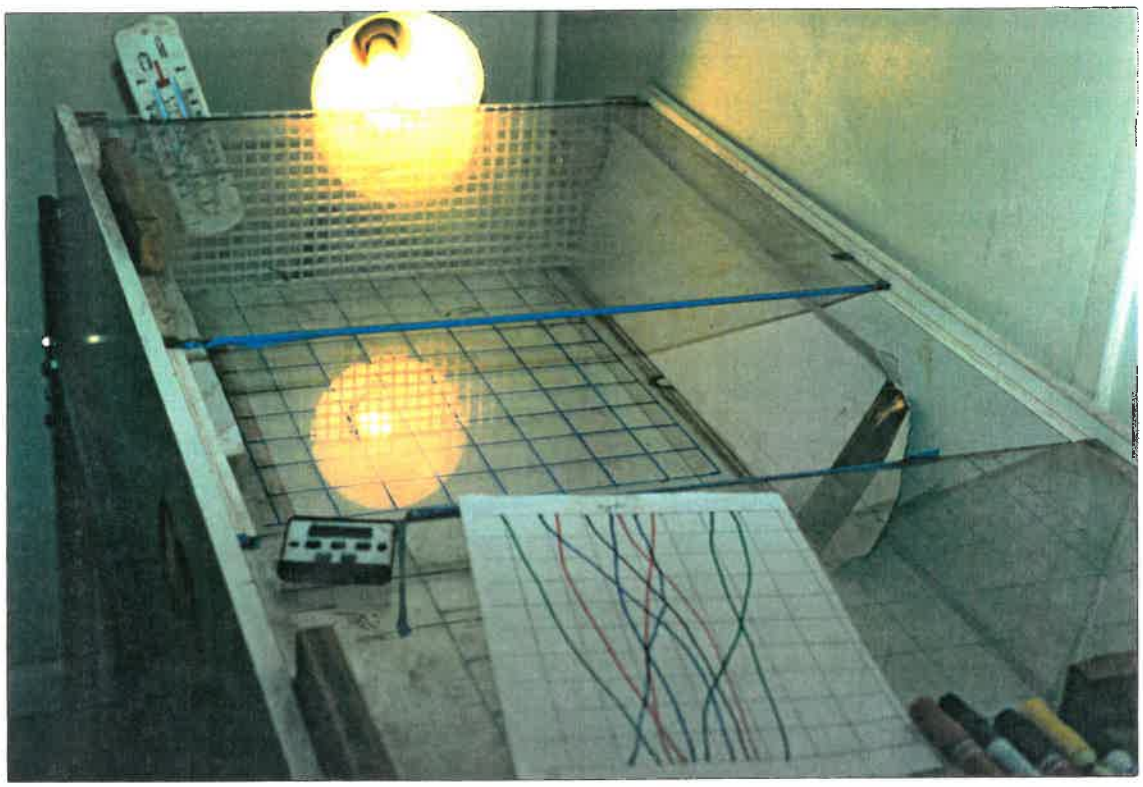


Fig. 3.1 A photograph showing the wind tunnel and acetate paper sheets used in this experiment.

Fig 3.2 A photograph showing the wind tunnel used in this experiment.

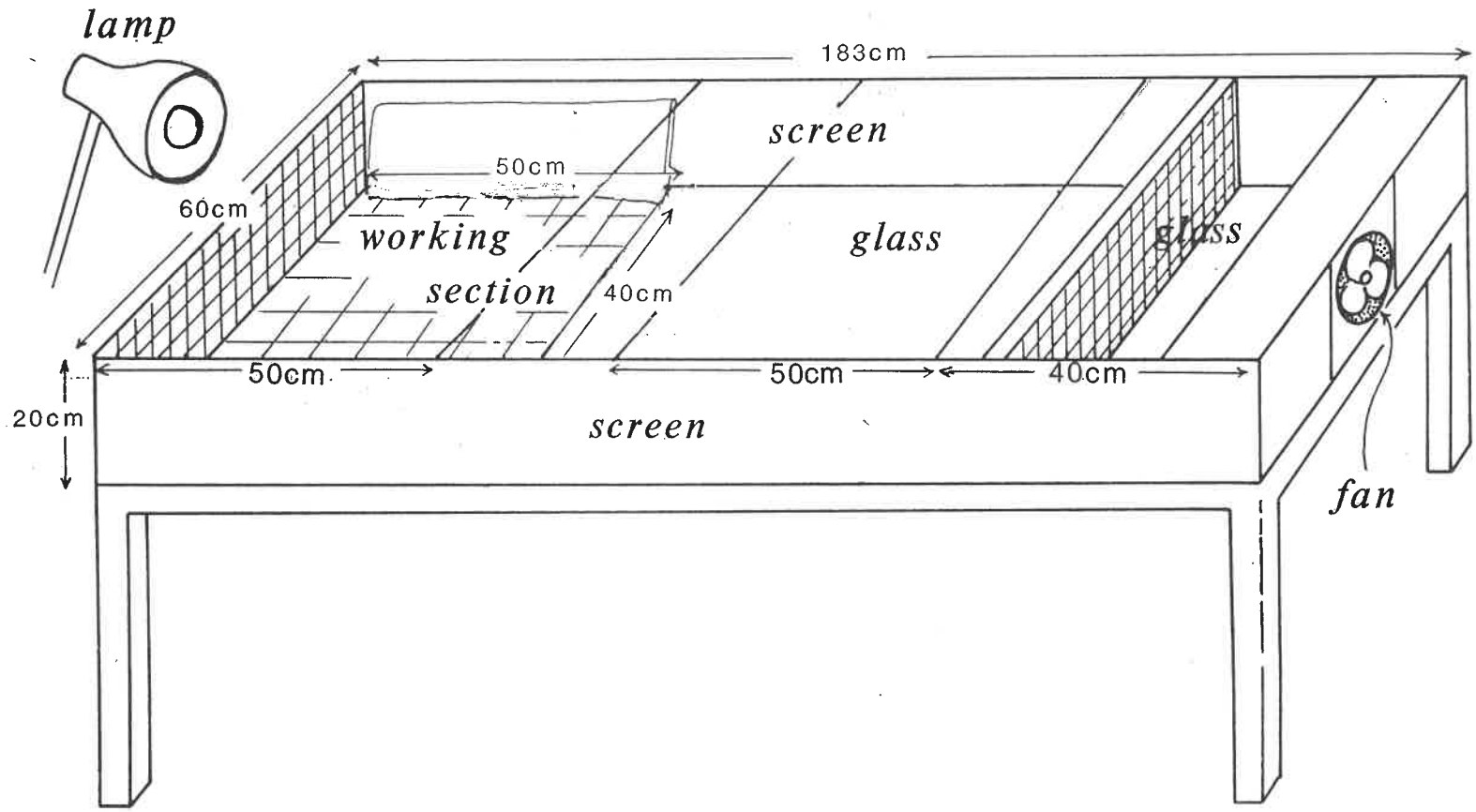


Fig. 3.3 A diagram of the wind tunnel.

temperature of the surroundings and adjust themselves to normal behaviour.

3.2.2 Surfaces Used In the Experiment

As mentioned earlier, four different kinds of surfaces were used in this experiment to measure the speed of the locusts and hoppers. These surfaces were washed fine sea sand; soil (alluvial based loam derived mainly from red sandstone rock (D. Lewis pers. comm.); glass and grass. The ground area of each of sand, soil, grass and glass surfaces was 2,000 cm^2. That of the grass leaf area was 2,370 cm^2. Surface area of grass was measured using a surface area meter, calibrated using pieces of graph papers of known area. Average surface area of a grass leaf was 6 cm^2 (n=15), and there were approximately 395 grass leaves covering the total grass area. A stop watch was used to measure the time required for the locusts and hopper to walk from the starting point to the opposite end of the surface.

3.2.3. Description of the Wind Tunnel

A wind tunnel (figures 3.1 and 3.2) was used in this experiment. A diagram of the apparatus used is given in figure 3.3. Wind tunnels have been used previously in

connection with studies of factors affecting movements of hoppers and locusts, with some variation to the structure of the wind tunnel to fit certain purposes (Haskell et al, 1962; Kennedy and Moorehouse, 1970; Moorehouse, 1970, 1971).

The wind tunnel used in this experiment is a flatbed tunnel, the working section of which is enclosed by a glass-plate roof through which experimental animals are observed and their movement could be recorded. The floor and sides of the tunnel were constructed of melamine covered chipboard, in order to cut out external visual stimuli (Haskell et al, 1962). The tunnel was illuminated by a 60 watt electric bulb filled at one end of the tunnel. This arrangement ensured a constant radiation and illumination through the experiment. Wind was generated by sucking air through the tunnel at a speed of 0.3 cm s^{-1}, using a centrifugal fan attached to the opposite end facing the light source.

3.2.4 Calculation of Walking Speed of Experimental Animals

The walking or marching locusts and hoppers were observed and time required for the animals to walk from the starting point to the end of the walking surface was measured. The paths of individual locusts and hoppers were traced on

acetate paper sheets marked out in a grid placed on the wind tunnel above the experimental surface. A corresponding grid was marked on the experimental surface. The distance walked was then measured using a thread laid on the marked path. Having measured the time (t) required by the individual to cross the length (l) of the grid, the walking or marching speed can be obtained using the following formula $s(cm/s) = \frac{l}{t}$.

This experiment was repeated for ten individuals of each age group, and the mean speed then calculated.

3.2.5 Temperature Regimes

Five different temperature regimes were used to measure the effect of temperature on the walking or marching speed of the locusts and hoppers. Acclimation of the insects was achieved by placing them in controlled temperature incubator cages at 25°, 27°, 29°, 30° and 32°C, prior to the experiment

The previous experiment 3.2.4 was then repeated at each of the above 5 temperatures.

3.3 RESULTS

Results of the data obtained in this experiment are given in Tables 3.1 to 4 and in Figures 3.4 to 7.

3.3.1 Walking Speed on Different Surfaces

Table 3.1 and Figure 3.4 summarise and illustrate the results obtained for all developmental stages at the different temperature regimes using the grass surface. It is evident that for all developmental stages, except for the second instar hopper, walking speed increased with temperature reaching a maximum at 29°C and was maintained as such at 30°C. Data given in Table 3.1 and Figure 3.4 also clearly indicate that walking speed increased substantially at all temperature regimes with the developmental stages, being lowest for the second instar hopper and highest for the adult locusts, that is walking speed increased with age of the hoppers and adult locusts. With regard to using soil as surface for walking (Table 3.2 and Figure 3.6) a different pattern of responses toward temperature was noticed. In this case, all developmental stages used, except the fifth instar hopper, showed steady increase in speed with the increase in temperature, reaching maximum at 32°C. Walking speed on soil using the fifth instar hoppers was highest at 29°C. Table 3.2 and

Figure 3.6 also show that walking speed also increased at all temperature regimes with age, as described earlier.

Walking speed on sand gave a totally different picture, in comparison with the results given above (Table 3.3 and Figure 3.6). Here, there was a great variation in response to the different temperature regimes by the different developmental stages. For instance, walking speed of the second instar hoppers showed a steady increase with increasing temperature reaching a speed of 1.50 cms^{-1} at 29°C, and a marked increase in walking speed at 32°C when a speed 2.2 cms^{-1} was recorded. However, it is unlikely that these differica are significant. Walking speed of the third instar hoppers showed two peaks at 27°C (2.32 cms^{-1}) and at 30°C (2.74 cms^{-1}). Walking speeds of the fourth instar hoppers had levelled off at 27°C, while the adults reached a maximum walking speed at this temperature. Hoppers generally showed a slow but steady increase in their walking speed with the increasing temperature. The increase in speed with age of hoppers and adult at all temperature regimes was also consistent with the other two surfaces.

Anomalous results were also obtained with respect to using glass as a surface for measures walking speed (Table 3.4 and Figure 3.7). Walking speed of second, third and fourth

instar hoppers was relatively high at 25°C but declined markedly at 27°C, to increase again at 29, 30 and 32°C. With regard to the walking speed of the fifth instar hoppers and adult locusts, highest walking speeds were recorded at 32° and 30°C respectively.This increase in walking speed with age of insects is also generally consistent with the other surfaces.

Table 3.1 Adult and Hopper Average Speed Grass Surface

Temperature Age	25°C	27°C	29°C	30°C	32°C
Second-instar	0.38	0.41	0.50	0.50	0.49
Third instar	0.53	0.61	0.65	0.61	0.65
Fourth-instar	0.77	0.89	0.95	0.89	0.96
Fifth-instar	1.33	1.55	1.91	1.74	1.81
Adult	2.17	2.50	3.01	2.69	2.91

Table 3.2 Adult and Hopper Average Speed Soil Surface

Temperature Age	25°C	27°C	29°C	30°C	32°C
Second-instar	1.01	1.10	1.25	1.34	1.52
Third instar	1.38	1.59	1.78	2.08	2.54
Fourth-instar	2.46	2.97	3.51	3.67	3.96
Fifth-instar	3.37	4.28	5.56	5.29	5.19
Adult	3.74	4.91	6.47	6.75	6.93

Table 3.3 Adult and Hopper Average Speed Sand Surface

Temperature Age	25°C	27°C	29°C	30°C	32°C
Second-instar	0.94	1.30	1.50	1.39	2.20
Third instar	1.61	2.32	1.84	2.74	2.49
Fourth-instar	2.36	3.69	3.31	3.90	4.30
Fifth-instar	4.43	4.76	4.79	5.43	6.68
Adult	6.01	8.57	5.36	6.53	7.49

Table 3.4 Adult and Hopper Average Speed Glass Surface

Temperature Age	25°C	27°C	29°C	30°C	32°C
Second-instar	2.93	1.65	1.61	2.61	1.83
Third instar	3.70	2.16	3.66	4.22	3.11
Fourth-instar	4.91	2.19	5.64	5.67	5.28
Fifth-instar	5.88	6.71	6.55	6.89	8.34
Adult	5.85	8.04	7.37	9.36	8.91

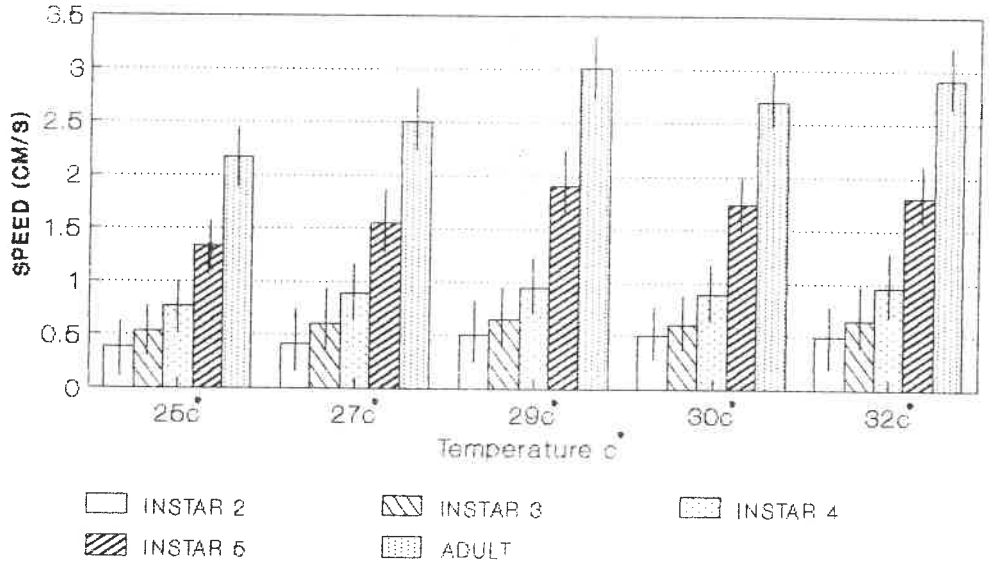


Fig 3.4 The Averag of desert locust Adu
It&Hopper walkin speed cms^{-1}Grass Surface

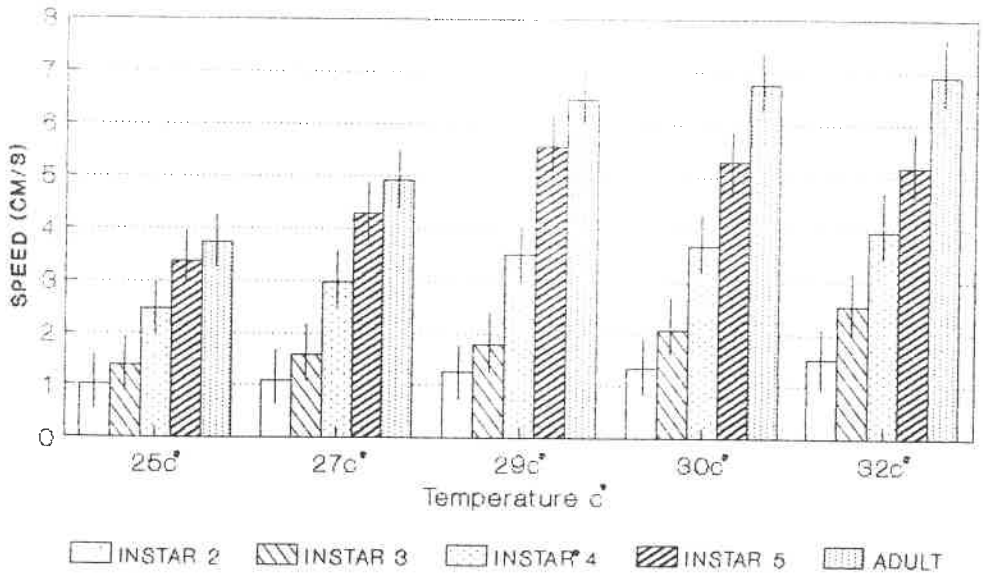


Fig 3.5 The Averag of Desert Locust Adu
It&Hopper Walking speed cms^{-1}Soil Surface

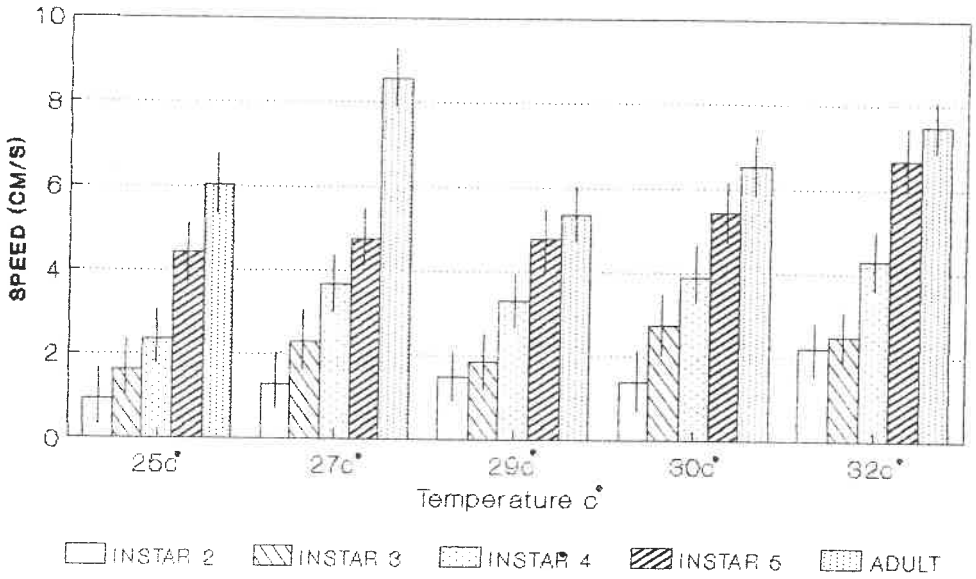


Fig 3.6 The Averag of Desert Locust Adu
lt&Hopper Walking Speed cms^{-1} Sand Surface

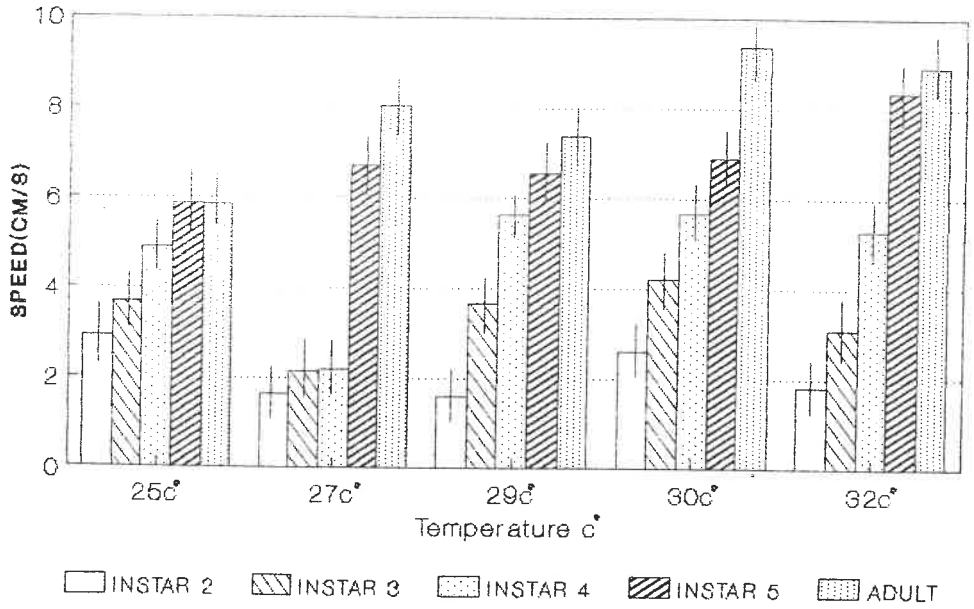


Fig 3.7 The Averag of Desert Locust Adul
t&Hopper Walking Speed cms^{-1} Grass Surface

3.3.2 Comparison of Walking Speed of Hoppers and Locusts on Different Surfaces

Comparison of walking speeds of the different developmental stages on the different surfaces at different temperature regimes are illustrated in Figures 3.8 to 3.32.

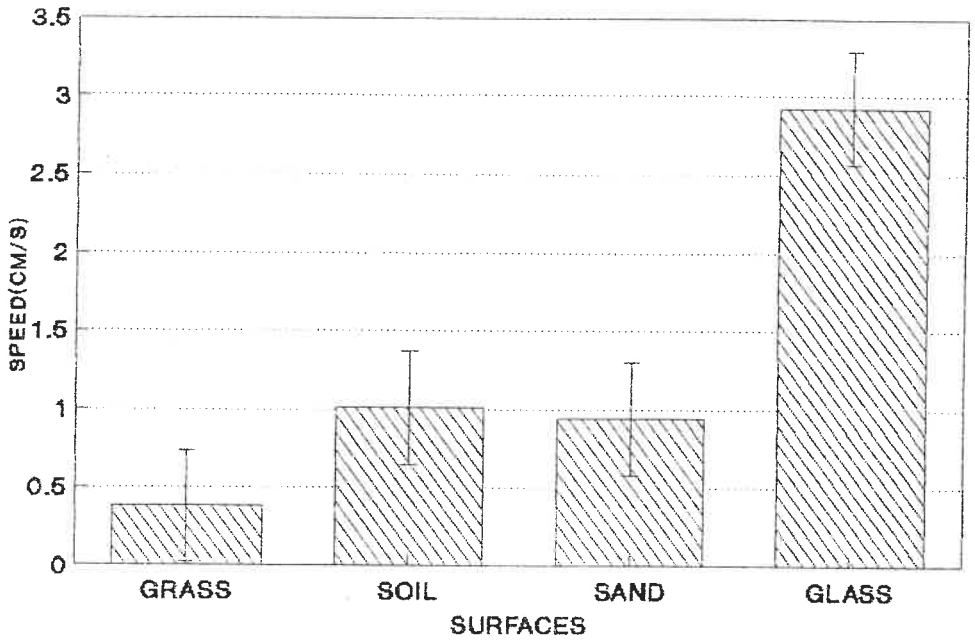


Fig 3.8 Desert Locust Hopper Instar2
Walking Speed cms^{-1} at 25c With Surface

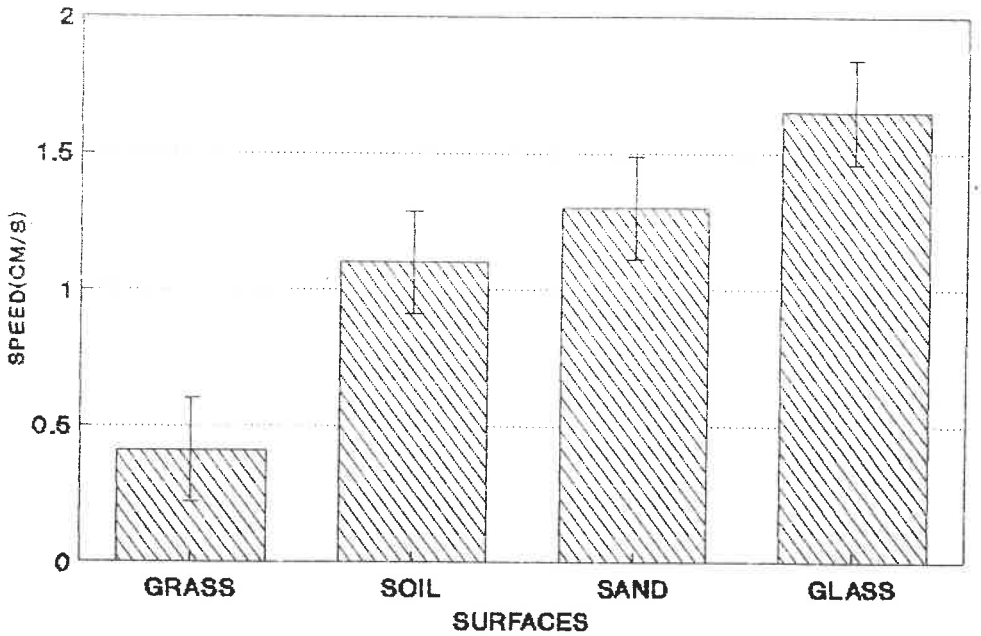


Fig 3.9 Desert Locust Hopper Instar2
Walking Speed cms^{-1} at 27c For All Surface

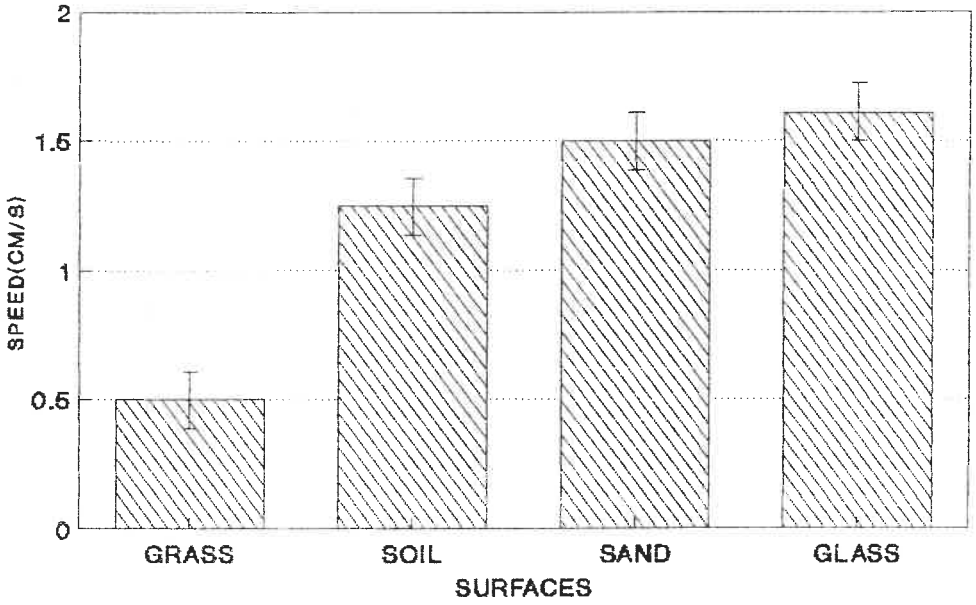


Fig 3.10 Desert Locust Hopper Instar2
Walking Speed cms^{-1} at 29c$^{\circ}$ With Surface

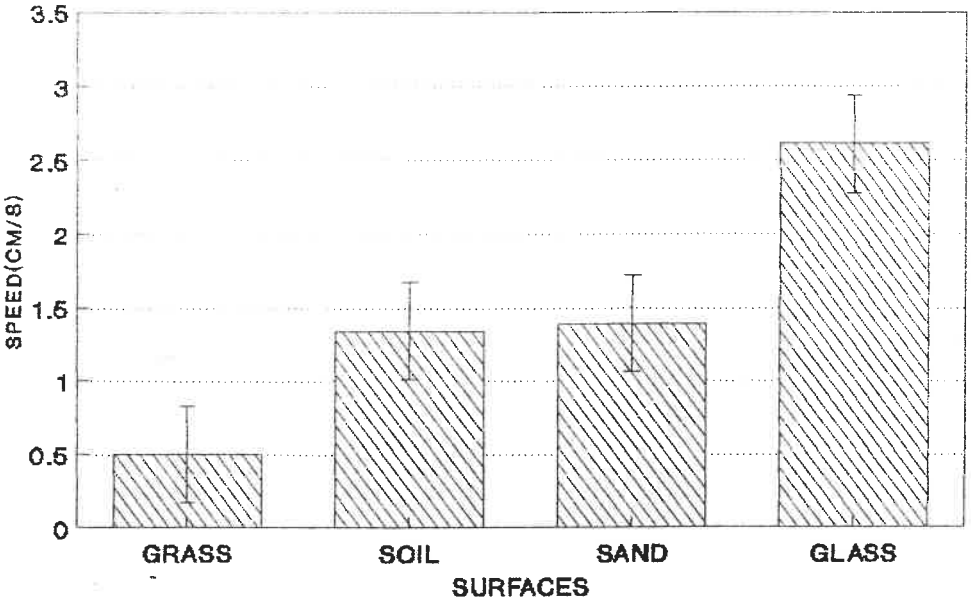


Fig 3.11 Desert Locust Hopper Instar2
Walking Speed cms^{-1} at 30c$^{\circ}$ With Surface

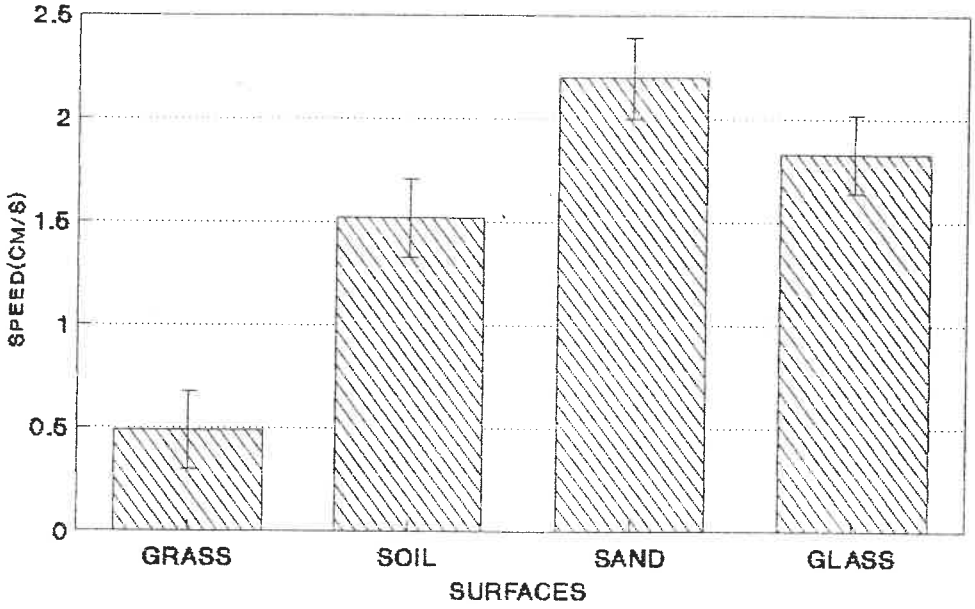


Fig 3.12 Desert Locust Hopper Instar2
Walking Speed cms^{-1} at $32c^{\circ}$ With Surface

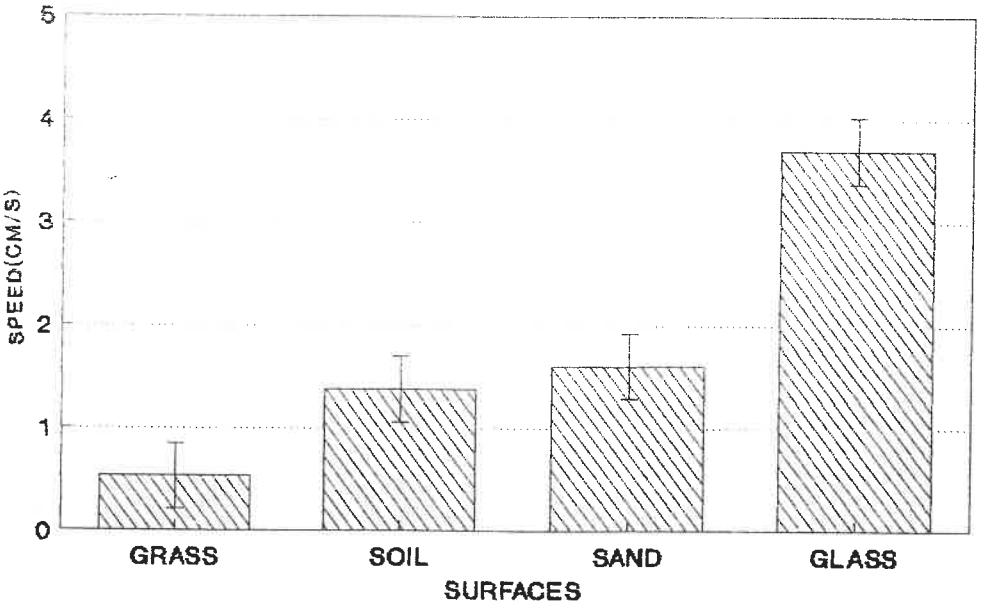


Fig 3.13 Desert Locust Hopper Instar3
Walking Speed cms^{-1} at $25c^{\circ}$ With Surface

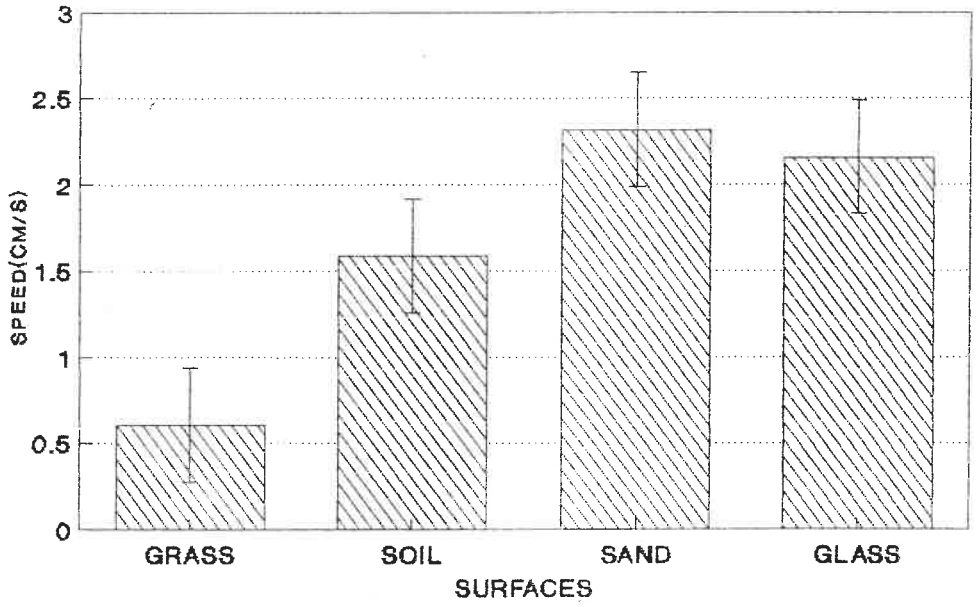


Fig 3.14 Desert Locust Hopper Instar3
Walking Speed cms^{-1} at 27c° With Surface

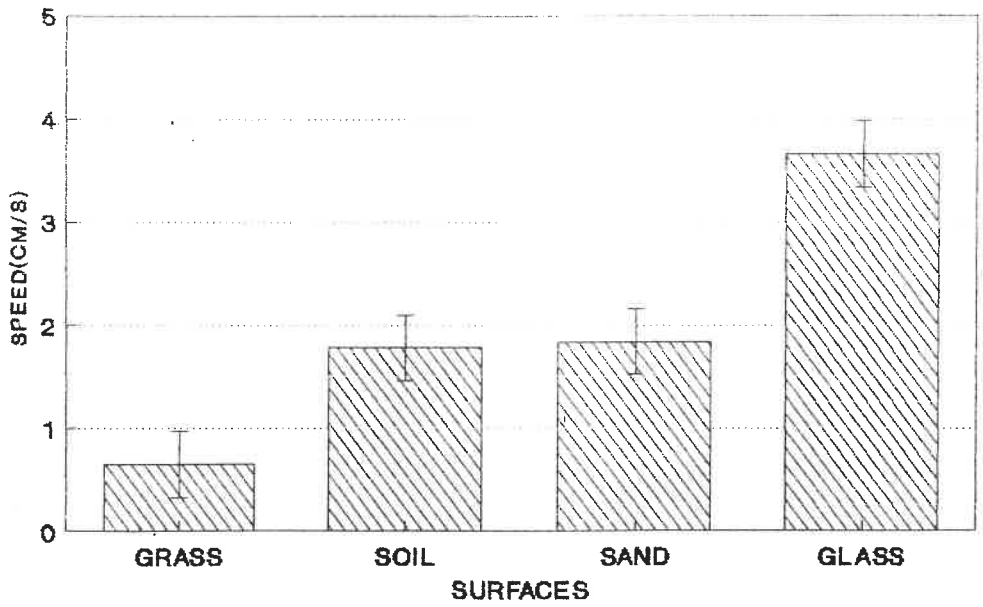


Fig 3.15 Desert Locust Hopper Instar3
Walking Speed cms^{-1} at 29c° With Surface

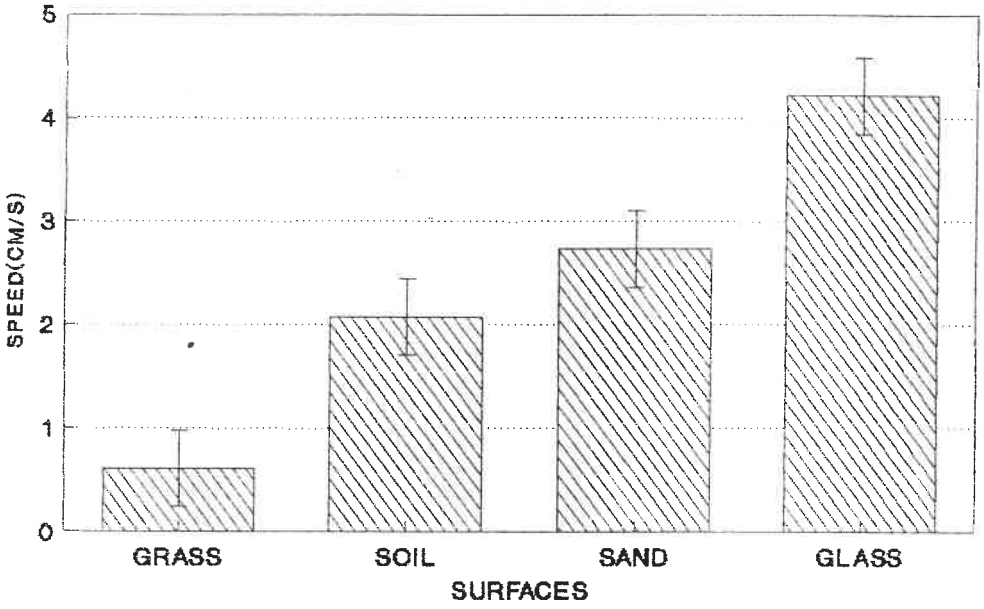


Fig 3.16 Desert Locust Hopper Instar3
Walking Speed cms^{-1}at 30c^{o} With surface

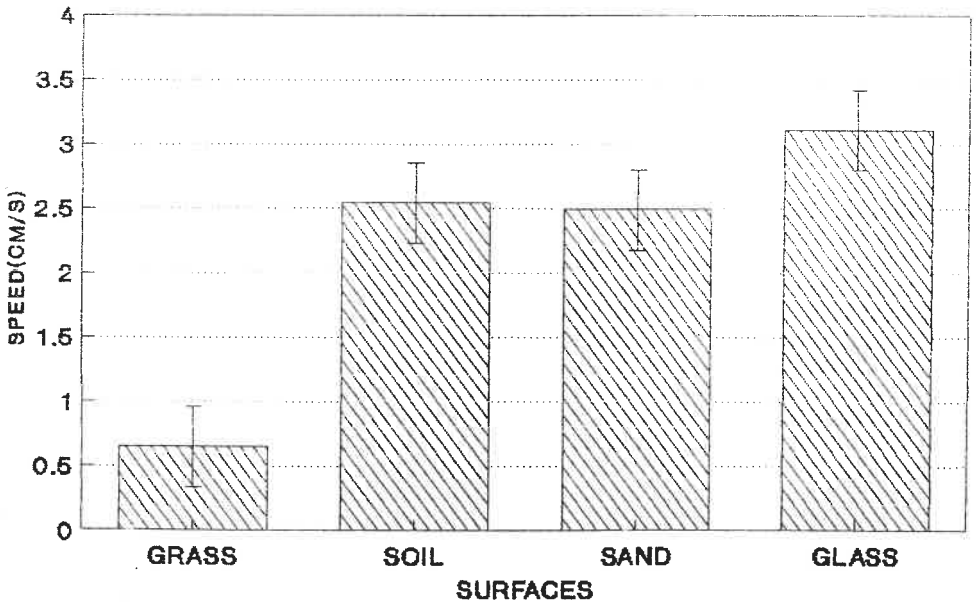


Fig 3.17 Desert Locust Hopper Instar3
Walking Speed cms^{-1}at 32c^{o} With Surface

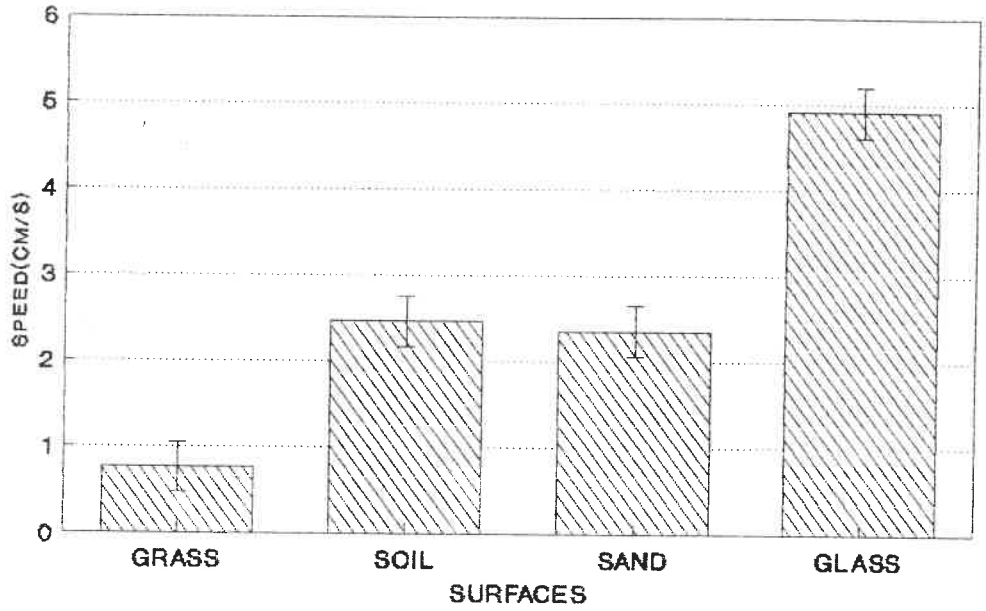


Fig 3.18 Desert Locust Hopper Instar4
Walking Speed cms^{-1}at 25c° With Surface

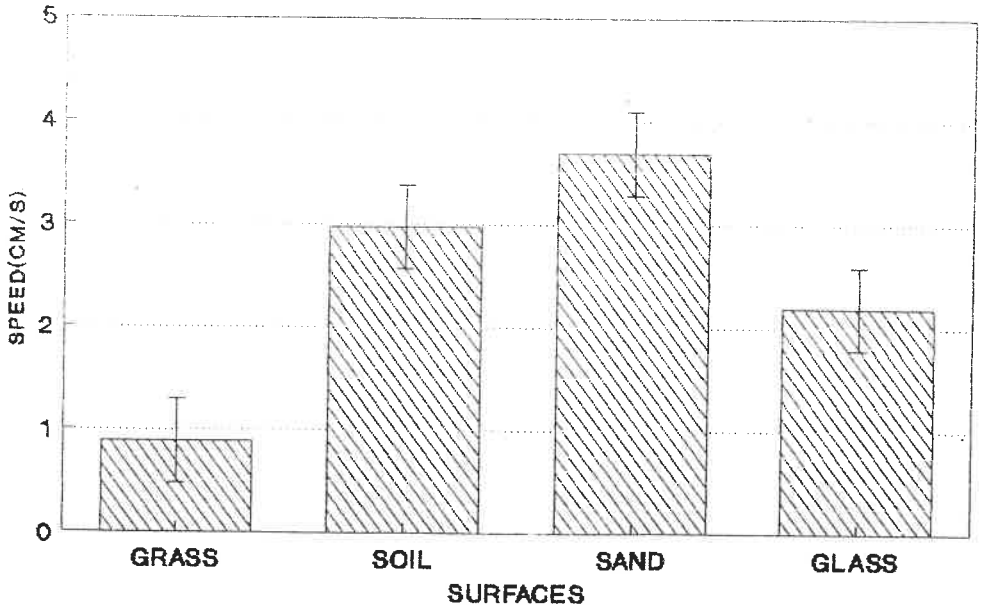


Fig 3.19 Desert Locust Hopper Instar4
Walking Speed cms^{-1}at 27c° With Surface

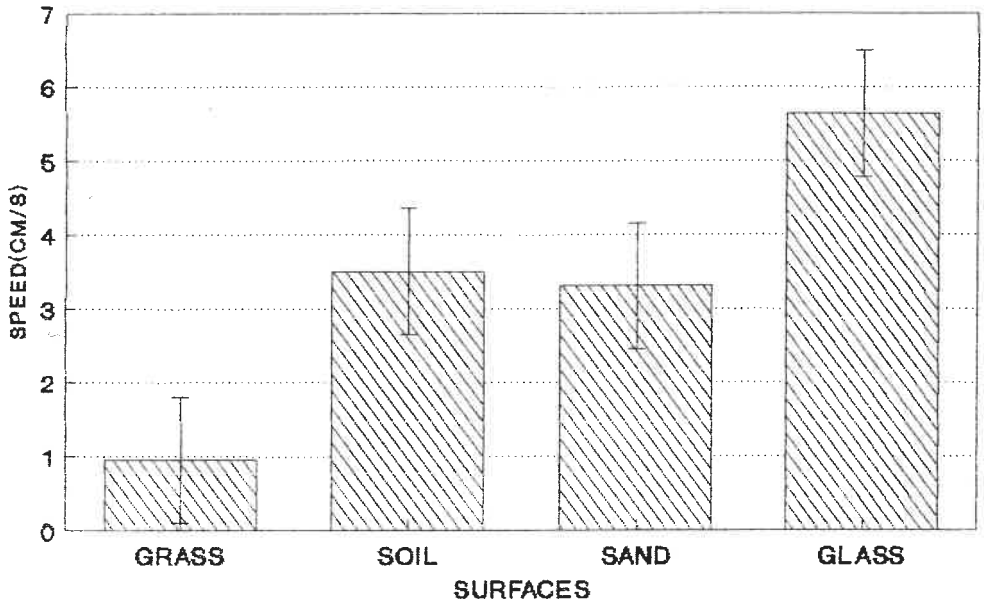


Fig 3.20 Desert Locust Hopper Instar4
Walking Speed cms^{-1} at 29c° With Surface

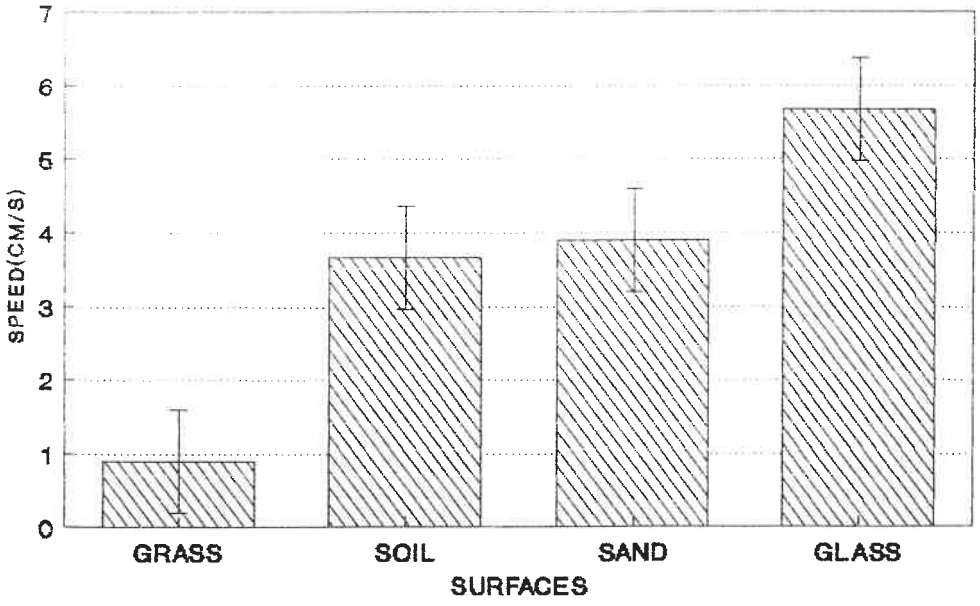


Fig 3.21 Desert Locust Hopper Instar4
Walking Speed cms^{-1} at 30c° With Surface

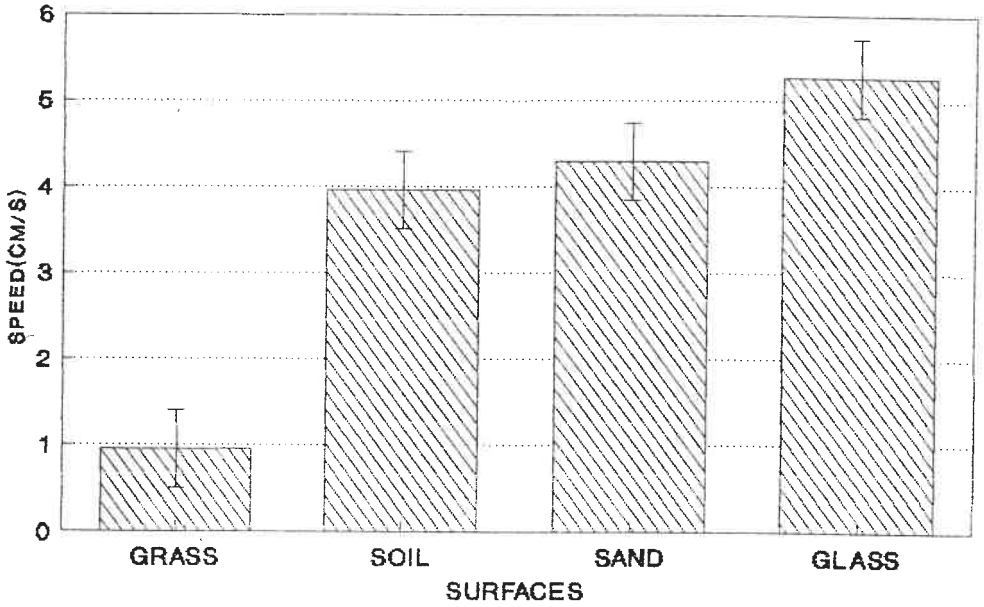


Fig 3.22 Desert Locust Hopper Instar4
Walking Speed cms^{-1} at 32c°With Surface

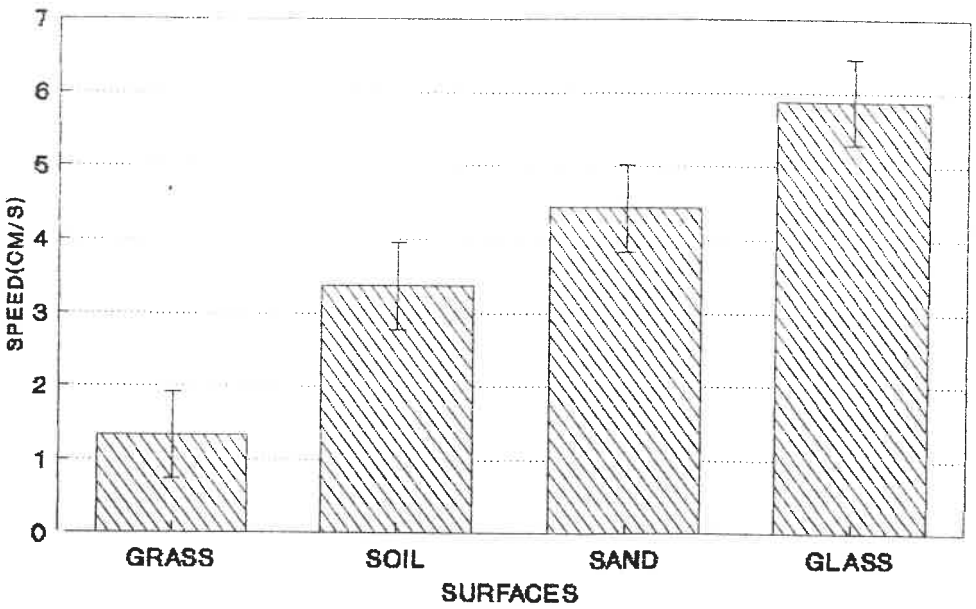


Fig 3.23 Desert Locust Hopper Instar5
Walking Speed cms^{-1} at 25c° With Surface

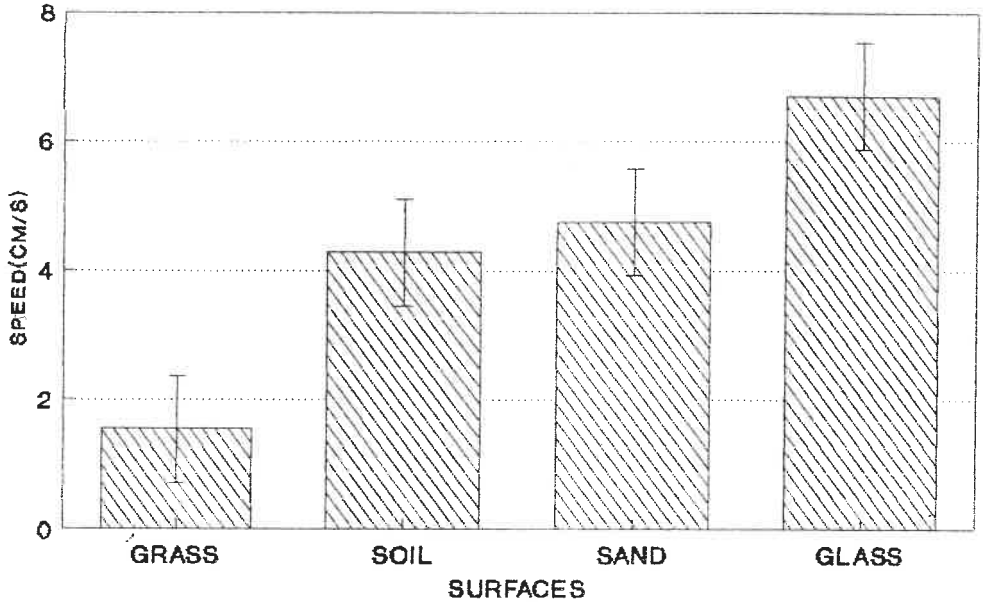


Fig 3.24 Desert Locust Hopper Instar5
Walking Speed cms^{-1}at 27c° With Surface

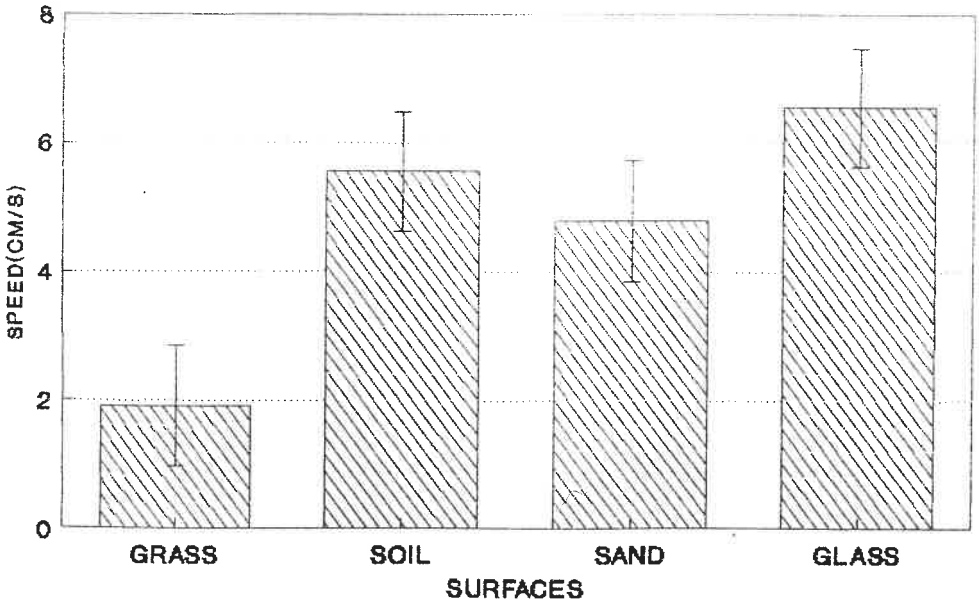


Fig 3.25 Desert Locust Hopper Instar5
Walking Speed cms^{-1}at 29c° With Surface

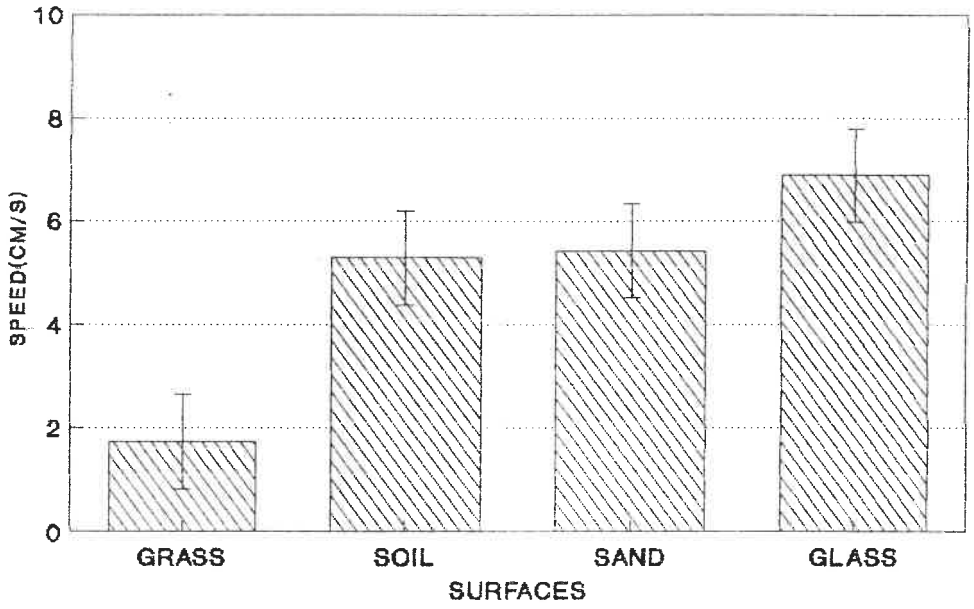


Fig 3.26 Desert Locust Hopper Instar5
Walking Speed cms^{-1} at 30c° With Surface

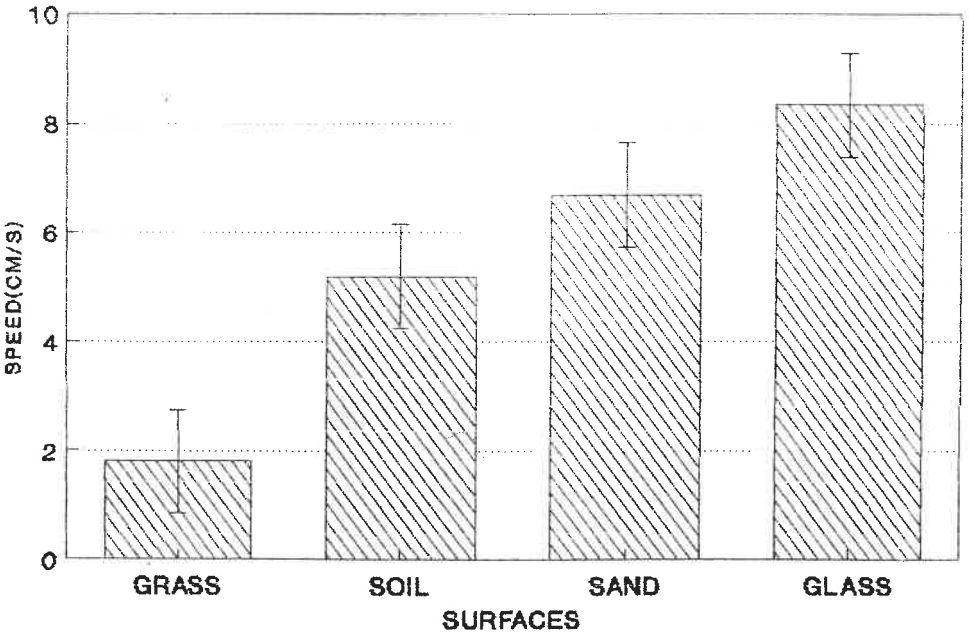


Fig 3.27 Desert Locust Hopper Instar5
Walking Speed cms^{-1} at 32c With Surface

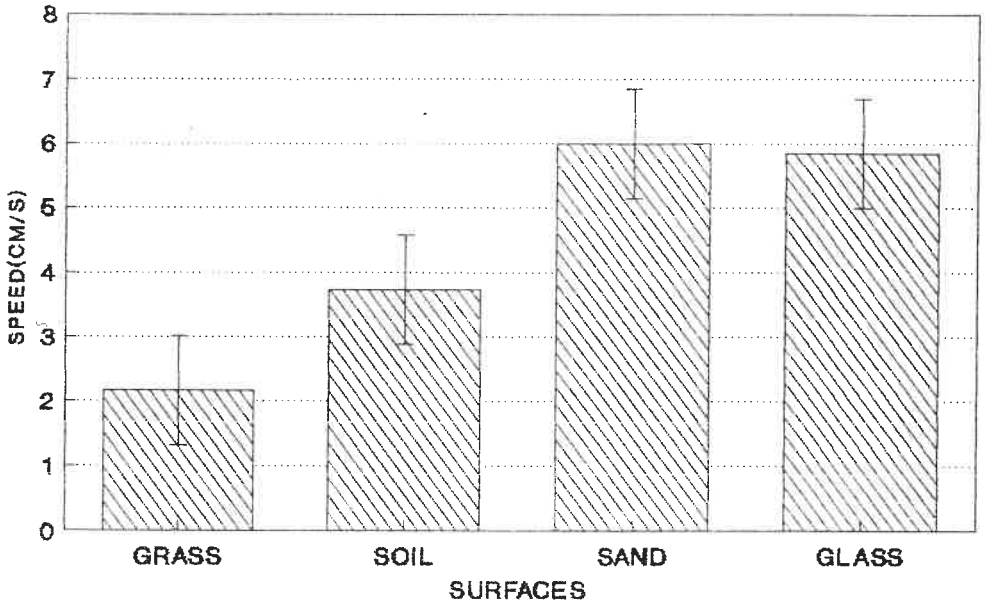


Fig 3.28 Desert Locust Adult
Walking Speed cms^{-1} at 25c°With surface

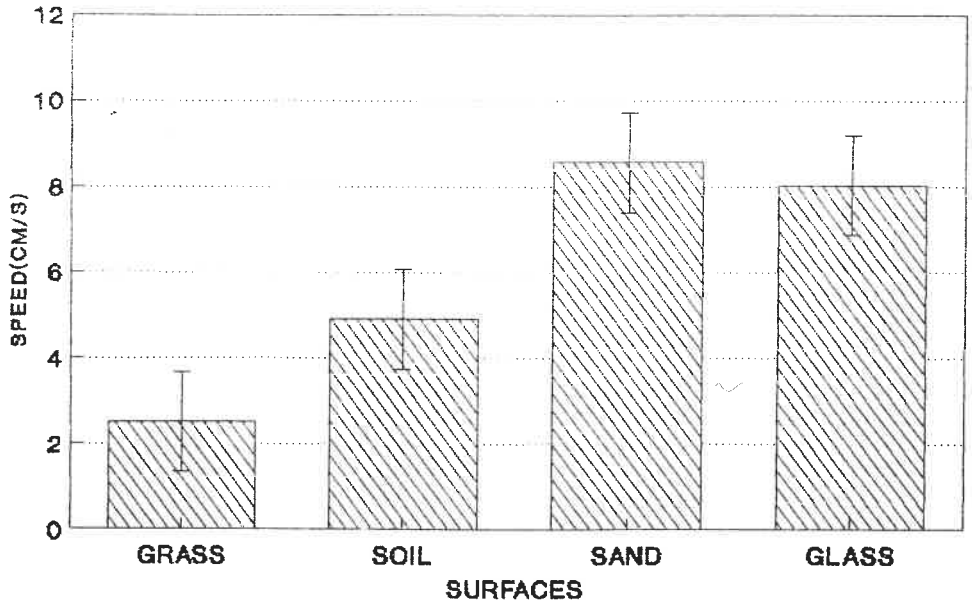


Fig 3.29 Desert Locust Adult
Walking Speed cms^{-1} at 27c°With Surface

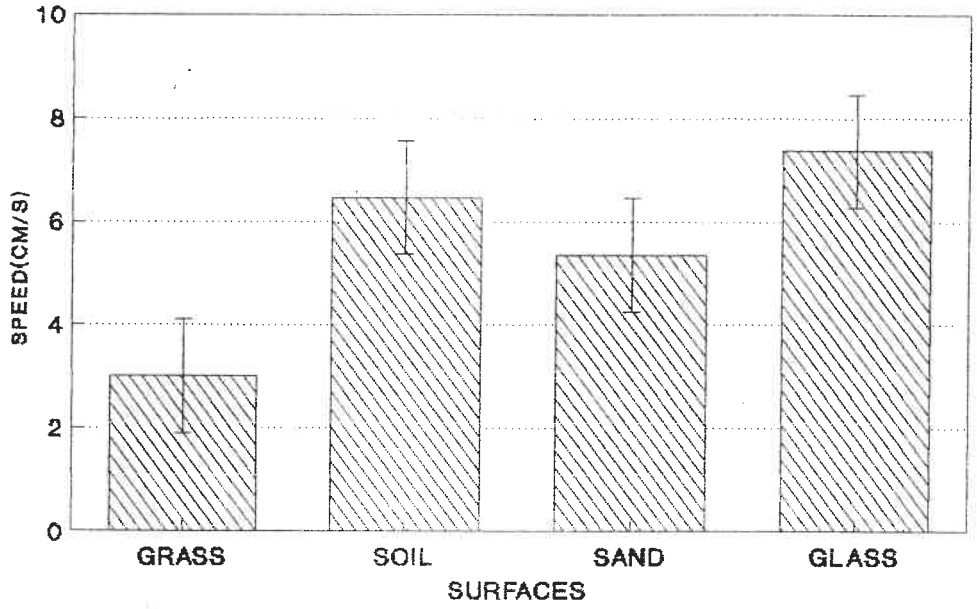


Fig 3.30 Desert Locust Adult
Walking Speed cms^{-1} at $29c^{0}$ With Surface

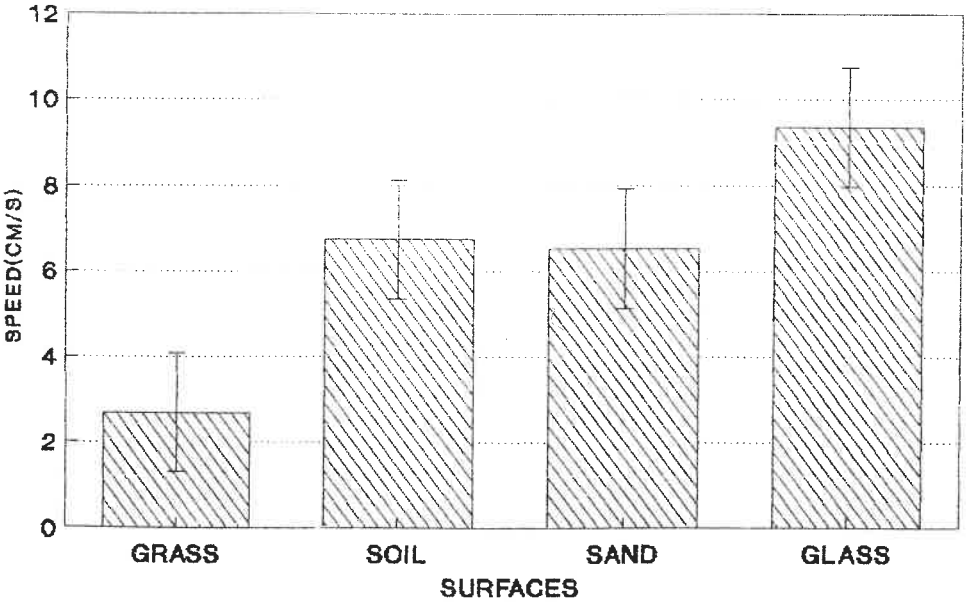


Fig 3.31 Desert Locust Adult
Walking Speed cms^{-1} at $30c^{0}$ With surface

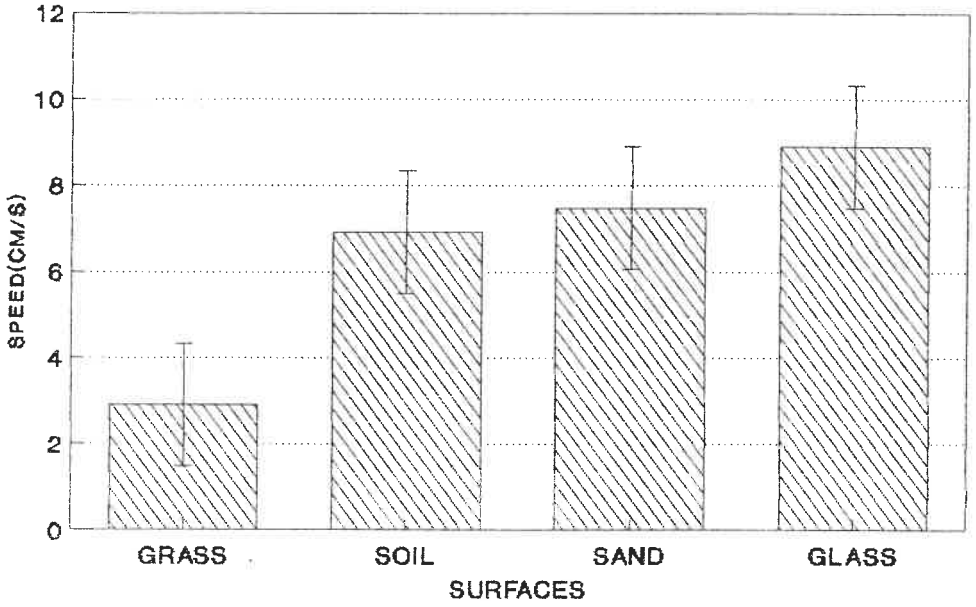


Fig 3.32 Desert Locust Adult
Walking Speed cms^{-1}at 32c° With Surface

A. Second Instar Hoppers

These hoppers exhibited three patterns of walking speeds on the four surfaces mentioned earlier and at the different temperature regimes. The first pattern is that exhibited by hoppers at 25°C (Figure 3.8) when the highest speed was recorded on glass (2.93 cms^{-1}), followed by that on soil (1.01 cms^{-1}) and the slowest movement was on plants (0.38 cms^{-1}). At 27°, 29° and 30°C, the walking speeds, recorded in descending order, were as follows; glass, sand, soil and plant (Figures 3.9, 3.10 and 3.11). At 32°C (Figure 3.12), the fastest walking speed occurred on sand, followed by glass (1.83 cms^{-1}) and the slowest speed was on plants (0.49 cms^{-1}).

B. Third Instar Hoppers

There were also three patterns recorded here similar to those given above (Figures 3.13, 3.14, 3.15, 3.16 and 3.17). However, the only difference was with the temperature regimes these patterns were observed. For instance, the first group here recorded their speed patterns on the different surfaces at 25°, 29° and 30°C, which were similar to the 27°, 29° and 30°C of the second instar hoppers. Speed at 27°C resembled that of 32°C for

the second instar and that at 32°C resembled that at 25°C for the second instar.

C. Fourth Instar Hoppers

The patterns shown here resembled those illustrated by the third instar hoppers (Figures, 3.18, 3.19, 3.20, 3.21 and 3.22). Patterns of walking speeds on the different surfaces at 25°, 29° and 30°C, at 27°C and at 32°C were similar to those of the previous developmental stage. The only difference was in the magnitude of speed between the two stages, being faster on all surfaces at this stage that in the third stage.

D. Fifth Instar Hoppers

Hoppers of this stage exhibited two patterns of walking speeds on the different surfaces (Figures 3.23, 3.24, 3.25, 3.26 and 3.27). Speeds at all temperature regimes, except at 29°C, were similar to those recorded for the fourth instars at 25°, 27° and 30°C. Speed recorded at 29°C resemble that recorded at 25°C for the second instar.

E. Adult Desert Locust

Three patterns were exhibited by this stage on the different surfaces at the different temperature regimes (Figures 3.28, 3.29, 3.30, 3.31 and 3.32). The first pattern is illustrated by locusts at 25° and 27°C. The fastest speed was recorded on sand, followed by that on soil and the slowest was on grass. At 29° and 30°C, the fastest speed was on glass, followed by that on soil, and the slowest was also recorded on grass. At 32°C, the fastest speed was on glass, followed by that on sand and once again the slowest movement was on grass.

To sum up, the different stages of hoppers and the adult locusts, followed one or two similar patterns of walking speed on the different surfaces, but not with respect to the same temperature regimes these patterns were also similar in sequence rather that magnitude, adults and advanced instars were faster than younger and juvenile stage. Walking of locusts and hoppers on the different surface reached its optimum speed at 29°C in most cases.

Data obtained for walking speeds on different surfaces, temperature and developmental stages of insects were statistically analysed using two and three-way analysis of variance (ANOVA) package.

With respect to the main effects, data indicate that there was a highly significant difference in walking speed regarding stage (d.f. = 4,900; F = 517.5; P ≤ 0.001), surfaces (d.f. = 3,900; F = 470.8; P ≤ 0.001) and temperature (d.f. = 4,900; F = 30.2; P ≤ 0.001). This pattern of results indicate that there was a highly significant difference in walking speed irrespective of stage, surface and temperature (d.f. = 11,900; F = 327.6; P ≤ 0.001).

The two-way interaction results indicate that there was a highly significant difference in walking speed (d.f. = 40,900; F = 9.2; P ≤ 0.001) within each stage group irrespective of surface (d.f. = 12.900; F = 18.5; P ≤ 0.001) and temperature (d.f. = 16,900; F = 4.3; P ≤ 0.001). Difference in walking speed were also highly significant regardless of surface and temperature (d.f. = 12,900; F = 6.5; P ≤ 0.001).

The three-way interaction results also indicate a highly significant difference in walking speed (d.f. = 48,900; F = 2.6; P ≤ 0.001).

Figures 3.6 to 3.32 clearly illustrate the relationships with walking speed and insect stage, surface and temperature.

3.4 DISCUSSION

Hoppers of all ages and adults of S. gregaria reached their optimum walking speed at 29.0°C. Metabolism of insects is affected by environmental conditions. For instance, at low temperatures the metabolism is sluggish and inhibits activity, only when the temperature rises above the activity threshold would activity be possible (Dent, 1991). Insects may also have an upper threshold for activity. In this experiment, this upper threshold seemed to have been reached at 29.0°C for all age groups of S. gregaria and that above it walking activity either declined or maintained steady. Hussain (1937) reported that temperature for the normal activities of all developmental stages of Schistocerca ranges between 23.0 and 37.0°C.

Walking speed also showed a direct relationship with age, thus walking speed also increased. This observation agrees with that of Uvarov (1977) who reported that older hoppers were faster that young ones. Data given by Ellis & Ashell (1957) seem to partly contradict this observation, however, according to Uvarov (1977) their figures are the mean of many cases observed on a variety of unspecified conditions. Uvarov (1977) also maintained that in marching bands of mixed instars the smaller hoppers are nevertheless able to keep pace with the larger ones. Ashall (1956) (cited by

Uvarov, 1977) found that the fourth instar hoppers of Schistocerca in such bands marched at a rate of 664-961 cm min^{-1}, but those of the second instar though marching at 563-722 cm min^{-1}, were not behind. Statistical analysis of the marching speeds has shown that the variance of the speed of the smaller hoppers was greater than that of the larger ones; ie. they had to accelerate from time to time in order to keep up with this band. According to Uvarov (1977) this is an excellent example of gregarious inertia.

The fastest speed was recorded on glass for all age groups, except for the adults of Schistocerca gregaria at 25.0°C and 27.0°C. It is possible that such fastest speed on glass was due to the larger tarsal ariola of the hoppers. Uvarov (1977) reported that hoppers of Schistocerca are all able to walk on glass walls of a cage presumably because of their larger tarsal ariola. Another factor of great importance for the speed of insect marching is the nature of the terrain. The smooth, regular surface of glass helped insects to march faster on it than on other surfaces used in the present study.

Terrain seems also to affect walking speed on other surfaces. Walking on sand or soil surfaces was faster than on grass. Kennedy (1939) recorded Schistocerca hoppers moving at a rate of 500 cm min^{-1} over bare sand and at 390

cm min^{-1} in dense grass. This, according to Uvarov (1977) does not necessarily mean a reduction in the actual marching speed, but mainly in the time spent moving. In the present study insects walking over grass spent longer time than on other surfaces, thus resulting in the lowest walking speed for all ages.

The lower speed on this surface was not unexpected since the terrain is more complex and difficult to negotiate and secondly the insects were moving over a food substance and were likely to be arrested by presence of food stimuli.

The walking speed across the different surfaces will affect the transfer of insecticides applied to those surfaces. The slower an insect walks across a surface the more likely transfer would seem or the greater distance covered the higher the probability of contact with insecticide deposits.

CHAPTER 4

SURFACE EFFECTS ON INSECTICIDE TRANSFER AND MORTALITY

4.1 INTRODUCTION

Pesticides have been and are still inefficiently applied (Graham-Bryce, 1977), though there are a few attempts to reduce wastage of these highly active biocides (Munthali, 1981). A large amount of research on pesticides involves either comparisons of the potency of different compounds or comparisons of the susceptibility of different species or strains of insect (Busvine, 1971). Finney (1963) argues that there are general ways of assessing poisons to find the equitoxic doses of pesticides. These involve direct assay or indirect assay; the latter being based on quantitative or quantal response. Busvine (1971) points out that direct assay involves measuring the exact doses necessary to kill individual animals, or to produce a certain level of poisoning. Direct assay involves the gradual increase in dose up to the critical point. This method may be feasible with large animals, but is generally impracticable with insects.

Indirect assay, on the other hand, depends on giving standard doses to batches of individuals and recording the responses obtained. This is the type of assay that has

generally been adopted for assessing the potency of insecticides. However as a laboratory based approach it has little relevance to the field situation.

The majority of insecticides are applied to sprays with water as the diluent. Spraying of plants with pesticides has a long history dating back to the end of the nineteenth century when a spraying equipment was made to apply Bordeaux mixtures to grapevines (Loderman, 1896). Pesticides, diluted with large volumes of water, were sprayed in large quantities so that they completely cover the foliage. Much of the spray liquid could not be retained on the leaf and other plant surfaces (Munthali, 1981). This type of spraying to the point of 'run-off' was labour intensive, so new techniques had to be introduced whereby smaller volumes of spray are to be applied. Spraying techniques are usually classified in accordance with volume used in application. Matthews (1979) classified spraying techniques into high volume (HV), low volume (LV) and ultra-low volume (ULV), whereby more than 400 l ha^{-1}, between 5 and 400 l ha^{-1} and less than 5 l ha^{-1} are sprayed using the HV, LV, ULV techniques respectively. These rate were then reclassified between volume used for field and tree crops (see Table 4.1).

Table 4.1 The approximate range of spray volumes applied in field crops and trees and bushes (after Matthews, 1979)

Description of Spray	Volume of Spray (l ha^{-1})	
	Field crops	Trees and bushes
High volume (HV)	600	1,000
Medium volume (MV)	200 - 600	500 - 1,000
Low volume (LV)	50 - 200	200 - 500
Very low volume (VLV)	5 - 50	50 - 200
Ultra low volume (ULV)	5	50

The high volume (HV) techniques has been widely used, though it is extremely laborious and inefficient; medium volume (MV) sprays being more commonly used in Europe, according to Munthali (1981).

More expensive labour led to encouraging the ULV application. According to Symmons et al. (1991), the basis of controlled droplet application (CDA) is that ULV pesticides will have the greatest effect in particular situations if they are applied in droplets within a particular narrow size range. Unfortunately, there is little experimental data to indicate which sized droplet should be used in which situation. Insecticides in small droplets of less than 100 m have been shown to be more efficient and effective in killing both sessile insects (Munthali, 1984) and mobile insects (Reay & Ford, 1977;

Omar & Matthews, 1987). The biological activity is influenced by different insecticide formulations according to Wyatt et al (1984). Dubs et. al. (1985) applied three effectively mono-sized droplet clouds of insecticide to young cotton and found that more chemical was collected by the leaves with droplets of diameter 115 μm than either larger or smaller droplets. However, according to Symmons et al (1991) direct impingement of an insect might be a different matter; as a collecting surface an insect differs from a leaf. In addition, the more numerous very small droplets of a finer spray might produce a more uniform dose, and because of the greater number of contact points, one which might have a greater effect (Symmons et. al., 1991).

The ULV technique originated in East Africa shortly after the Second World War for the control of S. gregaria (Sayer, 1959). Rapid treatment of large areas can be achieved and this technique is especially suited where water is in short supply and transportation of large volumes of spray liquid is a problem (Munthali, 1981). This technique has been also used, after its success in East Africa, against a variety of pests (Munthali, 1981).

Apart from the initial mortality achieved immediately after spraying using the ULV technique, insecticide deposits need

to persist over a certain length of time (Omar & Matthews, 1991). The persistence of spray deposits on leaf surfaces, for instance, depends on a number of environmental factors, such as temperature, humidity and rain (Phillips, 1968), and intrinsic properties of the chemical, formulation and size of spray droplets (Graham-Bryce, 1975; Watkins, 1987). Amsden (1962) showed that a 100 μm droplet may exist for only 50 and 14 seconds at 20°C and 80.0% RH, and at 30.0°C and 50.0% RH respectively. The formulation and method of application either chemically or biologically affect the persistence of insecticide deposits on the leaf surfaces (Omar & Matthews, 1991). Undiluted technical Malathion was dissipated more slowly than a water-based emulsion (Awad et. al., 1967; Wheeler et. al., 1967; Sinai & Dorough, 1970) Emulsifiable concentrate (EC) residue of permethrin, on the other hand, disappeared more quickly than the ULV spray (McDaniel, 1980; Ware et. al., 1983).

Different types of equipment have been used to apply ULV sprays from airplanes and ground machines (Munthali, 1981; Matthews, 1979). Airplanes have been fitted with spinning cages (Microair units), especially for the control of locusts. Manual, battery operated spinning disc sprayers have been in use (Matthews, 1979; Omar & Matthews, 1991; Symmons et. al., 1991) some fitted with fans (Fuller-Lewis et. al., 1978; Boize et. al., 1975) or adapted

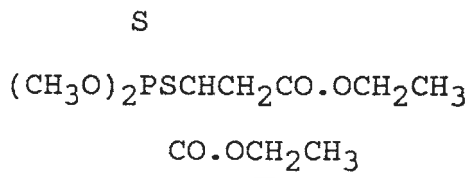
knapsack mist blowers (Clayton, 1974; Thornhill, 1974; Arnold & Thornhill, 1979). ULV sprayers such as Turbair Tot, the Micro-Gen and the Micron ULVA, produce narrower range of droplet sizes (Mhoob, 1975; Fuller-Lewis et. al., 1978). The mean size for spinning disc is inversely related to the speed of rotation (Bals, 1975; Boize et. al., 1975).

The availability of equipment providing controlled droplet application has meant is it possible to spray surfaces with a relatively consistent dosage of insecticide having a narrow range of droplet sizes. This allows for a change in approach away from previously limited laboratory experiments using micro syringes to apply highly accurate doses to the insects to a more realistic evaluation that takes into account the problems of insecticide deposit transfer to the insects.

To develop more effective and economic methods of controlling swarms of Desert Locust (especially the nymphal stages) insecticide evaluations must take into account factors affecting spray droplet deposition and deposit transfer to walking locusts. The research carried out here looked to determine the effect of age of locusts and surface characteristics on the effectiveness of deposit transfer and subsequent locust mortality.

4.2 MATERIALS AND METHODS

Malathion, supplied by MTM Agrochemicals Ltd, was the only insecticide used in this experiment. It was supplied and used in its undlited form in a ULV turbair sprayer. Malathion is the common name of S[1,2-di(ethyoxycarbonyl) ethyl] 0.0-dimethyl phosphorodithioate. Its chemical structure is as follows:



Three different methods were employed in this experiment to estimate the following:

1. Mortality due to the accumulation of the insecticide by the insects while walking on the different surfaces; glass, grass, soil and sand, at a constant temperature of 30°C ± 0.5. This method was repeated for each of five application doses (0.475, 0.95, 1.9, 2.85 and 3.8 mls^{-1}) and for all developmental stages; 2nd, 3rd, 4th and 5th instar hoppers and adult locusts.

2. Number of insecticide droplets of each dose per square cm using glass surface only and oil sensitive paper.

3. The amount of insecticide picked by the insects while walking on glass surface at 30°C ± 0.5. This method was also repeated for one dose 3.8 mls^{-1}, and for all developmental stages.

4.2.1 Estimation of Mortality Rate

The ULV sprayer was used to spray the different surfaces. Each surface covered an area of 2,000 cm^2, except grass surface where a total area of 2,370 cm^2 was measured by a surface area meter (see chapter three).

The spraying apparatus consisted of a turbair 12V for spraying the insecticide and a spray track/trolley system. This consisted of a two-speed electrical drill operating at low and high speeds, using a control speed variable resistance 'Potentiometer', was connected to a bobbin by plastic thread which was also connected to a trolley (62 x 47 cm) moving on a track (392 x 40 cm) in a channel 300 x 60 x 100 cm). The track and trolley were covered with polythene, except for a 91.4cm section facing the turbair which was left uncovered to allow spraying of the different surfaces that were mounted on the spraying trolley. The turbair apparatus was fixed at a distance of 91.4cm above ground and 256cm from the trolley at an angle of 78.1° (see

Figures 4.1 to 4.3). All experiments were carried out in a large glasshouse under conditions of still air.

Each sprayed surface was transferred to the constant temperature room and kept inside the flat-bed wind tunnel (see chapter three). Ten insects were then taken from each developmental stage and were placed individually on the sprayed surface to walk to the opposite illuminated end of the surface; a distance of 50cm. The time required for each insect to cross the sprayed surface was measured. This step was repeated ten times for each developmental stage. Insects were then collected and kept in plastic cages for 24 hours, after which period dead insects were counted. Data of dose application and time of experiment were also recorded. This experiment was repeated three times, using freshly sprayed surfaces for each dose. Also, it is repeated for each developmental stage for the five application doses.

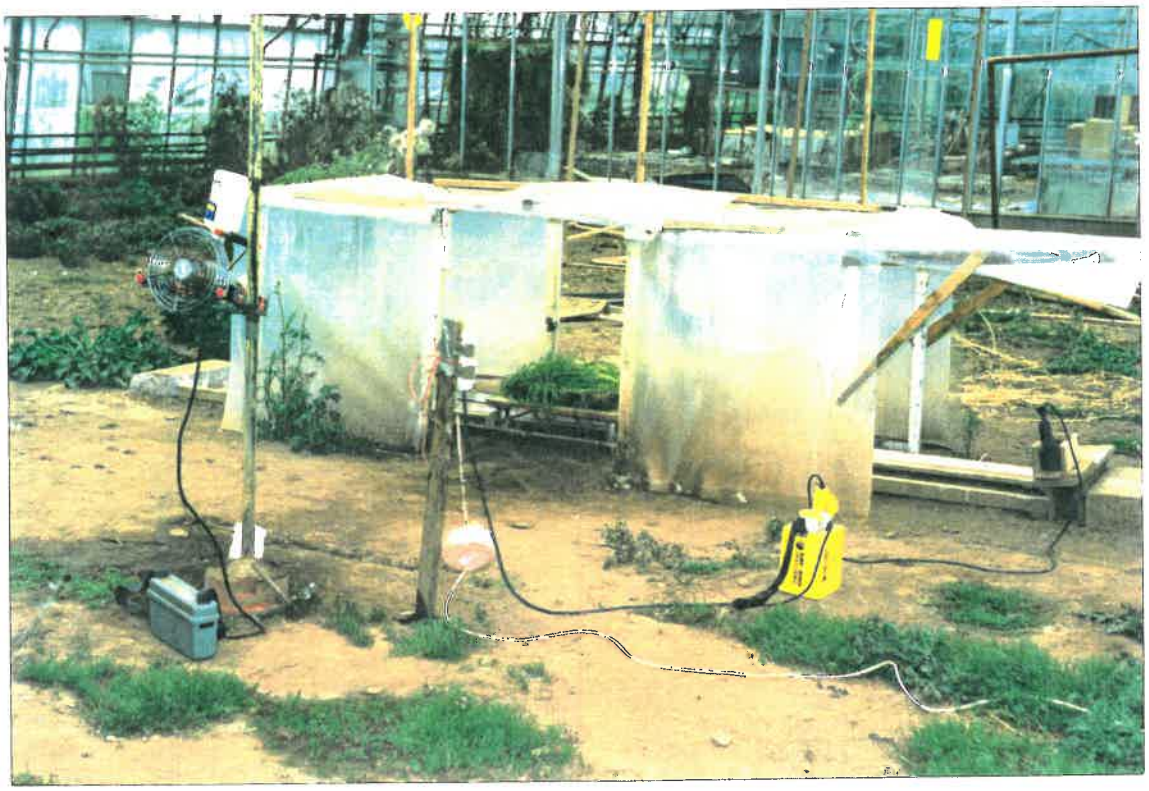


Fig. 4.1 A photograph showing the spraying set up used in this experiment.

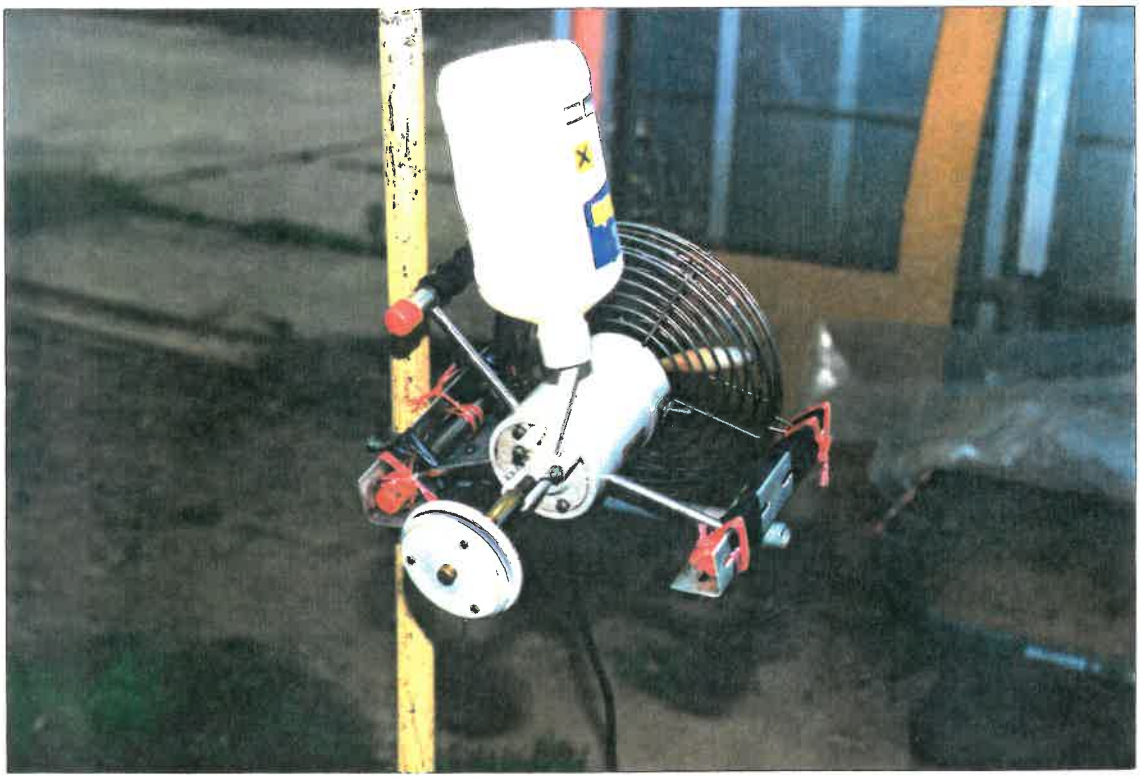


Fig. 4.2 A photograph showing the turbair sprayer

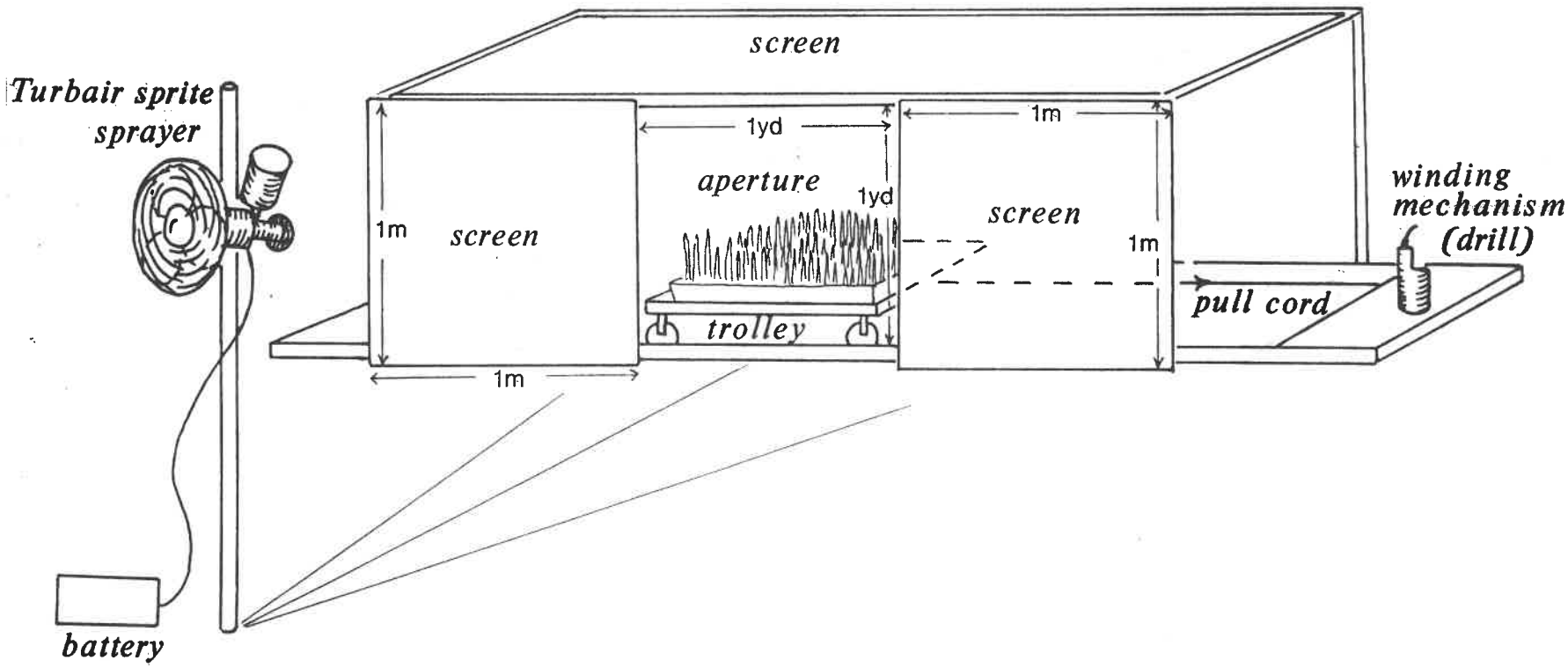


Fig. 4.3 A diagram of the spraying set up used in this experiment.

4.2.2 Estimation of Number of Insect Droplets

The same spraying technique using the same apparatus set up was also employed in this experiment (see 4.2.1). Only one surface was used - glass surfaces. Five pieces of oil sensitive paper were placed on the glass surface, as illustrated in Figure 4.4, each paper measuring 1.5 x 2.5 cm. The surface was then put on the trolley of the spraying apparatus. The doses were varied as follows: 0.467, o.95, 1.9, 2.85 and 3.8 mls^{-1}, so that the distance of 91.4cm (Figure 4.4)was covered in 0.5, 1.0, 2.0, 3.0 and 4.0 seconds. This step was repeated three times each dose and speed. The oil sensitive paper was then removed and a square of $1cm^2$ was drown in the middle of each paper and droplets were counted in this area using a microscope and a manual counter. A mean of fifteen counts (five papers x 3 replicates) was then calculated to determine the number of insecticide drops per cm^2.

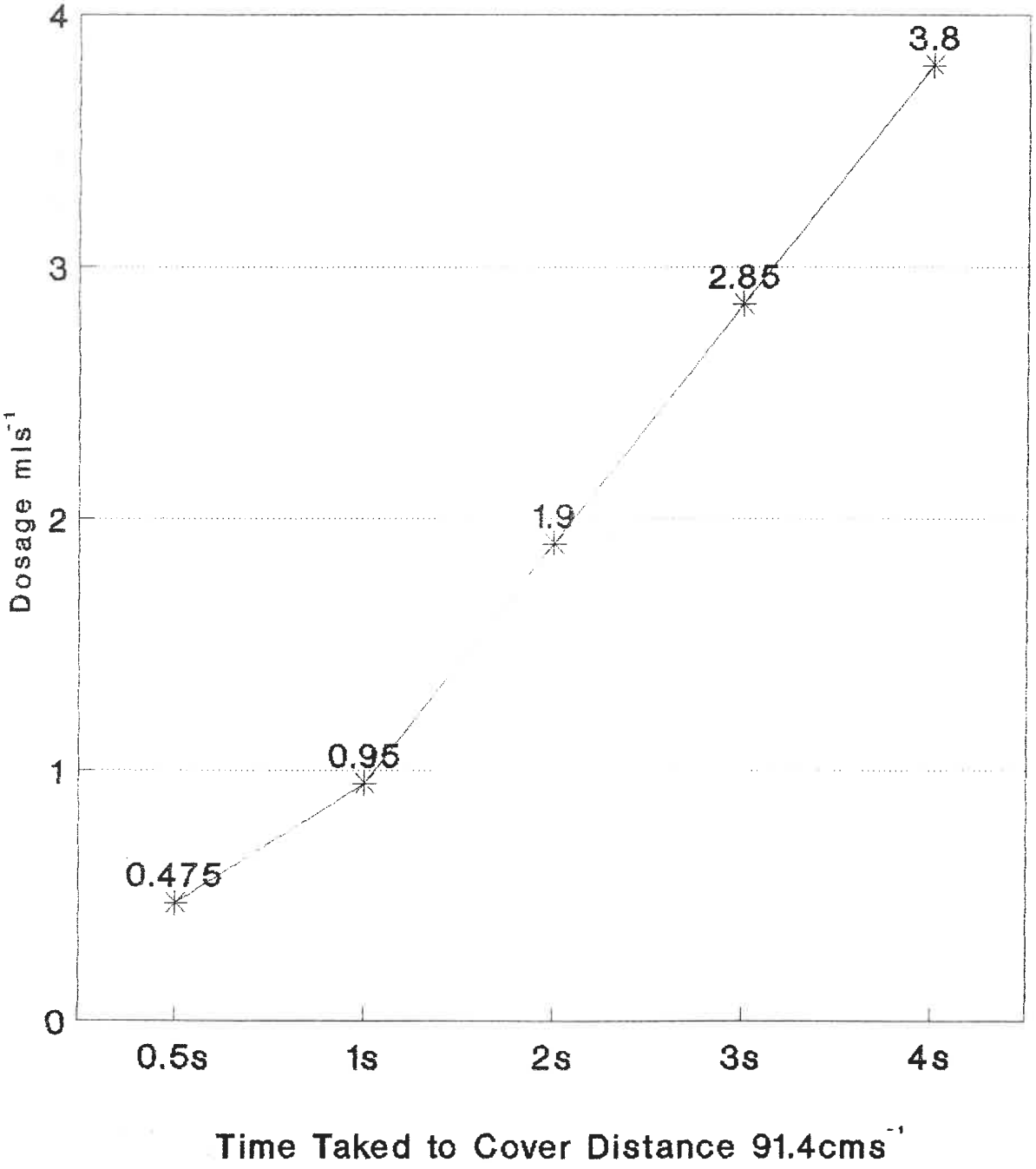


Fig 4.4 The relationship between the application rate and time taken by the trolley to move across spraying area.

4.2.3 Estimation of Amount of Insecticide Picked up by Insects

The same spraying technique and glass surface was used as described in 4.2.2. Only one dosage, 3.8 mls^{-1} was used for all developmental stages.

Twenty individual insects were left to walk across the glass surface, and after one hour ten insects were picked and divided into two groups; five each. The weight of each group of 5 insects was measured before proceeding further in the experiment. Ten antennae from each group were then detached and placed in a previously weighed glass tube with a narrowed and a sealed end. The open end of the tube was then sealed. The tube and its antennae was then weighed and the difference in weight between the tube and the antennae, and the empty tube represents the weight of the ten antennae. The tubes with the antennae were then analysed using mass spectrophotometry in the chemistry department in order to estimate the amount of insecticide picked by each age of locust after one hour. The antennae of the other ten individuals were removed after two hours and treated as above.

4.2.3.1 Solid Sample Injection (SSI)

This technique of solid sample injection (SSI) gas chromatograph mass spectrophotometer analysis is a useful technique for determining the change of concentration of an analyte in solid samples. The samples injected were the antennae of S. gregaria. The antennae samples were taken to be representative of the concentration of Malathion throughout the body of the insect. No solvent extraction is required, thus it minimises loss of sample. Ten antennae were sealed in a gas tight capillary tube, placed in the SSI inside the heated injector port of the gas chromatograph, and heated to volatise all the Malathion. After a set equilibrium time of 5 minutes in the heated injector port, the capillary was crushed to allow the vaporised volatiles down the gas chromatograph column to the mass spectrophotometer.

4.2.3.2 Calibration Curve

A calibration curve was made from several serial dilutions of stock Malathion to give a range of counts observed in the locust antennae (see Figure 4.5). The mass spectrophotometer was set in single ion monitoring mode to increase the sensitivity of the

machine; characteristic ion monitored was 127 inz^{-1}. An internal standard was also used having similar retention time to that of Malathion, this showed very little difference for all the injections from the calibration curve, however, the sample introduction to the gas chromatograph/mass spectrophotometer is different when using locust antennae solid sample injection as compared to a syringe injection for the calibration graph. This means no internal standard could be introduced for the locust antennae and it was therefore decided that the calibration graph should be used. This method is semi-quantitative as both injection methods differed. A graph of counts against injected Malathion per g can be drawn (Figure 4.17).

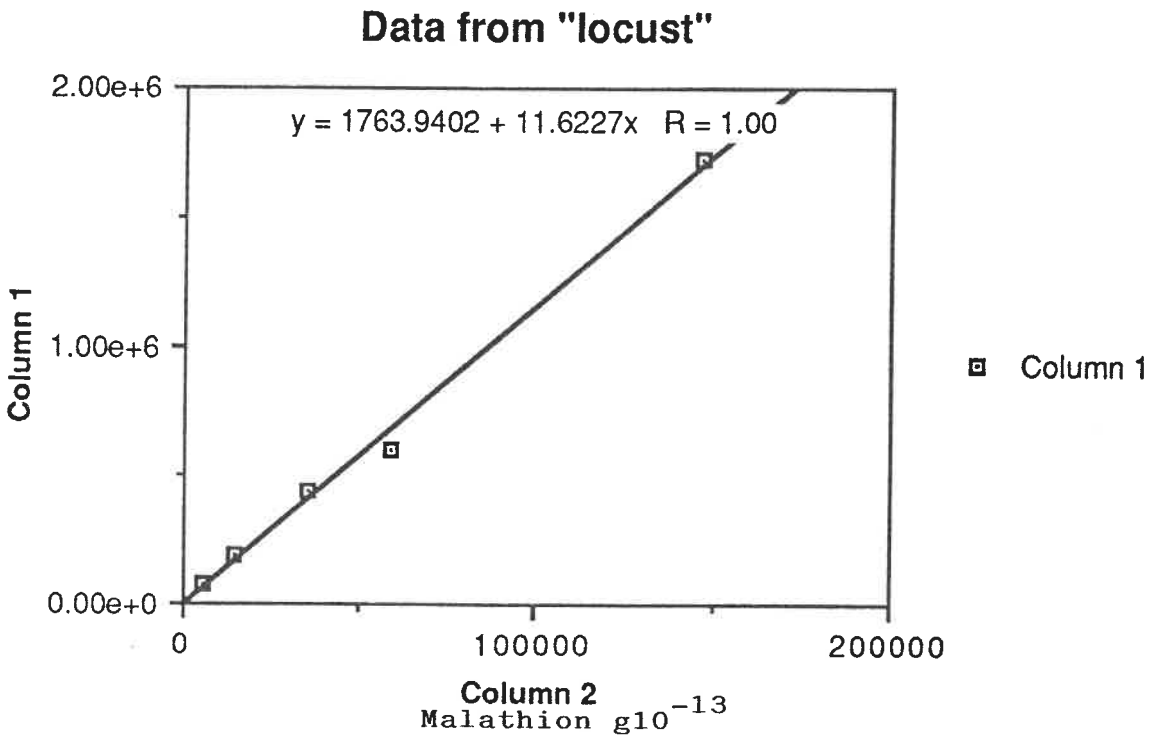


Fig. 4.5 A calibration curve.

4.3 RESULTS

Data obtained for the three different experiments mentioned above are given in Tables 4.1 and 4.2 and in Figures 4.6 to 4.17.

4.3.1 Estimation of Mortality Rate

The LD_{50} and LD_{95} of Malathion were estimated for different age groups and for the four surfaces. Results are given in Figures 4.6 to 4.10.

The probit programme for the dose and response analysis, is based on Finney (1963) 'probit analysis'.

Figures 4.8 to 4.10 show that the dosage required to achieve the LD_{50} mortality rate in hoppers and adult locusts increases with age of insects for all surfaces used.

Results also indicate that the LD_{50} dosage was higher using soil and sand surfaces, particularly the latter, than using grass and glass surfaces. The lowest dosage required to achieve the LD_{50} was recorded using grass as the walking surface.

Similar results but showing less differentiation between surfaces were also obtained to achieve the LD_{95} dosage values, as indicated in Figures 4.11 to 4.15.

Plots of probit-transformed reponse proportion against log-transformed value of dosage indicated that:

1. Relation of the variables for all instars and adult locusts moving across sprayed glass, grass and sand were not linear.
2. Relations of variables appear to be linear for the fourth-instar hoppers, but not linear for insects of other age groups moving on soil surface.

In all cases goodness-of-fi Chi-square was not significant, hence no heterogeneity factor was used in the calculation of confidence limits. The parallelism Chi-square test was also not significant.

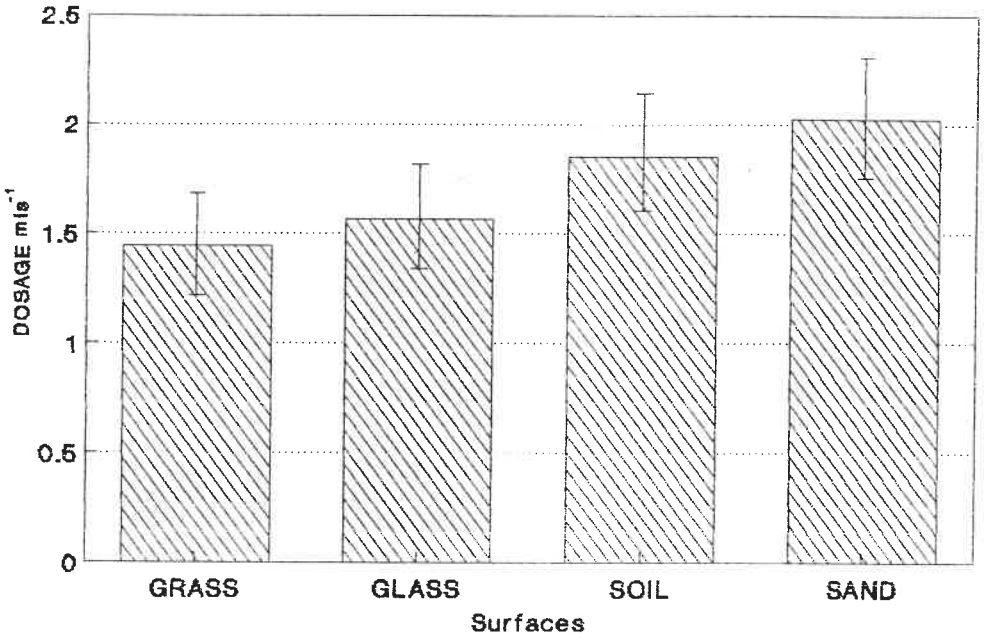


Fig 4.6 LD50 For Desert Locust Hopper Instar2 With Surfaces

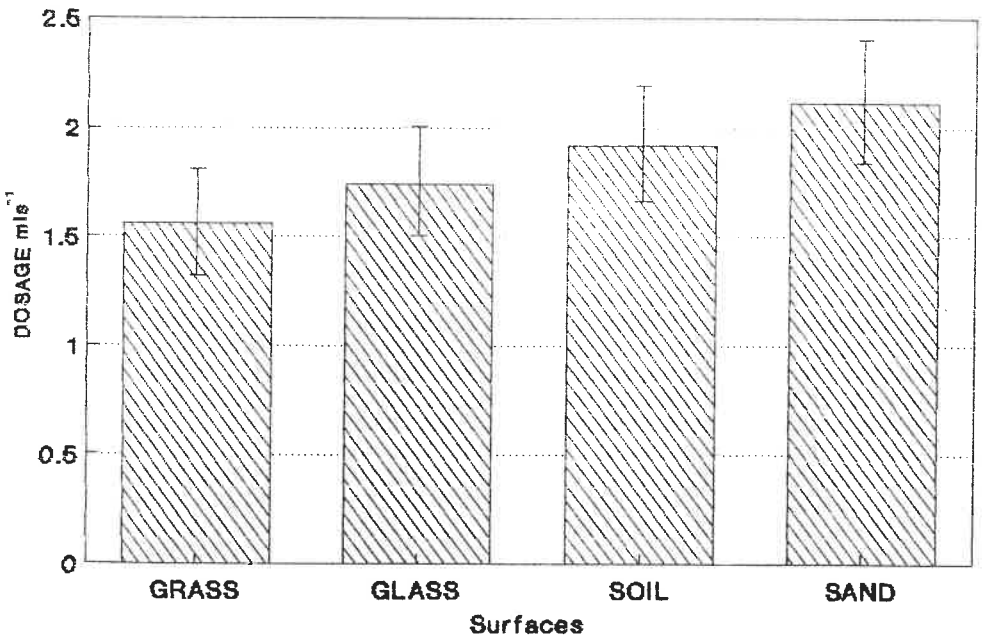


Fig 4.7 LD50 For Desert Locust Hopper Instar3 With Surfaces

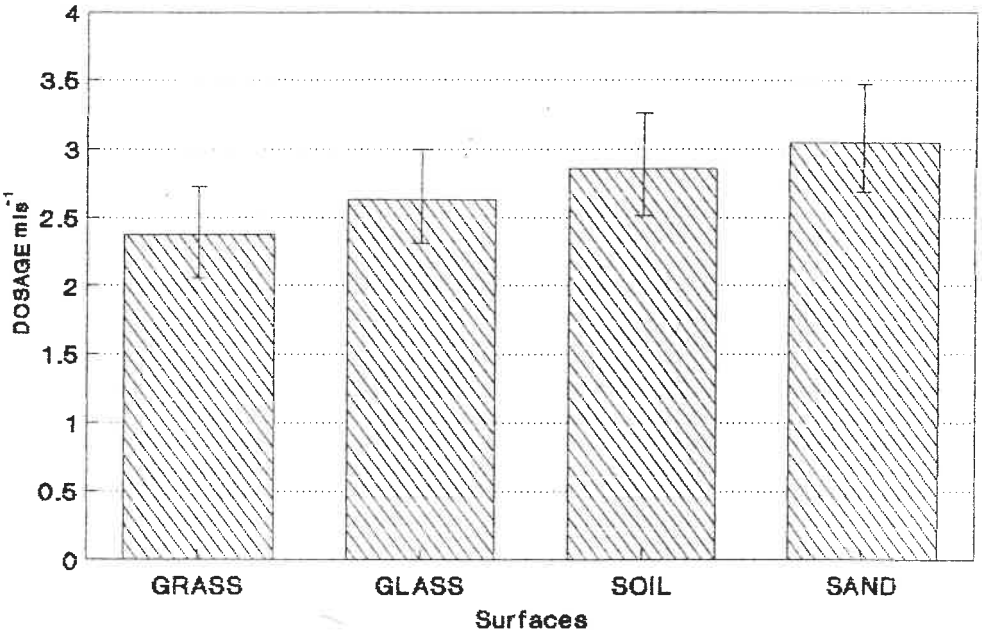


Fig 4.8 LD50 For Desert Locust Hopper
Instar4 With Surfaces

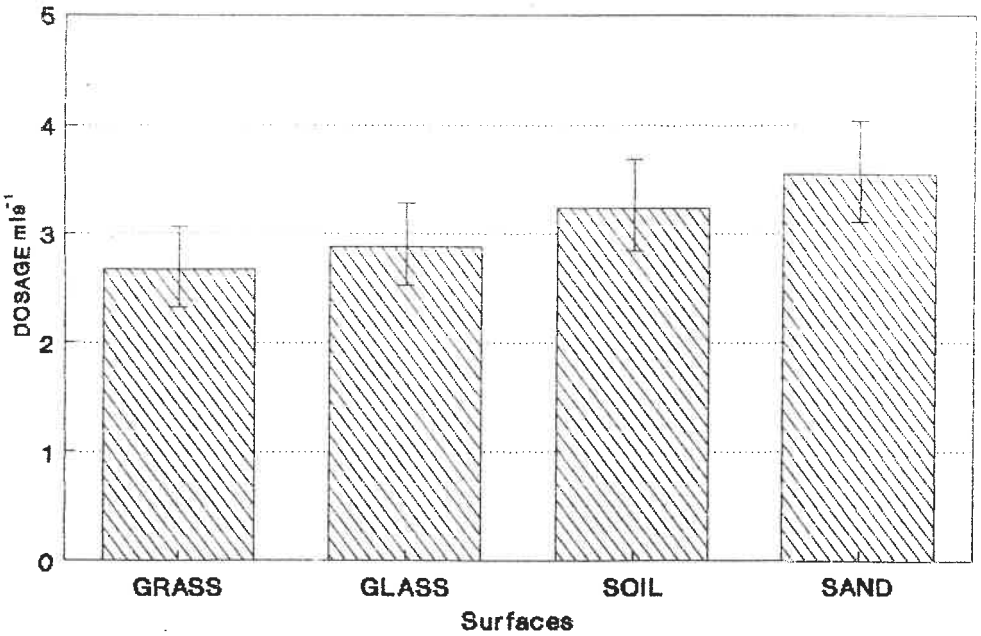


Fig 4.9 LD50 For Desert Locuet Hopper
Instar5 With Surfaces

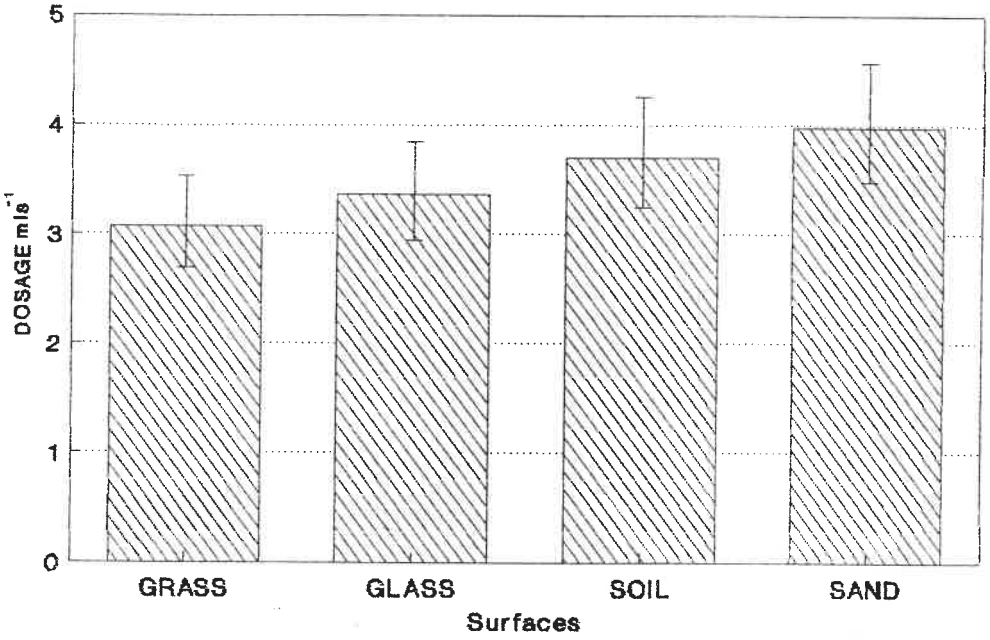


Fig 4.10 LD50 For Desert Locust Adult With Surfaces

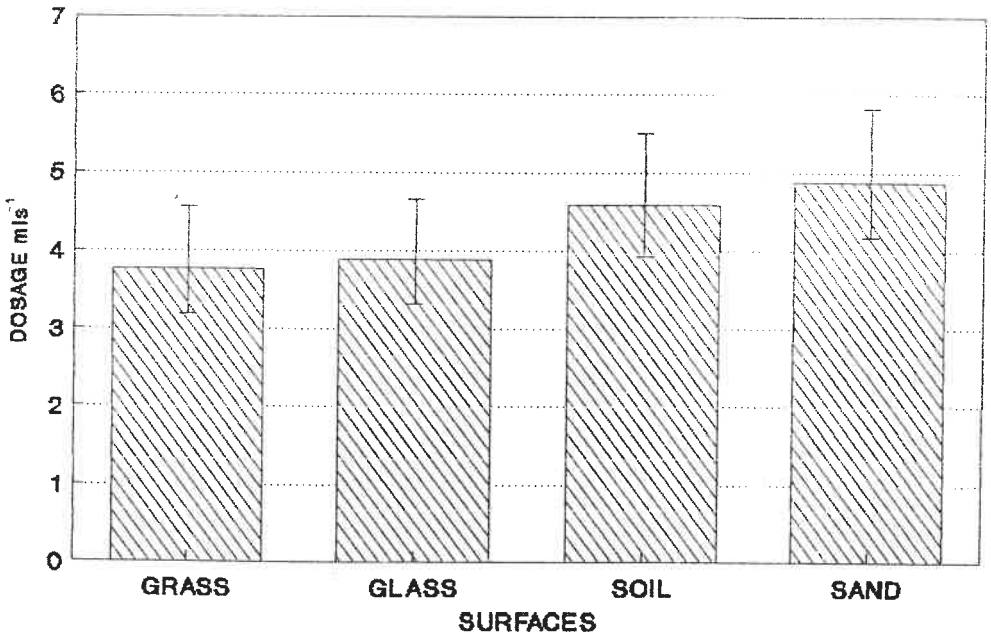


Fig 4.11 LD95 For Desert Locust Hopper Instar2 With Surfaces

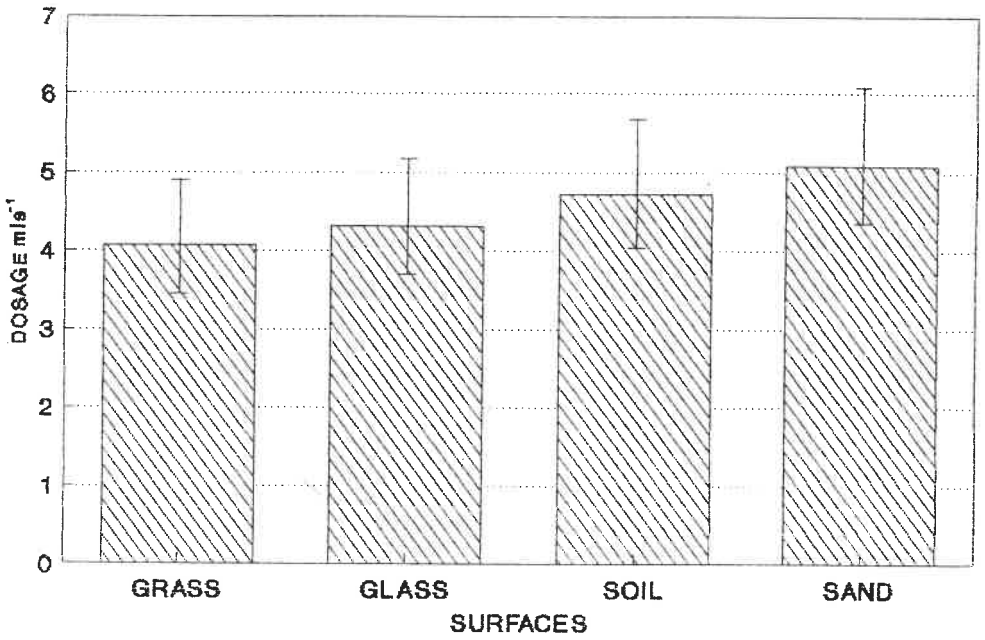


Fig 4.12 LD95 For Desert Locust Hopper Instar3 With Surfaces

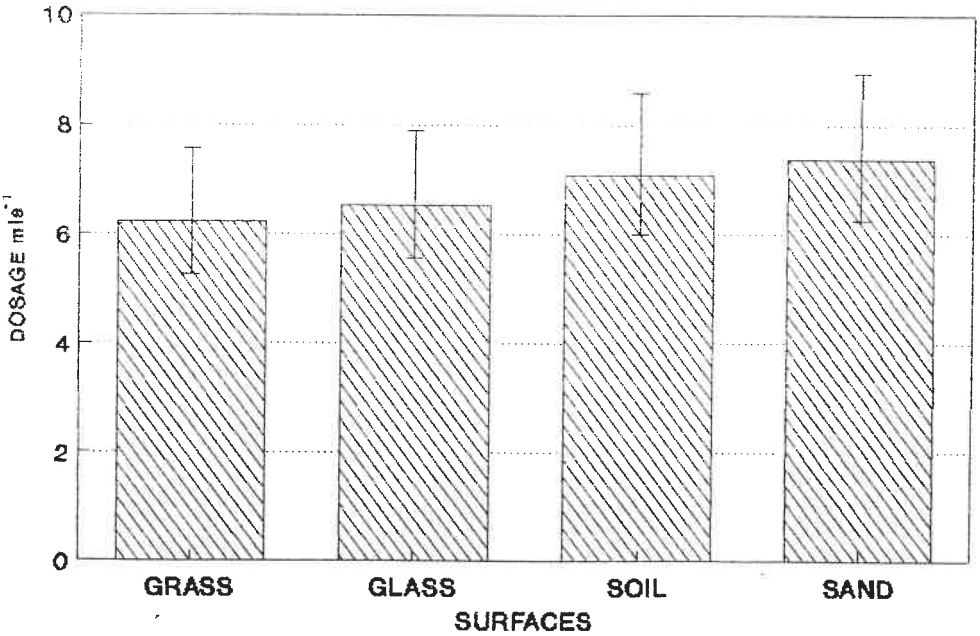


Fig 4.13 LD95 For Desert Locust Hopper Instar4 With Surfaces

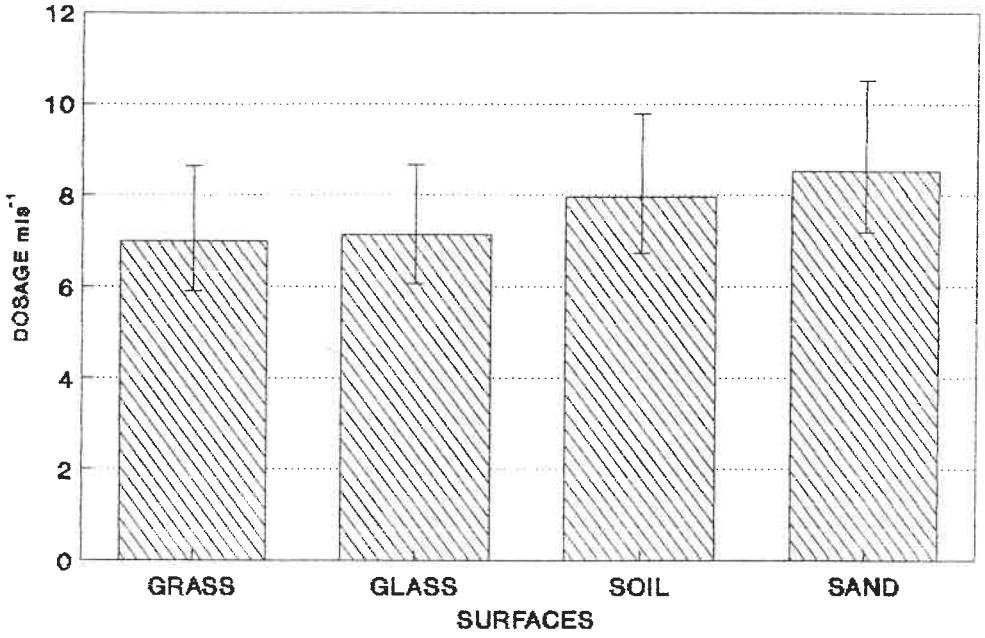


Fig 4.14 LD95 For Desert Locust Hopper Instar5 With Surfaces

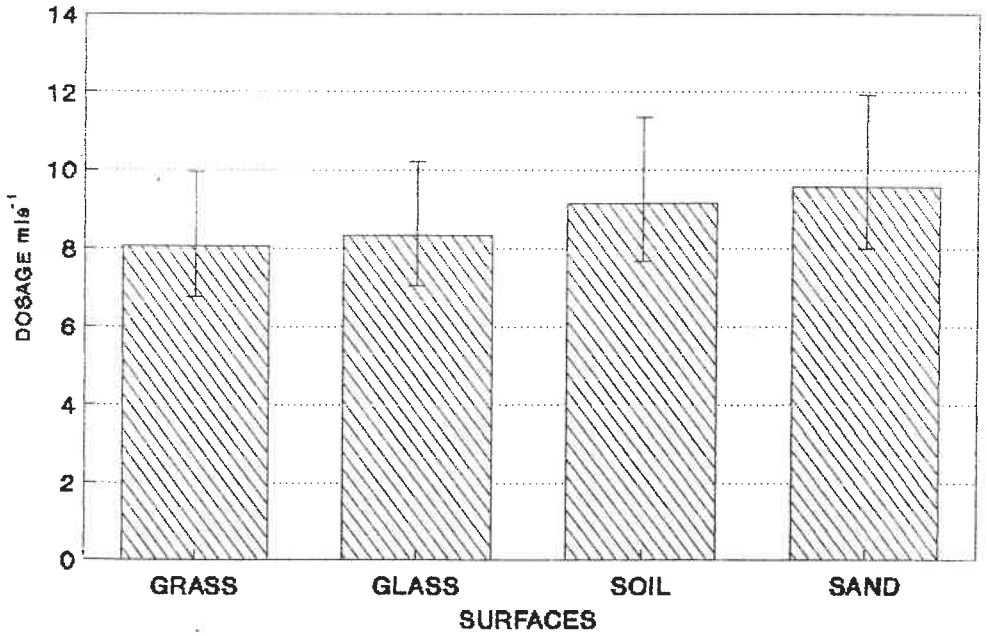


Fig 4.15 LD95 For Desert Locust Adult With Surfaces

4.3.2 Estimation of Number of Insecticide Droplets

Table 4.2 and Figure 4.16 clearly indicate a positive relationship between the application rate and the number of Malathion droplets per cm^2 of the glass surface.

Table 4.2 Average Droplet Density ULV cm^2 at Dosage mls^{-1} Application Rate

Dosage Application Rate mls^{-1}	Average Droplet Density cm^2
0.475	93
0.95	155
1.9	218
2.85	279
3.8	398

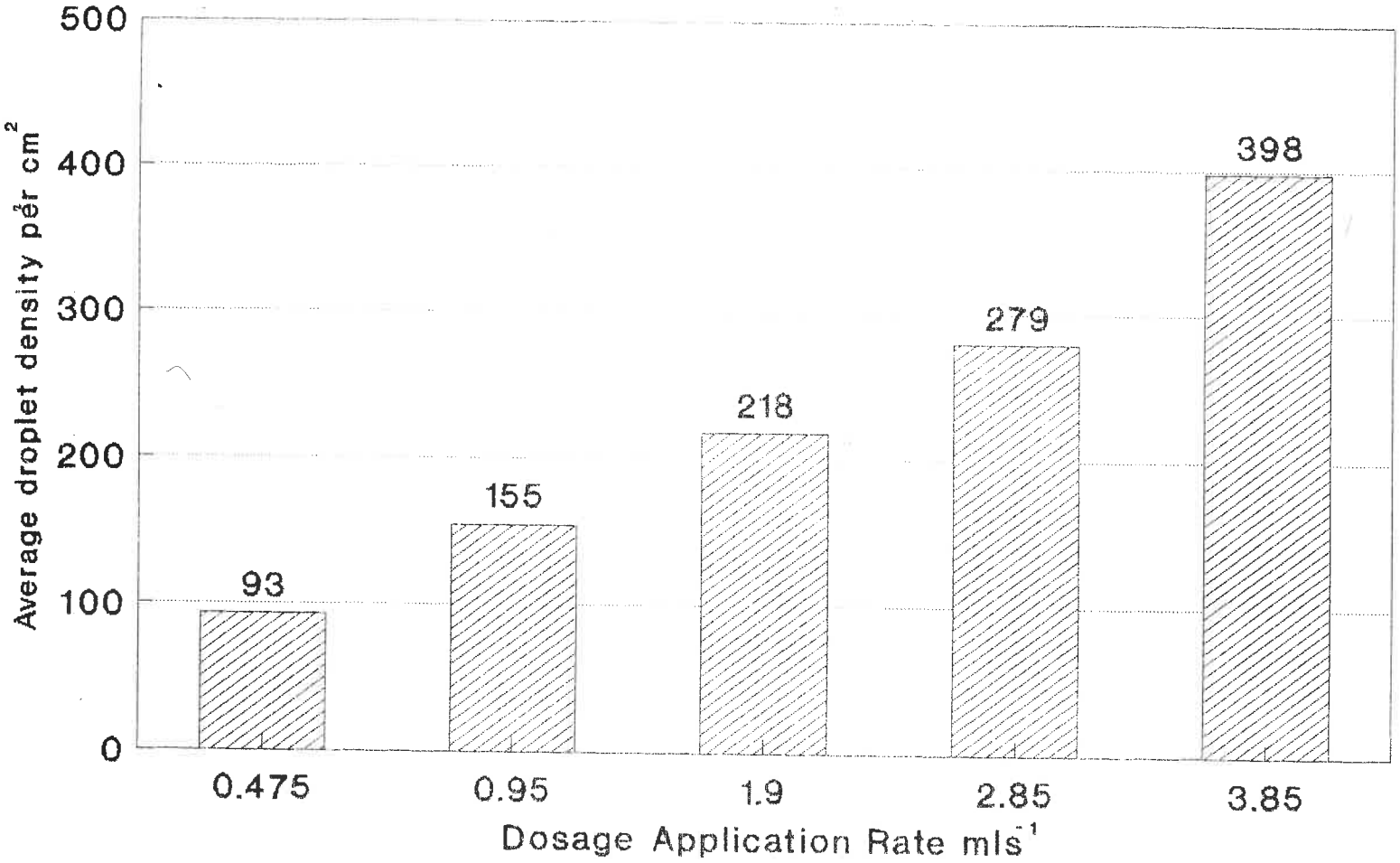


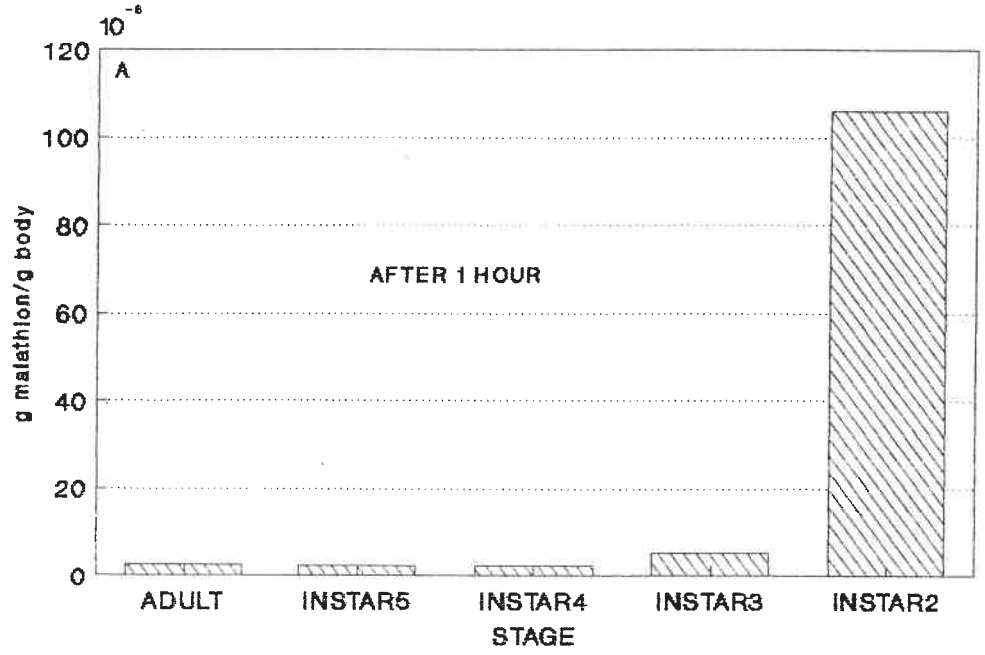
Fig 4.16 Averag Droplet Density cm^{2} at Dosage mls^{-1} Application Rate

4.3.3 Estimation of Amount of Insecticide Picked up by Insects

Amounts of Malathion picked up by individuals of the different developmental stages of S. gregaria are given in Table 4.5 and presented in Figure 4.17 A & B.

Results in Table 4.2 and Figure 4.17 B indicate an inverse relationship between the amount of Malathion picked up by insects and age of individual insects after one hour of exposure to Malathion. It seems that markedly higher Malathion concentration was picked up and absorbed by the second-instar hoppers of S. gregaria than other developmental stages.

Table 4.2 and Figure 4.17 B on the other hand, show a marked decline in the concentration of Malathion two hours after exposure to the insecticide. However, higher concentrations of Malathion were also recorded in the younger hopper than in older ones and the adult insects.



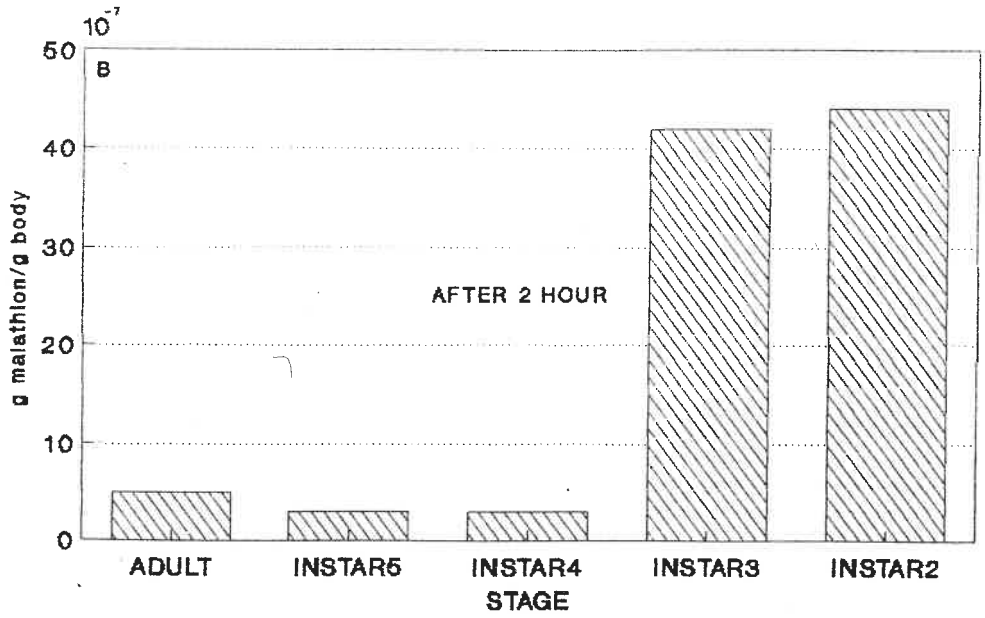


Fig4.17A&B Estimation of Amount of Insecticide Picked-up by Insect After1&2hour

Table 4.3 Amount of Malathion picked up by Desert Locust. Adult and hoppers from glass surface of mal/g body after (1 and 2 hour)

Stage	one hour	two hours
Adult	2.669×10^{-6}	5×10^{-7}
instar 5	2.245×10^{-6}	3×10^{-7}
instar 4	2.335×10^{-6}	3×10^{-7}
instar 3	5.335×10^{-6}	4.2×10^{-6}
instar 2	1.062×10^{-4}	4.4×10^{-6}

4.4 DISCUSSION

4.4.1. Mortality Rate

Results shown in Tables 4.2 to 4.4 and Figures 4.4 to 4.14 clearly indicate that lethal dose is directly proportional to the age of hoppers and adults of S. gregaria. This relationship is irrespective of the type of surfaces used in this experiment, though to a varying degree, as will be discussed later.

The area of contact with the surface during walking (direct interception), body, weight and size and lateral migration of insecticide through integuments are some of the factors that may affect the mortality of the insects.

Direct interception of droplets by a target insect can occur by either compaction or sedimentation and is dependent on the insect size and shape, as well as droplet size and density (Dent, 1991; Ford & Salt, 1987). Area of contact with the surface decreases with age, varying from second instar hoppers with the ventral part of the insect being totally in contact with the surface to partially in contact with the surface in the case of adult insects. In the latter only the posterior part of the ventral side of the abdomen is raised from the ground. In this case similar doses of Malathion applied to the surface affect different age groups differently, being more effective in younger hoppers than in older ones or than adult insects. It was suggested that the area of contact between the deposit and the recipient surface will also be a dominant factor which determines the transfer of insecticide to target insects (Hartley & Graham-Bryce, 1980). Salt & Ford (1984) showed with scanning electron microscopy that the surface of larvae of Spodoptera lilloralis is extensively papillate which results in up to doubling the surface area, depending on the stage of larval development, and that this

observation may partly explain the very high adhesion between the larval cuticle and the oil droplets of permethrin.

Body weight and size increase with age, hence larger doses of Malathion are required to achieve the LD_{50} and LD_{96} mortality rate with increasing size and age of insects.

Reviews on the penetration of contact insecticide (Brown, 1951; Richards, 1951; Winteringham, 1957; O'Brien, 1960, 1967; Ebeling, 1964) assumed that the insecticides enter the insect by penetrating through the integument of the body wall and subsequently dissolve in the haemolymph. These reviews also indicate that some of the dissolved poison is then absorbed by the medullary sheath enclosing the central nervous system (CNS) and protecting the underlying tissues. Gerolt (1969), on the other hand, showed that his result threw considerable doubt on the validity of the widely accepted interpretation of the mode of entry of contact insecticide, ie. insecticides penetrating through the integument of the body wall of the insect and then being carried out to the CNS by haemolymph. Gerolt (1969) found out experimentally that little or no insecticide penetrates through the integument of some insects, including isolated integuments of the ventral abdomen of an adult S. gregaria. It seems that

insecticides accumulate in the integument but do not diffuse freely into the haemolymph (Lewis, 1965; Matsumura, 1963; Gerolt, 1969). The possibility was that contact insecticides enter the body through the trachea. According to Gerolt (1969), the most likely alternative is that of entry via the integument in a lateral fashion, the insecticide reaching the target organ via the integument of the tracheal system and that in this manner it has very few barriers to pass. He also reported that ^{14}C-dieldrin was found in the deeper layers of the integuments, possibly in the epicuticle. He concluded that in the endocuticle, dieldrin seems to be very mobile despite its high partition ratio in favour of fatty material, and that other insecticides, mostly being less hydrophobic in nature than dieldrin, can be expected to reach the site of action in this manner, ie. through lateral migration.

Other possible site of entrance is via nerve tissues as suggested by Ball & Beck (1951).

Results obtained in this work indicate that a higher dosage of Malathion is required on soil and sand than on grass or glass surfaces in order to obtain the same LD_{50} and LD_{95} mortalities. Malathion spray deposits seem to be lost in sand and soil, perhaps due to binding with large particles. Therefore, larger doses of the insecticide are required in

this case to retain deposits on these surfaces in order to provide sufficient active ingredient on the surface for transfer to the insect.

Gordon et al (1989) indicated that the fate and performance of a soil-applied insecticide is determined by a host of factors. From a physical and chemical point of view, the insecticide may be lost as a vapour to the atmosphere, degraded chemically or biologically by soil microorganisms, adsorbed by soil colloids, that may or may not be biologically active, precipitated or chelated as unavailable complexes, degraded by sunlight, lost by leaching, or taken up and degraded by plants.

It is difficult to know which of these processes will have affected the availability of Malathion on the experimental surfaces but it seems likely that since there was little time between application to the surface and use in the experiment only the processes that act quickly would be relevant. A certain amount of adsorbtion and 'leaching' may have occurred so the deposits were lost from the surface and were then not available for transfer.
With regard to grass surface, spray droplets of the applied insecticide must impinge and be retained on the plant surface before they penetrate through the cuticle (Holloway, 1990). Holloway added that surface chemistry of

the cuticle is governed by a superficial wax layer which is normally present, and that the hydrophobic nature of superficial waxes is their most important physico-chemcial properties, since these properties are of a paramount importance in determining the wettability of the leaf surface (Kirkwood, 1987; Davies & Blackman, 1989). Plant waxes are complex mixtures of long chain molecules including alkanes, alcohols and ketones (Martin & Juniper, 1970; Kolattukudy & Walton 1972).

In the present study the retention time of Malathion on grass leaves appears to be much longer than its persistence on both sand and soil surfaces, hence treated grass leaves were more effective in inducing the higher LD_{50} and LD_{95} mortality due to the fact that more Malathion was picked up here than on sand and soil.

Recently, Ford & Salt (1987) reviewed the behaviour of insecticide deposits and their transfer from plant to insect surfaces. They reported several factors which determine the availability of insecticide at the plant surface; these are behaviour of deposits at impaction, wettability of leaf surfaces, penetration into the plant cuticle, evaporative loss of volatile materials and weathering of insecticide deposits.

Airborne drops moving towards a plant have kinetic energies proportional to the masses, according to Ford & Salt (1987). On impaction, this energy will be dissipated as damped oscillations of droplet spread and recoil. When oscillations cease, liquid deposits tend to spread across the surface at an initial rate determined by the drop viscosity (Brown, 1951; Crease et al, 1985; Ford & Salt, 1987) and the extent to which the underlying surface is wetted (Ford & Salt, 1987). Gravity will influence the rate of spread of large drops (≥ 200 μm diameter) but will have less influence on small drops and that gravity may generally be ignored for drops less than 80 μm in diameter (Ford & Salt, 1987). Hartley & Graham-Bryce (1980) indicated that further complexity is introduced by the dynamic changes in surface tension which accompany the loss of volatile carrier as the deposit dries.

The affinity of a deposit for the plant surface will determine the extent of wetting of the leaf surface by the deposit, a process related the surface tensions and hence, forces of adhesion. Wettability of plant surfaces varies and Holloway (1970) observed that external surfaces of plants range from strongly water repellant to completely wettable. The principle factors that govern the wettability of plant surfaces are the degrees of hydrophobicity (Adam & Jessop 1925; Holloway, 1970, Jefree

et al, 1976: and the roughness (Holloway, 1970; Wensel, 1936) of the surface. Grass leaf surfaces are highly hydrophobic and hence spray droplets are retained on the surface for a long time, therefore, there is the possibility of more insecticide being picked by insects walking across the grass leaf surface than on walking over soil or sand. Further details regarding the behaviour of insecticide deposits are reviewed by Ford & Salt (1987).

Glass surfaces resemble, to some extent, the grass leaf surfaces. They are totally repellant to liquids thus Malathion droplets were also available to be picked by insects walking on them. However, evaporation and loss to the atmosphere would be greater on glass than on grass surfaces.

4.4.2 Number of Droplets

Results of the present study indicate that the density of Malathion droplets per unit area of the glass surface increased with increasing application rates. At higher levels of application droplets are prone to drift and hence their sedimentation and collection on the glass surface will be low. In this experiment, the size of droplets was uniform for all of application (doses) since they were all sprayed using the same apparatus, only the speed of the

trolley holding the glass varied. Hence, size was not a limiting factor in determining the density of the droplets.

4.4.3 Amounts of Insecticide Picked up by Insects

According to Malsumura (1985) Malathion kills insects by contact or vapour action and also is a stomach poison (vapour pressure is 1.25×10^{-4} mmHg at 20°C). He also added that, in general, the site of entry is largely dependent on the type of insecticide; for instance, if the insecticide has high vapour pressure it tends to enter through the spiracles and antennae. For this reason and due to the fact that using the solid sample injection technique requires very small objects, antennae were found the most suitable part of the body to determine the amounts of Malathion picked up by the Desert Locust.

The mass of the antennae are not representative of the mass of the total body, however, it was assumed that the concentration of Malathion in the antennae is the same as that in the body as a whole. Results of this experiment agree with this assumption.

Results shown in Table 4.3 and Figure 4.7 A indicate that the dose of Malathion sprayed on glass (3.8 mls^{-1}) adversely affected different developmental stages of S.

gregaria. Since body area of contact decreased with age, as discussed in 4.4.1, more Malathion was picked up by younger than by older insects, hence higher concentrations of Malathion were found in the antennae of the second-instar hoppers than in other age groups.

However, after two hours of exposure to Malathion, the concentration of insecticide dropped significantly in all ages, probably for the following reasons:

1. Malathion may be disintegrated, bound or complexed in the body of insects, thus lower concentration was detected.
2. It is possible that Malathion has been translocated to other parts of the body within the second hour of exposure of insects to Malathion, thus its concentration in the antennae dropped.
3. The above mentioned activities seemed to be more actively operational in younger than in older insects, hence the loss in younger insects was significantly higher than in older ones.
4. Malathion may be lost by secretion or excretion to the environment, hence its concentration drops within the body.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The purpose of this chapter is to give an overall discussion of the findings reported in present work and to present the main conclusions. Recommendations for future work regarding the control of S. gregaria in Saudi Arabia will also be proposed. The main objective of the experiments carried out during the course of the study was to develop and improve the method of controlling Desert Locusts and hoppers of all developmental stages through more efficient and economic application of Malathion using a turbair sprayer. A greater understanding of the relationships between rates of application and transfer of insecticide deposits to the locusts from different surfaces should permit a more rational approach to developing pesticide application strategies for control of S. gregaria.

5.2 GENERAL DISCUSSION

Malathion was used in the present work as the only insecticide since it is currently used in large quantities in Saudi Arabia for the control of S. gregaria swarms, although other insecticides are also used for this purpose, such as Sumithion Super 100% ULV, Fenitrathion 96% ULV, Volatoun 300 etc.

Movement of swarms of S. gregaria covers vast areas including north Africa, the Middle East and eastern and south eastern Asia. Saudi Arabia is affected by swarms resulting from the spring and winter breeding seasons, whereby environmental and climate logical conditions and vegetation cover are appropriate for supporting and maintaining these swarms. In late 1988 (October) to early 1989 (February) Saudi Arabia was plagued by huge swarms of S. gregaria from neighbouring and nearby African countries. Large quantities of eight kinds of insecticides (517,125 litres) were sprayed, using airplanes and ground control team, during this period until the country was declared free of Desert Locust and hopper swarms in February 1989.

The ULV spraying technique was used throughout this study, since targeting locusts and hoppers using smaller droplets

containing concentrated insecticide is thought to achieve better levels of control.

Fourth instar nymphs and adults S. gregaria were used as the experimental animals. All insects were reared from a breeding stock obtained from a culture at Queen Mary College, University of London. Insects were reared and maintained in experimental cages, whereby light, humidity and temperature were under control.

Walking speed of hoppers and adult insects was measured on four types of surfaces; grass, glass, sand and soil, at five different temperature regimes; 25°, 27°, 29°, 30° and 32°C.

Malathion was sprayed on the four surfaces at five different doses and ten insects of each development stage were left to walk across the sprayed surface. Data obtained on walking speed indicated that maximum speeds were achieved at 29°C, particularly in the case of advanced developmental stages. Although walking activities increased with temperature, the relationship between the two was not always directly proportional since at higher temperature walking activities tended to be constant or declined. Walking speed on grass was slower than on other surfaces.

Data of the present work also indicated that the quantities of Malathion picked by insects decreased with age, this means an inverse relationship between these two parameters, due to the fact that different parts of the insect body and the area of body in contact with the treated substrate that picked-up the insecticide differ from one age to the other. In younger insects the area of the body in contact with the surface is greater that the older ones. This finding was substantiated by the results obtained from experiments on the amount of Malathion picked by insects after one hours exposure to the insecticide (see chapter four) and from the observations using a red dye as described below. In order to know which parts and appendages of the body picked Malathion from sprayed glass surface, the glass was covered with a thin film (10 x 40 cm) of red dye (Kenacid red dye) and insects of all developmental stages were left to walk over this coloured film. Upon microscopical examination the following observations were made:

1. Insects of all ages picked the dye through tarsus or appendages.
2. Second and third-instar hoppers also picked the red dye by the body area in contact with the dye; ie. on the ventral abdominal and thorax segments and on the mouth parts.

3. The fourth-instar hoppers also picked the dye on all the ventral abdominal segments, only a small quantity on the last thorax segments adjacent to the abdomen.
4. The fifth-instar hoppers picked the red dye on the second abdominal segments down to the last segment.
5. Adult Desert Locusts picked the red dye on the last four abdominal segments, as well as the ovipositor apparatus of the females and the copulating organ of the males.

The findings of the present study agreed with those reports by many authors working in this field, particularly those of Salt & Ford (1984), Hartley & Graham-Bryce (1980). Salt & Ford (1984) considered that the quantity of insecticide encountered can be determined from the area swept by the larvae of Spodoptera littoralis as it moves over a treated surface, the density and diameter of the droplets, the proportion of the body making contact with the plant surface and the behavioural state of the larva.

Similar views have also been reported by Hartley & Graham-Bryce (1980). Salt & Ford (1984) also realised that the kinetics of the pick-up process and subsequent intoxication might be profoundly affected by the different modes of contact associated with each state. Droplet density was found to increase with the increase in the dosage of application rate. Experiments on insects indicate that

some Malathion is lost after two hours of exposure, due to disintegration complexing, translocation and or loss through secretion on excretion of Malathion after a longer period of exposure.

As mentioned earlier, five different application rates of spraying Malathion were used. These were 0.5, 1.0, 2.0, 3.0 and 4.0 seconds and amounts of Malathion sprayed on a trolley moving 91.4 cm distance equivalent to about 1,40.5, 2,805, 8,149, 11,220 $mlha^{-1}$ respectively. Experience of the researcher in controlling Desert Locust in Saudi Arabia at application rates ranging from 2 to 3 lha^{-1} since the areas treated were sprayed more than once at a rate of 1 to 1.5 lha^{-1} for each application, to ensure achieving LD_{95} mortality rate at the field. In this experiment soil and sand surfaces required more Malathion than grass or glass for reasons discussed earlier. Taking into consideration the limitations of laboratory controlled experiments, our results show that the application rate used in the field in Saudi Arabia approaches to some extent the optimum application rate on grass and soil in this experiment. It can be deduced that spraying 2 to 3 lha^{-1} in the field on vegetation, crops and soils is economic in the sense that crops are protected and it is efficient in the sense that the environment is protected from over-dose application of Malathion.

The approach taken here was a good one in the sense that applying Malathion in more appropriate dosages will cause less harm or hazard to the natural habitat while achieving higher rates of mortality. In this case the objectives and aims of the present study have been achieved and fulfilled. The use of the ULV spraying techniques would be advantageous and beneficial in controlling locust swarms in Saudi Arabia. Results of the present study can be applied in the field since the temperature regimes, illumination, moisture content and other environmental variables are similar to those in the field in Saudi Arabia. In addition, the insects used were fed before commencing the experiments, a case similar to those found in the field, hence, the starvation regime which is followed by some other authors before commencing their trials was excluded. Hence, the results obtained reflect the situation in the field, whereby insects are not starved at all. Three of the surfaces used, grass, soil and sand are representative of the surfaces in Saudi Arabia, since areas at times of invasion are rich in vegetation cover, whereas the invasion grounds are composed mainly of sand and alluvial soils from the surrounding hilly areas.

From the results given in this study, it can also be assumed that at temperatures lower than the optimum, mortality rates would be expected to increase due to

slowing down of insects therefore, the insects spent longer time in contact with the sprayed surface. At higher temperatures, insects either accelerate or start climbing surrounding vegetation or march towards shady areas in the field, hence, time of contact with the sprayed surface would be much reduced; hence, a lower mortality rate would be expected.

5.3 CONCLUSIONS

From the preceding discussion throughout the thesis the following conclusions can be drawn:

1. Optimum temperature for maximum walking activity was around 29°C.
2. Walking activities are directly proportional to insect age. This is one of the reasons why advanced hoppers and adult S. gregaria required higher Malathion doses to result in the maximum LD_{50} and LD_{95} mortality rates, since they were able to cross the sprayed surfaces faster than younger adults, hence time of contact is reduced and subsequently larger doses of the insecticide are required.
3. Nature of terrain of surfaces used is one of the important factors in walking activities.

4. There was a relationship between type of surface, amount of insecticide picked up and age of insects.
5. An inverse relationship was obtained between the amount of insecticide picked and age of insects.
6. There was a loss in the amount of Malathion in the antennae of S. gregaria after two hours of exposure to the insecticide.

5.4 RECOMMENDATIONS

The following recommendations have been drawn up by the researcher are a result of this work in relation to his experience in controlling Desert Locust in Saudi Arabia.

1. It is advisable to control swarms of the first three instar hoppers whereby spraying is more economic and efficient and less polluting to the environment.
2. The type of surface sprayed and age of the insect must be taken into consideration to estimate the appropriate concentration of the insecticide to give the highest mortality rate.
3. Insecticide must be tested in every region to test their efficacy on all stages of S. gregaria before application in the field.

4. Workers in the control of Desert Locust must have a good knowledge of the life-cycle of S. gregaria and the behaviours of each developmental stage, so that the control becomes successful, efficient and economic as well as eradication of the swarms is achieved in a short period of time.

5. It is also recommended that further detailed studies should be carried out which involve both laboratory and field trial experiments, in order to realistically improve the techniques currently used, so that they can be used efficiently, effectively and economically.

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