

EFFECTS OF INSECTICIDES ON PREDATOR-PREY  
INTERACTIONS IN CEREAL FIELDS

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## DECLARATION

Chapter 3, except the addendum, has been accepted for publication in Environmental Entomology.

Chapter 5 has been submitted as a paper for publication in Environmental Entomology.

These papers were written by the present author, with comments from my supervisors Dr Shires at Shell and Dr Lawton at York. The experiments described in them were carried out entirely, by the present author.

## ABSTRACT

There has been considerable interest in parasites and predators as possible control agents of cereal aphids (Homoptera: Aphididae) in Britain. This thesis is concerned with the effects of 3 insecticides on a guild of natural enemies and their prey, both in the laboratory and in the field.

In the laboratory the cereal aphids Metopolophium dirhodum Walker and 6 potentially important predators were exposed to dry insecticide films for 24h. after which time they were recorded as alive, moribund or dead. The insecticides tested were pirimicarb, cypermethrin and parathion methyl. The animals tested were the insects Coccinella septempunctata L. (Coleoptera, Coccinellidae), Syrphus spp. (Diptera, Syrphidae), Pterostichus melanarius Illiger (Coleoptera, Carabidae), Agonum dorsale Pont. (Coleoptera, Carabidae) and spiders Erigone spp. (Araneae, Linyphiidae). Parathion methyl was overall the most toxic compound, cypermethrin was less toxic and pirimicarb was the least toxic. The relative susceptibility of the predators and the aphid varied considerably between insecticides as did the slope of the dose/response curve.

In the field the effects of the same three insecticides, and a fourth (demeton-s-methyl) on polyphagous predators of the families Carabidae, Staphylinidae and Linyphiidae were determined in 2 consecutive years within barriered plots. In 1982 the impact of the 4 insecticides on the aphids M. dirhodum and Sitobion avenae F.

were also ascertained. All insecticides were effective in reducing aphid numbers. Some selective toxicity against predators occurred. Field results were similar but not identical to those obtained in the laboratory. Barriered plot experiments were also carried out in 1982 to determine which predators were important in containing aphid outbreaks. Selective toxicity enabled differential manipulation of predators. Although only polyphagous predators were observed no one predator was clearly responsible for a reduction in aphid numbers. Results suggest that polyphagous predators as a whole play only a cursory role in limiting cereal aphid population growth.



## CHAPTER 1

### INTRODUCTION

"To prevent to calamities which would infallably result from the accumulated multiplication of the more prolific animals, it has been ordained by the Author of Nature, that such should be diminished by serving as food for others. On this principle, we find that most animals in this predicament have one or more natural enemies. The helpless Aphis, the scourge of the vegetable kingdom, has to contend with many."

Curtiss, W. (1802)

- 1.1 The use of insecticides in British cereal production has been common practice since the late 1950's. It is however alarming that little information is available on the impact of these compounds on the cereal ecosystem as a whole. Perhaps more surprising, considering the worldwide importance of cereals, is how little is known of the ecosystem itself. Prior to the study of Potts and Vickerman (1974), the components of the cereal ecosystem were virtually undocumented. Although the pest fauna of individual crops has been well studied the role of parasites and predators has only recently received attention.

There has been widespread concern over pesticide use in agroecosystems for some time. Where agricultural pests are preyed upon or parasitised by natural enemies the use of pesticides may, in the long term, exacerbate the problem. The use of broad spectrum pesticides eliminates many arthropods which are important as a food source for vertebrates or predatory arthropods. Indeed, concern for the grey partridge (Perdix perdix L.) whose chicks feed largely on cereal arthropods has prompted much cereal ecosystem research under the Partridge Survival Project at the Game Conservancy.

Many authors (Croft, 1972; Croft and Brown, 1975; Georghiou, 1972 and Newson, 1974) have emphasised the need for more study of the specific responses of predators and parasites to insecticides. This thesis sets out to examine the effects of a range of insecticides on cereal aphids (Homoptera, Aphididae) and their predators as a contribution to an understanding of the ecology of modern, intensively managed cereal ecosystems. Although parasites may be of great importance, only predators are considered here. The aims of the study are to (i) assess the impact of a range of insecticides on cereal aphids and selected arthropod predators, both in the laboratory and in the field; and (ii) to determine the impact of different predatory groups on cereal aphid populations in the field using insecticides to selectively manipulate predators. Comparisons are then made between laboratory and field results, and the relevance of laboratory studies in predicting field results is discussed.

## 1.2 Cereal Aphids

Cereal aphid outbreaks have occurred occasionally in Britain for many years. Indeed Marsham (1798) and Curtiss (1845) describe an outbreak which occurred in 1797. There was an outbreak in France in 1830 (Macquart 1831) and Blomeyer (1889) reports aphids in grainfields in 1889. Despite these early reports there are few records of cereal aphids reaching pest status in Britain until the 1960's. In Britain and Europe cereal aphid outbreaks were reported in 1968. In five of the 11 years between 1968 and 1979 aphids occurred as a pest in Britain (Carter et al. 1980). The recent increase in the size and frequency of aphid outbreaks has been related to recent changes in agricultural practices (Baranyovits, 1973; Kolbe, 1969; Potts and Vickerman, 1974). Between 1952 and 1973 the area of cereals in Britain increased by 800,000 ha. Most of this change had occurred by 1965 (North, 1978). The availability of manufactured chemical fertilizers heralded a departure from traditional farming methods involving cereals as part of a rotation. The continuous growing of cereals was made possible by the extensive use of pesticides to combat problems resulting from changes in farming practice. Cereal aphids are one such problem.

The aphids of importance in cereal fields in Britain are Sitobion avenae (F.), Metopolophium dirhodum (Walk.) and Rhopalosiphum padi (L.). Three other species occur less frequently, these are Metopolophium festucae (Theob.), Sitobion fragariae (Wlk.) and Rhopalosiphum insertum (Wlk.). These aphids infest wheat (Triticum aestivum L.), oats (Avena

sativa L.) and less often Barley (Hordeum vulgare L.). The life cycles of the three major species are shown in Figs. 1.1 to 1.3 (After Carter et al. 1980).

S. avenae is autoecious, spending the whole year on cereals or grasses. Outbreaks of this aphid in cereals can arise from aphids that have overwintered on the crop or from the arrival of alate immigrants. M. dirhodum and R. padi are both heteroecious species overwintering on Rose (Rosa spp.) and bird cherry (Prunus padus L.) respectively. Outbreaks of these aphids arise almost entirely from alates arriving in the crop although there are reports of M. dirhodum overwintering viviparously on grasses or cereals (Dean, 1978; George, 1974). The biology of cereal aphids is reviewed by Carter et al. (1980).

Feeding by cereal aphids causes direct damage to the crop. Wratten (1975) showed that post-anthesis populations of S. avenae and M. dirhodum reduced grain weight by 14% and 7% respectively and significantly reduced the percentage protein of wheat. Rautapaa (1966) reports 30% losses in wheat in 1964 due to heavy ear infestation of S. avenae. However, in Britain cereal aphids are of greatest importance as vectors of plant viruses.

### 1.3 Barley Yellow Dwarf Virus

Oswald and Houston (1951) showed that several species transmit barley yellow dwarf virus (BYDV) which infects wheat, barley and many other Gramineae. Doodson and Saunders (1970) estimated that yield losses in England due to BYDV were between 3 and 10%

in most years. Smith (1963) observed 15% reduction in the yield of wheat in New Zealand due to Barley Yellow Dwarf Virus inoculation. B.Y.D.V. is a type member of the Luteovirus group. Five serologically different isolates of the virus have been identified and these are transmitted in a vector specific manner (Gildow and Rochow, 1980). Virus infected plants show discolouration of the distal parts of the leaves, yellow in barley, bronze red in wheat and red in oats. In severely infected plants there are marked decreases in height and grain yield. The virus also infects a number of meadow and weed grasses (Watson, 1958). These may act as reservoirs and may be of particular importance with S. avenae which overwinters on grasses. There is no evidence of B.Y.D.V. replication within aphids.

Barley Yellow Dwarf Virus is more serious in winter cereals and is more damaging to barley and oats than to wheat. When crops are drilled soon after grass has been ploughed there is risk of aphids transferring directly onto emerging cereals. Infections of B.Y.D.V. by this means are more common in South West England and Wales (Ministry of Agriculture, Fisheries and Food, 1982).

#### 1.4 Pesticides

The use of pesticides in cereal production is directly related to the economics of production. Where probable benefits, in terms of increased yield and higher quality, are greater than the cost of treatment then pesticide application becomes sensible farming practice. Until recently cereals were of sufficiently low value as to limit pesticides to seed dressings, insecticides

for the control of stored product pests and herbicides for the control of broad-leaved weeds (North, 1978). This situation has now changed. The value of cereals has risen dramatically and E.F.C. support provides incentive to produce cereals of high quality. These factors, together with the need to protect large capital investment involved in modern cereal production favour the use of pesticides to avoid potential crop losses.

Pesticides, however, are becoming increasingly expensive. The economics governing pesticide production and use are important in pest control problems. Metcalf (1980) considered that "...Several factors quite apart from global inflation are affecting a rapid increase in the cost of insecticides :

(a) pesticides are largely petrochemicals and their prices are inextricably linked to the escalating costs of this increasingly scarce material, (b) newer, more effective insecticide molecules are much more sophisticated in chemical structure and require many additional synthetic steps, and (c) developmental costs for pesticides have increased manyfold during the past 30 years due to inflation and to increasingly stringent requirements for legislation".

This increased cost of pesticides coupled with the increasing difficulty in discovering effective new pesticides must promote careful and economic use of existing compounds. Excessive or unnecessary use of insecticides is not only environmentally undesirable but increases the likelihood of pest resistance and resurgence. It is surely sensible to preserve the useful life

of existing compounds whilst at the same time making use of the beneficial properties of natural enemies. In practical terms this could be achieved by encouraging the grower to apply the right concentration of a specific compound at the right time. Although primarily aimed at understanding interactions within the cereal ecosystem the work described in this thesis also indicates the feasibility of this approach.

A wide range of pesticides are currently in use in cereal production. In this context pesticides are considered to be fungicides, herbicides, molluscicides and insecticides.

Routine prophylactic treatment with fungicides is now common place, particularly in winter cereals as protection against mildew, rusts, Septoria and eyespot. Broad spectrum herbicides are now in use to control many MCPA-tolerant weeds such as chickweed, (Stellaria media (L.) Vill.), common knotgrass (Polygonum aviculare L.), redshank (P. persicaria L.), black bindweed (P. convulvulus L.) and Speedwells (Veronica spp.) (Potts and Vickerman, 1974; Potts, 1970). Molluscicides are increasingly being used against slugs. A range of insecticides, many of them broad spectrum are in use against wheat bulb fly, (Delia coarctata), (Leptohylemia (= Hylemyia) coarctata (Fall)), Opomyza florum (F.), wireworms (Elateridae), Leatherjackets (Tiulidae), and cereal aphids (S. avenae, M. dirhodum and R. padi). (Ministry of Agriculture, Fisheries and Food, 1982). This thesis is concerned only with insecticides.

From a large range of potential insecticides, four were selected for study. To some extent this choice was arbitrary and dictated by ease of purchase or availability at Shell Research. All except parathion-methyl are used, or have been used in the cereal ecosystem in the U.K. Insecticides chosen were known or suspected to cover a range of toxicities to different groups of arthropods. The compounds were :

pirimicarb, a carbamate  
cypermethrin, a pyrethroid  
parathion-methyl, an organophosphate  
demeton-s-methyl, an organophosphate

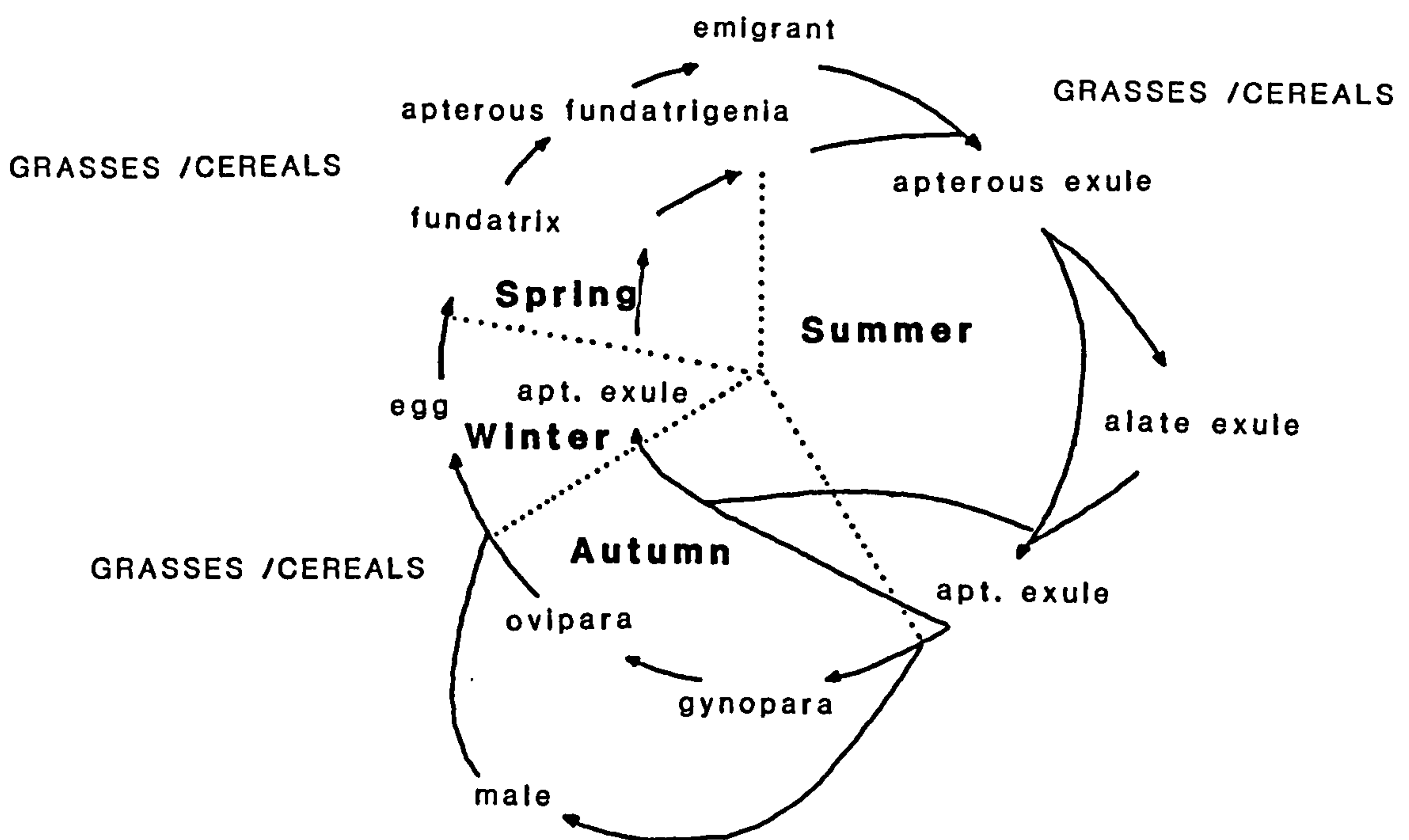
A key theme of the thesis is the selective toxicity of insecticides; accordingly it is necessary to mention here the dilemma facing the agricultural community over the problem of selectively toxic pesticides. Clearly the use of selective pesticides, which affect only the target animal, offers major advantages in crop protection, both from the human safety aspect and in preserving natural enemies and reducing environmental contamination. However, the companies involved in insecticide production must recoup the cost of development and production in the form of sales. It cannot be commercially viable for them to produce highly selective pesticides if the market place is too small. It is for this reason that the broad spectrum insecticide is, to the producer, a better economic proposition than the highly selective one. This contrast between the ecologically sound pesticide and that which is commercially viable is at the heart



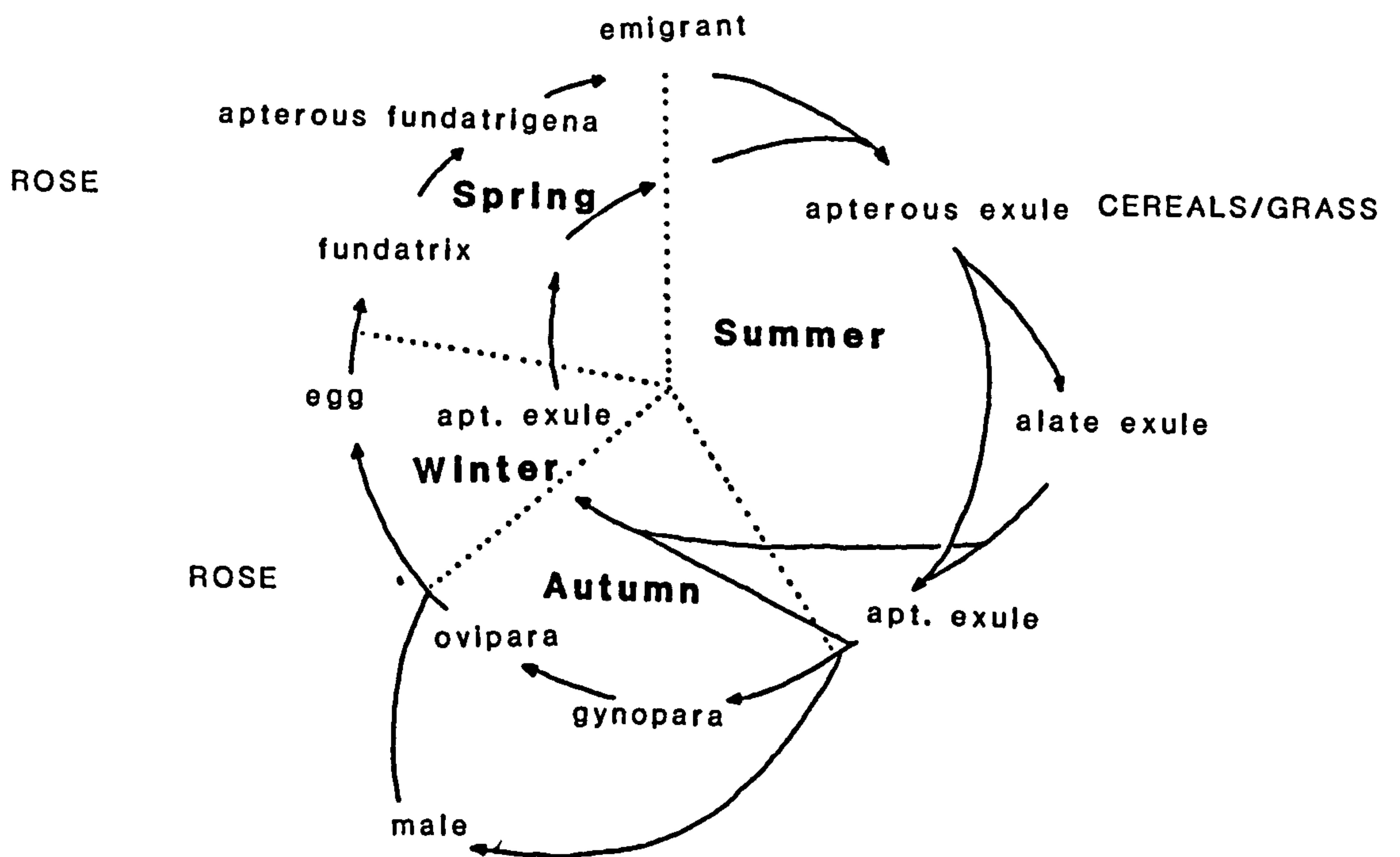
of the pesticide problem.

In this thesis the impact of only a small number of insecticides on cereal aphids and predators is examined. Ideally, the precise effects of all applications to cereals on both predators and prey should be determined. There is little point in selecting an aphicide so as to preserve beneficial arthropods if a herbicide or fungicide subsequently reduces their numbers. In the time available such a comprehensive approach was not possible and work was confined to a limited range of pesticides.

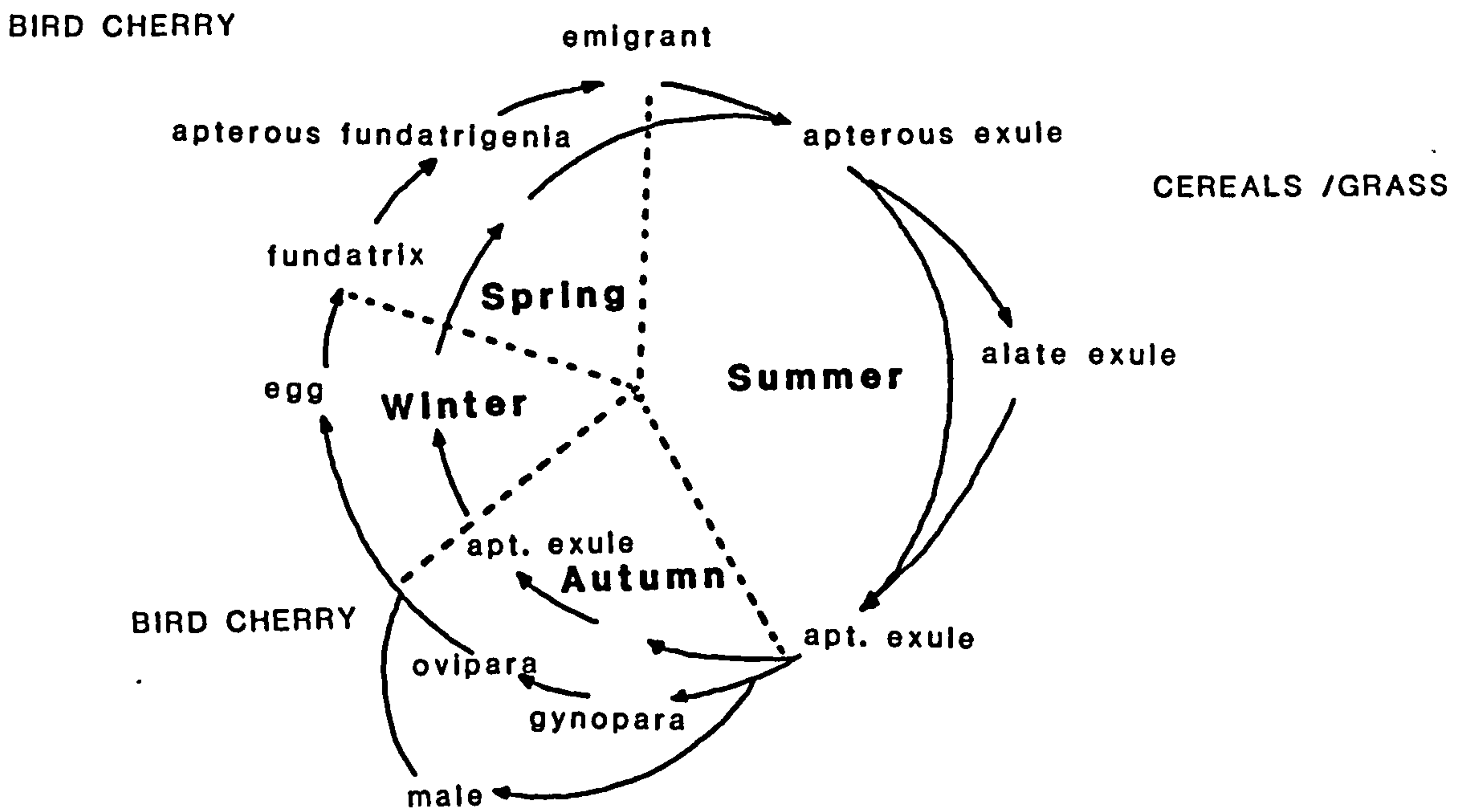
**Fig. 1.1 : Life Cycle of Sitoblon avenae**



**Fig. 1.2 : Life Cycle of Metopolophium dirhodum**

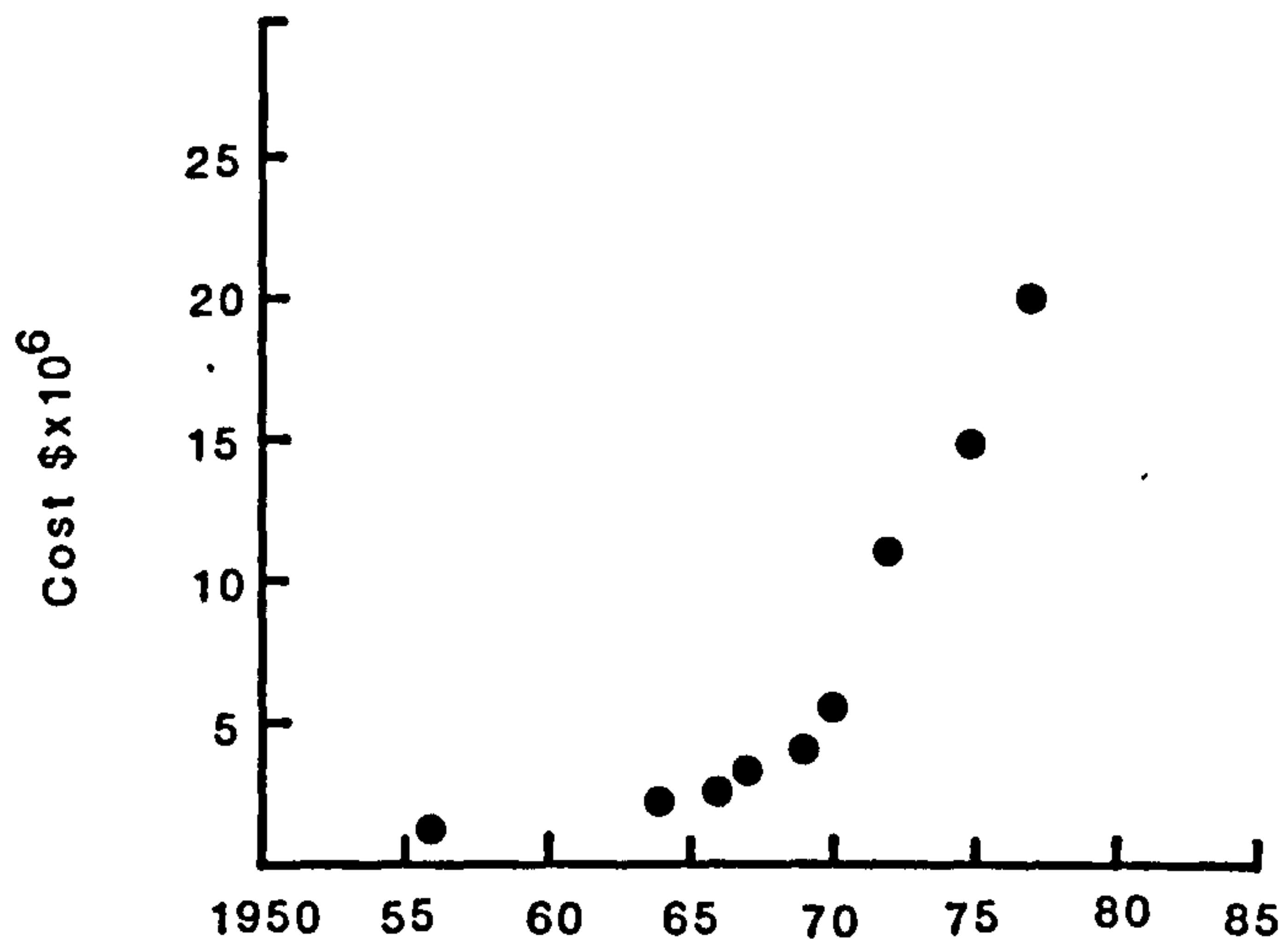


**Fig. 1.3 : Life Cycle of Rhopalosiphum padi**



**Figs. 1.1-1.3 are after Carter (1980)**

**Fig.1.4 : The Increasing Developmental Costs For  
New Pesticides (after Metcalf ,1980).**



## CHAPTER 2

### THE PREDATORS OF CEREAL APHIDS

"I'm a reliable witness, you're a reliable witness, practically all God's children are reliable witnesses in their own estimation - which makes it funny how such different ideas of the same affair get about".

John Wyndham (1953),

The Kraken Wakes.

#### 2.1 Introduction

The predators of cereal aphids are generally considered in two groups : aphid specific (or Stenophagous) predators and polyphagous predators. Interest in aphid predators is not recent; indeed, nearly two hundred years ago Marsham (1798) described important aphidophages, all of which are considered important aphid specific predators today.

As their name implies, aphid specific predators feed almost exclusively on aphids. Species involved are clearly defined and their biology well understood. Most early work concentrated on these predators, possibly because they tend to be active during the day and are clearly visible on the crop. In contrast, many

polyphagous predators are active at night (Vickerman and Sunderland, 1975), and are ground dwelling. Polyphagous predators are omnivorous, with a wide range of food items. For example, Luff (1974) showed that the Carabid beetle Pterostichus madidus Fab. consumes leaf fragments, fungal hyphae and spores, as well as aphids and other arthropods. Hengeveld (1980) describes the extent to which 24 species of Carabid are polyphagous.

In recent years there has been an increased interest in the role of polyphagous predators in the control of cereal aphids. The realisation that one aphid consumed in May by a polyphagous predator is the equivalent of several hundred consumed in late June and July by a stenophagous predator is relatively clear, (Mclean, 1980; Griffiths, 1982). Polyphagous predators are present at the crucial establishment phase immediately after alate immigration (Mclean, 1980). Predation at this time may make a difference between an outbreak occurring or not. In Britain cereal aphids are primarily of importance as vectors of Barley Yellow Dwarf Virus. In this context the establishment phase of an aphid colony is critical. Once the colony is large, predation by stenophagous predators may reduce aphid numbers but Barley Yellow Dwarf Virus will have been transmitted to each plant leading to reduced yield (Watson, 1958; Doodson and Saunders, 1970). Of course, this is not to say that predation by stenophagous predators on established aphid colonies is of no benefit. Such predation on established colonies will greatly reduce the direct impact of aphids on the plant, and hence reduce any subsequent loss of yield.

## 2.2 Aphid Specific (Stenophagous) Predators

The most important aphid specific predators belong to the families Coccinellidae, Chrysopidae and Syrphidae. Coccinellids are predatory as adults and larvae. Syrphids and Chrysopids are predatory only as larvae. Early reports supported the view that aphid specific predators had a major limiting effect on aphid population growth. Sundby (1966) compared the efficiency of three predators (Coccinella septempunctata L., Syrphus ribesii L. and Chrysopa carnea (Stevens)) in the laboratory and determined optimum conditions for each. Van Emden (1966) put forward a quantitative definition for the effectiveness of an aphidophagous predator based on voracity (being a function of appetite, activity and abundance), synchronisation with the prey and rate of reproduction. Dunn (1952) studied the reproductive rate of the pea aphid (Acyrtosiphon pisum Harr.) and the feeding rate of adult Coccinella septempunctata at various temperatures. C. septempunctata can consume up to 100 aphids/day as a 4th instar larva (Blackman, 1974). Hence the potential impact of this species as a predator of cereal aphids is enormous. Coccinellids move in May and June from their spring breeding sites to habitats where prey is most common. These habitats may or may not be cereal fields. Their reappearance, along with Syrphids in July and August coincides with eclusion from pupae, when feeding may cause a reduction in aphid numbers in cereals (Banks, 1955), although Hodek (1967) considers that they are unlikely to affect large aphid populations.

Unlike Coccinellids the Syrphids, or hoverflies, are potentially important aphid predators only as larvae. Adult Syrphidae

feed on nectar and pollen from flowers. Schneider (1969) states that such feeding is important for females to lay their full complement of eggs. The most important Syrphid in cereals in England is Episyrphus balteatus (Degeer). Dean (1974a) found this to be overall the most important predator in cereals in 1971. Other species of Syrphid which breed in cereals are Metasyrphus corollae F., Scaeva pyrastris L. and Metasyrphus luniger Mg.

Syrphid larvae appear to be well adapted for aphid predation. They move slowly, causing little disturbance which might result in aphid dispersal, and larvae have high potential feeding rates (Bankowska et al., 1978). However, adult Syrphid ovipositional behaviour is related to aphid density and this may limit their importance in cereal fields, because predatory larvae appear only in areas where the aphid population is already large (Chandler, 1967).

The importance of the third group of stenophagous predators, the Chrysopidae, in particular Chrysoperla carnea Stevens (= Chrysopa carnea Stevens) as predators of cereal aphids is virtually unknown. Few were encountered by Dean (1974) or Mclean (1980), or during the course of this study. It must be assumed that in general, Chrysopidae are usually relatively rare in cereal crops and hence comparatively unimportant as predators.

### 2.3 Polyphagous predators

Unlike the aphid specific predators there is no clear cut answer to the question "which animals are involved?" There is



evidence that a great many arthropods are aphidophagous. Most of the potentially important polyphagous predators in Northern Europe belong to the Carabidae (ground beetles), Staphylinidae (rove beetles) or Linyphiidae (Linyphiid spiders). The earwig Forficula auricularia L. may also be important. Penny (1966) found aphid remains amongst the gut contents of a number of adult Carabid beetles. Luff (1974) reported that 26% of adult Pterostichus madidus had aphid remains in their guts. Sunderland (1975) found aphids in the guts of 30-40% of adult Agonum dorsale Pont. However, such evidence of aphid predation can be misleading. Is such predation of consequence to the aphid population? Predation determined by gut analysis could involve consumption of already dead aphids, parasitised aphids, or simply old apterae whose reproductive output was declining. It could also involve too few aphids to significantly reduce the size of any subsequent aphid population.

Despite such difficulties of interpretation, a number of publications have recently increased our understanding of the importance of polyphagous predators in cereal crops. Speight and Lawton (1976) found that beetle catch size was directly related to frequency and density of weed cover in cereals and that enhanced beetle numbers lead to increased rates of predation on artificial prey. Whether it also leads to increased predation on aphids is unknown. However, Potts and Vickerman (1974) showed negative correlations between an index of arthropod diversity,  $\alpha$ , excluding aphids and the density of apterous aphids occurring in both winter wheat and spring barley in June. Furthermore, they described a positive correlation between the faunal diversity



and the percentage of individuals which were classified as predatory, the implication being that enhanced predator numbers reduced aphid numbers. Sunderland (1975) showed that significant numbers of predatory arthropods in cereal crops feed on aphids. Clearly from these studies polyphagous predators could have an impact on cereal aphid populations.

Further work has attempted to determine which of the polyphagous predators are of particular importance. Is there a key polyphagous predator which consistently acts to contain or limit aphid populations or are all species important all or some of the time? There is little information on the predatory behaviour of either Staphylinid or Carabid larvae; most recent work concentrates on adult beetles. Edwards and George (1977) showed strong negative correlations between populations of cereal aphids and those of three Carabid beetles Harpalus rufipes, De Geer, Pterostichus madidus & Agonum dorsale. Edwards et al. (1979) concluded that A. dorsale was the most important aphid predator, but that polyphagous predators other than Carabids could decrease cereal aphid populations. The work of Griffiths (1982) similarly points to A. dorsale as the species with the biggest potential impact on cereal aphids. Vickerman and Sunderland (1975) also show that A. dorsale is an important aphid predator but state that Demetrios atricapillus L., Bembidion lampros (Herbst.) and Trechus quadristriatus (Schrank) also all feed regularly on aphids. Sunderland (1975) also showed that A. dorsale feed on aphids, as did H. rufipes, Pterostichus melanaria (Illiger), Nebria brevicollis F. and B. lampros. Hence, whilst adult A. dorsale are frequently cited as a

potentially valuable aphid predators, common in cereal crops, other carabids may also eat significant numbers with different authors selecting different species for particular mention.

Staphylinid beetles are also abundant predators in the cereal field. The family Tachyporinae in particular is considered by some to be important. Vickerman and Sunderland (1975) report that Tachyporus hypnorum F., T. obtusus L. and T. chrysomelinus feed on aphids. Potts and Vickerman (1975) showed that adult T. hypnorum could consume between 4.8 and 5.2 aphids per day. Dicker (1944) reported Tachyporus larvae preying on strawberry aphids and suggested that they might prey on other aphid species. In general Staphylinids have received less attention than Carabids.

Linyphiid spiders are the most abundant spiders in cereal fields. They build horizontal non-sticky webs between tillers into which aphids walk or fall. Although rarely cited as important predators they are polyphagous and have been shown to feed on aphids both in the field and the laboratory (Carter et al., 1982). For linyphiid predation to be important a large number of aphids must regularly walk or fall off the plant and into linyphiid webs. Such mortality would only be significant in cereal aphid population dynamics if, in the absence of spiders, dislodged aphids would normally return to the plant in significant numbers.

Hence, predation by polyphagous predators inevitably leads to the question "Where does this predation occur?". Griffiths (1982) found that the Carabid A. dorsale caught and consumed aphid prey

whilst on the ground. Climbing of wheat plants by A. dorsale occurred rarely and climbs were not sufficiently high as to encounter aphids. Prior to this discovery it was always assumed that small predatory carabids such as A. dorsale climbed plants and that predation occurred on the crop. If aphids are falling off or walking off the plant, possibly as a means of dispersal, then clearly it is essential to discover their fate. This is particularly so if aphids that deliberately leave or fall off the plant but are not eaten by predators have little or no chance of reestablishing themselves on the crop. The implications of such aphid dispersal and subsequent predation will be discussed in Chapter 3.

#### 2.4 Concluding Remarks

Drawing these arguments together, it is apparent that despite many detailed studies, the real impact of stenophagous and polyphagous predators on cereal aphids is enigmatic. It is generally felt that the aphid specific predators tend to reduce peak numbers of aphids rather than prevent outbreaks, a conclusion supported by the model of Carter (1978). Polyphagous predators are important in determining whether or not outbreaks occur. In this light the impact of pesticides on the polyphagous predators of cereal fields is of direct importance. For example routine "insurance" spraying that leads to a reduction in polyphagous predators could obviously lead to more frequent outbreaks of cereal aphids. Consistent with this view is the fact that aphids resurgence to higher populations after insecticide applications

to wheat have been reported, (Apablaza and Tiska, 1973). It is important to know whether such resurgence is due to loss of stenophagous predators, polyphagous predators or parasitoids of some combination of these three groups. Parasites of cereal aphids are not included in this thesis but have been studied by Jones (1972), Vickerman (1982) . Only with such knowledge will more effective use of insecticides against cereal aphids be possible.

## CHAPTER 3

### EFFECTS OF INSECTICIDES ON INVERTEBRATE PREDATORS AND THEIR CEREAL APHID PREY : LABORATORY EXPERIMENTS

#### 3.1 Introduction

This chapter is presented in the form of paper accepted for publication in Environmental Entomology, but excludes the references, and with figures and tables renumbered. The references are consistent with the rest of the thesis and appear in the bibliography at the end of the thesis.

The work described in this paper is the starting point in looking for selective toxicity of pesticides to cereal aphids and to different groups of predators. Experiments were designed to determine the precise nature of the dose-response curve for aphids and predators exposed to three insecticides.

#### 3.2 Manuscript of Paper

THE EFFECTS OF INSECTICIDES ON  
INVERTEBRATE PREDATORS AND THEIR  
CEREAL APHID PREY :  
LABORATORY EXPERIMENTS

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## ABSTRACT

The effects of 3 insecticides on a guild of natural enemies and their prey were determined in the laboratory. The cereal aphid Metopolophium dirhodum Walker (Hemiptera, Aphididae) and 6 potentially important predators were exposed to dry insecticide films for 24 hours after which time they were examined and recorded as alive, moribund or dead. The insecticides tested were pirimicarb, cypermethrin and parathion methyl. The predators tested were the insects, Coccinella septempunctata L. (Coleoptera, Coccinellidae), Syrphus spp (Diptera, Syrphidae), Pterostichus melanarius Illiger (Coleoptera, Carabidae), Nebria brevicollis F. (Coleoptera Carabidae), Agonum dorsale Pont. (Coleoptera, Carabidae) and spiders, Erigone spp. (Araneae Linyphiidae). Parathion methyl was overall the most toxic compound, cypermethrin was less toxic and pirimicarb the least toxic. The relative susceptibility of the predators and the aphid varied considerably between insecticides as did the slope of the dose/response curve.

We discuss our data in the light of these findings, particularly the possibility that different insecticides might be used to differentially kill selected groups of predators and/or their prey in the field.



## INTRODUCTION

Despite several reports on the laboratory effects of insecticides on individual predators or groups of predators (e.g. Bartlett 1967 and Teotia and Tiwari 1972) only a small number of workers have looked at the effects of insecticides on a group of coexisting predators and their prey. Hamilton and Kieckhefer (1962) studied the toxicity of malathion and parathion to the English grain aphid Macrosiphum avenae F. (= Sitobion avenae F.) and its predators in South Dakota. Croft and Brown (1975) found only 13 instances in the literature where LD<sub>50</sub> and LC<sub>50</sub> values had been determined for predators and prey by the same methods.

This study determines the laboratory effects of three insecticides on the cereal aphid Metopolophium dirhodum (Walker) and a range of predators which may limit aphid populations in cereals. The insecticides used were the carbamate pirimicarb, the pyrethroid cypermethrin and the organophosphate parathion methyl. One of the long term aims of the present work was to manipulate field populations of cereal aphids and their predators by using insecticides. The three insecticides were therefore chosen because we suspected from preliminary work that they might differ in their effects on predators.

The predators of cereal aphids are conventionally assigned to two groups : the polyphagous and the aphid specific predators. Early reports suggested that aphid specific predators had the major limiting effect on aphid populations (e.g. Sundby (1966) studying

the ladybeetle Coccinella septempunctata L., hoverflies Syrphus spp. larvae and lacewings Chrysopa carnea (Stephens) and Dean (1966) on Syrphus balteatus). However, polyphagous predators have recently also been considered as important in controlling aphid populations since they are present in the crop when the first alates arrive (e.g. Potts and Vickerman, 1974; Sunderland 1975).

This paper deals with both aphid specific and polyphagous predators. The aphid specific predators were :

Coccinella septempunctata Linn. Adults (Ladybird beetle)  
(Coccinellidae)

Syrphus spp 4th Instar larvae (Hoverflies) (Syrphidae)

The polyphagous predators were :

Pterostichus melanarius Illiger Adults (Ground beetle)  
(Carabidae)

Nebria brevicollis Fabricus Adults (Ground beetle)  
(Carabidae)

Agonum dorsale Pont. Adults (Ground beetle) (Carabidae)

Erigone spp. Adults (Linyphiid spiders) (Linyphiidae)

All are common components of the cereal field ecosystem in Northern Europe.

## METHODS

All tests were carried out in the laboratory by exposing aphids and their predators to a dry film of insecticide. Individual test animals were enclosed in cells 4cm in diameter between two sheets of ground glass. Cells were constructed by drilling perspex sheets of thickness 0.5cm. Ten chambers were drilled in each sheet 32cm x 14cm. The glass surfaces above and below each chamber were treated by pipetting 0.09ml of insecticide solution; with practice this covered the same area of ground glass ( $12.5\text{cm}^2$ ) on each occasion enabling the actual insecticide concentration ( $\text{g ha}^{-1}$ ) to be calculated. Animals were exposed in darkness at  $16 \pm 1^\circ\text{C}$  for 24 hours, after which time they were examined and recorded as either alive, "moribund" (i.e. showing extreme signs of toxification such as total immobility) or dead. Stock solutions of pirimicarb, cypermethrin and parathion-methyl were made using technical grade insecticide in acetone (% weight by weight). Test solutions in acetone were prepared from these stock solutions.

Ten individuals of each predator were exposed at each insecticide concentration. Experiments with M. dirhodum involved 100 animals for each concentration. Results were analysed by probit analysis (Finney, 1971). Median lethal doses were calculated for each animal with each insecticide.

Adults of C. septempunctata and 4th instar larvae of Syrphus spp were collected from birch woodland by beating aphid infested trees. Although collected from trees, adults of these predators are

active over wide areas and also occur in cereal fields. Polyphagous predators were collected by pitfall trapping in fields of wheat at Sittingbourne in Kent. A culture of M. dirhodum was maintained at York on wheat at 18°C with a diurnal regime of 16 hours light and 8 hours darkness. Nymphs were reared in single age batches. Apterous virginopara individuals were removed for testing when 12 days old.

## RESULTS

The results are summarised in Table 1 and Figs. 1 and 2. Insufficient Syrphus spp. larvae were available for tests to be carried out with cypermethrin and parathion methyl. In order to simplify presentation of the results, "moribund" animals were treated as dead in the main analysis, although clearly, given sufficient time some moribund individuals may have recovered. Analysis of the data using dead individuals obviously moves the dose/response curves to the right, but it does not alter the combination. An example of data showing the difference between dead and "moribund" animals is shown in Fig. 1. A summary of all the data, (fitted regression lines but without individual data points to avoid confusion) will be found in Fig. 2. Responses including moribund animals have been used to calculate ED<sub>50</sub> values (Figure 1b); only dead animals were included in calculations of LD<sub>50</sub> values.

TABLE 1 : Laboratory 24 hour ED<sub>50</sub> values for pirimicarb, cypermethrin and parathion methyl, with M. dirhodum and a range of predators. ED<sub>50</sub> values include dead and moribund animals.

Animal Tested	PIRIMICARB ED <sub>50</sub> (g ai h <sup>-1</sup> ) with 95% Fiducial limits	CYPERMETHRIN ED <sub>50</sub> (g ha <sup>-1</sup> ) with 95% Fiducial limits	PARATHION METHYL ED <sub>50</sub> (g ha <sup>-1</sup> ) with 95% Fiducial limits
<u>Metopolophium dirhodum</u>	18.5 (15.8-21.1)	80.5 (41.8-160)	0.01 (0.8x10 <sup>-4</sup> -3.8x10 <sup>-2</sup> )
<u>Syrphus</u> spp larvae	68.6 (15.0-165.0)	-	-
<u>Coccinella septempunctata</u>	2921.6 (1690.0-3924.0)	4.8 (0.9-13)	3.8x10 <sup>-3</sup> (1.78x10 <sup>-3</sup> -6.52x10 <sup>-3</sup> )
<u>Agonum dorsale</u>	7.9 (2.2-83.2)	3.3 (0.7-14.2)	0.32 (0.27-0.37)
<u>Nebria brevicollis</u>	1415.9 (214-2643)	377.0 (165.0-794.4)	0.27 (0.23-0.31)
<u>Pterostichus melanarius</u>	Essentially non-toxic	345.0 (184.8-646.4)	1.96 (1.12-3.4)
<u>Erigone</u> spp	8.8 (0.8-38.2)	2.2 (0.22-8.4)	0.42 (0.09-2.04)
Recommended field application rate (Worthing 1979)	125 g ai ha <sup>-1</sup>	25 g ai ha <sup>-1</sup>	Not available

Fig. 3.1 ; Probit lines for *C.septempunctata* (▲-▲) and *N.brevicollis* (● - ●) exposed to cypermethrin showing data points for (a) true death and (b) death with moribund animals included. (b) shows the regression lines from (a) to indicate the degree of shift in the data when moribund animals are included in the calculation.

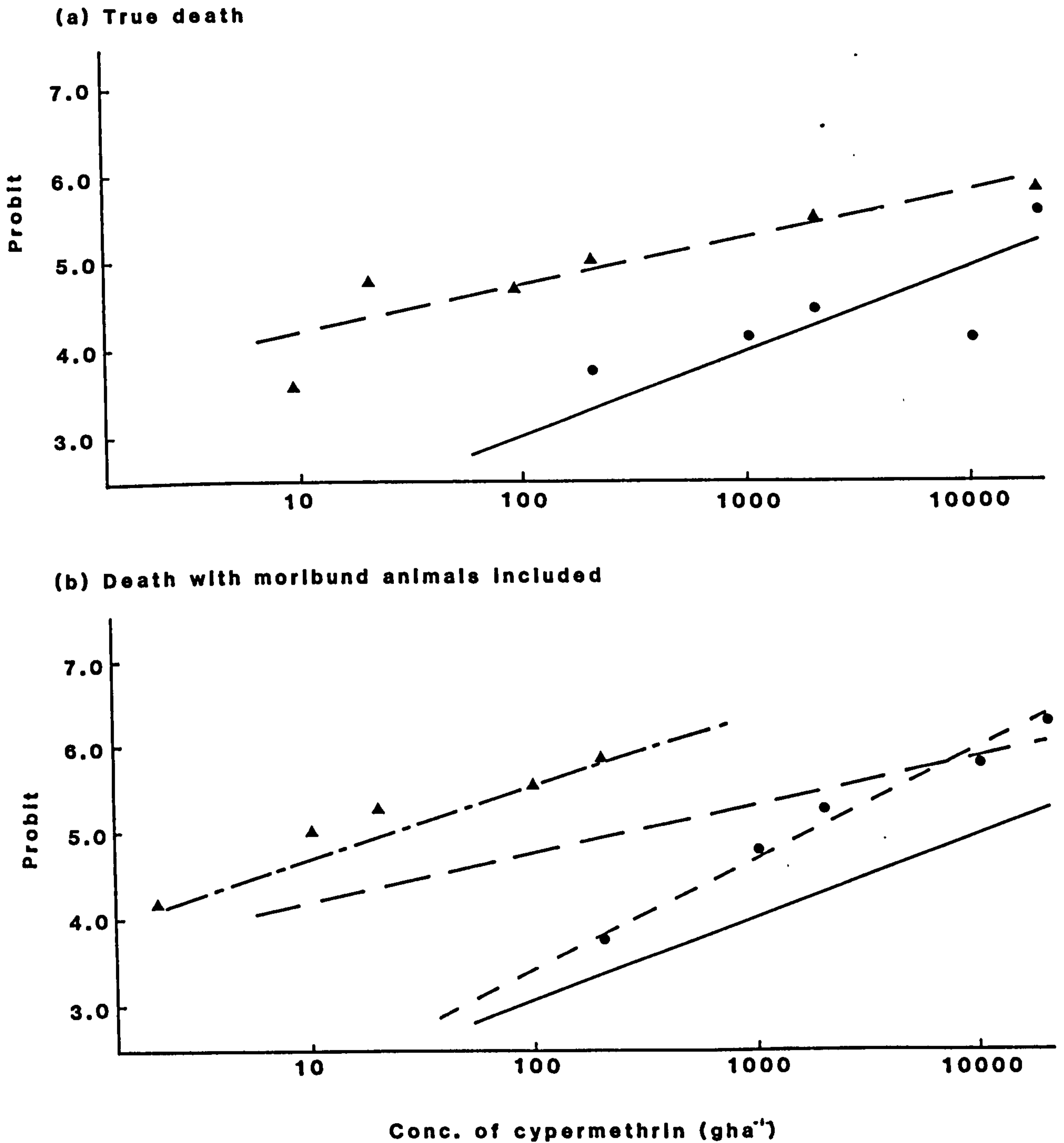
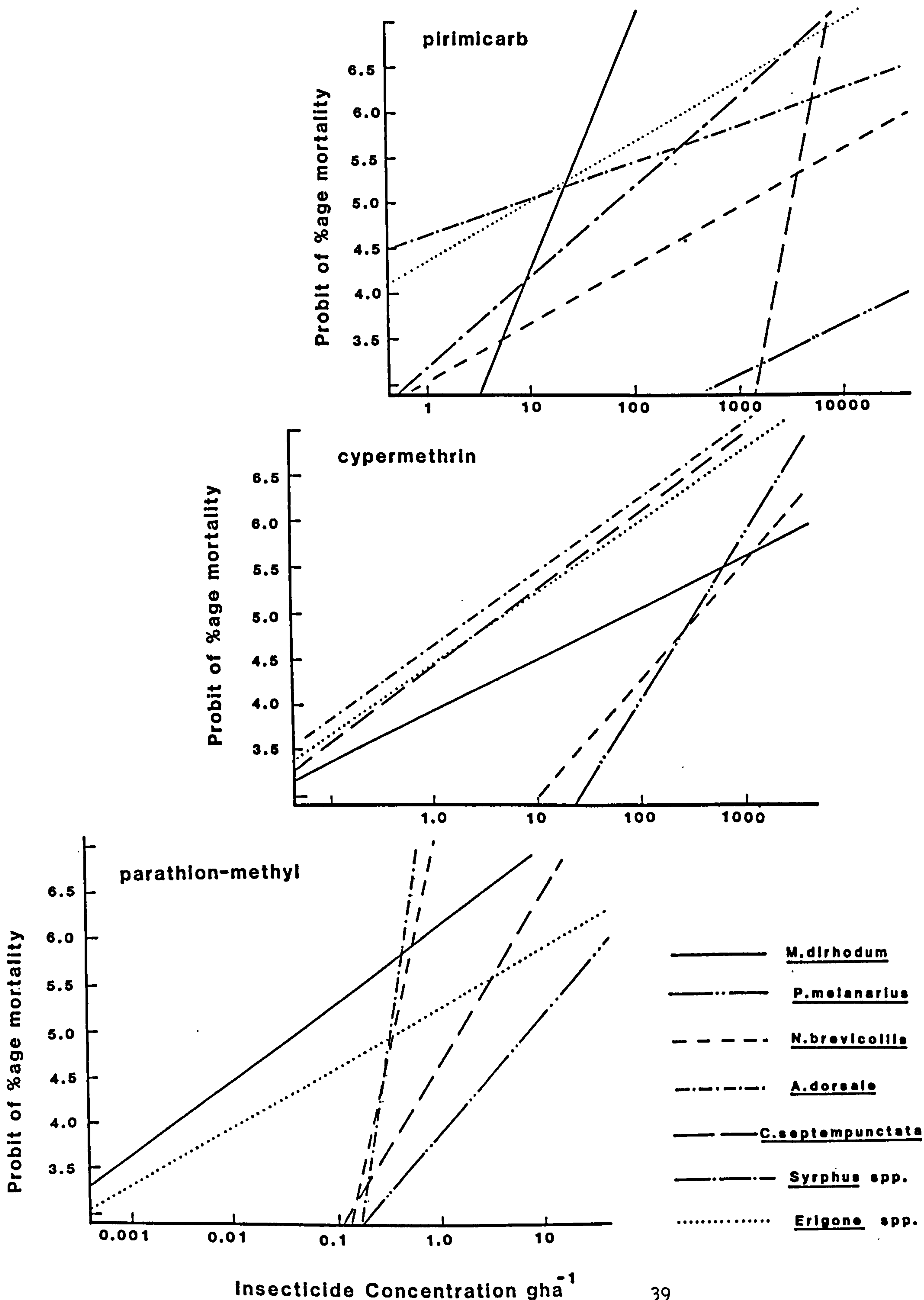


Fig.3.2 . :Laboratory Dose / Response Lines for M.dirhodum  
and a range of Predators with three Insecticides



## DISCUSSION

The three insecticides studied are clearly of different toxicities to the aphid M. dirhodum and its guild of natural enemies. Fig. 2 shows that parathion-methyl is on average the most toxic compound, cypermethrin is less toxic and pirimicarb is overall the least toxic in the laboratory. The relative effects of each insecticide on the aphid and its predators show considerable variation, both in ED<sub>50</sub> values and in the nature of the dose response curve.

The relative toxicity of each insecticide to each predator and to the cereal aphid was surprisingly variable. P. melanarius and C. septempunctata are unaffected by pirimicarb except at high concentrations, equivalent to much greater than the field application rate of 125 g ha<sup>-1</sup>. At 125 g ha<sup>-1</sup> pirimicarb is highly toxic to the aphid and three of its potential predators, i.e. A. dorsale, Erigone spp., and Syrphus spp. The results obtained with cypermethrin were somewhat different. At the recommended field application rate of 25 g ha<sup>-1</sup>, A. dorsale, C. septempunctata and Erigone spp were more susceptible than M. dirhodum to cypermethrin, but P. melanarius and N. brevicollis were less susceptible. The relatively low susceptibility of M. dirhodum to cypermethrin is difficult to interpret since good control of this species is usually obtained at dose rates considerably below the estimated ED<sub>50</sub> value. Perhaps the dose response with M. dirhodum and cypermethrin is more time dependent than it is with other compounds.



Parathion-methyl was toxic to M. dirhodum at concentrations of less than  $0.1 \text{ g ha}^{-1}$  but not toxic to all of the predators except Erigone spp. (Fig. 2). Above a dose rate of  $0.1 \text{ g ha}^{-1}$  parathion-methyl was very toxic to all of the test animals, especially A. dorsale and N. brevicollis.

Clearly, the relative susceptibility of a group of predators and their prey to one insecticide cannot be used to rank their susceptibility to other insecticides. The  $ED_{50}$  values (Table 1) make this obvious. For example, C. septempunctata is less susceptible than the aphid to cypermethrin. However, the problem is more complex than this. Because dose response curves differ markedly in slope  $ED_{50}$  (or  $LD_{50}$ ) values alone may be misleading. A subjective assessment of Fig. 2 suggests that there are mainly two kinds of responses. Relatively shallow dose response curves were obtained with most combinations of insect and insecticide although a few very steep curves were also found (e.g. M. dirhodum and C. septempunctata with pirimicarb, A. dorsale and N. brevicollis with parathion-methyl and N. brevicollis with cypermethrin). The reason why the slope of the dose-response curves vary in this way is unclear.

The majority of studies of the effects of pesticides on natural enemies present their results only in the form of  $LD_{50}$  values, (e.g. Coats et al., 1978). The results of this study show that different animals may have similar  $ED_{50}$  or  $LD_{50}$  values, but markedly different responses to the toxicant. Parathion-methyl produces similar  $ED_{50}$  values for Erigone spp, A. dorsale and N. brevicollis (Table 1). However, the slopes of the dose/response lines of the

two carabids to the insecticide differs greatly from that of the Linyphiid spider. In consequence, ED<sub>50</sub> values alone are an inadequate description of effects.

Although it is ultimately intended to relate these laboratory dose/response curves to field use there are a number of reasons why the data must be interpreted carefully. (i) Test chambers may allow a build up of vapour pressure which could increase mortality. (ii) All the laboratory responses discussed are after only 24 hours exposure to the toxicant. Field insecticide applications are often active for considerable lengths of time and long term or cumulative effects resulting from this increased exposure period cannot be determined from this study. (iii) Field mortality may occur due to a number of exposure routes, e.g. exposure to a dry residual film of toxicant, direct contact during application and consumption of contaminated prey. This laboratory study attempts to relate only to the first of these routes. (iv) Relative field toxicity may change with respect to temperature and other climatic factors. (v) Biological availability of insecticide residues on natural surfaces such as soil and plants may be much lower than that on a relatively inert surface such as glass.

Despite these difficulties, the broad ranking of relative toxicities to this group of predators and their cereal aphid prey are useful for designing and interpreting field experiments (Brown et al., in press). In particular, they suggest that careful use of selected insecticides should permit the experimental manipulation of field predator-prey complexes by selectively removing prey

or different groups of predators. Experiments of this nature will be reported in a later publication.

### 3.3 Addendum : Laboratory work carried out since acceptance of the paper.

One criticism of the laboratory work described so far in this chapter is that within enclosed chambers, mortality of test animals might occur due to a build up of toxic vapour within the chamber, over and above mortality due to direct contact with insecticide films. Since vapour pressure mortality does not occur in the field, such results could be misleading. It was therefore necessary to determine to what extent, if at all, mortality occurred due to vapour pressure. Before reporting such experiments it is, however, encouraging to note that the most volatile compound tested, pirimicarb (vapour pressure =  $3 \times 10^{-5}$  mm Hg at  $30^{\circ}\text{C}$ : (Worthing, 1979)) was also the least toxic.

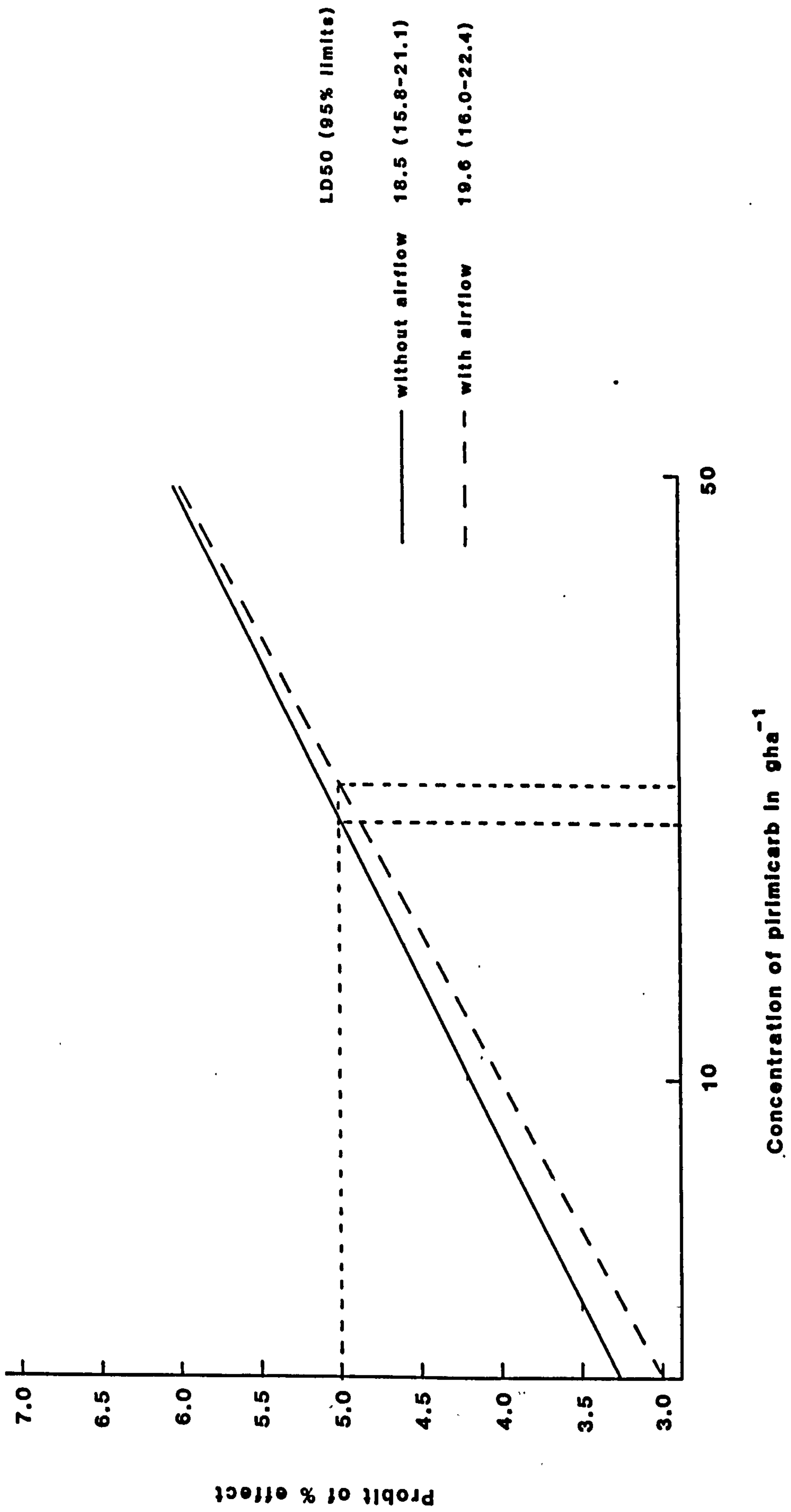
Existing test chambers (as described earlier in this chapter) were modified to allow a constant airflow to be maintained through each chamber, thus preventing the build up of toxic vapour. Two adjacent holes (1mm in diameter) were drilled from the side of the perspex sheet into each chamber. Into one of each pair of holes a conical pipette tip (for a C20 micropipette) was inserted. A tube fitted to the pipette was connected to air supply which had been bubbled through saturated sodium chloride solution to achieve 76% relative humidity. With ten chambers (one complete perspex sheet) modified in this way a resulting problem was that those chambers furthest from the air supply had a considerably reduced airflow. This was overcome by fitting adjustable tube clamps to the air

input tube for each chamber. In order to quantify and regulate the airflow to each chamber the complete test plate was immersed in a shallow water bath. A 10ml. measuring cylinder filled with water was held upside down over each air outlet hole allowing an airflow calibration in  $\text{ml h}^{-1}$  to be made. The tube clamps were adjusted to give the same rate of airflow to each chamber, namely  $120 \text{ ml h}^{-1}$ . Since the volume of each chamber was 6.28 ml, there were 19.1 air changes per hour.

Because pirimicarb was the most volatile insecticide tested it was chosen for use in this experiment. The aphid M. dirhodum was used because of the availability of large numbers from cultures. As in the earlier experiments 100 aphids, each 12 day old apterous virginopare, were exposed to a range of insecticide concentrations in darkness at  $16^{\circ}\text{C}$  for 24 h. Calculated probit lines along with  $\text{LD}_{50}$  values are shown for M. dirhodum with and without the airflow in Fig. 3.3. There was no statistically significant difference in mortality between the two experiments; therefore, I conclude that significant mortality did not occur in the earlier experiments due to build up of toxic vapour. If however, a more volatile insecticide such as demeton-s-methyl was used in these chambers then such mortality could occur. In other words, the laboratory techniques developed in this study are suitable for testing some, but not all, insecticides. With compounds no more volatile than pirimicarb, the build up of toxic vapour in the experimental chambers is not considered to be a problem.

However, in order to make this laboratory technique applicable for use with all insecticides, it would be wise to incorporate an air flow system in future experiments.

Fig.3.3 :Probit lines for *M.dirhodum* exposed to pirimicarb with and without airflow



## CHAPTER 4

### EFFECTS OF INSECTICIDES ON INVERTEBRATE

#### PREDATORS IN CEREAL FIELDS

##### : FIELD EXPERIMENTS I

#### 4.1 Introduction

Chapter 3 established that different groups of predators differ in their susceptibility to different insecticides in the laboratory. This opens up the possibility of selectively killing groups of predators in the field by use of certain insecticides. In practical terms this could mean that some insecticides might do less harm to beneficial predators than others when used against cereal aphid pests. It also opens up the ecologically interesting possibility of using insecticides as experimental tools in the field, for example by monitoring the performance of aphids in the presence or absence of particular groups of predators.

The role of these predators in controlling aphid population growth might then become much clearer (see Chapter 2). Obviously spraying with insecticides in the field also kills aphids. Hence experiments need to be carefully designed and monitored.

During the summer months of 1981 two barriered plot experiments (Sittingbourne Experiments 1 and 2) and one open field

experiment (Herne Bay Experiment) were carried out in Kent in South East England. These experiments were designed to determine the field effects of insecticides on the predators of cereal aphids and upon the aphids themselves. The principle aim of this experiment was to see if differential predator mortality achieved by selective insecticide use would allow aphids to reach significantly higher numbers in the absence of key predators.

In 1981 climatic conditions were poor (weather data are presented in Appendix). There was high rainfall in May and June, temperatures were low and difficulties were encountered in sampling for both aphids and predators. To compound these problems no natural cereal aphid outbreak occurred. However, useful data were obtained on the insecticide/predator interaction and valuable experience gained in the design and implementation of barriered plot field experiments. The three experiments described in this chapter can therefore be considered as pilot experiments. Further, more successful experiments were carried out in 1982 (see chapter 5). Sampling techniques and the nature of barriered plot experiments are discussed in this chapter.

#### 4.2 Sampling Methods

Throughout the 1981 field experiments sampling of aphid and predator populations was undertaken by 4 methods : pitfall traps, water traps, D-vac suction sampling and visual counting. Details and the relative bias of each sampling technique are discussed here. All experiments in this study involved comparative sampling to determine treatment effects relative to controls. No attempt



was made to determine the absolute sizes of any arthropod population.

4.2.1. Pitfall Traps. Almost all studies of invertebrate ground dwelling predators in cereals and other ecosystems involve the use of pitfall traps (e.g. Penny, 1966; Luff, 1974; Sunderland, 1975; Speight and Lawton, 1976; Den Boer, 1977; Edwards et al., 1979; Sunderland et al., 1980). Being cheap and requiring little labour, pitfall traps offer a potentially valuable means of monitoring certain animal populations. In its simplest form a pitfall trap is a container, sunk into the soil with its upper rim level with the soil surface. Animals moving in the vicinity of the trap fall into the container and are unable to escape. Pitfall traps can be operated dry or containing preservatives. Dry traps are useful if living material is required but have the disadvantage that predators can consume each other within the container. The use of preservatives such as alcohol and formalin in pitfall traps ensures that trapped specimens remain intact and reduces the possibility of animals escaping. Preservatives may distort trap catches acting differentially as attractants or as repellants (e.g. Luff, 1968; Greenslade and Greenslade, 1971; Luff, 1975).

Pitfall trap catch is determined by the population density of the animals to be trapped, their movement, the boundary of the pitfall, the outer boundary of the study area, and the extent to which animals can penetrate it (Jansen and Metz, 1977). Clearly the design and construction of a pitfall trap must reflect the

characteristics of the species likely to be caught. Luff (1975) showed that pitfall trap efficiency depended on size, shape and material of construction. Small traps were more efficient for small species of carabid, large traps were better for larger species. Square or rectangular traps are directional but perimeter differences can be adjusted to make them comparable with circular traps. Glass traps are more efficient than plastic or metal ones. Greenslade (1964) showed a correlation between temperature and catch size and also considered the abundance of vegetation (since it impedes movement) as well as behavioural differences between species to affect catch size. Pitfall trap efficiency is reviewed by Southwood (1978).

In this study one main type of pitfall trap was used. It consisted of a length of perspex piping 15 cm. long with 10 cm. external diameter, one end of which had been machined to receive a plastic funnel which had had the spout sawn off (Fig. 4.1). Having prepared a hole with a trowel the piping was placed with the machined end upwards and the soil packed around the upper lip. Care was taken to ensure that the lip was level with the soil surface since this can influence trap efficiency (Greenslade, 1964). A lid was placed over the opening when the trap was not in use. A square perspex sheet (15 cm. x 15 cm.) was supported over the trap on four nails to prevent rainwater entering the collecting vessel. When in use the collecting vessel contained 50 ml. of 5% formalin with a drop of Teepol to reduce surface tension. Although good catches were obtained with this trap design on a number of occasions the smaller predators, especially Staphylinidae, were observed walking up the collecting funnels.

**Fig.4.1 : Diagram of Pitfall Trap**

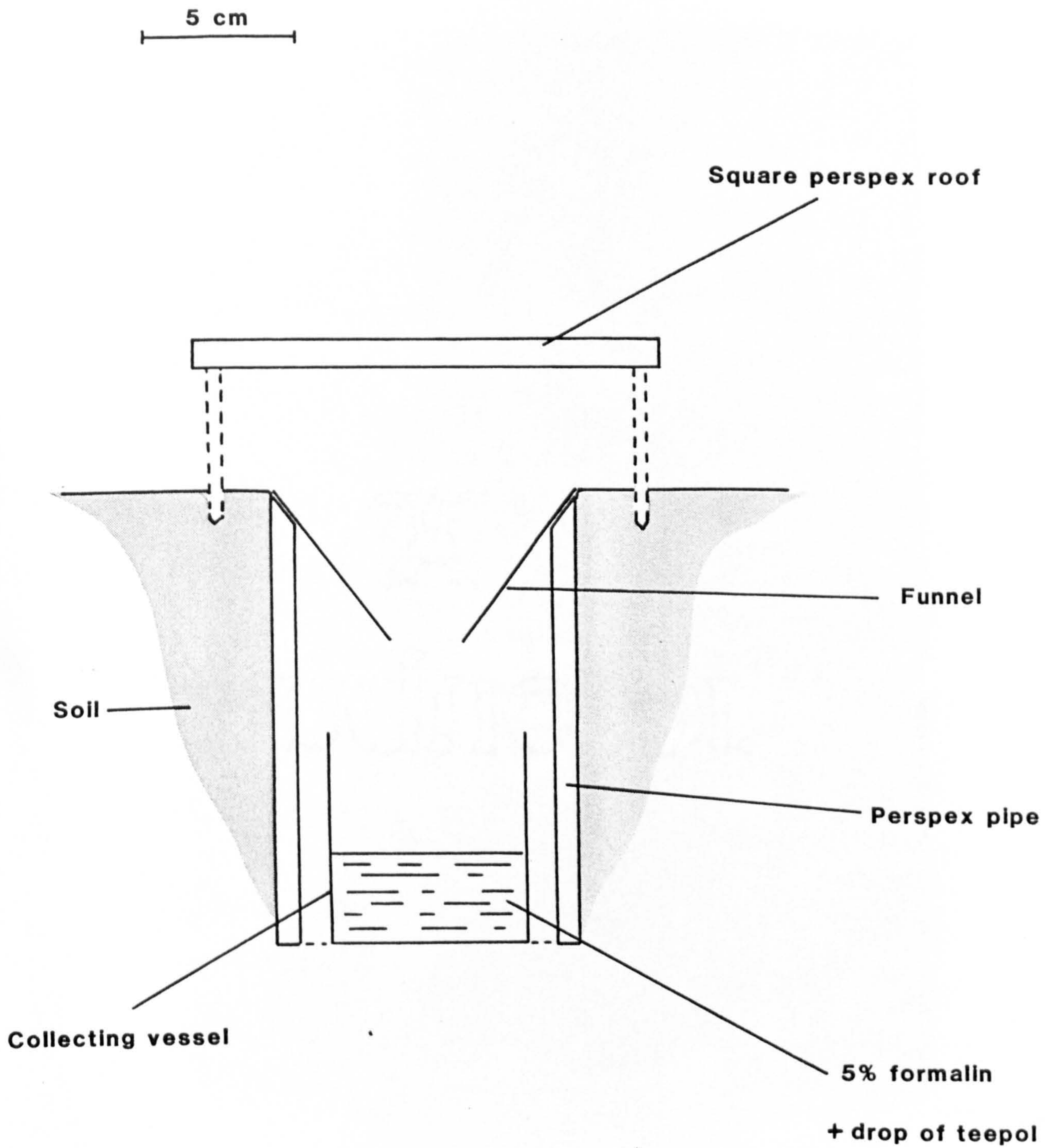


Fig. 4.2 Pitfall Trap viewed from above



This problem could perhaps be overcome in future work by use of glass funnels.

4.2.2. Water traps. Water traps were used in 1981 to sample aphids and adult Syrphids and Chrysopids. Traps consisted of yellow bowls 30 cm. in diameter supported on metal rings attached to wooden posts. The rings could be raised or lowered on the posts to alter the height of the trap within the crop. Traps were set with the bowl 5 cm. below crop height. In use the water traps contained 800 ml. of water with two drops of Teepol. Harper and Story (1962) showed that without detergent catches were greatly reduced. Many workers have used yellow bowls for trapping aphids as well as other flying insects, (e.g. Moericke, 1950; Frohlich, 1956) and the method is known to be reasonably effective. In the present study, the water trap catches showed no variation between plots. With hindsight this is not surprising. One would not expect large differences in the numbers of alate animals caught, resulting from pesticide treatments over small plots of wheat. Use in large fields, such as at Herne Bay, may provide more useful data. After the 1981 experiments, the use of the water traps was therefore abandoned as a means of monitoring aphid predator populations. ac

4.2.3. D-Vac Suction Sampling. Suction sampling has been widely used for monitoring of aphid populations in cereals as well as other ecosystems (e.g. Edwards et al., 1979; Sunderland et al., 1980). Stenophagous predators in cereals have also been sampled by this technique (Chambers et al., 1983).

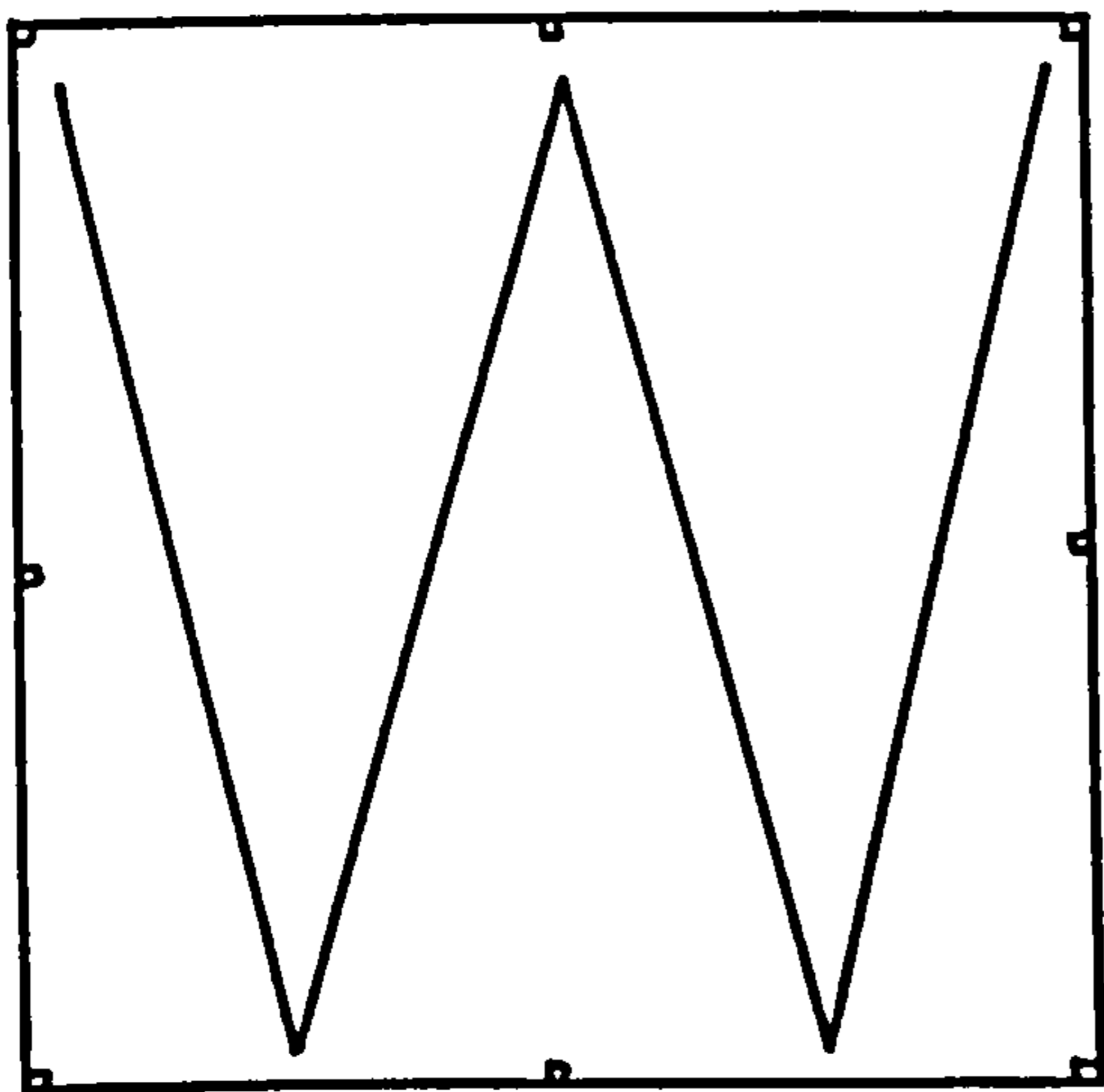
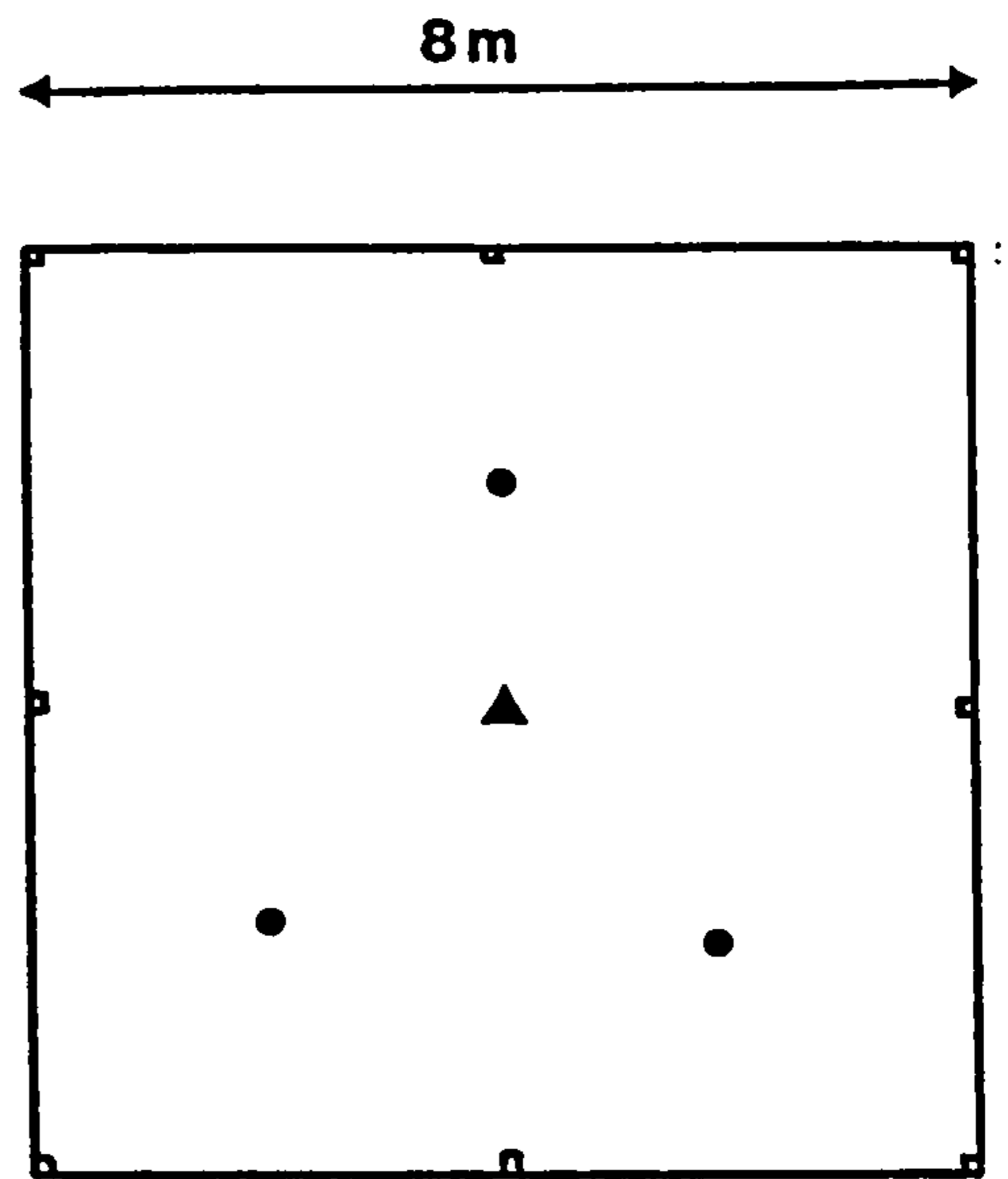
Efficiency of the D-Vac in sampling aphid populations depends considerably on the mode of operation. In all barriered plot experiments, both in 1981 (and subsequently in 1982) a standard sampling procedure was used. Each plot was considered in thirds and three D-Vac samples taken from each plot, one from each third. Each sample consisted of three subsamples, each from a third of the part of the plot being sampled (see Fig. 4.3). Each sub-sample involved placing the nozzle vertically over the crop and moving it slowly from side to side for ten seconds. D-Vac sampling could not be carried out in damp conditions (early in the morning, or during or after rainfall) since a film of water traps animals on the plants and greatly reduces sampling efficiency. In 1981 excessive rainfall made D-Vac sampling virtually impossible.

4.2.4. Visual Counting. Visual counting of aphids on the crop has been successfully used as a method for studying aphid populations, (e.g. Wratten, 1975; Mclean, 1980; Chambers et al., 1983). Dewar et al. (1982) assessed methods for estimating the numbers of aphids in cereals and concluded that visual counting was the most effective.

During experiments in 1981 (and again, in 1982) a standard technique was used. In each plot 75 plants were examined, located in the form of a 'W' across the area (see Fig. 4.3). This was reduced to 50 plants in 1982. Care was taken not to disturb plants prior to counting as aphids may fall off. The numbers of each species of aphid, their morph and instar were recorded.

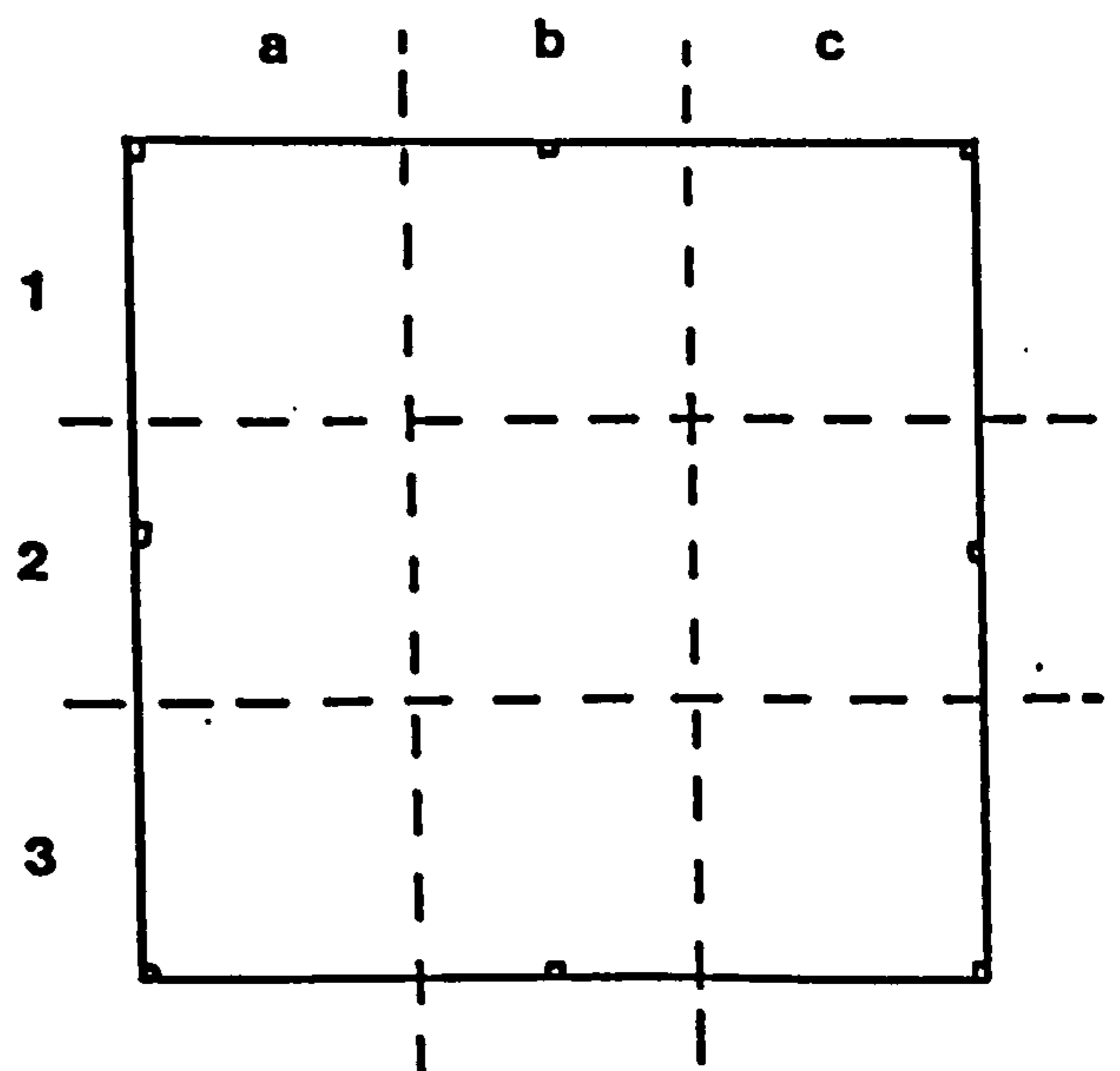
# Fig.4.3 Sampling methods

(a) Position of pitfall traps ●  
and water trap ▲  
within each plot



(b) Path taken during visual  
counting within each plot

(c) D-Vac sampling zones  
1,2 and 3 are samples  
a,b,c are subsamples



### 4.3 Other Experimental Methods

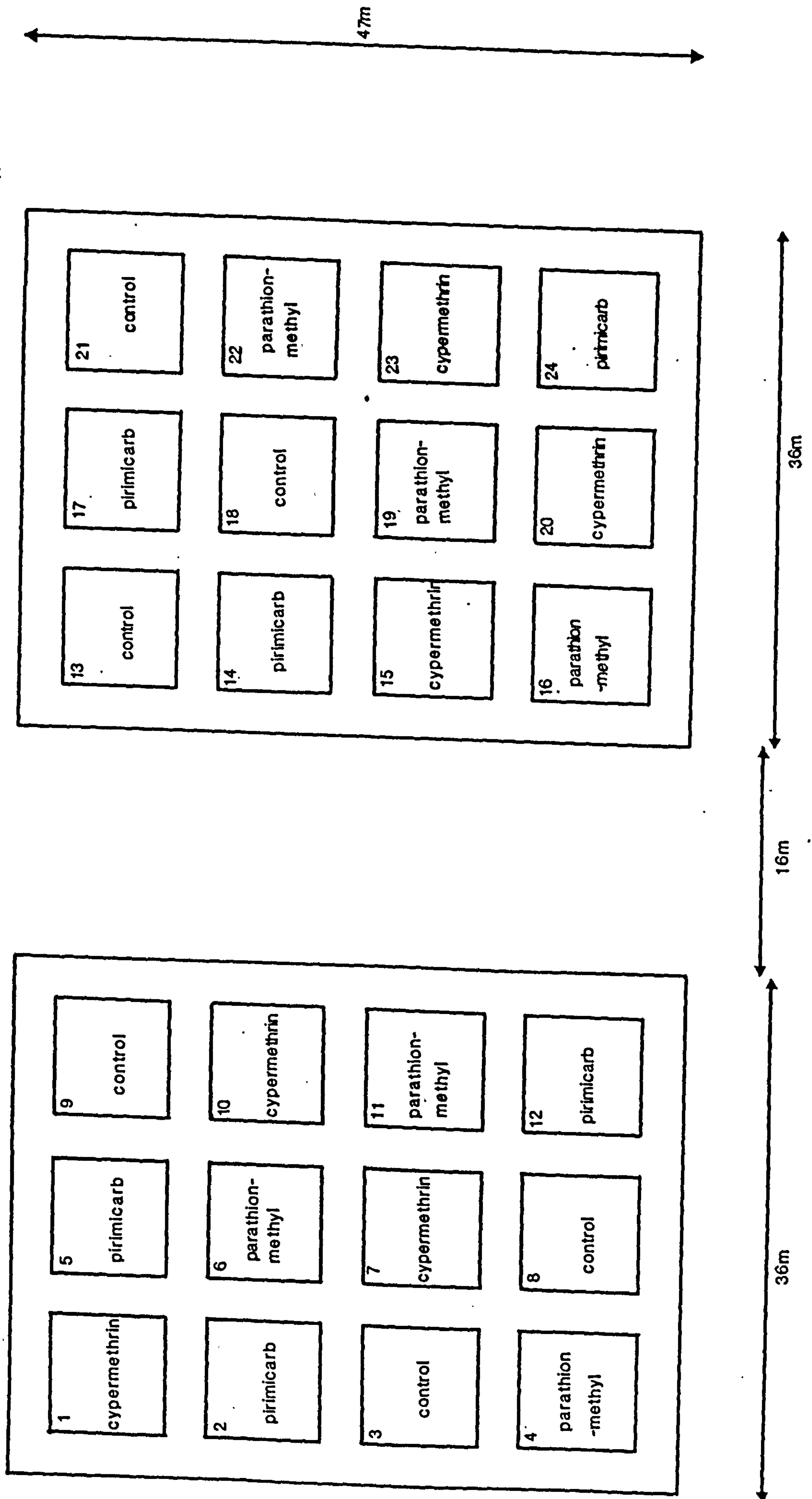
4.3.1. 1981 Sittingbourne Experiment 1. In this experiment, carried out in May and June, it was intended to determine the effects of insecticides on predators present early in the crop's development. These predators consist mostly of the polyphagous predators described in chapter 2. Predation early in the season is more likely to reduce the size of any subsequent aphid population (McClean, 1980).

In April 1981 twelve plots for Experiment 1 (and twelve for Experiment 2) were marked with canes in a field of winter sown wheat (cv. Bounty) at the Woodstock Farm, Shell Research Ltd., Sittingbourne, Kent (O.S. map reference T.Q. 895 602). The plots were 8 m. square with a 3 m. discard between adjacent plots to facilitate spraying with a tractor mounted sprayer (fig. 4.4). The plots were arranged according to a randomised block design. In mid May plastic sheeting barriers were erected around the perimeter of plots 1-12. The sheeting was of double thickness, buried to a depth of between 20-25 cm. and supported by posts at corners and midpoints of each side. A topline of polypropylene twine was incorporated into the fold of the sheeting and stapled to the posts 40 cm. above surface level. After the sheeting had been buried the discards were rotivated to provide a level surface for a tractor with a boom sprayer.

The plots were sampled using the four methods described above (Section 4.2) : pitfall traps for ground living predators; yellow



Fig.4.4 : Sittingbourne, 1981 Field sites



water traps for predators and aphids flying over the crop; D-Vac suction samples and visual counts for aphids and predators present on the crop. The plots were sampled before spraying (pretreatment) and after spraying using all these methods. Three pitfall traps and one water trap were set up in each plot. Water traps were positioned centrally and pitfall traps midway between the centre and perimeter of each plot. Traps were emptied every 24 h. from 18 May until spraying.

On 20 May three samples were taken from each plot with a Dietrick suction sampler (D-Vac). A pretreatment visual count was also carried out. Before spraying three aluminium foil plates were prepared for each of the three treatments. These provided information on the quantity of insecticide falling on the crop at various heights. One plate, 250 mm. x 250 mm. was placed at crop height (51 cm. above the soil surface). One plate (500 mm. x 50 mm.) was placed on top of a cane at mid crop height and another plate (500 mm. x 50 mm.) was placed at soil height. Spray volumes were calculated to apply insecticides at the following rates.

cypermethrin	25 g (ai) ha <sup>-1</sup>
parathion methyl	500 g (ai) ha <sup>-1</sup>
pirimicarb	125 g (ai) ha <sup>-1</sup>

On 22 May the plots were sprayed with a tractor mounted boom sprayer to plot locations determined by the randomised block design (fig. 4.4). Immediately after spraying the aluminium foil plates were washed in acetone and the solutions taken for

quantitative analysis by Shell Research Ltd.

Post treatment pitfall trapping and water trapping were carried out at increasing intervals on a logarithmic time scale. Although it had been hoped to take D-Vac samples at intervals after treatment the exceptional rainfall towards the end of May 1981 prevented sampling. Visual counts were carried out at increasing time intervals.

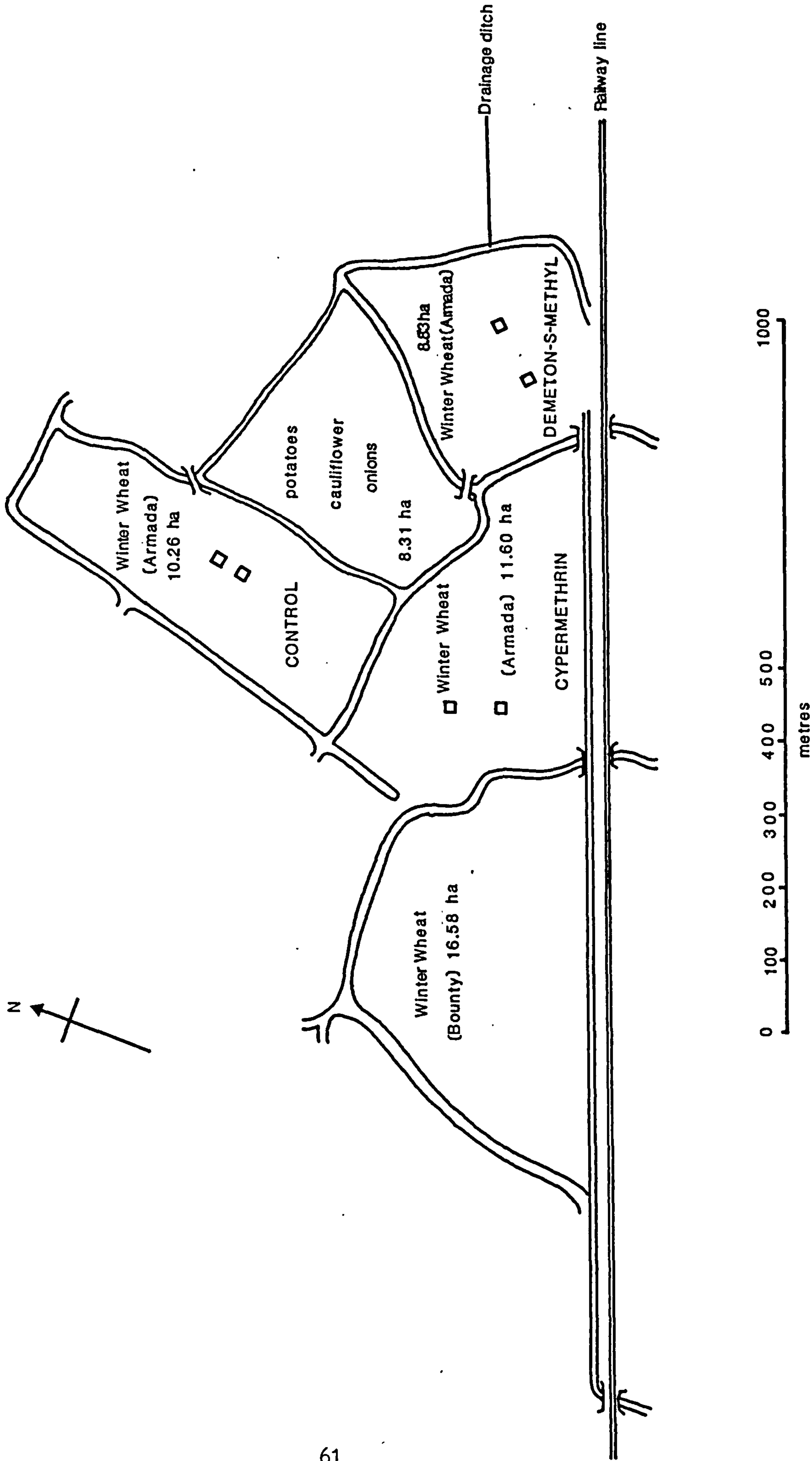
4.3.2. Sittingbourne 1981 Experiment 2. It was intended that this second experiment would provide data on the effect of insecticides on aphid-specific predators which tend to occur in peak numbers later in the season. In fact none appeared on the crop but the experiment did provide valuable additional data on polyphagous predators.

In mid-June 1981 barriers were erected around plots 13-24 (fig.4.4). Prior to this the plots had been marked by canes and in no way isolated from the cereal field. In each plot three pitfall traps and one water trap were set up. In this experiment, unlike Experiment 1 pitfall traps consisted of two plastic coffee cups sunk in the soil. The lower cup had holes in the bottom to allow for drainage. This type of trap was used successfully by Speight (1976). Otherwise, sampling methods were identical to those used in Experiment 1.

On 23 June pretreatment D-Vac, pitfall and water trap samples were taken and seventy-five plants examined for aphids. Due to unsettled weather, spraying was delayed until a fine day with a good forecast. On 30 June plots 13-24 were sprayed according to the randomised block design (fig. 4.4). Spraying rates were the same as for Experiment 1. Post-treatment sampling was carried out at regular intervals.

4.3.3. Herne Bay Experiment 1981. The experimental site was at Brook Farm, Reculver, Herne Bay, Kent, approximately 25 miles East South East of Sittingbourne. ( ES ) This site was being used by Shell Research Ltd. for field trials, and I was able to adapt part of their study for my own work. Three adjacent fields had been sown with the same variety of winter wheat (Armada). There were two treatments, cypermethrin (applied to field 1), demeton-s-methyl (applied to field 2). The third was a control field (fig. 4.5). (Note : a properly replicated experimental design for my purpose would apply treatment and controls to each field. Unfortunately the design was formulated by Shell Research for other purposes and it was not possible to change it). In each field two sampling areas were established at least 85 m. from the field boundary. In each sampling area three pitfall traps and three water traps were positioned. Traps were of the type described in Sittingbourne Experiment 1. One pretreatment sample was taken at Herne Bay with 48 h. pitfall and water trapping. Weather conditions were unsuitable for D-Vac sampling. On 12 June the fields were sprayed by aerial application at the following rates.

Fig.4.5 : Trial Site at Herne Bay ,1981



cypermethrin	25 g (ai) ha <sup>-1</sup>
demeton-s-methyl	500 g (ai) ha <sup>-1</sup>

After spraying, 48 h. pitfall and water trap samples were taken at increasing time intervals. The weather and difficulties with the machine prevented D-Vac sampling.

Ideally it would have been sensible to spray the Herne Bay fields with two of the three insecticides used at Sittingbourne in the barriered plot experiments. Instead, only cypermethrin was used at both Sittingbourne and Herne Bay. An additional insecticide (demeton-s-methyl) was used at Herne Bay. Choice of insecticide in this experiment was determined by Shell Research and not by me. Another disadvantage was that laboratory toxicity data (chapter 3) were not available for demeton-s-methyl.

#### 4.4 Results.

4.4.1 Sittingbourne Experiment 1. Results from this experiment were clearly adversely affected by weather conditions. (Rainfall and temperature data are presented in Appendices 1&2). Numbers of predators caught in pitfall traps were very low and water trap catches were small. Results have been analysed statistically and show no significant effects.

4.4.2. Sittingbourne Experiment 2. Pitfall trap catches were analysed to family level. Numbers of Carabidae, Staphylinidae and Linyphiidae are presented in fig. 4.6. Data were analysed by a one way analysis of covariance with pretreatment sample and blocks as covariates. Catches were transformed to  $\log_e (n+1)$  before analysis. Significant effects ( $P < 0.05$ ) are shown in Appendix 8 for Carabidae, Staphylinidae and Linyphiidae. In order to determine which treatment or treatments were producing the significant effects, paired t-tests on adjusted means were carried out between appropriate controls and treatments, although in most cases effects were clear by examination of fig. 4.6.

Fig. 4.6 shows a clear effect of parathion-methyl on carabid beetles whereas no other compound affected carabid numbers. Both parathion-methyl and pirimicarb reduced staphylinid numbers immediately post treatment. The pirimicarb effect was short lived whereas that of parathion-methyl was still significant 6 days post-treatment. Linyphiid spiders appear affected by parathion-methyl and by cypermethrin. The effect of cypermethrin on Linyphiids was still significant 10 days post-treatment. A summary of significant effects for each pesticide with each predatory group is shown in Appendix 8. The significant effects are indicated by points surrounded by circles in fig. 4.6.

D-Vac samples and water trap catches contained no aphids. Water trap catches of syrphid and chrysophid adults were small and showed no variation between treatments.

4.4.3. Herne Bay Experiment Results from this experiment were analysed in the manner described for Sittingbourne Experiment 2. Results of analysis of covariance are shown in Appendix 9 . Fig. 4.7 shows effects of demeton-s-methyl and cypermethrin on Carabidae, Staphylinidae and Linyphiidae. Significant points ( $P < 0.05$ ) are encircled in fig. 4.7. Although no effects on carabid or staphylinid beetles were observed with either compound, cypermethrin apparently had a major effect on linyphiid spiders, markedly depressing numbers, subject of course to the caveat that the experiment was not properly replicated. However, since cypermethrin also killed Linyphiidae in the barriered plot experiments the Herne Bay result for cypermethrin on this group is probably a real effect.

Numbers of syrphids caught in water traps were also analysed by analysis of covariance. There was no significant difference between either treatment and the control at any time.

#### 4.5 Discussion

Taken together, these 1981 experiments demonstrate the potential for selective field manipulation of predators with insecticides. For example, cypermethrin was particularly effective in reducing numbers of Linyphiid spiders whilst being relatively innocuous to other predatory groups. Parathion methyl was to some extent toxic to all predators. Pirimicarb, in contrast, had surprisingly little effect on any group. Before these results can be applied in further experiments a number of problems remain to be discussed.



Barriered plot experiments have previously been used successfully in field trials by other workers (e.g. Edwards et al., 1979, and Sunderland et al., 1980). There are, however, problems inherent in the use of barriered plots for studying predators in cereal fields.

(i) The establishment of polythene sheeting barriers almost certainly alters the microclimate, particularly on the ground. Shelter provided by the barriers may lead to increased temperatures within plots and may increase relative humidity. It is not known how these changes influence predator behaviour, or their susceptibility to insecticides, but possible effects should be borne in mind.

(ii) The effectiveness of the barrier may vary between predatory groups. Whilst clearly ineffective against winged insects, such as adult Chrysopidae, it is possible that some ingress or egress of ground dwelling predators occurs, particularly in the case of Staphylinidae which are known to fly. Linyphiid spiders have been observed moving easily up vertical polythene barriers (M. MacGarvin pers. comm. 1983) although none were seen on barriers during field experiments in cereals. Any egress due to animals climbing barriers will of course be more important as plot size gets smaller and the ratio of plot edge to plot area increases. The presence of a discard area between adjacent plots will act to reduce subsequent stabilisation of predator populations between two plots. Results from the 1981 experiments suggest that in the case of Linyphiid spiders such behaviour did not significantly alter the effectiveness of the experiment.

(iii) Barriered plots, once established by definition impair predator movements within the field. Predators which hunt from field boundaries, or which move into the field during the season, may be excluded. Hence possible predation on aphids by such predators cannot be determined. For example, the earwig Forficula auricularia, which was rarely encountered within barriered plots although it has been shown to feed on cereal aphids (Sunderland, 1975) may move into the fields after barriers were established.

Obviously the Herne Bay Experiment suffered from none of these problems. Encouragingly, results with cypermethrin were the same from both the Herne Bay open field experiment and the barriered plot experiment. No effect was observed against carabid or staphylinid beetles and a major reduction occurred in Linyphiid numbers. This confirms that for Linyphiids at least, the polythene sheeting was an effective barrier and there was no significant egress.

Drawing these data together, and despite problems with weather and proper replication of field trials (both beyond my control), these experiments were encouraging. They suggested that it was possible to differentially kill certain groups of predators in the field. Accordingly, in 1982, the experiments were repeated in a modified form.

Fig.4.6 :Sittingbourne 1981 , Experiment 2

Effects of Insecticides on Predators Numbers Caught In Pitfall Traps

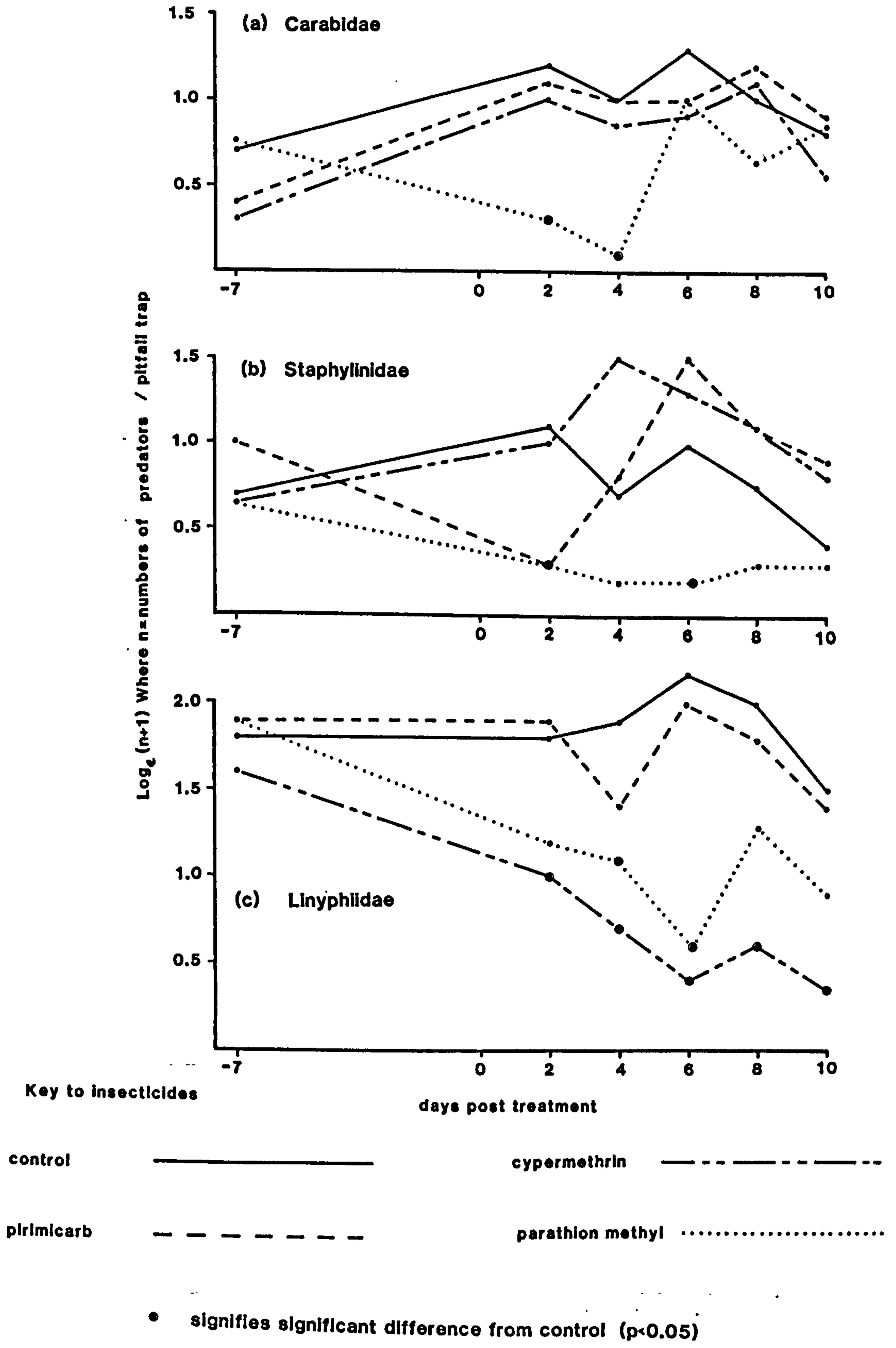
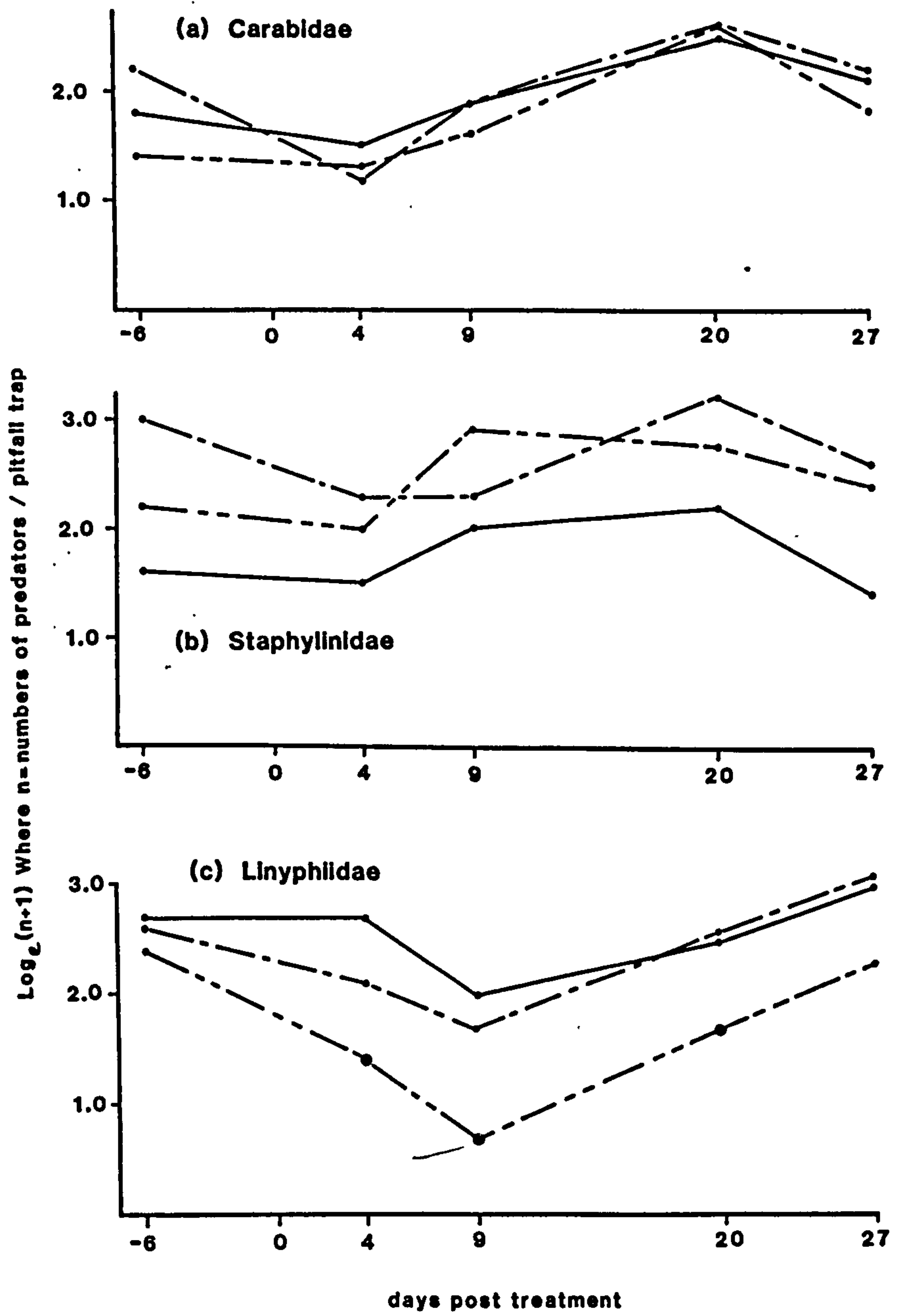


Fig.4.7 : Herne Bay Experiment 1981

Effects of Insecticides on Predator Numbers Caught in Pitfall Traps



Key to Insecticides

- control
- cypermethrin
- demeton-s-methyl

● Signifies significant difference from control ( 0.05)

## CHAPTER 5

### EFFECTS OF INSECTICIDES ON INVERTEBRATE PREDATORS AND THEIR CEREAL APHID PREY : FIELD EXPERIMENTS II

#### 5.1 Introduction

This chapter is presented in the form of a paper submitted to Environmental Entomology. As in chapter 4 references are excluded and occur in the bibliography at the end of the thesis.

The work described here was carried out in 1982, taking the concepts and methods developed in the 1981 experiments (described in chapter 4) and extending them. Four insecticides were used (as opposed to three in 1981) in two barriered plot experiments. Pirimicarb, cypermethrin and parathion methyl, as used at Sittingbourne in 1981 and in the laboratory tests (chapter 3) were used in these 1982 field experiments, together with demeton-s-methyl which was used at Herne Bay in 1981. Results presented here give further weight to those obtained in chapter 4, since effects with each insecticide were the same from year to year.

In 1982 the barriered plots were seeded with laboratory reared aphids to overcome the need for a natural cereal aphid outbreak. The subsequent effect of predators on the artificially initiated aphid populations, and on a natural one, are described in chapter 6. This chapter concentrates on the effect of insecticides on the predators, and hence is directly comparable with chapter 4, although brief mention is also made here of the effect of insecticides on aphids. The methods followed in this chapter are identical to those described in this previous chapter, except that no water traps were used.

## 5.2 Manuscript of Paper

THE EFFECTS OF INSECTICIDES ON  
INVERTEBRATE PREDATORS AND THEIR  
CEREAL APHID PREY :  
FIELD EXPERIMENTS

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## ABSTRACT

The effects of four insecticides on cereal aphids and predators were determined in the field. Barriered plot experiments were carried out in winter sown wheat during 1982. The insecticides, parathion-methyl, pirimicarb, demeton-s-methyl and cypermethrin were applied by tractor mounted sprayer. Their impact on the aphids Sitobion avenae F. (Hemiptera, Aphididae) and Metopolophium dirhodum Walker (Hemiptera, Aphididae) and polyphagous predators in the families Carabidae, Staphylinidae and Linyphiidae are discussed. All the insecticides were effective in reducing aphid numbers. Some selective toxicity against predators occurred. A comparison is made with laboratory studies involving the same animals and insecticides.



## INTRODUCTION

Despite widespread concern on the effects of agrochemicals on cereal and grassland ecosystems (e.g. Potts and Vickerman 1974, Vickerman and Sunderland 1977) there is little information on the effects of pesticides on non-target organisms. Vickerman and Sunderland (1977) studied the effects of dimethoate on arthropods in winter wheat and found that its use had a prolonged effect against a wide range of predators. Araneae were reduced by 90% seven days after treatment and predatory carabids by 76% for up to six weeks after treatment. Clearly prolonged reduction of predator numbers after insecticide use increases the likelihood of pest resurgence. Thirteen insecticides are recommended for application against aphids in cereals in the U.K. (M.A.F.F. 1982). Many of these are known to be broad spectrum insecticides which, although effective against aphids, may also reduce predator populations. Potts and Vickerman (1974) have shown significant inverse relationships between the numbers of apterous cereal aphids and the proportion of predatory arthropods present in samples from different fields.

This paper describes the field effects of four insecticides on the aphids Sitobion avenae F. and Metopolophium dirhodum W. and their polyphagous predators occurring in winter wheat in Britain. Three of the

insecticides used are recommended for use against cereal aphids (M.A.F.F. 1982); the fourth is a broad spectrum organophosphate insecticide. Laboratory studies suggest that it may be possible to selectively kill aphids (Brown et al 1984) leaving certain groups of predatory arthropods unaffected and that different insecticides differ markedly in predator selectivity. This study determines the extent to which such selective predator toxicity occurs in the field.

## METHODS

Two barriered plot experiments were carried out in a field of winter sown wheat (c.v. Bounty) at Sittingbourne in Kent during 1982. The first experiment, carried out in May and June (hereafter referred to as the 'early' experiment) was designed to look at the effects of pesticides on polyphagous predators (aphids were absent from the crop). The second experiment (the 'late' experiment) was designed to study effects on both aphids and predators. Each experiment consisted of 15 plots, each 8 x 8 m with a 3m discard between adjacent plots to facilitate spraying with a tractor mounted sprayer. In mid-May plastic sheeting barriers were placed around the perimeter of plots 1-15; the 'early' experiment. The sheeting was of double thickness, buried to a depth of between 20-25 cm and supported by posts at corners and midpoints of each side. A topline of polypropylene twine was incorporated into the sheeting and stapled to the posts 40 cm above the ground. After the sheeting had been buried the discards were rotivated to provide a level surface for a tractor with a boom sprayer.

Aphids and predators were sampled in three ways :  
Pitfall trapping for ground living predators. D-vac suction sampling and visual whole plant counts for aphids and predators present on the crop. Dewar et al (1982) considered visual counts to be the most effective method for determining aphid numbers, with D-vac sampling also useful at low aphid densities. Three pitfall traps were set up within each plot,

each midway between the centre and perimeter. The pitfall traps had a diameter of 8 cm with a square perspex roof (15 cm x 15 cm) to keep out the rain. Captured insects fell into 50ml of 2% formalin. Traps were kept open for 48h for each sample. Two pitfall trap samples were taken pretreatment and at increasing time intervals post-treatment.

D-vac samples consisted of 3 subsamples, each of 10 seconds taken from each third of the plot. Visual counting involved examining 50 plants selected at random across the plot. Numbers of aphids, species, morphs and appropriate instars were recorded per plant, as were mummies, incidences of entomophthora and aphid specific predators.

On 28 May the 'early' experiment plots were sprayed according to a randomised block design, with 3 replicates per treatment and 3 controls. Insecticides were applied to the following concentrations, determined by standard commercial application rates :

cypermethrin	:	25 g ai ha <sup>-1</sup>
demeton-s-methyl	:	250 g ai ha <sup>-1</sup>
parathion methyl	:	500 g ai ha <sup>-1</sup>
pirimicarb	:	125 g ai ha <sup>-1</sup>

Immediately prior to spraying the 'early' experiment two aluminium foil plates were placed in each of the cypermethrin

plots. One plate (250 mm x 250 mm) was placed at crop height, 51 cm above the soil surface. The second, 500 mm x 50 mm was placed at soil level. These plots provided information on insecticide concentrations reaching the crop and the soil surface. After spraying, the foil plates were washed in acetone and the solutions taken for quantitative analysis by gas liquid chromatography.

The plots for the 'late' experiment were established on 20 June, exactly as described for the 'early' experiment. By 20 June outbreaks of S. avenae and M. dirhodum had occurred in the part of the field used for the experiment. Sampling was as described for the 'early' experiment. The 'late' experiment plots were sprayed on 8 July. Insecticides were applied at the same concentrations except parathion-methyl which was applied at 75 g ai ha<sup>-1</sup>.

## RESULTS

The numbers of predators caught in pitfall traps for each treatment over both experiments are shown in Figs. 1 and 2. Because few individuals of any one species were present, taxa are not subdivided beyond family level. The three major predatory groups present throughout the season were ground beetles (Carabidae (Coleoptera)), rove beetles (Staphylinidae (Coleoptera)) and the Linyphiid spiders (Linyphiidae (Araneae)). Only a very small number of aphid specific predators occurred. Adults of Coccinella septempunctata (L.) and larvae of Chrysoperla carnea (Stephens) and Syrphus spp were recorded, but numbers were insufficient to merit analysis. Of the Carabidae the commonest species for the early experiment were Agonum dorsale (Pont.), Nebria brevicollis (F.) and Trechus quadristriatus (Schrank). N. brevicollis became scarce during late May. In the late experiment Pterostichus melanarius (Illiger) and P. madidus (F.) became very abundant. The Staphylinidae consisted of a number of Aleocharinae, as well as Tachyporus hypnorum (F.) and T. obtusus (L.). Note that Tachyporinae were observed on several occasions walking up and escaping from pitfall trap funnels. This suggests that the pitfall trap design may underestimate numbers of Tachyporinae.

Most of the Linyphiid spiders present belong to the Erigonine. Erigone dentipalpis (Wilder) and Erigone atra (Blackwell) were the commonest species.

Numbers of aphids recorded by visual counting and by D-Vac sampling are shown in Figs. 3 and 4 for the late experiment. Aphids were not present in the early experiment. Only one post-treatment D-Vac sample was taken; wet and windy weather prevented further sampling. A visual count at 20 days found no aphids.

Analysis of cypermethrin residues for the 'early' experiment showed that 68% of the applied dose fell at crop height and 8% at soil level with the crop at growth stage 35 (Tottman and Makepeace 1979). It is probably safe to assume that similar amounts of the other insecticides reached the crop canopy and the soil surface.

The major effects of spraying are apparent from Figs. 1 and 2 and are summarised in Tables 1 and 2. Significant effects are based on Analysis of Covariance with pretreatment counts and blocks as covariates and insecticides as treatments, followed by a t-test on adjusted means when significant effects were revealed by ANOCOVAR (Table 1).

Parathion-methyl sprayed at  $500 \text{ g ha}^{-1}$  (in the early experiment) greatly reduced numbers of Carabidae and Staphylinidae caught in pitfall traps; however parathion methyl had no effect on Linyphiid spiders. After twelve days for both predatory groups, numbers returned to levels similar to those in control plots. At  $75 \text{ g ha}^{-1}$  (late experiment) parathion methyl did not affect any of the predators. In both experiments cypermethrin

had a major effect against Linyphiid spiders. This effect was observed throughout the early experiment, but in the 'late' experiment there was no significant difference from the control plots beyond 16 days post treatment.

Several short term effects were observed in the immediate post treatment samples only. For example the effects of demeton-s-methyl on Linyphiid spiders (Figs. 1a, 2a) was marked, but of short duration in both experiments. Such short term effects may be due to sublethal action of the insecticides rather than predator mortality. Pitfall trap catches are a function of the abundance and mobility of the trapped animals. Sub lethal doses may reduce activity, and hence catches, until predators recover.

The effects of the insecticides on the two species of aphid are shown in Figs. 3 and 4. Both S. avenae and M. dirhodum were present on the crop as natural infestations prior to treatment in the late experiment. Five days post treatment numbers were significantly lower than in the control plots for each compound. Visual counting resulted in fewer M. dirhodum being recorded than would be expected from D-Vac samples. It is possible that disturbance prior to counting resulted in M. dirhodum falling off the plant. Visual counts for S. avenae are shown in Fig. 4. All compounds caused a significant reduction in the numbers of S. avenae immediately post treatment. With all the insecticides, aphid numbers had increased 14 days after treatment.



## DISCUSSION

Although all four insecticides were effective against aphids they differed greatly in their effects on predators. Several insecticides appeared to be highly selective against certain predatory groups, others are relatively innocuous to predators.

The concentrations of insecticides falling on the foil plates give an indication of the relative doses that crop and soil dwelling animals might receive. Although this will vary throughout the season with crop cover, approximate concentrations of insecticide reaching the crop canopy and the soil surface are useful for comparing field toxicities to prey and predators with effects obtained in the laboratory. Table 3 shows laboratory effects obtained with three of the insecticides (Brown et al : in press) at concentrations approximating those at crop and soil height. Unfortunately Staphylinids could not be collected in sufficient numbers to screen in the laboratory so direct comparisons with field tests are impossible. For carabids, linyphiids and aphids laboratory and field results (Tables 2 and 3) are broadly similar although there are some noticeable differences. Parathion methyl, whilst highly toxic to linyphiid spiders in the laboratory, had no significant effects on them in the field. It was however noticeably toxic to carabids both in the laboratory and in the field. Pirimicarb had no significant effect on carabid and linyphiid numbers in the field; laboratory tests had predicted some mortality in both groups. Cypermethrin was apparently

much more toxic to aphids in the field than in the laboratory, but shows similar effects on spiders and Carabids in both field and laboratory.

Laboratory and field comparisons aside, the most obvious point to emerge from Tables 2 and 3 is the selective toxicity of different insecticides to predators in the field. Knowledge of such effects may ultimately prove to be beneficial in achieving a greater degree of pest control for a minimum of predator mortality. Furthermore selective toxicity opens up the possibility of determining experimentally the effect of predators on the growth of prey populations by selective manipulation of predator and prey populations. Results of a set of experiments along these lines will be presented in a future publication.

Laboratory studies are apparently useful for suggesting which groups may be affected but as Tables 1 and 2 make plain correlations are not perfect. Field experiments are essential.

### 5.3 Addendum : Laboratory and field surface film comparisons.

In this paper, and in Chapter 4, reference is made to the use of foil plates to calculate effective concentrations of insecticides falling as film on plant and other surfaces. Laboratory experiments were carried out on dry films and, although known field application rates are not directly comparable, some idea of resulting concentrations on surfaces in the field helps link laboratory (Chapter 3) and field (Chapters 4 & 5) experiments.

Analysis of acetone solutions containing washed foil plate residues was carried out by Shell Research Ltd. Results are presented in Table 3. Knowing percentage of applications reaching various positions in the crop, and initial spray concentration, broad, order of magnitude, comparisons with laboratory dry film experiments are possible. Of course the percentage penetration of the crop will depend on the growth stage of the crop.

Table 1(a) - Sittingbourne Early Experiment : 1982. Value of P from 1 Way Analysis of Covariance

date	days post treatment	Carabidae	Staphylinidae	Linyphiidae
31.5.82	+3	0.077	0.001 *	0.021 *
2.6.82	+5	0.017 *	<0.001 *	0.002 *
5.6.82	+8	0.105	0.001 *	0.014 *
9.6.82	+12	0.010 *	<0.001 *	0.019 *
14.6.82	+17	0.633	0.388	0.002 *
21.6.82	+24	0.014 *	0.116	<0.001
30.6.82	+33	0.010	0.154	0.002 *

\* denotes P<0.05

Table 1(b) - Sittingbourne Early Experiment : 1982 Values of t, Control : treatments

	Carabidae						Staphylinidae						Linyphiidae					
	MEP	PIR	DEM	CYP	MEP	PIR	DEM	CYP	MEP	PIR	DEM	CYP	MEP	PIR	DEM	CYP		
31.5.82 +3	-	-	-	-	***	3.70	*	2.14	0.14	0.68	1.43	0.58	**	3.04	**	3.07		
2.6.82 +5	**	3.44	0.11	0.26	1.64	***	4.54	0.11	-0.55	-0.44	*	2.55	**	2.71	***	4.92		
5.6.82 +8	-	-	-	-	-	**	3.12	-0.51	-1.71	0.18	1.13	0.98	**	0.71	**	3.02		
9.6.82 +12	***	3.97	0.24	2.42	0.24	***	5.38	1.87	0.04	0.42	*	2.59	*	2.35	***	4.11		
14.6.82 +17	-	-	-	-	-	-	-	-	-	-	1.06	1.57	***	1.06	***	4.77		
21.6.82 +24	*	2.29	-0.22	0.22	2.82	**	-	-	-	-	-0.21	0.04	***	0.68	***	4.47		
30.6.82 +33	-2.17	-3.69	-3.16	-2.01	-	-	-	-	-	-	1.06	1.57	***	1.06	***	4.76		

values of t, with 40 degrees of freedom, denoted above by

p = 0.05      t = 2.021      \*  
 0.01          2.704      \*\*  
 0.001        3.551      \*\*\*

Table 1(c) - Sittingbourne Late Experiment : 1982

Values of P. from analysis of covariance.

date	days post treatment	Carabidae	Staphylinidae	Linyphiidae
11.7.82	+3	0.521	0.253	<0.001 *
16.7.82	+8	0.376	0.253	<0.001 *
23.7.82	+15	<0.001 *	0.825	0.426
4.8.82	+27	0.772	0.130	0.033 *

Table 1(d) - Sittingbourne Late Experiment , 1982. values of t, Control : treatments

	CARABIDAE					STAPHYLINIDAE					LINYPHIIDAE					
	MEP	PIR	DEM	CYP	MEP	PIR	DEM	CYP	MEP	PIR	DEM	CYP	MEP	PIR	DEM	CYP
+3	-	-	-	-	-	-	-	-	0.812	-0.595	7.15	6.61				
+8	-	-	-	-	-	-	-	-	-1.77	-1.04	-0.38	4.73				
+15	3.12	3.86	0.51	-1.54	-	-	-	-	-	-	-	-				
+27	-	-	-	-	-	-	-	0.17	0.66	3.29	1.55					

Table 2(a) : Summary of Field Effects of Insecticides on Aphids and Polyphagous Predators

Insecticide	Conc. gha <sup>-1</sup>	Carabidae	Staphylinidae	Linyphiidae	Aphididae
parathion-methyl	500	++	++		++
pirimicarb	125		+		++
demeton-s-methyl	250			+	++
cypermethrin	25		+	++	++

+ = short term effect (numbers return to normal after 1 week)

++= long term effect (sustained reduction in numbers)



Table 2 (b) Laboratory Effects of Insecticides on Aphids and Polyphagous Predators  
 at Concentrations approximating those at crop and soil height as used  
 in this study

Insecticide	Conc. gha <sup>-1</sup>	Carabidae	Linyphiidae	Aphididae
parathion- methyl	500	++	++	++
	50	++	++	++
pirimicarb	125	+	+	++
	12.5	+	+	+
cypermethrin	25		+	+
	2.5		+	+

+ = some mortality

++ = 100% mortality

Table 5.3 Analysis for cypermethrin residues on foil plates at crop and soil height after application at 25gha<sup>-1</sup>

Sampling level	Concentration of cypermethrin found at level (gha <sup>-1</sup> )	% of Nominal dose *
Crop height	17	68
Soil level	2.1	8

\* Nominal Dose = 25 gha<sup>-1</sup>

Fig.5.1 (a) Early Expt.

Effects of Insecticides on Carabidae caught in Pitfall traps

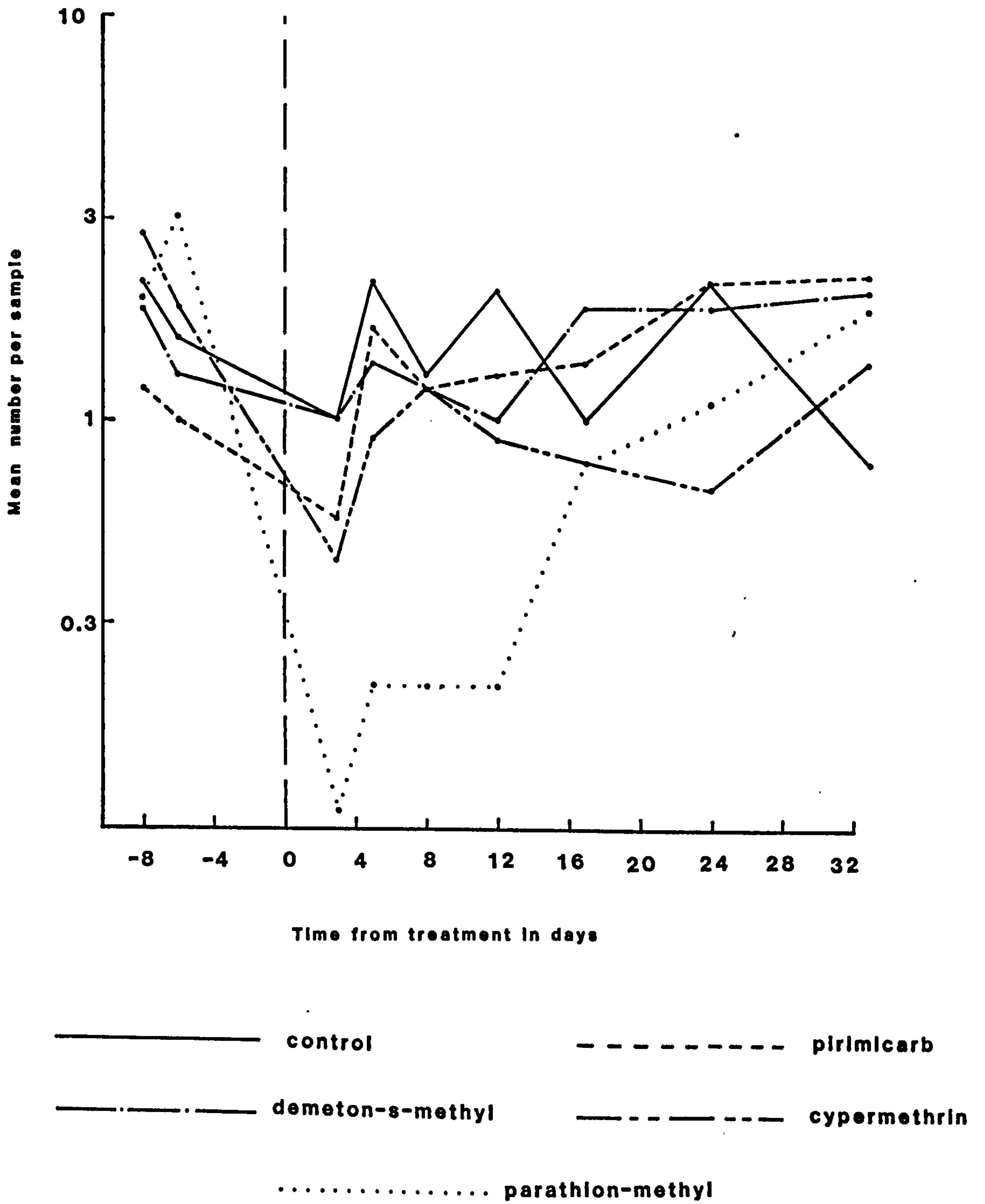


Fig.5.1 (b) Early Expt

Effects of Insecticides on Staphylinidae caught in Pitfalltraps

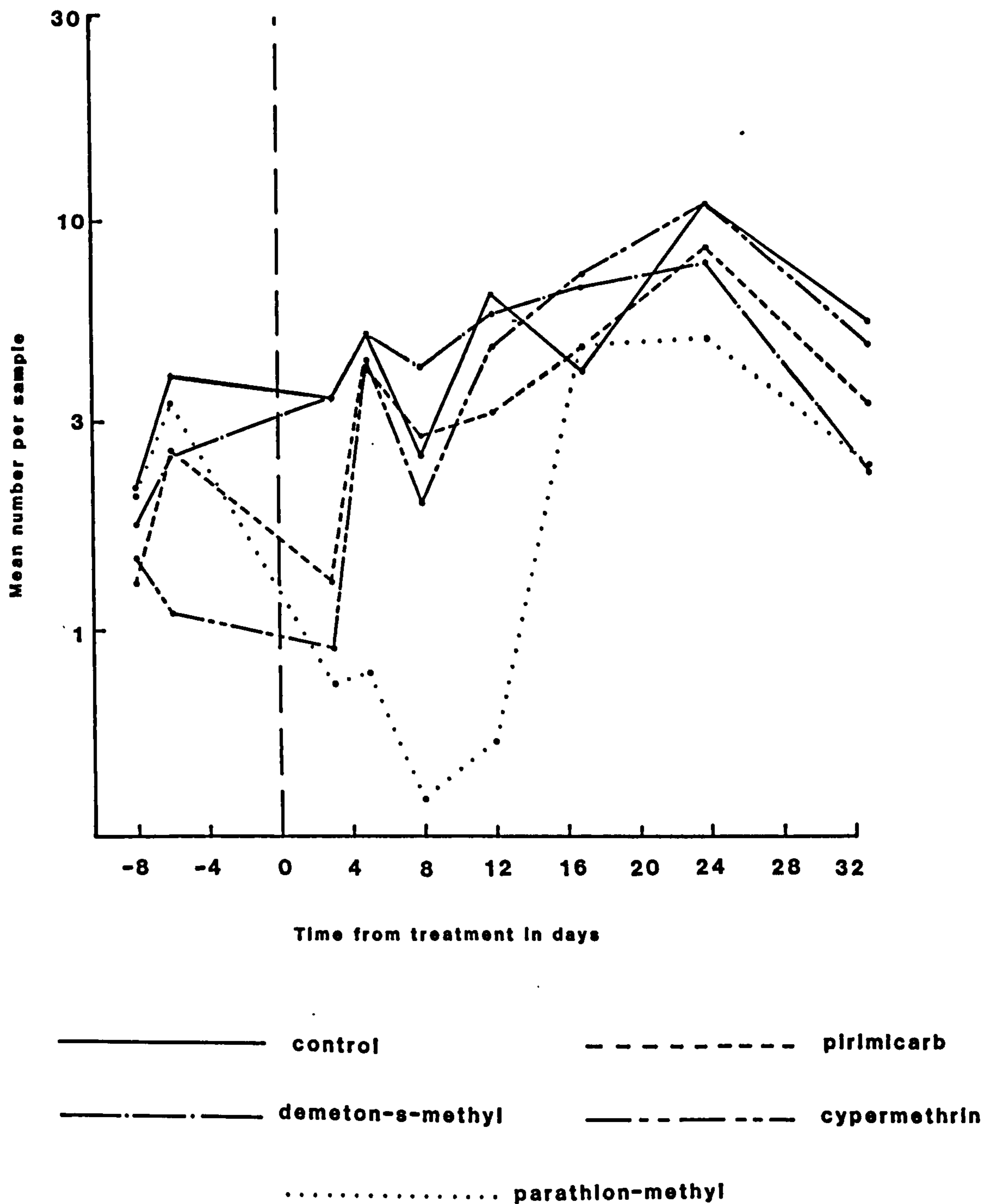


Fig.5.1 (c) Early Expt.

Effects of Insecticides on Linyphiidae caught in Pitfall traps

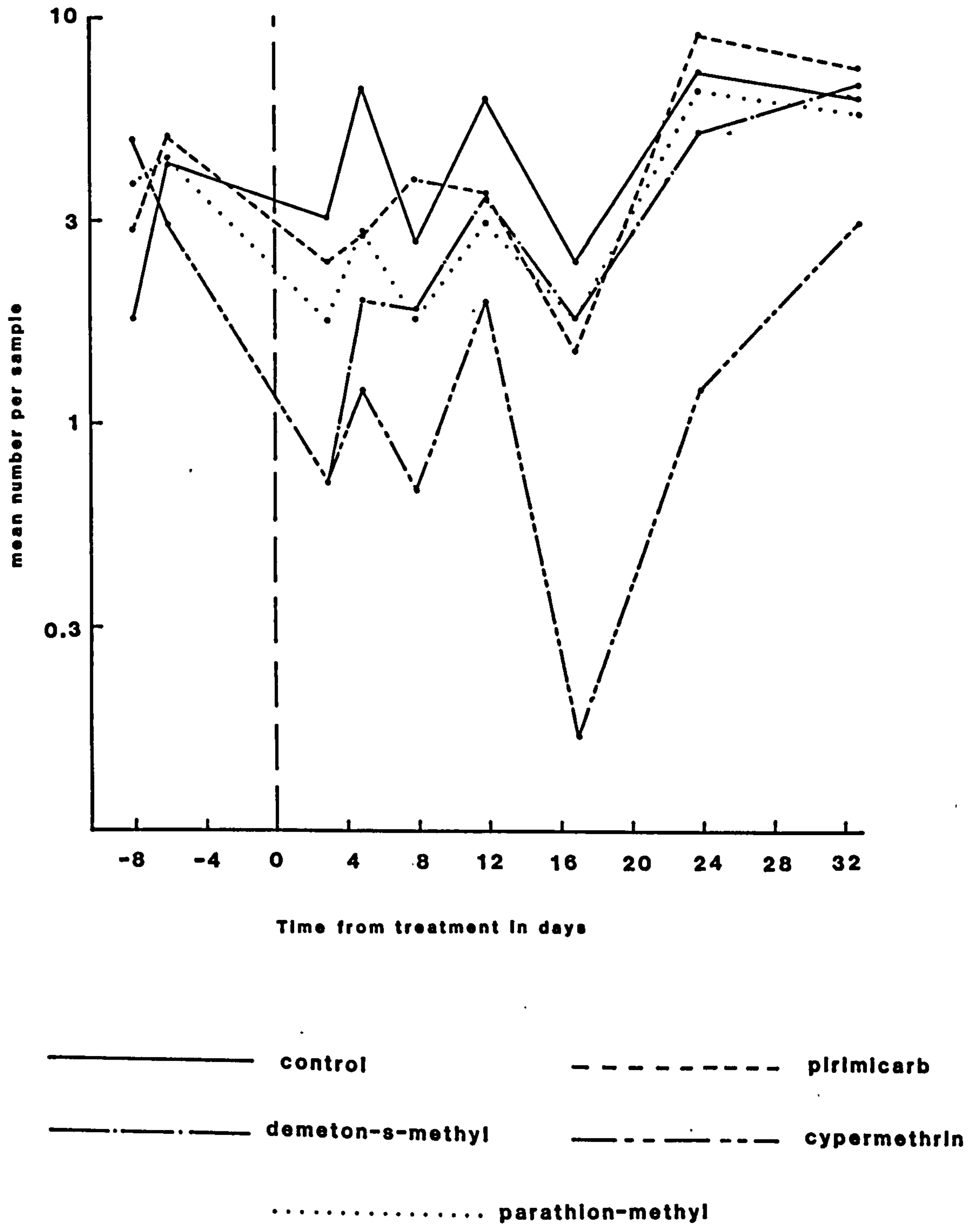


Fig.5.2 (a) Late Expt.

Effects of insecticides on Carabidae caught in Pitfall traps

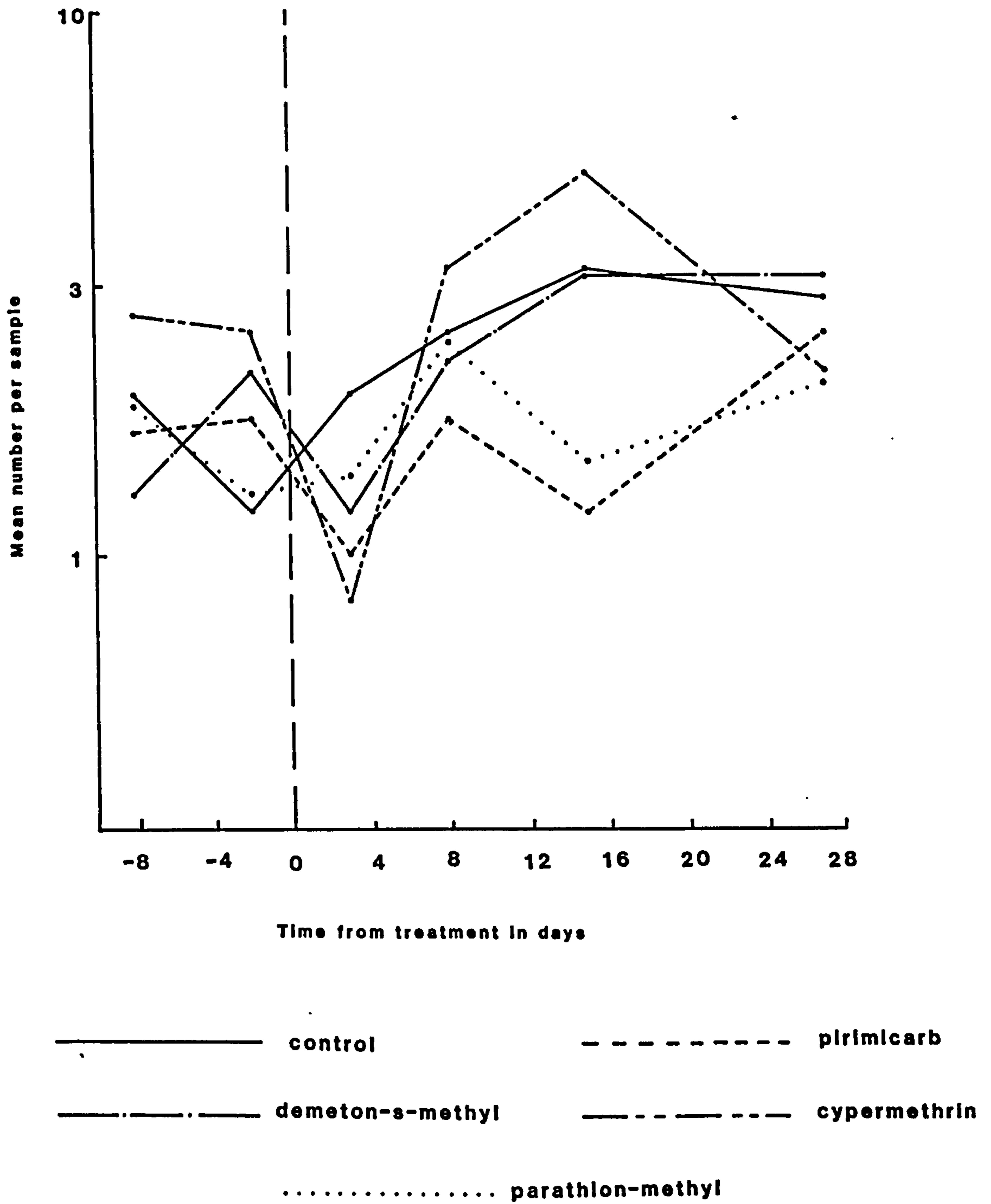




Fig.5.2(c) Late Expt..

Effects of insecticides on Linyphiidae caught in Pitfall traps

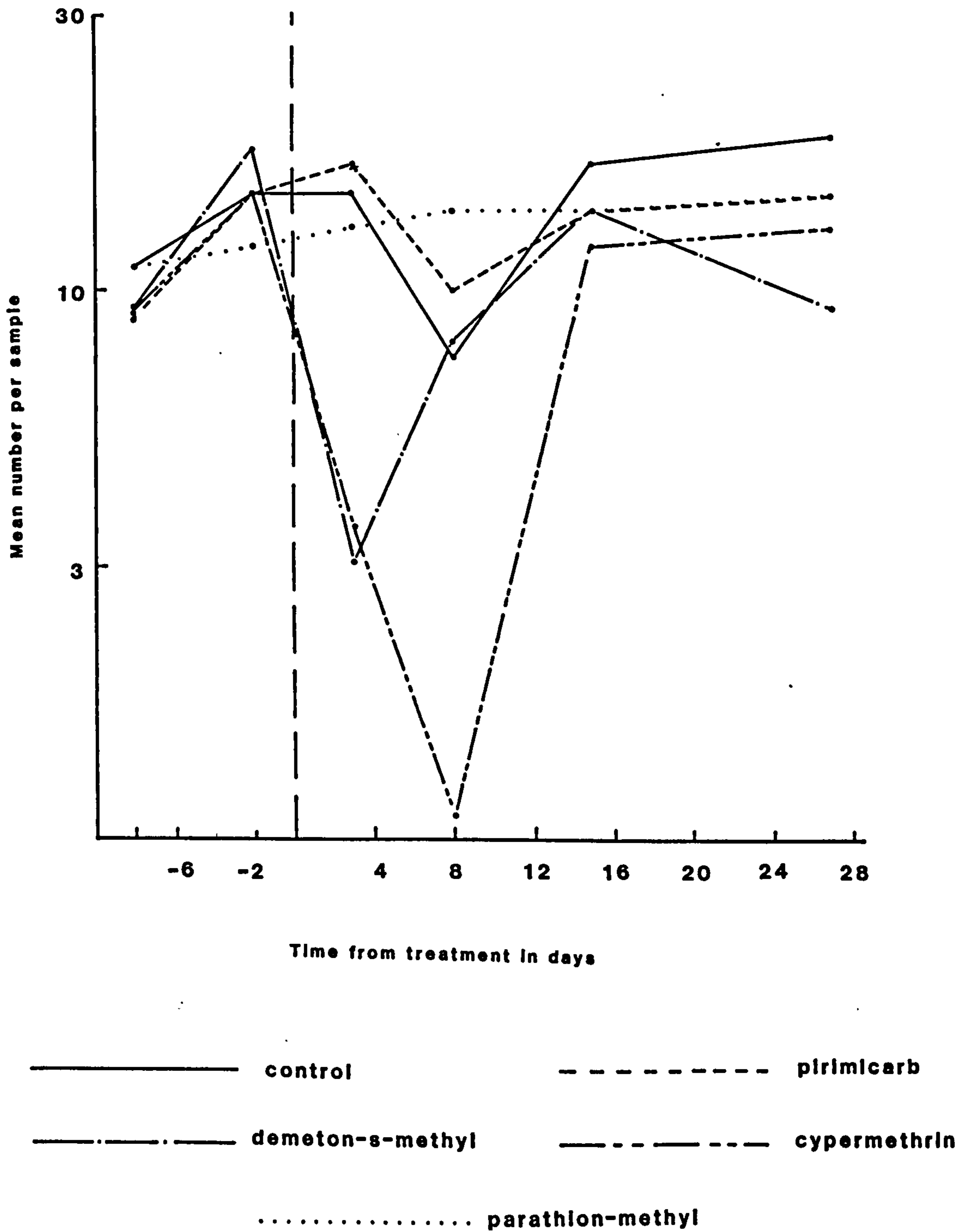




Fig.5.3 (a) Effects of Insecticides on S.avenae caught by D-Vac sampling

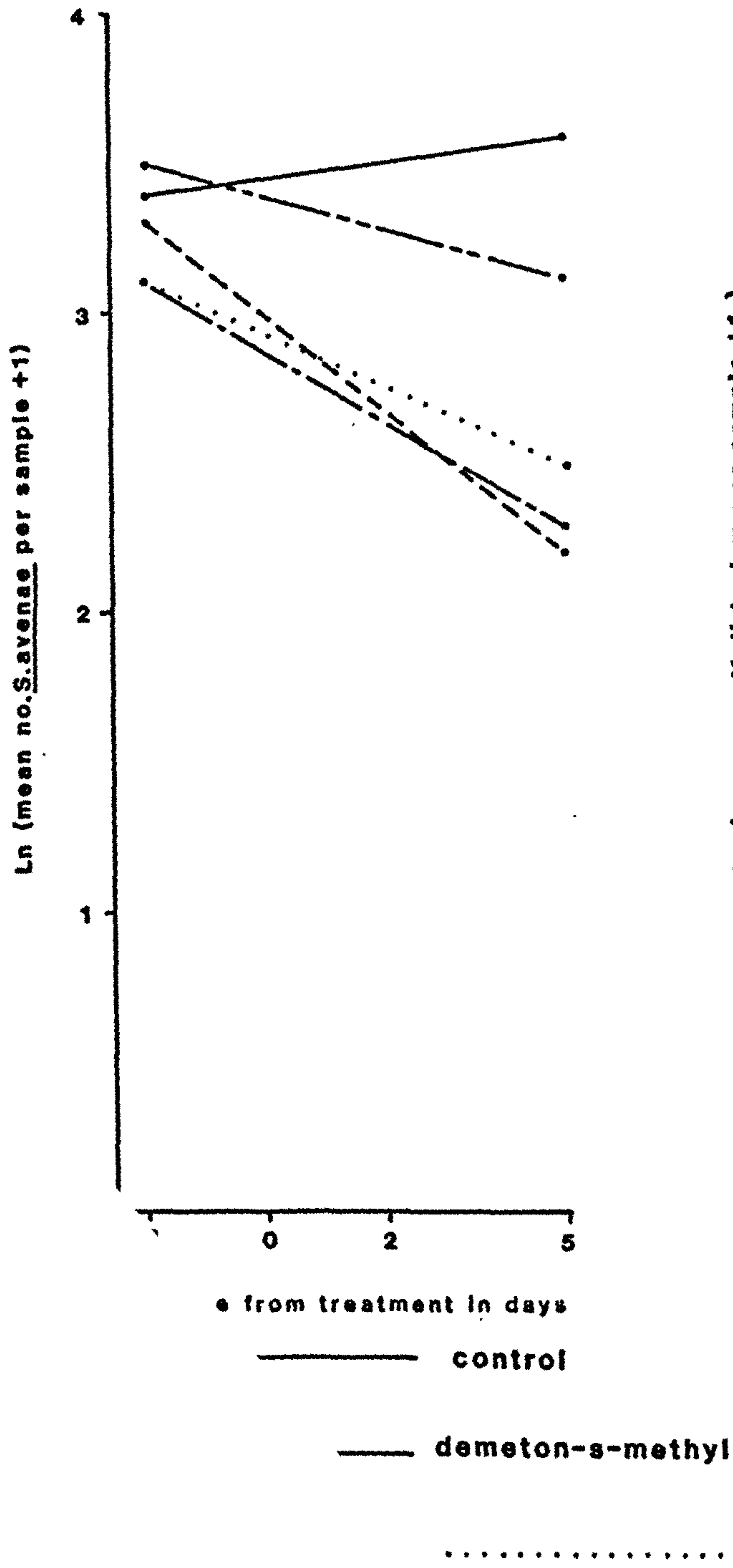


Fig .5.3

M.dirhodum

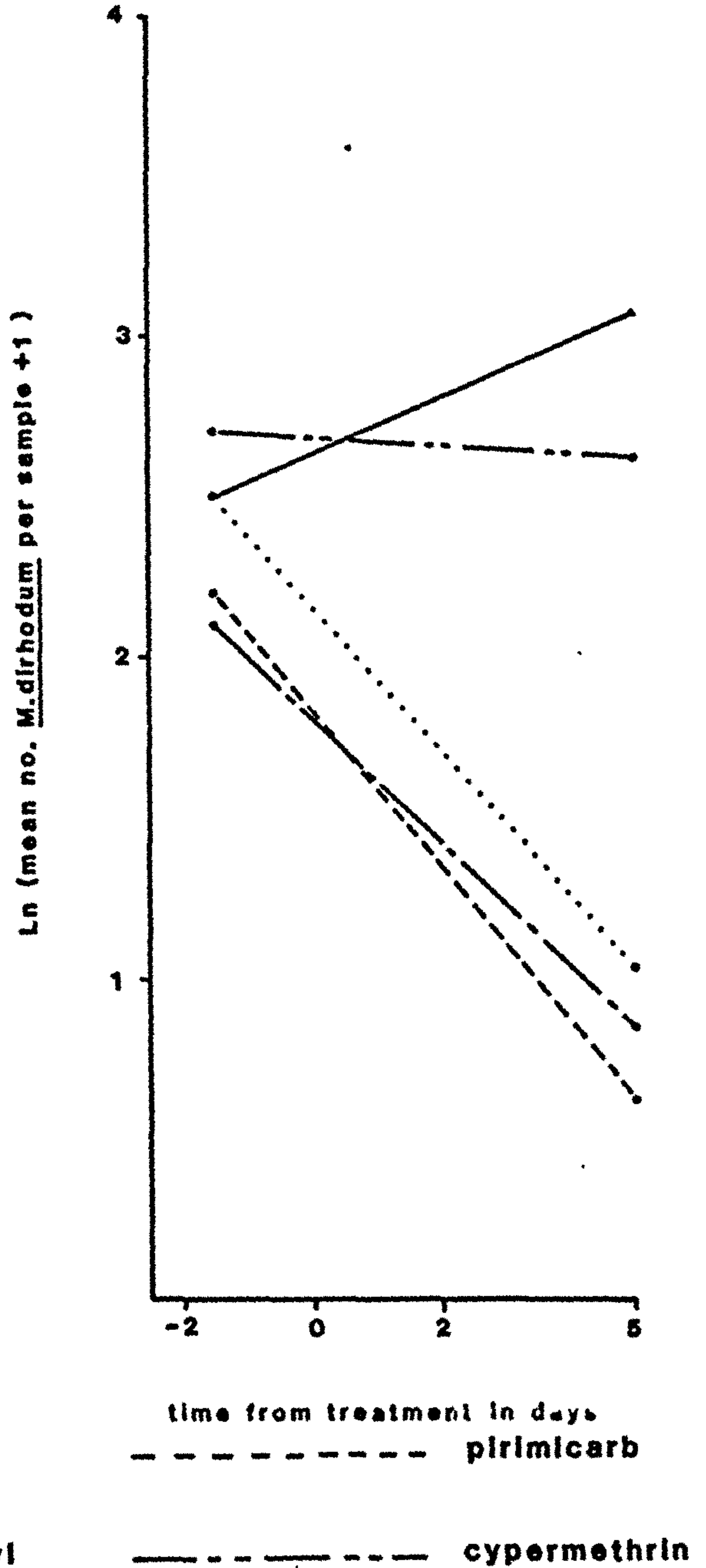




Fig. 5.5 Early Experiment Field Site after Rotivation of Discards



Fig. 5.6 Ploughing Plot Boundaries for  
Early Experiment



Fig. 5.7 Erecting Plastic Sheeting Barrier  
for Early Experiment



Fig. 5.8 Completed Early Experiment Field Site



Fig. 5.9 Spraying Early Experiment



Fig. 5.10 Sittingbourne 1982 Field Site Showing Both Experiments





## CHAPTER 6

### FIELD EFFECTS OF PREDATORS ON CEREAL APHIDS

6.1 This chapter examines the question "which predators are important in limiting cereal aphid populations?" It uses the barriered plot experiments described in chapter 5, focussing on the effect of changes in predator numbers induced by insecticide treatments on the growth of cereal aphid populations. It therefore seeks to clarify the situation on which predators are important, summarised in chapter 2.

#### 6.2 Methods

The 1982 Sittingbourne "Early" experiment described in chapter 6 employed barriered plots established in a field of winter wheat in May. Four different insecticides were applied and subsequent predator reductions observed. Twelve days after treatment (9.6.82) approximately 200 laboratory reared Metopolophium dirhodum were introduced into each plot. Nine plant pots, each containing infested wheat plants, were distributed evenly within each plot. A further four heavily infested plants were cut at soil level and placed evenly within each plot. Aphids from the latter plants would have been compelled to move rapidly onto the field grown crop. Aphids on plants

still growing in pots could make a slower transition to the crop. It was obviously important that residual pesticide toxicity in the treated plots did not kill the aphids. Each day post treatment, prior to infestation with aphids, laboratory reared aphids were placed on field collected leaves in a constant temperature room at 16°C, 8 h. dark, 16 h. light. When no mortality occurred in these aphids after 24h. (as happened on Day 11) the crop was considered to be essentially non toxic to aphids. With hindsight it is possible that there may have been sub-lethal residual effects on the aphids, and observations of reproductive rates on control and treated leaves may have helped determine whether this was so. However, I doubt whether sub-lethal effects were of significance. Obviously, an experiment of this kind is a finely balanced compromise between conflicting demands. Too long a delay before introducing aphids would have allowed predator numbers to recover. Too short a time lag would have meant high aphid mortality immediately after infestation due to residual insecticide effects. It was also important to minimise aphid mortality in the crucial post-infestation phase due to density independent factors. For example heavy rainfall could dramatically reduce aphid populations; hence aphid introduction had to be timed to coincide with settled, dry weather.

Although other workers, notably Edwards et al (1979) have relied on natural outbreaks, an artificial aphid population was established in this study for 2 reasons. Firstly, natural outbreaks do not always occur (there was no outbreak during

the 1981 field season, see chapter 4). Secondly, seeding with aphids creates a uniform outbreak of similar size in each plot; aphids in natural outbreaks may sometimes be very patchily distributed.

Interestingly, although the 1982 plots were artificially seeded with M. dirhodum at about 10 days post treatment a natural outbreak of Sitobion avenae (brown colour morphs) occurred and became established in similar numbers in each plot; confounding both my worries that no natural outbreak would occur, and, if it did, that aphids would be patchily distributed. This natural outbreak was fortunate since it meant that two species of cereal aphids (S. avenae and M. dirhodum) were available for study.

Aphid populations were sampled by D-Vac and by direct counting. Ground dwelling predators were sampled by pitfall trapping (for discussion of sampling, see chapter 4).

It had been hoped to use the "Late" Sittingbourne experiment to study the effects of aphid specific predators on aphids. Although aphids were observed on the crop during this "late" experiment virtually no aphid specific predators appeared. Finally, therefore, before crop senescence and the departure of aphids, it was decided to use the "late" experiment to provide information on the field effects of insecticides on the aphids as well as the predators present at that time. Plots

were sprayed, as described in chapter 5 and aphid mortality determined. In part, the effect of the insecticides on the aphids has already been reported in the paper that forms the core of chapter 5.

### 6.3 Results : Effect of Predators on Cereal Aphids in the Sittingbourne Early Experiment.

In this experiment differences in aphid numbers between treatments are attributable to different predator abundances, and are not a reflection of the toxicity of the insecticide to the aphid.

In order to give a preliminary indication of the relative importance of different predatory groups, aphid numbers for each treatment are shown in Figs. 6.1-6.4. Throughout this experiment the two species of aphid present (S. avenae and M. dirhodum) are considered separately. Results are presented for both the D-Vac and visually counted samples. Comparative effectiveness of each sampling technique is also discussed.

A more precise approach to determine predator importance was subsequently carried out. A daily rate of increase,  $r$ , was calculated for each aphid sampling interval for D-Vac and visual counts, derived from the formula :

$$\text{Log}_e \left( \frac{N_t}{N_0} \right) = rt$$

where  $N_t$  = aphid numbers at time  $t$

$N_0$  = aphid numbers at start of interval over which  
 $r$  is to be determined

$t$  = time interval in days.

(Williamson, 1972)

Regression analysis was carried out for values of  $r$  per day against predator numbers in pitfall traps corresponding to each time interval. Predators were included in the analysis in the following categories : Carabidae, Staphylinidae, Linyphiidae and the sum of these three, total polyphagous predators. Of a total of 36 regression analyses no one predator group had a consistently significant effect on aphid population growth rate, although a number of different significant results occurred at different times post treatment. Table 6.1 shows values for the probability of a significant effect,  $P$ , and the corresponding gradient  $G$  for each regression line. Selected regression lines showing typical significant and non significant results are shown in Figs. 6.5 and 6.6.

The small number of significant results shown in Table 1 is to some extent disappointing, particularly when (with 72

comparisons) one or two significant effects of predator numbers on aphid growth rates might have been expected at  $P = 0.05$  by chance. Moreover, significant effects appear haphazardly distributed over time and predator groups. In another attempt to clarify whether anything systematic was happening, values of  $P$  and  $G$  were plotted one against the other by aphid species and sampling methods, recording each predator type distinctly (Figs. 6.7-6.10). This way, one might expect to see if particular predator groups were consistently associated with low aphid growth rates. If there is no systematic relationship between predator numbers and aphid population growth rates then one would expect values of  $G$  to be evenly distributed about 0, with no grouping of predator points. Although such plots are very difficult to analyse statically, visual inspection of Figs. 6.7-6.10 does not suggest any consistent effect of one particular group of predators on aphid population growth rates. On any one figure, the points for, say, Carabidae, are scattered across the graph. In other words, there is no consistent effect of carabid numbers on aphid population growth rates.

Perhaps the one mildly encouraging feature to emerge from Figs. 6.7-6.10 is an excess of negative slopes (i.e. in general, aphid population growth rates appear to decline with increasing predator numbers more often than they increase with increasing predator numbers). A sensible statistical test of this observation is not possible because the data in Figs. 6.7-6.10 is not independent. All use the same predator numbers with different

species and methods of sampling aphids.

Many of the slopes (G) are not themselves significantly different from zero.

Finally, a multiple regression analysis was performed using aphid growth rates as a dependent variable and predator numbers as independent variables (i.e. entering carabid, staphylinid and linyphiid numbers as three independent variables.) None of the predators entered the regression in a statistically significant manner.

#### 6.4 Discussion

The results presented in this chapter clearly demonstrate that polyphagous predators can affect the rate of increase of cereal aphid populations. However, the importance of predators differs for the two aphid species. An inverse relationship between S. avenae rate of increase and total polyphagous predator numbers occurred over time interval 2 (see Table 6.1), but no such relationship occurred at this time with M. dirhodum. M. dirhodum rate of increase was inversely related to linyphiid spiders numbers over time interval 1, a period when no effects were observed with S. avenae. However, the presence of a significant positive correlation between S. avenae rate of increase and staphylinid numbers over time interval 3 emphasis the need for caution in interpreting all these results! Whilst one explanation might be that staphylinids inhibit other predators or consume their eggs or larvae, it is just as likely that this result is an anomaly. The inverse relationship between S. avenae rate

of increase and total polyphagous predators, observed over interval 2, does, however, appear to be a sensible result, observed both in analysis of visual counting and D-Vac data. It is interesting that only analysis of total polyphagous predators produced a significant relationship with S. avenae and that it was not possible to single out any one predatory group, as the major contributor to control of the aphid. This result, together with the large number of negative gradients in Table 6.1, leads to the conclusion that, with S. avenae, it is the combined effect of a number of predators which might be important. This view is supported by S. avenae numbers in Fig. 6.1. The insecticides which caused non selective predator mortality, i.e. parathion-methyl and demeton-s-methyl, resulted in S. avenae populations significantly (P 0.05) higher than controls in which all predators were present.

The importance of predators in reducing M. dirhodum populations is even less clear. It is likely that Linyphiid spiders do play a more important role with this species of aphid. Figs. 6.2 and 6.3 show that for both D-Vac and Tiller counts, in cypermethrin treated plots (which are the most spider deficient) M. dirhodum numbers were higher than in control plots.

More importantly, a significant negative relationship exists between linyphiid spiders numbers at +17 days and the rate of increase of M. dirhodum at this time (Table 6.1). It is possible that linyphiids, which spin horizontal webs, catch prey falling off, and that with M. dirhodum, which tends



to be found on the leaves, this is an important cause of mortality.

The combined importance of polyphagous predators in limiting S. avenae is certainly in keeping with the findings of previous workers. As mentioned in chapter 2, a large number of polyphagous arthropods have been earmarked as important by the discovery of aphid remains in their guts. The findings of this study indicate that, within the main predatory families Carabidae, Staphylinidae and Linyphiidae no one family is of sole importance in containing S. avenae populations. However, Linyphiidae alone may be particularly important in containing outbreaks of M. dirhodum.

Before attaching too much weight to these conclusions it is necessary to consider one further caveat. The results apply only to a cereal regime in Kent, in one year. If the experiments were carried out in East Anglia, or in land that had been sown with cereals for many years, or in a different year, the results might be quite different. Any factor, such as soil (ph) <sup>pH</sup> and moisture, size of fields, weediness or cultivations, which could influence arthropod diversity and abundance in the cereal ecosystem could produce a ranking of predator importance different from those described here. One possible reason for current confusion over which polyphagous predators are important (chapter 2) may be that different groups are of greater or lesser importance in different areas or years depending upon their abundance.

However, few attempts have been made to directly alter predator numbers and follow subsequent aphid performances, as here. It is therefore disappointing that the experiments reported here did not produce clearer results. The results were, however, unequivocal, if mainly negative.

a) Most of the time most polyphagous predators, individually or in total, did not significantly influence the rate of aphid population growth.

b) Where significant effects were found, they were different for two aphid species :

- Total polyphagous predators effected S. avenae rate of increase,
- Only linyphiid spiders effected M. dirhodum rate of increase.

Both observed effects were only over one time interval.

c) The main conclusion must be that polyphagous predators in general played a relatively unimportant and transitory role in limiting cereal aphid populations in these experiments. The onus is on those who argue otherwise to demonstrate the case by direct field experiments.

d) There are several ways in which my experiments may be misleading :

i) Small spatial scale

ii) Even after spraying predator numbers in general recovered fairly quickly

iii) The experiment says nothing about long-term very large scale role of predators, i.e. what would happen if polyphagous predator numbers were reduced by orders of magnitude over hundreds of hectares for several years.

Table 6.1 Values of Probability (P) and Gradient (G) for Regression lines of Daily Rates of Increase of Aphid Populations against corresponding Predator Numbers for S.avenae and M.dirhodum by both Visual Counting and D-Vac sampling.

Visual Counting	Days Post-treatment	Carabidae		Staphylinidae		Linyphiidae		Total Polyphagous Predators	
		P	G	P	G	P	G	P	G
<u>S.avenae</u>	+17	0.47	-3.1	0.78	-6.7	0.062	-15.15	0.27	-24
	+24	0.075	-0.02	0.2	-37	0.33	-29	0.04	-80
	+33	0.52	-8.7	0.03	74.9	0.98	$-0.9 \times 10^{-4}$	0.21	65.3
<u>M.dirhodum</u>	+17	0.63	0.51	0.51	3.9	0.03	-4.2	0.98	0.168
	+24	0.62	-1.6	0.18	-0.014	0.92	1.17	0.38	-15.2
D-Vac									
<u>S.avenae</u>	+17	0.32	2.2	0.84	2.53	0.98	-0.09	0.699	4.7
	+24	0.52	-0.008	0.26	-43.4	0.08	-51.9	0.02	-0.004
<u>M.dirhodum</u>	+17	0.85	0.15	0.99	-0.05	0.10	-2.3	0.59	-2.2
	+24	0.93	-0.38	0.30	-17.7	0.5	-9.5	0.23	-27.4

Significant values are those where P is less than 0.05

Fig.6.1 :Early Expt.

D-Vac catches of S.avenae after treatment  
to affect predators

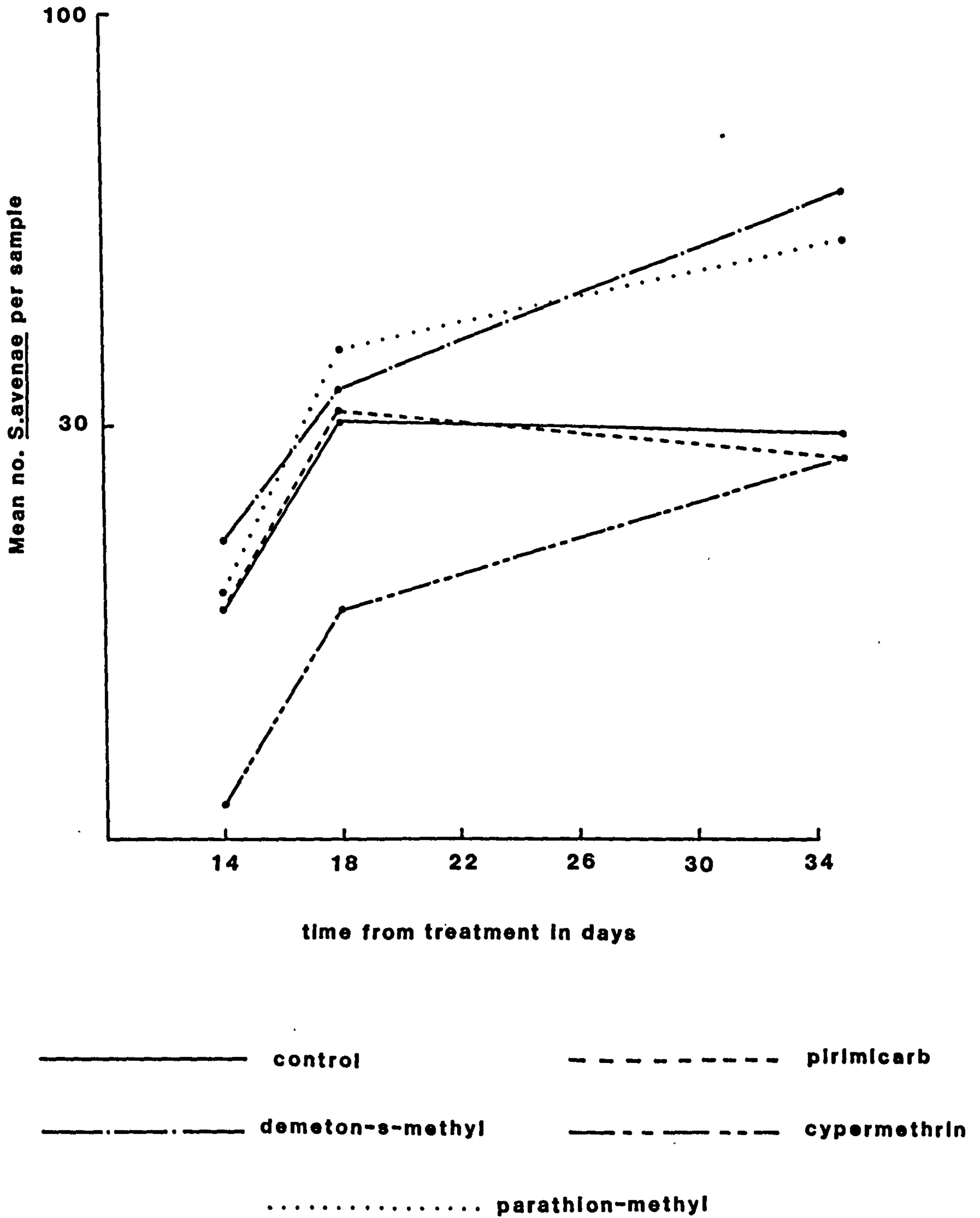




Fig.6.3 :Early Expt.

Visual Counts of of S.avenae after treatment to affect predators

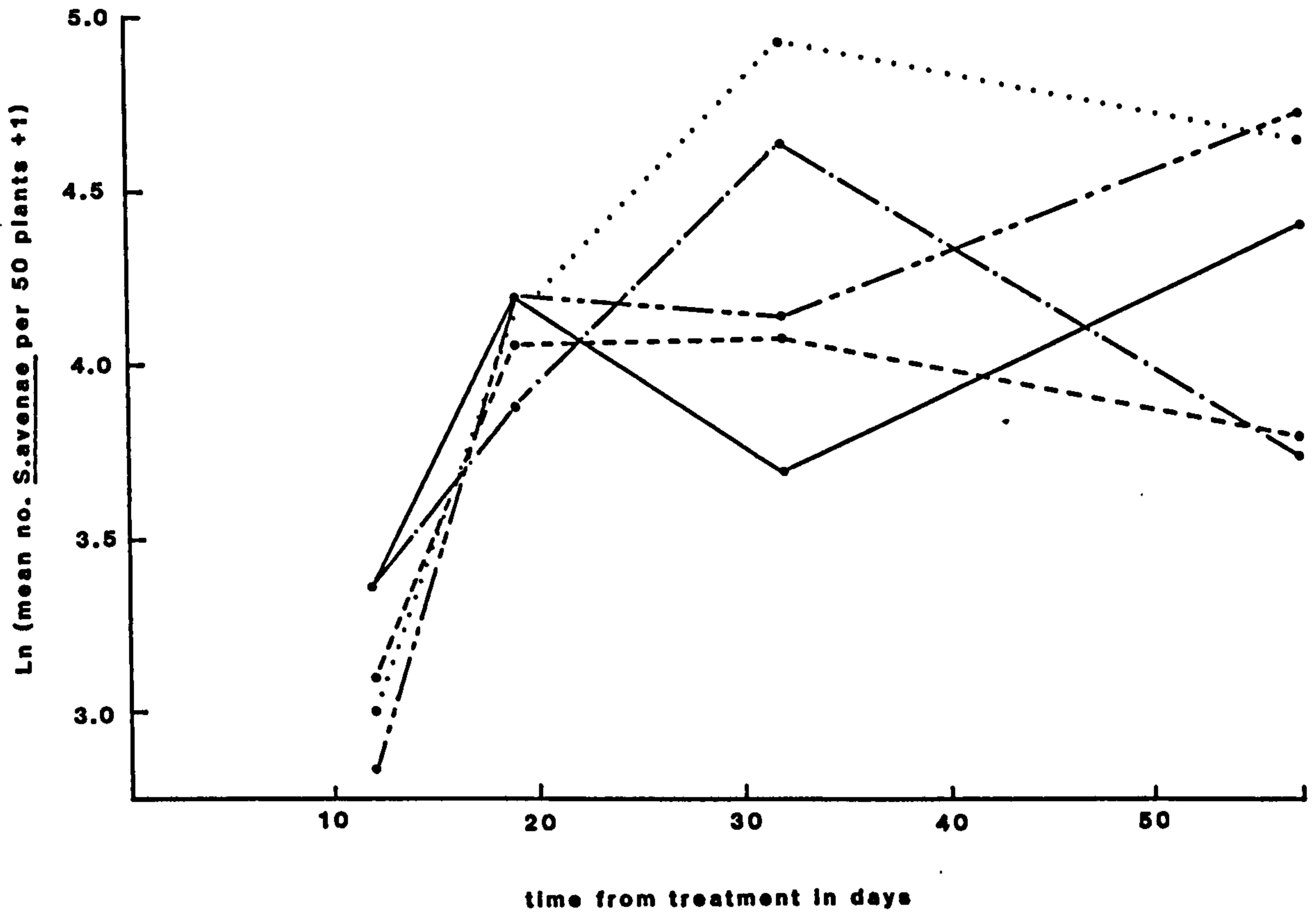


Fig.6.4 :Early Expt.

Visual Counts of M.dirrhodum after treatment to affect predators

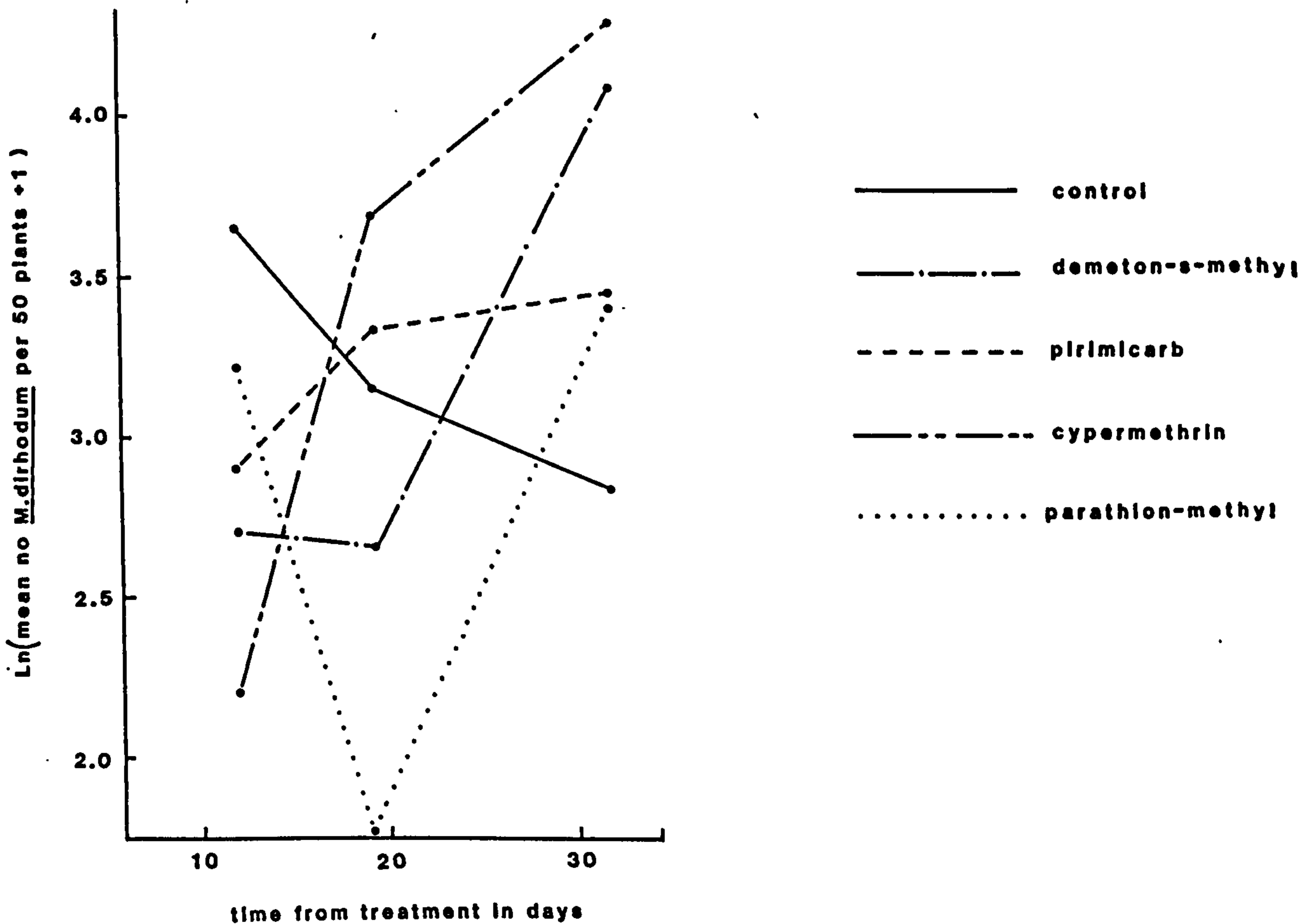


Fig. 6.5 Regression line of Total Polyphagous Predators per pitfall trap at +24 days (as the independent variable) against the daily rate of increase of *S.avenae* in D-Vac samples from +18 to +35 days (as the dependent variable) .

P= 0.022  
 C= 0.075  
 G= -0.0036

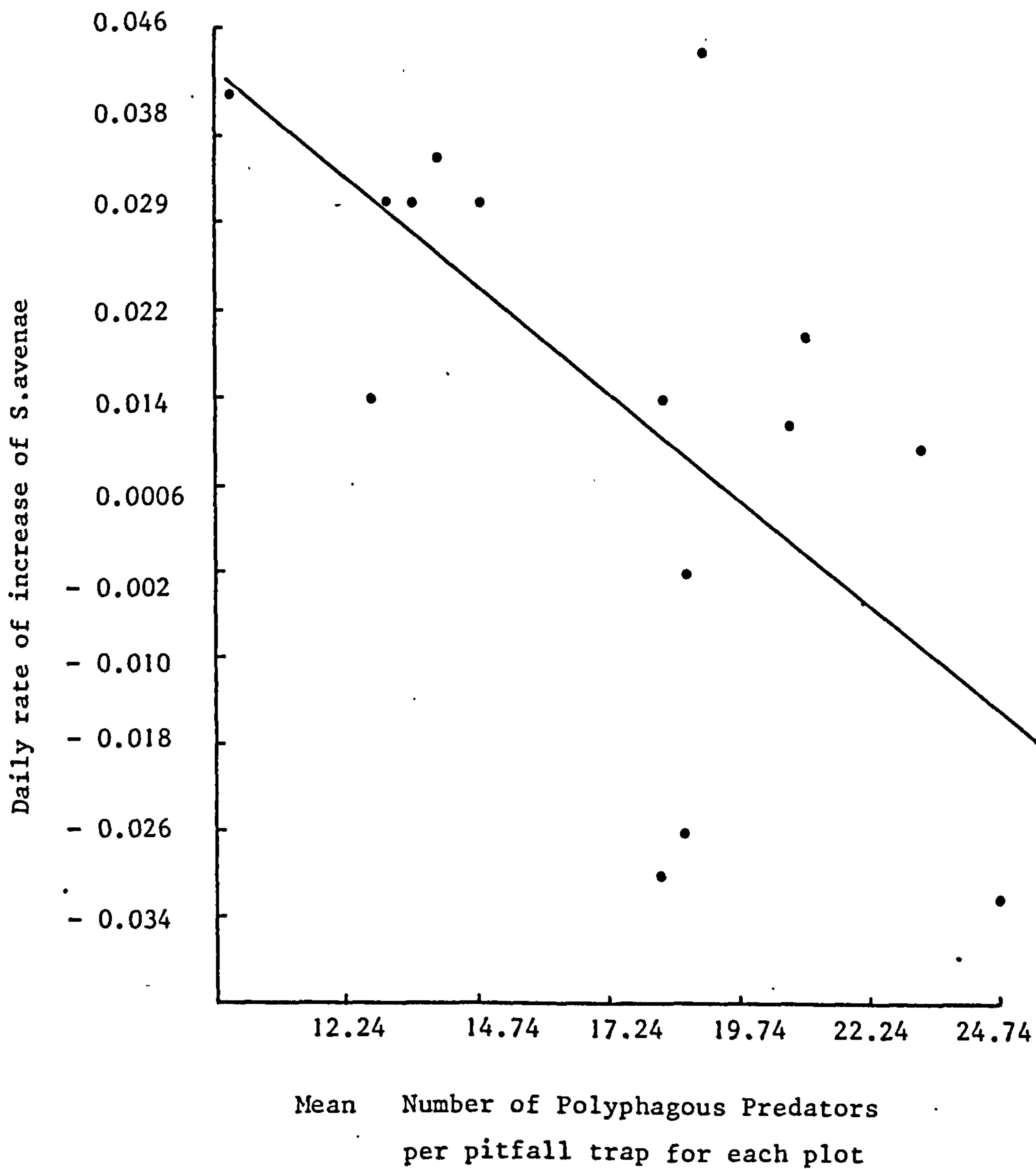




Fig.6.6 Plot of the number of Staphylinidae per pitfall for each plot at +24 days (as the independent variable) against the daily rate of increase of *S.avenae* in D-vac samples from +18 to +35 days . The regression analysis was not significant ( $P = 0.142$ )

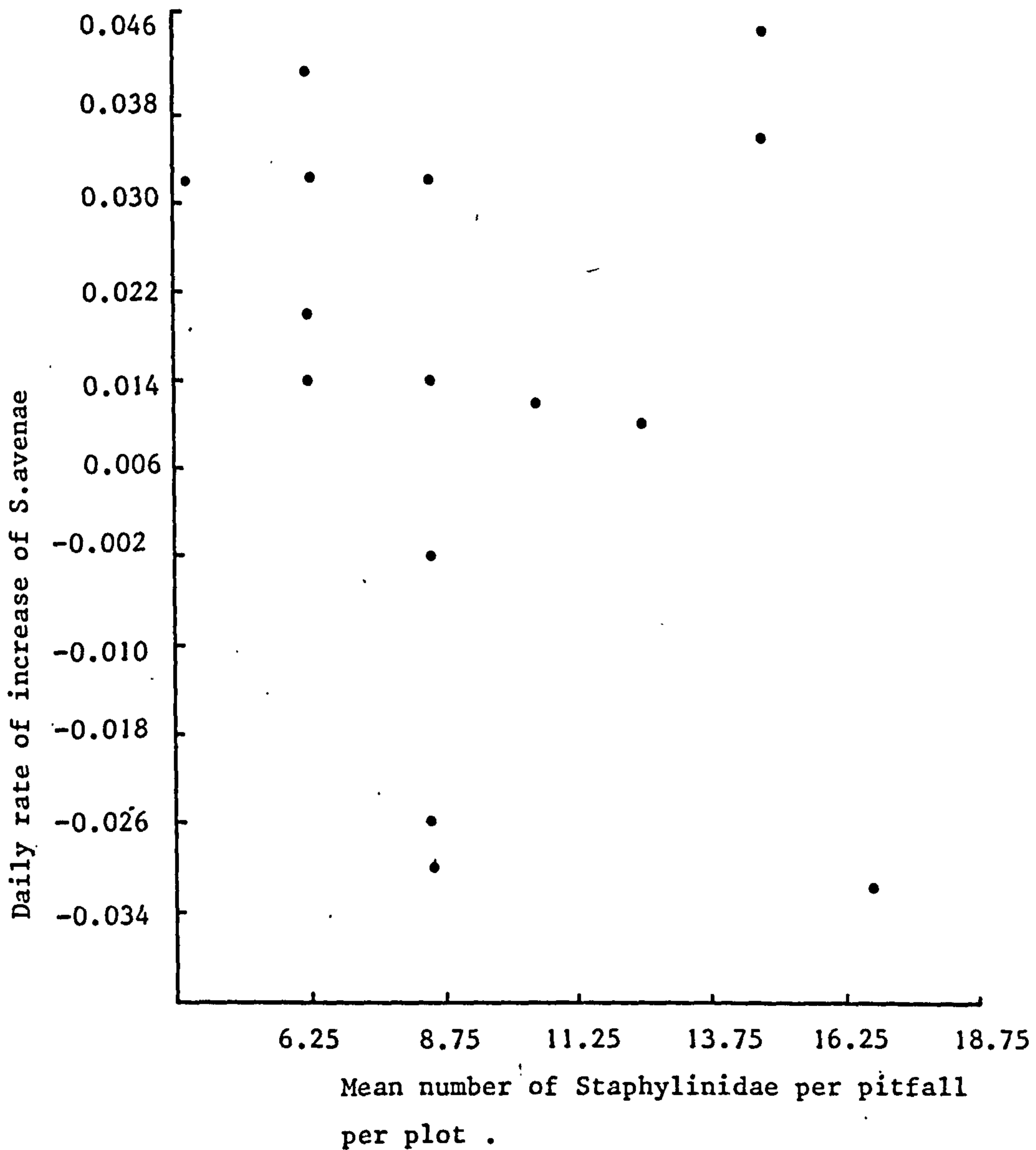


Fig. 6.7 Plot of Probability (P) against Gradient (G) (Table 6.1 )

for the regression line of the daily rate of increase of *S.avenae* observed by visual counting against predator numbers caught in pitfall traps. Negative gradients imply that aphid populations grew more slowly when predators were abundant and vice versa.

● total polyphagous predators

■ Carabidae

◆ Staphylinidae

▲ Linyphiidae

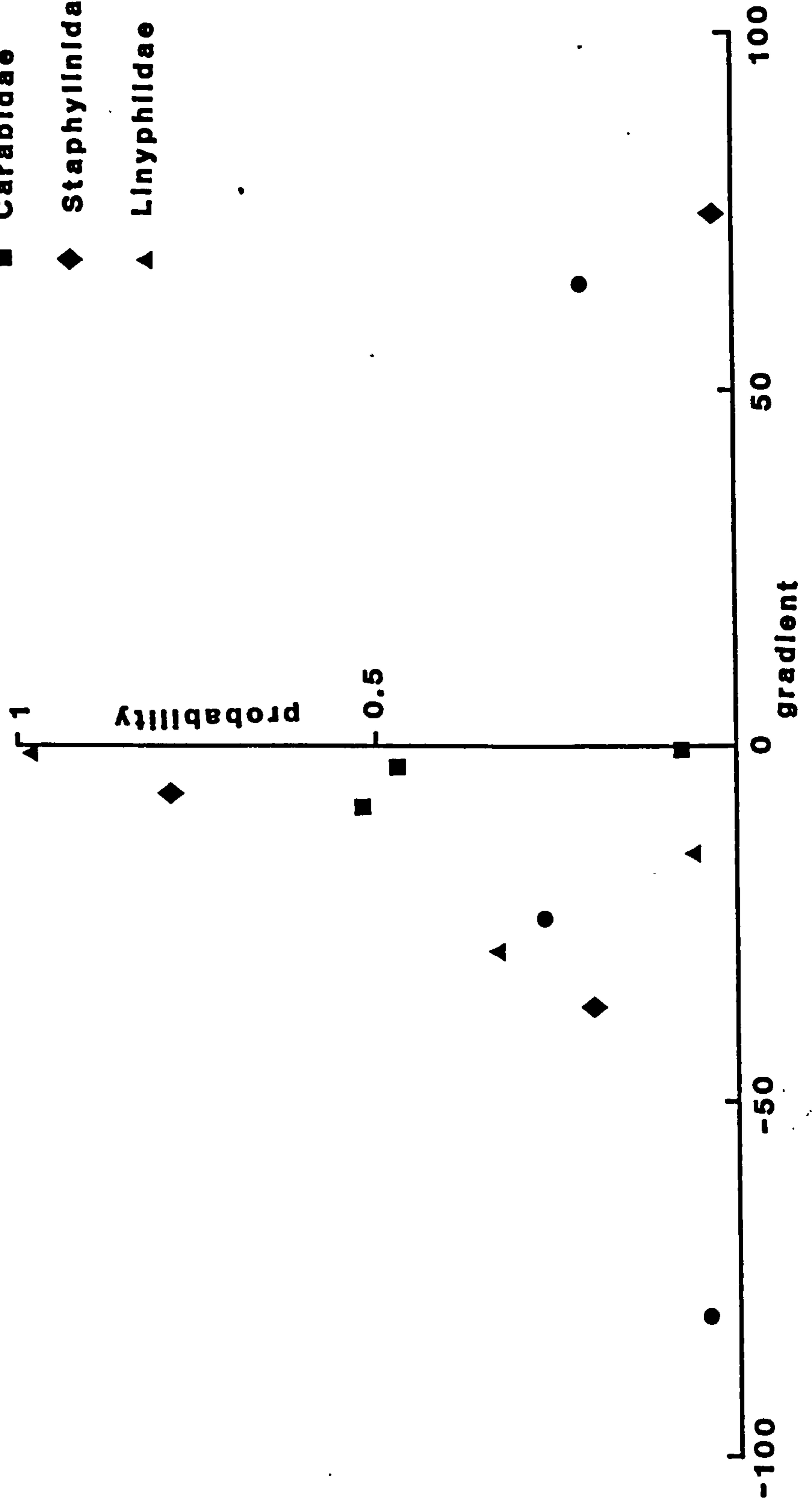


Fig. 6.8 Plot of probability (P) against Gradient (G) (Table 6.1 ) for the regression line of the daily rate of increase of Mdirhodum observed by visual counting against predator numbers caught in pitfall traps .

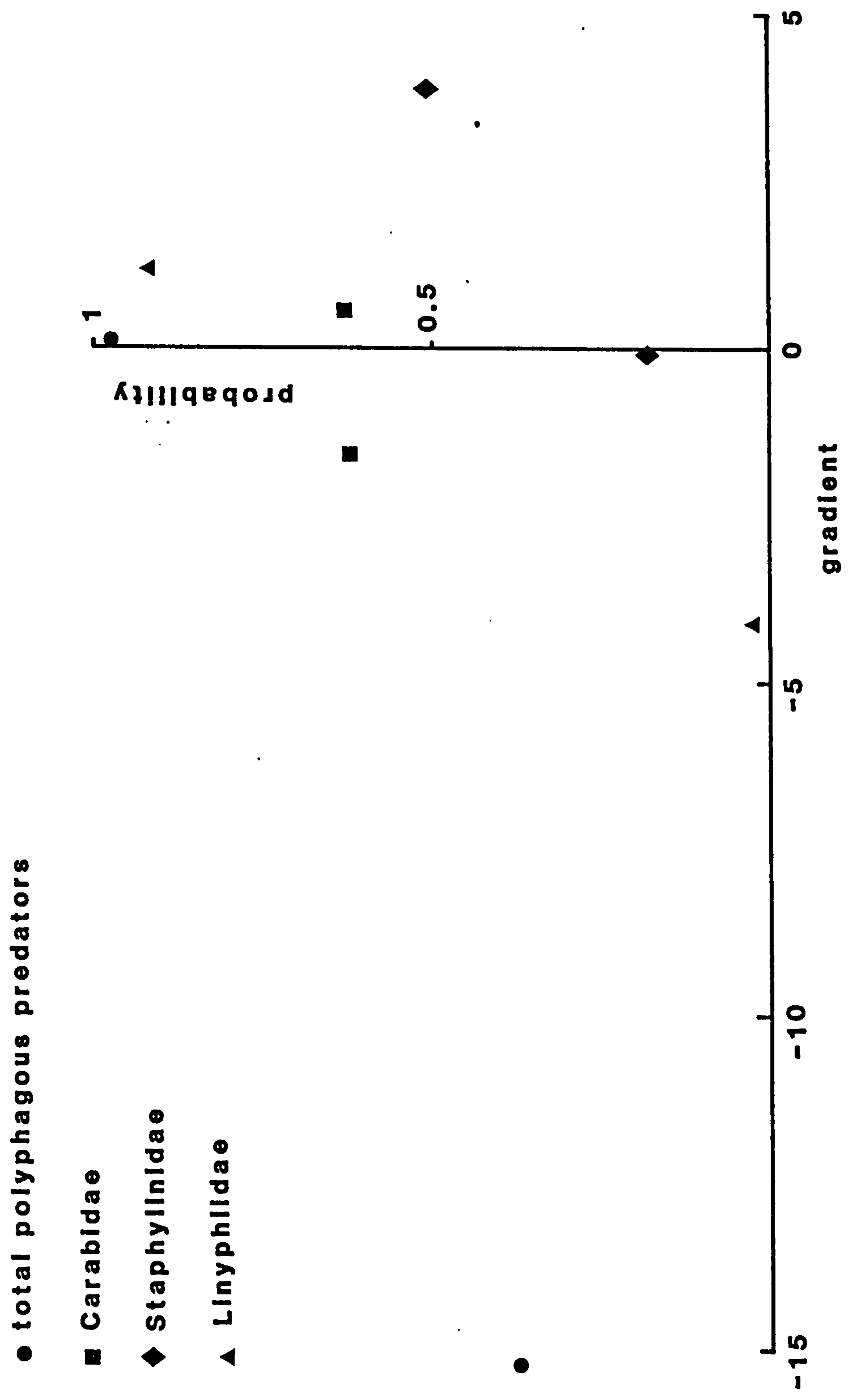


Fig. 6.9 Plot of probability (P) against gradient (G) (Table 6.1) for the regression

line of the daily rate of increase of *S. avenae* caught in D-Vac samples

against predator numbers caught in pitfall traps

● total polyphagous predators

■ Carabidae

◆ Staphylinidae

▲ Linyphiidae

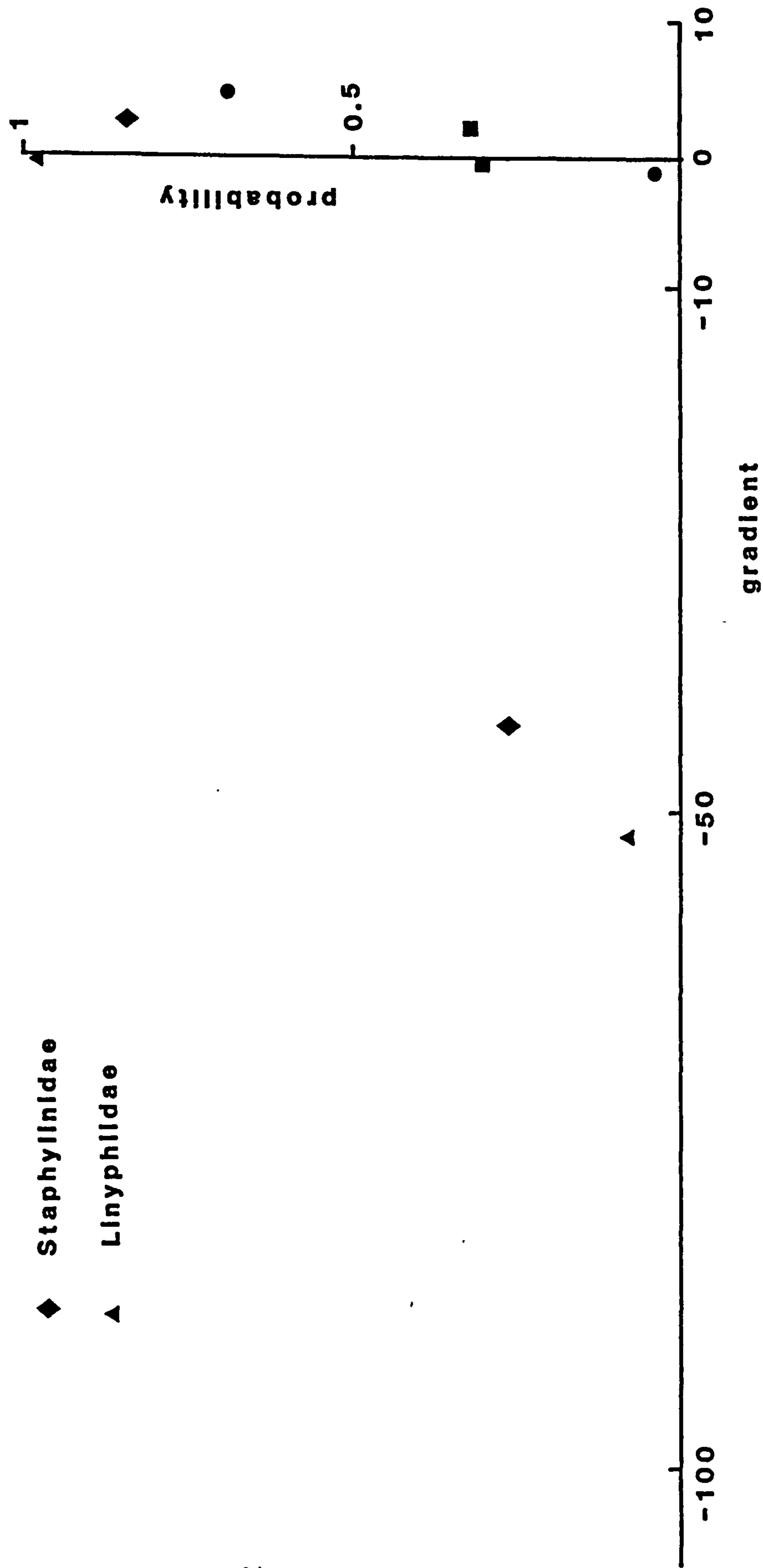


Fig. 6.10 Plot of probability (P) against gradient (C) (table 6.1) for the regression

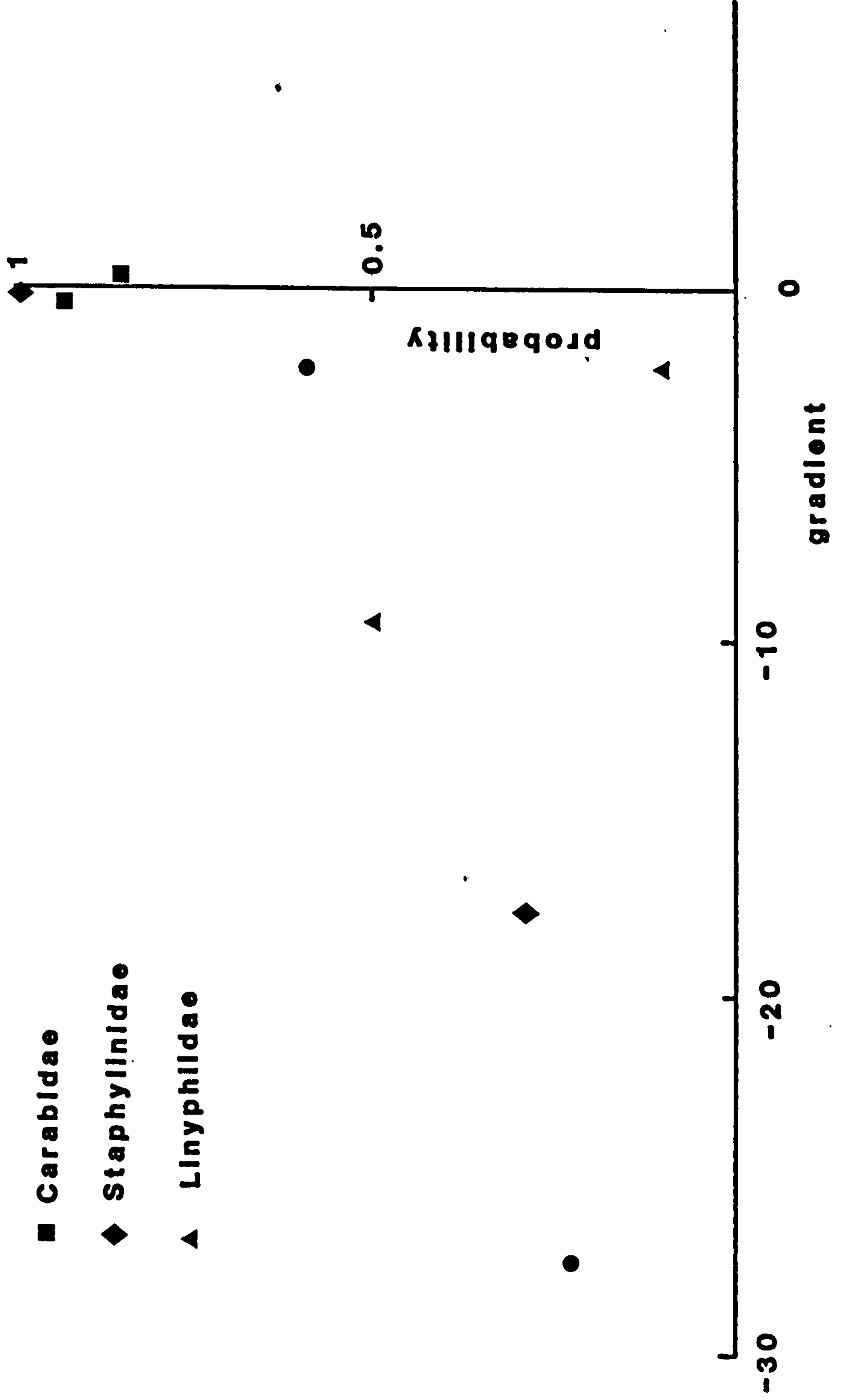
line of the daily rate of increase of *M.dirhodum* caught in D-Vac samples  
against predator numbers caught in pitfall traps

● total polyphagous predators

■ Carabidae

◆ Staphylinidae

▲ Linyphiidae



## CHAPTER 7

### CONCLUSIONS AND DISCUSSION

#### 7.1 Resumé

It is useful at this point to summarise the conclusions of the field and laboratory experiments as follows.

a) Laboratory studies have shown that cereal aphids and their predators differ in susceptibility to the insecticides pirimicarb, cypermethrin and parathion methyl. Field effects observed over two consecutive years were similar but not identical to those obtained in the laboratory. Field toxicity to predators was consistent in barriered plot experiments in both 1981 and 1982.

b) No one group of polyphagous predators consistently limited aphid population growth rates within barriered plots, but the combined effects of Carabidae, Staphylinidae and Linyphiidae significantly reduced the rate of increase of S. avenae populations over one experimental time period. Linyphiid spiders were apparently important in limiting outbreaks of M. dirhodum over another (earlier) time period. None of these predators could be shown to have consistent effects on aphid population growth rates over all time periods. The overall conclusion must be that polyphagous predators played an unpredictable minor role in limiting aphid population growth rates on the spatial and

temporal scale of these experiments.

c) Unfortunately no aphid specific predators occurred in detectable numbers in any of the field experiments despite the presence of aphids in 1982. Hence their role cannot be assessed.

## 7.2 Final Discussion

i) Selective insecticidal toxicity to different groups has been shown by others (Hamilton and Kieckhefer; 1962) but little is known of the mechanisms responsible for such efforts. Clearly differences in size and cuticle thickness are important. One would expect a large insect with a thick cuticle to be less susceptible than a smaller animal with a thin cuticle. However, mode of entry, and subsequent route to site of action are also thought to be important, although there is some dispute as to how the insecticide reaches its site of action. The most generally accepted view (Devonshire, 1973) is penetration through the cuticle into the haemolymph which transports the insecticide throughout the insect body. From the haemolymph the insecticide spreads to all tissues, including that containing the target site of action. At any stage within the insect body the insecticide may be accumulated in non sensitive tissue, excreted or detoxified. Differences in these factors may be responsible for selective toxicic effects. The other view, defended mainly by Gerolt (1972) is that the insecticide moves laterally in the integument and enters the target via the tracheal system. Welling (1977) says that the data suggested by Gerolt are not

sufficient to disprove the transport role of haemolymph. In the field selective toxic effects may be due to behavioural characteristics of the animal, which will determine the amount of insecticide taken up. Active animals, would encounter more insecticide residue than fairly static ones. Animals on the crop itself will be more likely to come into direct contact with spray particles and will receive a higher "dose" than those beneath the canopy.

ii) Sub-lethal effects of insecticides are not considered in this thesis. Exposure to non-lethal doses may impair hunting, increase dispersal or affect reproductive potential. Such effects have not been looked at but are possibly important.

iii) Simple laboratory toxicology can reveal selective toxicity to pests as well as pinpoint possible harmful effects to beneficial arthropods. Since laboratory results relate broadly to field effects, such studies could prove useful in evaluating the potential of a new compound. Many existing tests aimed at assessing toxicity to arthropods involve the use of costly equipment and elaborate technical procedures. Exposure to pesticide films on ground glass is a cheap and easily replicable method suitable for determining the impact of a compound on a wide range of arthropods. Because of its low cost, both in equipment and man hours, such a method could be incorporated at a fairly early stage in the development of a pesticide. Laboratory testing of a wide range of crop pests could help determine the market place for a new compound prior to investment in field trials.



It is clear from this study and others (Edwards et al., 1979; Sunderland et al., 1980) that enhancement of predator populations can sometimes be of benefit to the grower in reducing the size of an aphid outbreak. However, the present results suggest that the benefit is at best an unpredictable one in fields with a reasonable compliment of predators. What would happen if virtually all polyphagous predators were eliminated is not known. It could therefore be argued that despite my equivocal results use of pesticides to minimise predator mortality is still important. Preservation of hedgerows (Speight 1976) and tolerance of certain weeds (Potts and Vickerman, 1974; Speight and Lawton, 1976) will also enhance predator populations and possibly provide benefit from one year to the next. Incidentally, little is known of fluctuations in arthropod populations between years as a result of agricultural practice. Short term experiments on a small spatial scale, like those reported here, tell us nothing about long term large scale effects.

One suggestion for further work that emerges from this study is therefore the need for large scale (over hundreds of acres) long term field experiments designed to reveal whether there are sustained benefits from healthy field populations of polyphagous predators. One set of treatments might aim to enhance predator efficiency, tolerating certain weed species, the second maintaining a clean crop by using herbicides and insecticides. Such an experiment could only be carried out practically by the Ministry of Agriculture, Fisheries and Food working with the cooperation of a number of farmers. Detailed

costing of each management policy might then show predator enhancement to be financially viable. The sheer scale of this experiment makes it unlikely that it will ever be attempted. The practicability of such large-scale field experiments aside, having spent considerable time and effort on some relatively small scale field experiments involving cereal aphids, just how important are these supposed pests in the U.K.? What is the "economic threshold" for cereal aphids? George and Gair (1979), after 49 experiments over 4 years showed that one spray of pirimicarb applied at the beginning of flowering when there were five or more aphids per ear, and their numbers were rising, gave an increase in grain yield of 12.5%. Indeed, 5 aphids per ear has generally been considered as the economic threshold for aphicide application and has been used extensively by ADAS entomologists. Clearly a numerical guideline such as this helps the grower and also prevents unnecessary spraying. Surprisingly, one major omission from the work of George and Gair (1979) is whether or not Barley Yellow Dwarf Virus is present in the field. Is the threshold of 5 aphids per ear aimed only at controlling direct aphid damage to the plant? Given the nature of plant virus transmission one would expect so, and that if B.Y.D.V. was present the economic threshold would be considerably lower. Recent work (Ajayi and Dewar, 1983) has shown that alate aphids are visually attracted to the different colour of viriliferous plants. In view of this information farmers might well be advised to spray all or part of any field on detection of B.Y.D.V.

The question then is, how often do cereal aphids reach five /plant (or lower potential damaging numbers with B.Y.D.V.)? In fact not often. So highly sophisticated management with regard to cereal aphids may not be necessary. However, spraying is sometimes necessary. What the present study suggests is that spraying that kills polyphagous predators may sometimes exacerbate the problem. Hence it is probably sensible to avoid killing polyphagous predators where possible. Fortunately, one insecticide, pirimicarb, is a selective aphicide, having little or no effect on predators both in the laboratory and in the field. In 1976, which saw an unexpectedly high level of cereal aphid attack, pirimicarb was used on approximately 1 million acres of crops in the U.K. alone (Snell et al., 1978). Excessive use of pirimicarb in cereals is likely to bring about the development of resistance in cereal aphid populations, as has occurred with a number of organophosphate compounds. It would therefore be wise to consider the use of other pesticides, particularly at times when predators are less vulnerable. Both cypermethrin and demeton-s-methyl have been shown to be effective against aphid vectors of B.Y.D.V. as a single application in October or November. Later sprays with these compounds in December and March were less effective (Kendall et al., 1983). If use of a number of chemicals on different stages in the life history of a pest is adopted in order to reduce the selection pressure and avoid resistance, then it is essential that the alternative chemical selects for a different resistance mechanism. As Graham-Bryce (1983) makes clear, this cannot be assumed from differences in chemical class or mode of action.

Cereal aphids are r-strategy pests, having high potential rates of increase, strong dispersal and host finding ability and being small relative to other members of the same taxa. Conway (1976) considers that pesticides are likely to remain the main counter to r-pests being the only technique which has the speed and flexibility to respond to outbreaks. It is likely, then that pesticides will play a large part in the development of any integrated control strategy for cereals. With resistance to aphicides reported on a number of crops, chrysanthemums (Wyatt, 1966), sugar beet (Devonshire and Needham, 1975) and hops (Muir, 1979) it is important that all parties involved in crop protection consider integrated control as a means of extending the life of currently effective pesticides. Geissbühler (1981) describes problems encountered in defining integrated pest control since the term means different things to different people, who, in turn, are pursuing differing objectives. The definition chosen by the F.A.O. (1967) is as follows :

"Integrated Pest Control is a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury."

An important point, also made by Geissbühler (1981) is that "A number of national and international policy statements demonstrate that the agrochemical industry endorses the principles

of integrated pest management and supports their application and further extension in practice".

Successful integrated control in cereals could be brought about initially by predator enhancement (or at least by practices that do not markedly reduce predator numbers) and use of existing selective aphicides such as pirimicarb. The pursuit of what Graham-Bryce (1983) terms "Novel" chemical approaches to crop protection (such as use of pheromones, synergism, and new targets for toxic action) can only increase the effectiveness of any crop protection program in the future. More knowledge of toxicant action in beneficial and harmful species should make it possible to design compounds which maximise these differences and act selectively. For example (Graham-Bryce, 1975) it may be possible to determine optimum polarity for toxicity to different species.

It is important that integrated control in cereals in Britain is adopted prior to the failure of currently effective pesticides due to resistance, and not as a result of it. It is clear from this study that some polyphagous predators have a role to play in aphid control programmes, at least for some of the time. Surely the next step is for the design of trial programmes for integrated control in cereals?

The present study is the first to examine the selective toxicity of a range of insecticides on a number of polyphagous predators and their prey, the latter being considered a group of economically important cereal pests. As such it forms one

small part of the total picture that would need to be assembled in devising an integrated control program in cereals. On balance, it suggests that it will not be vital to conserve polyphagous predators at all costs. Other groups of natural enemies may be much more important. Furthermore, we have no idea what effect drastically reducing polyphagous predator numbers over large areas for long periods might have. Common sense suggests that more research on the effect of pesticides in cereal ecosystems would be highly beneficial in the long term.

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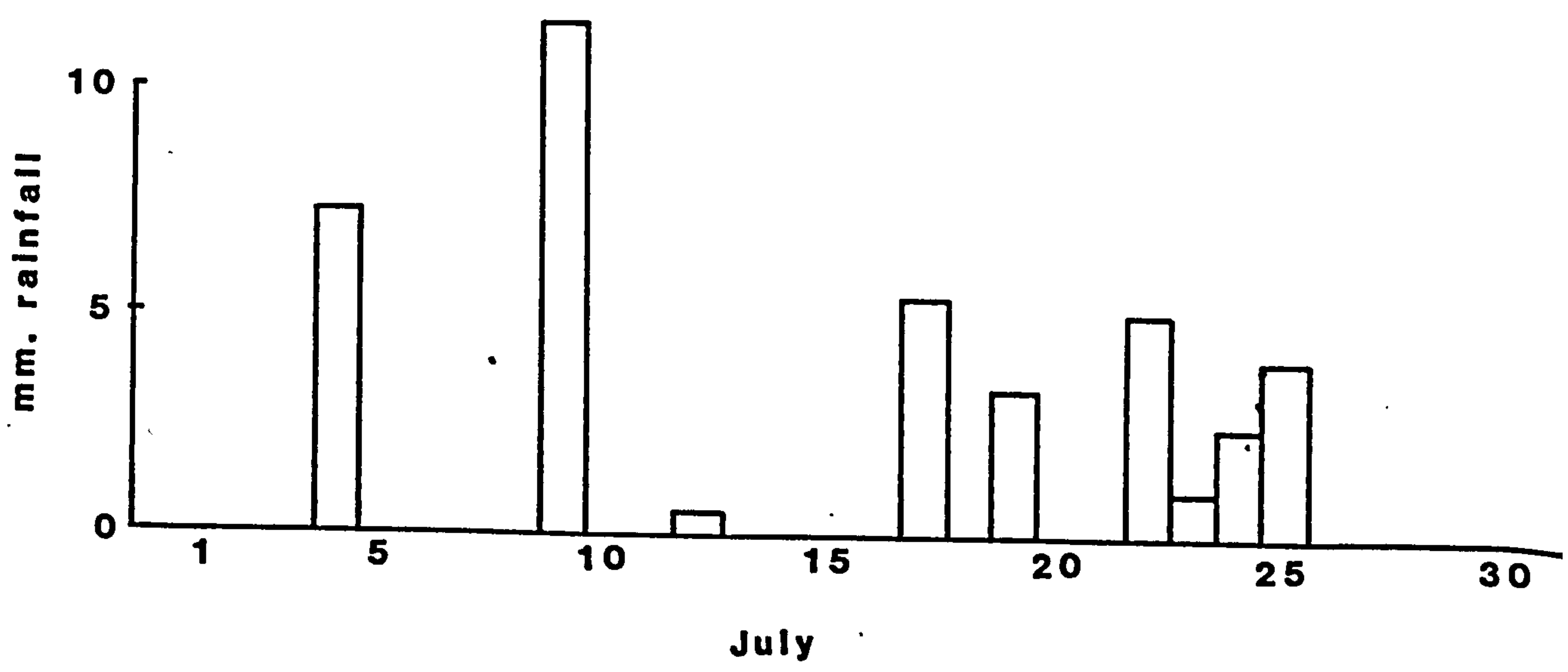
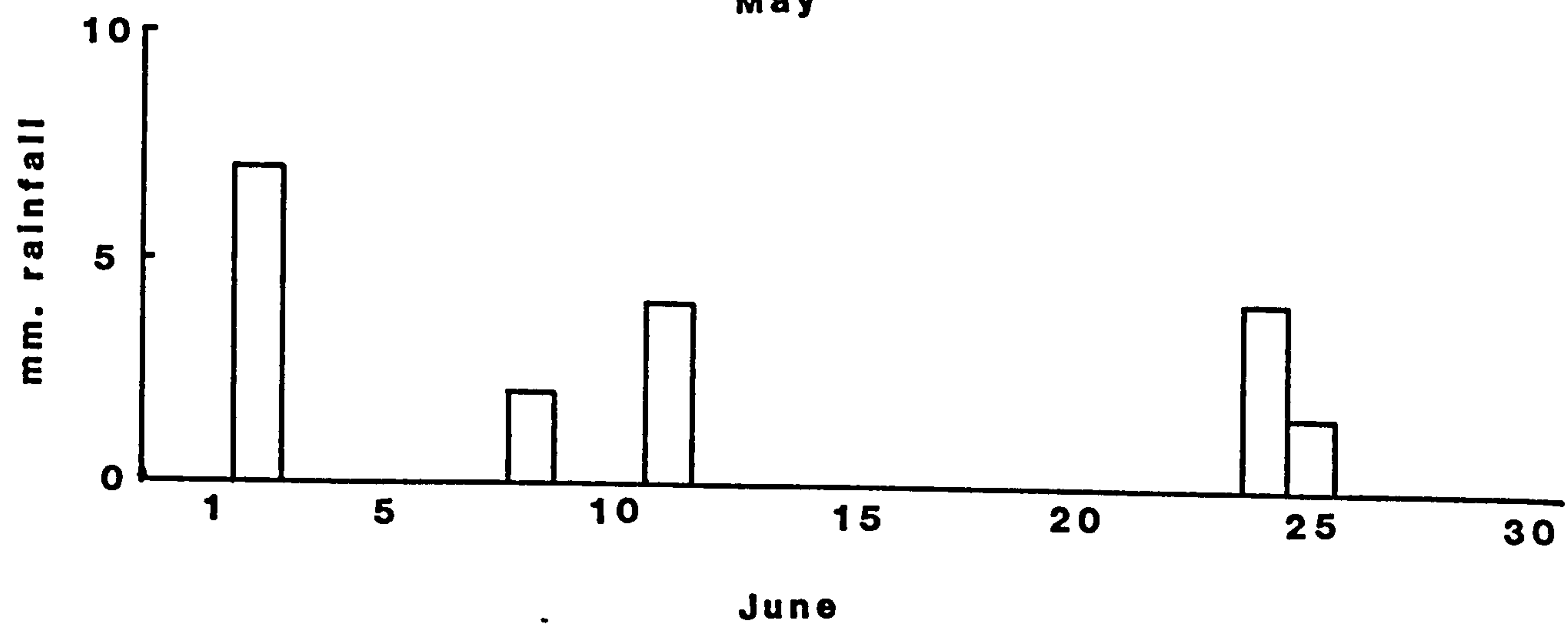
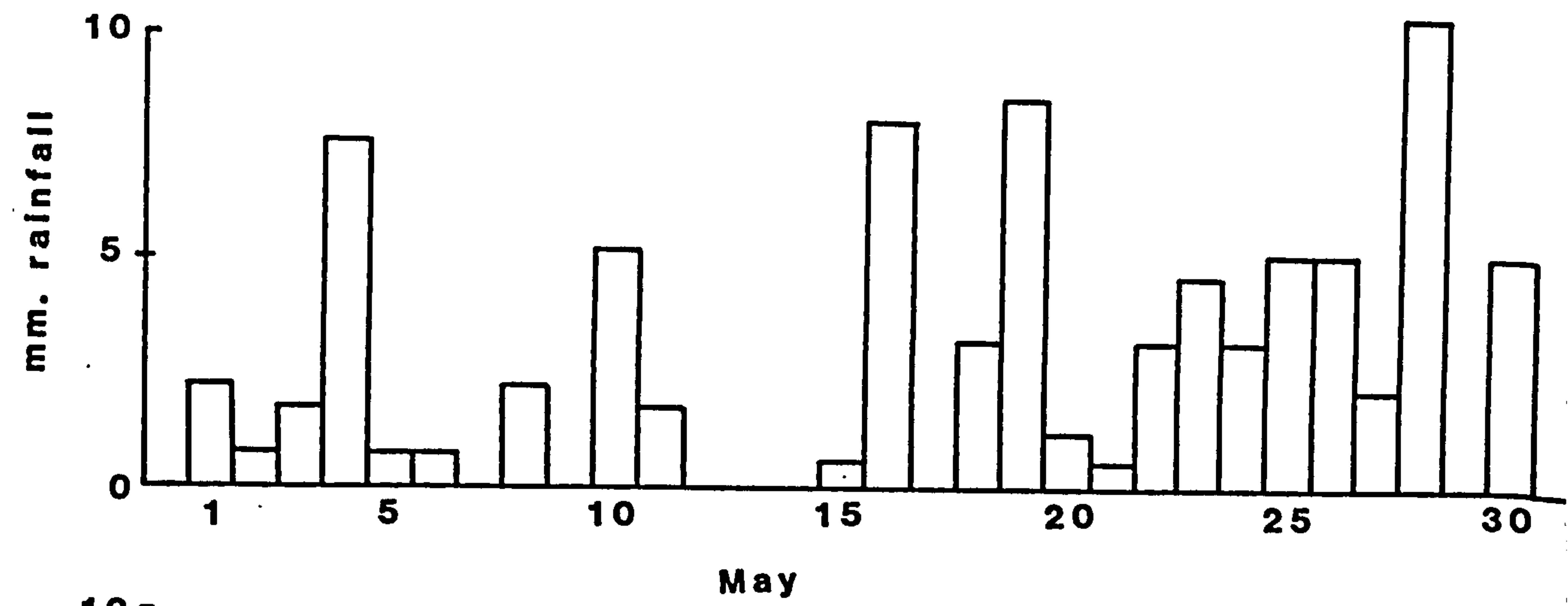
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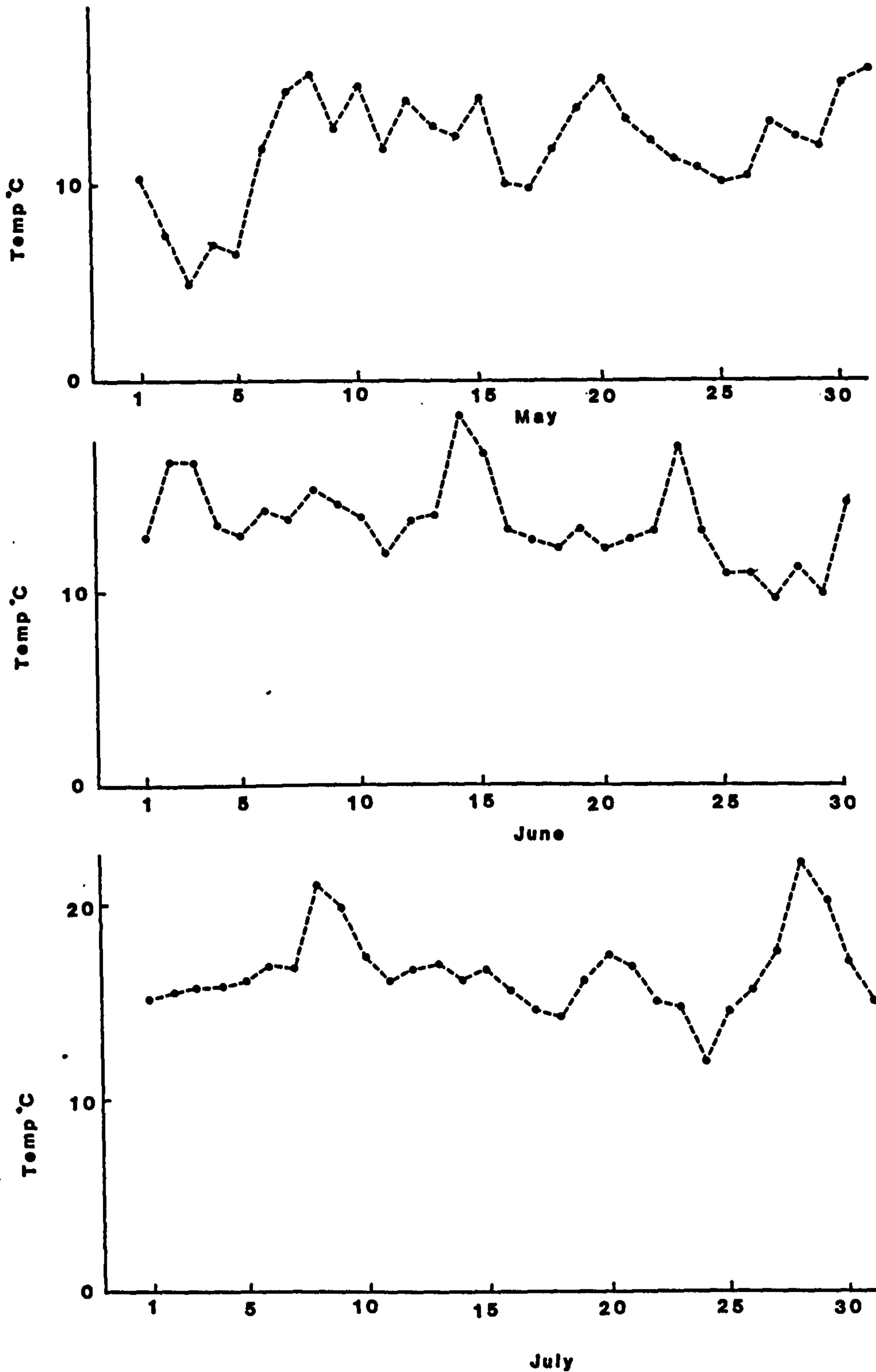
# Appendix 1 : 1981 Sittingbourne Climatic Data

## (a) Daily Rainfall



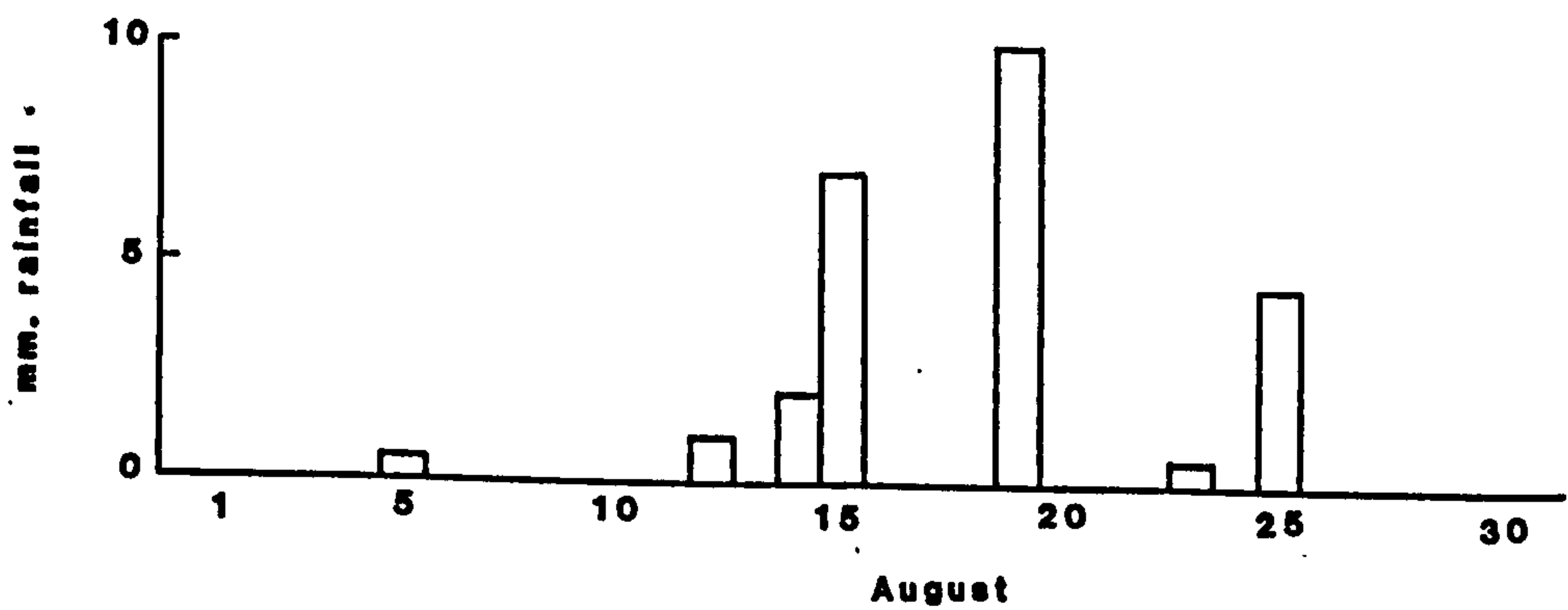
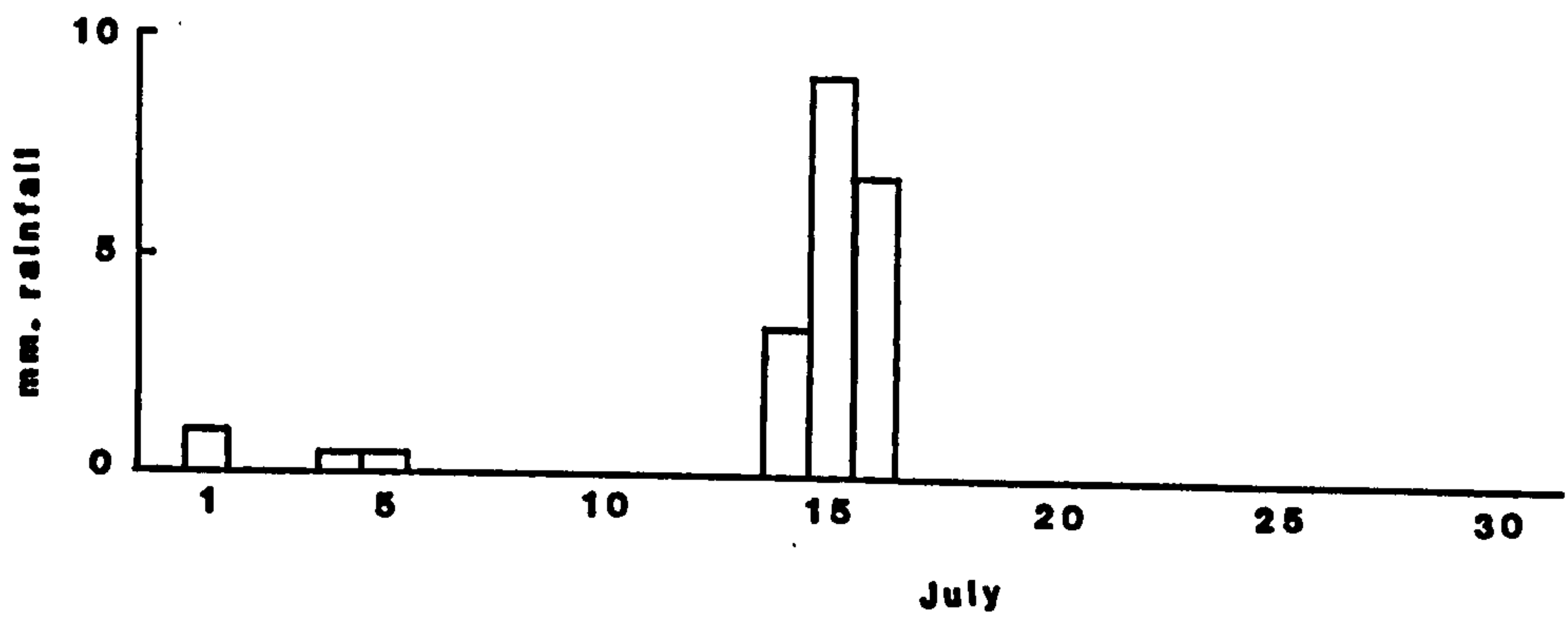
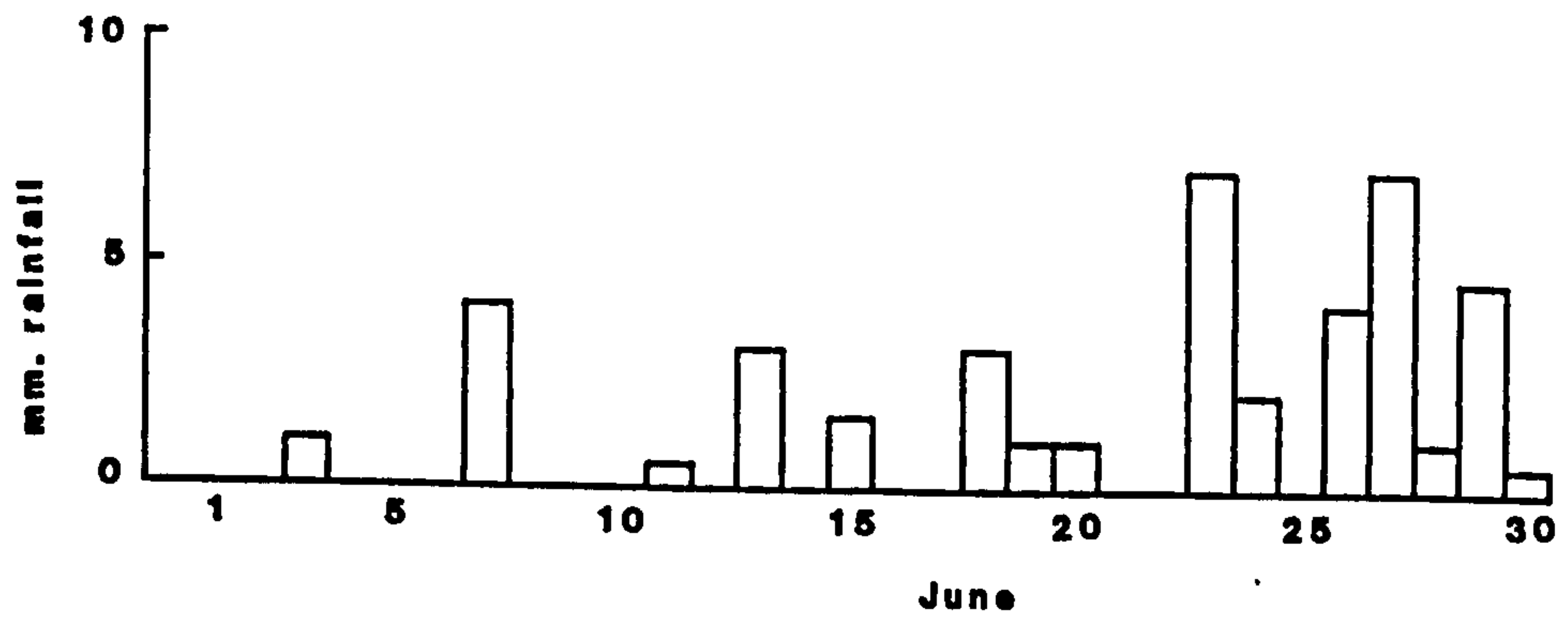
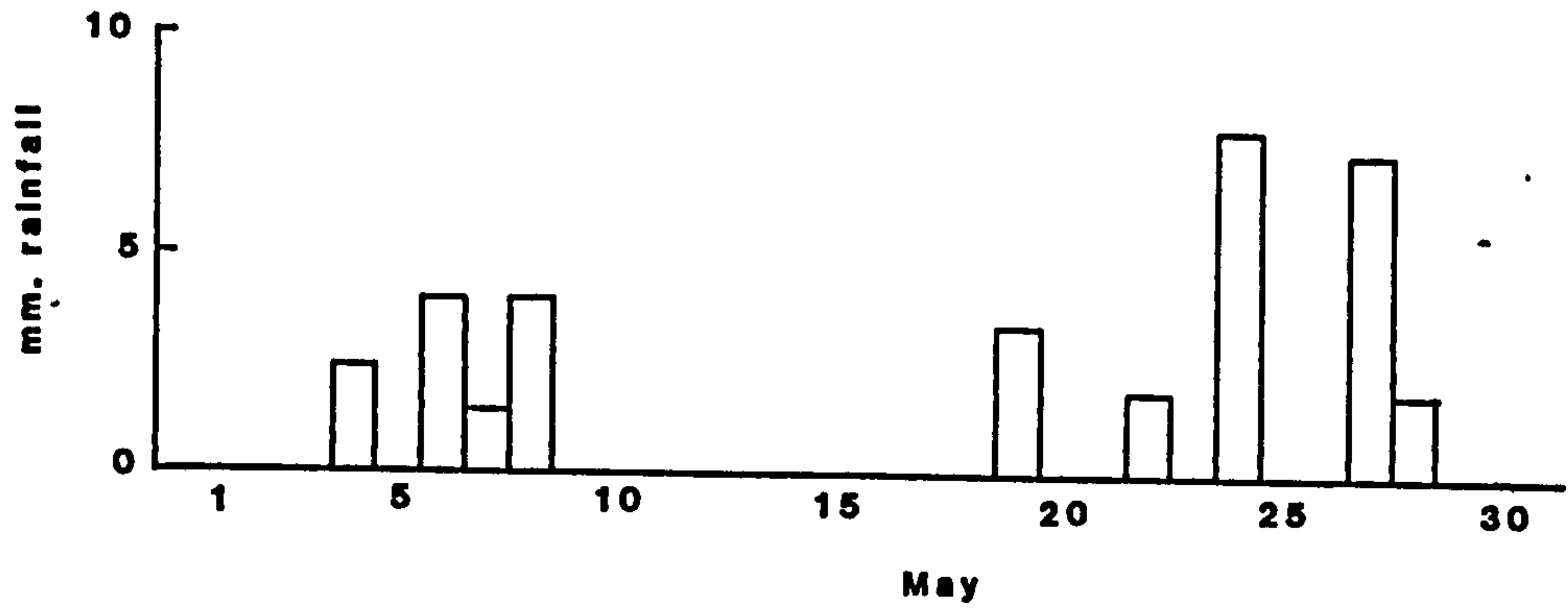
(b) Daily Temperature at crop height

(taken at 10.00 hrs )

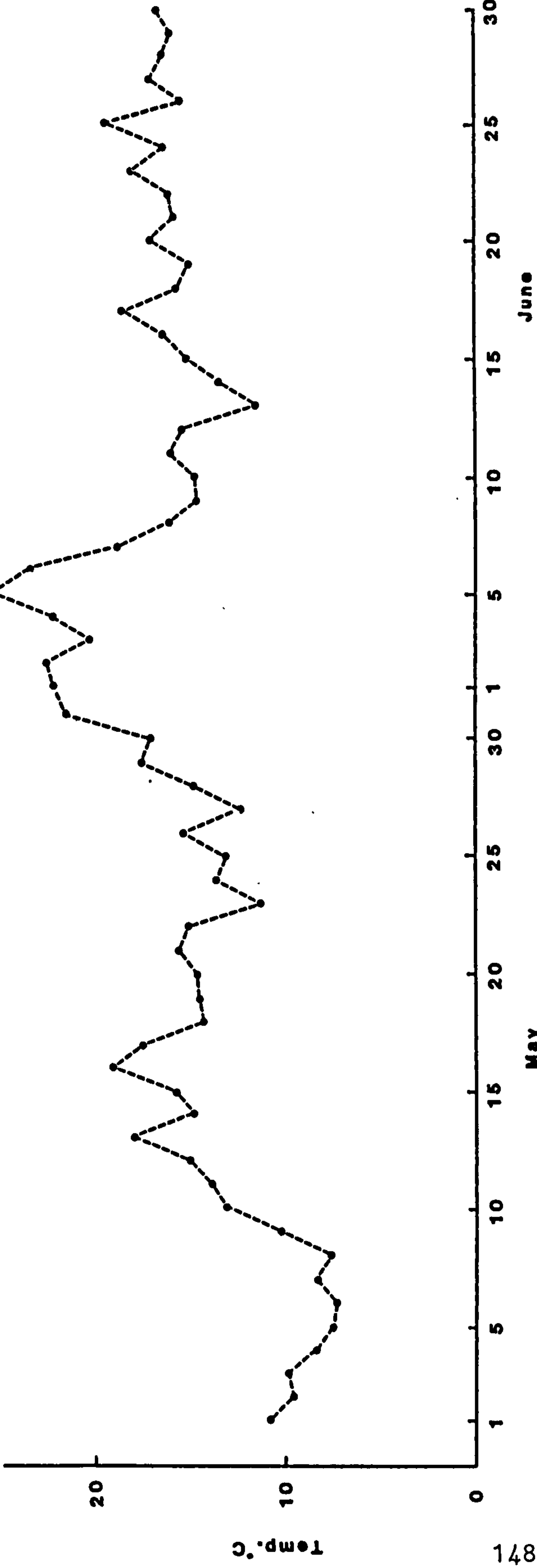


Appendix 2 : 1982 Sittingbourne Climatic Data

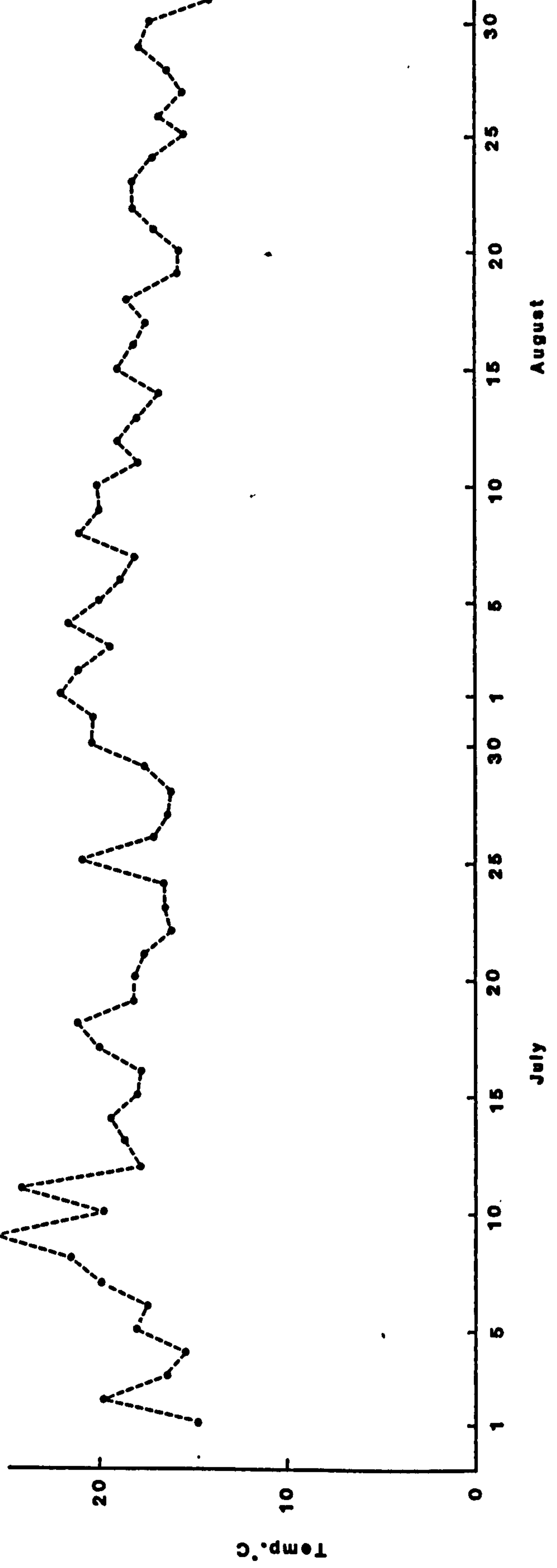
(a) Dally Rainfall



(b) Daily Temperature at crop height



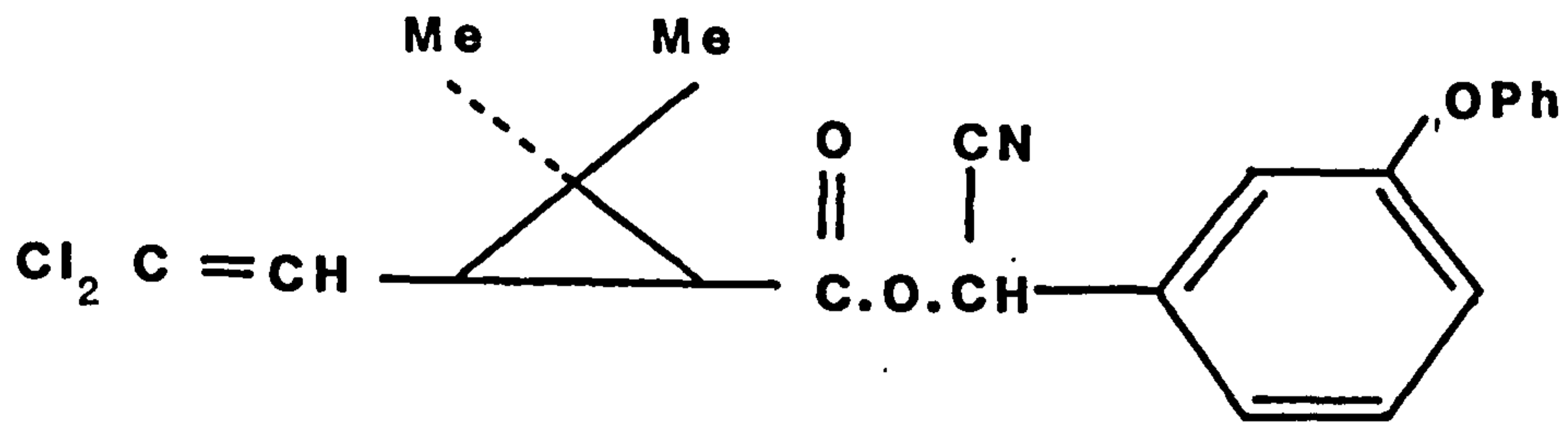
841



Temp. °C

# Appendix 3 :Structure of pesticides used in this study

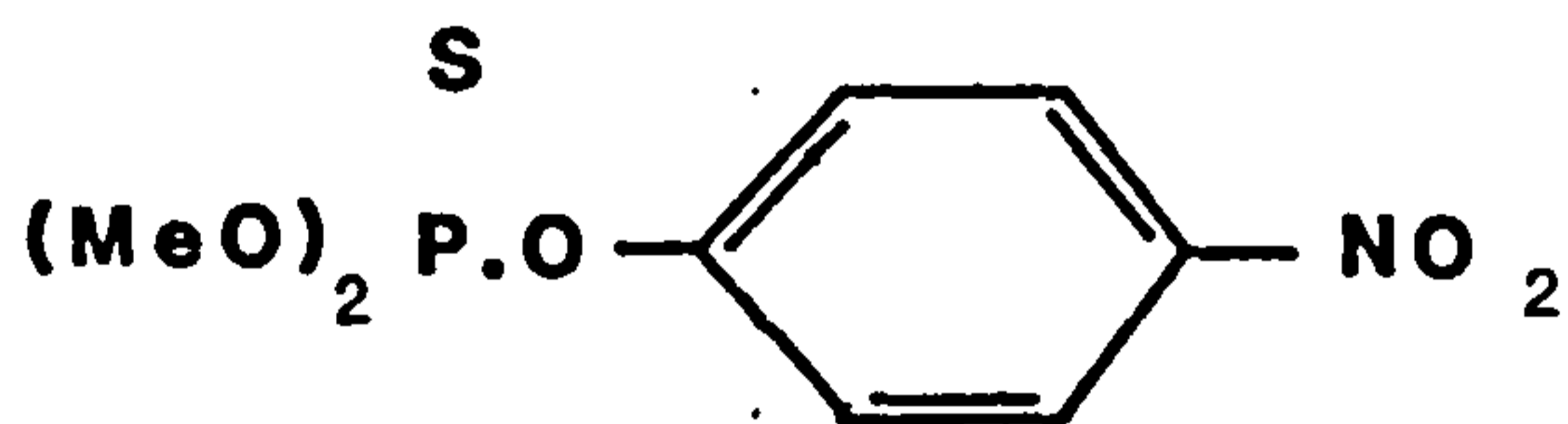
## Cypermethrin



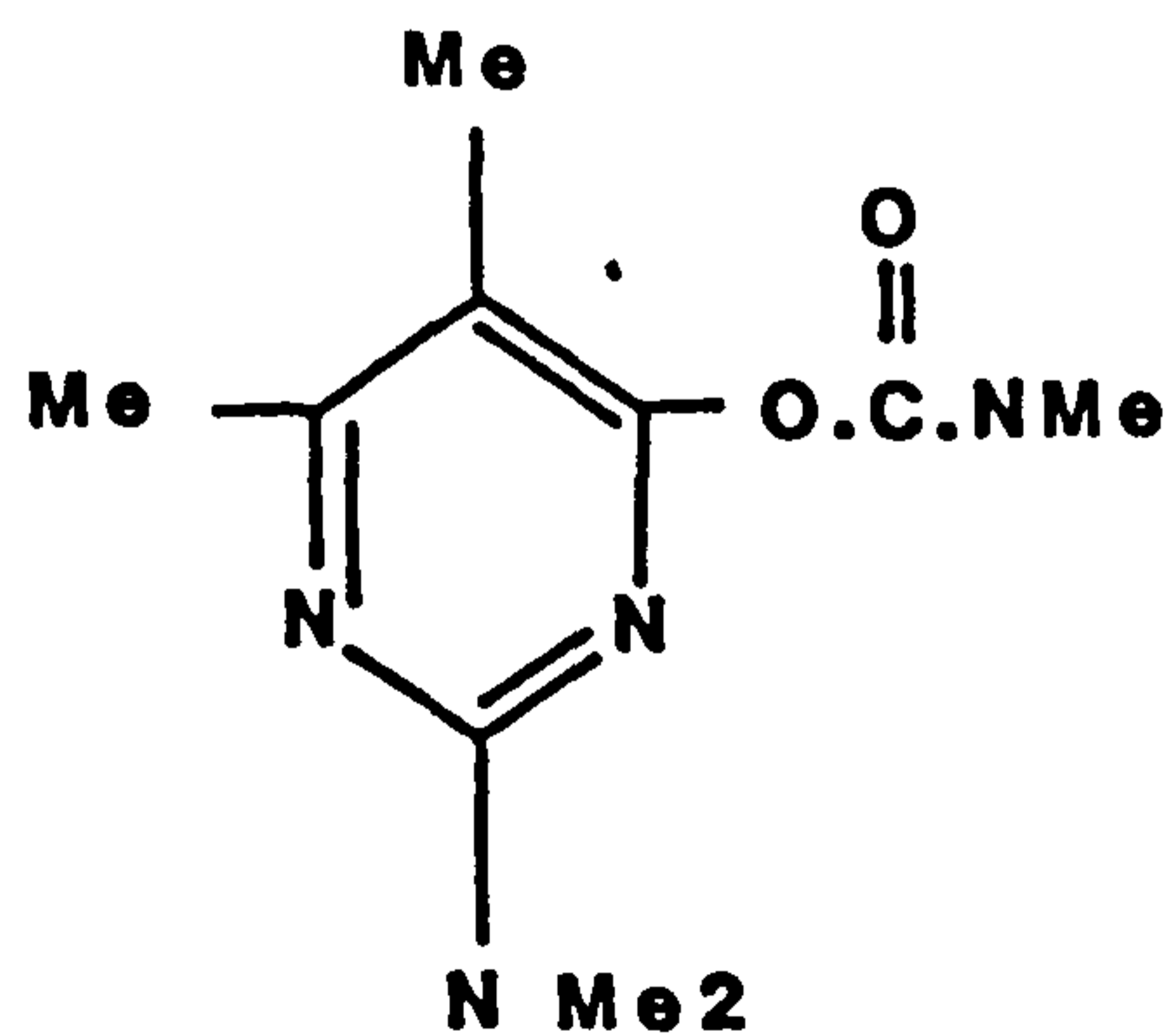
## Demeton-s-methyl



## Parathion-methyl



## Pirimicarb



Appendix 4: Sittingbourne 1982 Early Experiment Data

a) Mean number of *Carabidae* per pitfall trap sample (95% confidence limits)

$\frac{\text{days post treatment}}{\text{treatment}}$	-8	-6	3	5	8	12	17	24	33
control	2.22 $\pm$ 1.37	1.56 $\pm$ 1.50	1.00 $\pm$ 0.94	2.22 $\pm$ 2.10	1.33 $\pm$ 0.94	2.11 $\pm$ 1.24	1.00 $\pm$ 0.54	2.22 $\pm$ 1.57	0.78 $\pm$ 0.64
parathion methyl	2.00 $\pm$ 0.54	3.22 $\pm$ 2.16	0.11 $\pm$ 0.26	0.22 $\pm$ 0.34	0.22 $\pm$ 0.34	0.22 $\pm$ 0.34	0.78 $\pm$ 0.34	1.11 $\pm$ 0.90	1.89 $\pm$ 0.90
pirimicarb	1.22 $\pm$ 0.07	1.00 $\pm$ 1.15	0.56 $\pm$ 0.78	1.67 $\pm$ 0.94	1.22 $\pm$ 0.92	1.33 $\pm$ 0.86	1.44 $\pm$ 0.77	2.22 $\pm$ 1.07	2.33 $\pm$ 0.01
demeton-s-methyl	1.89 $\pm$ 1.30	1.33 $\pm$ 0.91	1.00 $\pm$ 0.77	1.44 $\pm$ 1.09	1.22 $\pm$ 0.51	1.00 $\pm$ 1.33	1.89 $\pm$ 1.51	1.89 $\pm$ 0.82	2.11 $\pm$ 0.90
cypermethrin	2.89 $\pm$ 2.35	1.89 $\pm$ 0.90	0.44 $\pm$ 0.56	0.89 $\pm$ 0.70	1.22 $\pm$ 1.00	0.89 $\pm$ 0.60	0.78 $\pm$ 0.59	0.67 $\pm$ 0.63	1.44 $\pm$ 0.40

Sample size is 9 on each occasion

b) Mean number of *Staphylinidae* per pitfall trap sample (95% confidence limits)

$\frac{\text{days post treatment}}{\text{treatment}}$	-8	-6	3	5	8	12	17	24	33
control	2.17 $\pm$ 0.88	4.12 $\pm$ 1.62	3.61 $\pm$ 0.94	5.16 $\pm$ 2.16	2.60 $\pm$ 1.12	6.51 $\pm$ 2.59	4.24 $\pm$ 2.45	10.87 $\pm$ 5.80	5.61 $\pm$ 2.50
parathion methyl	2.12 $\pm$ 1.42	3.48 $\pm$ 1.02	0.74 $\pm$ 0.07	0.79 $\pm$ 0.66	0.40 $\pm$	0.54 $\pm$ 0.53	4.87 $\pm$ 1.55	5.09 $\pm$ 2.48	2.48 $\pm$ 1.92
pirimicarb	1.30 $\pm$ 0.94	2.72 $\pm$ 1.68	1.35 $\pm$ 0.99	4.34 $\pm$ 1.87	2.87 $\pm$ 1.33	3.26 $\pm$ 1.85	4.81 $\pm$ 1.72	8.50 $\pm$ 3.44	3.51 $\pm$ 0.71
demeton-s-methyl	1.76 $\pm$ 0.76	2.58 $\pm$ 1.02	3.61 $\pm$ 1.74	5.25 $\pm$ 2.56	4.27 $\pm$ 2.10	5.82 $\pm$ 2.25	6.81 $\pm$ 4.13	7.81 $\pm$ 3.76	2.42 $\pm$ 1.43
cypermethrin	1.54 $\pm$ 0.78	1.12 $\pm$ 0.74	0.89 $\pm$ 0.76	4.49 $\pm$ 1.92	1.97 $\pm$ 1.10	4.77 $\pm$ 2.18	7.27 $\pm$ 2.94	10.55 $\pm$ 1.68	4.93 $\pm$ 2.60

c) Mean number of *Linyphiidae* per pitfall trap sample ( 95% confidence limits)

<del>day</del> treatment	-8	-6	3	5	8	12	17	24	33
control	1.81 ±1.01	4.36 ±1.26	3.15 ±1.47	6.72 ±1.23	2.76 ±1.37	6.32 ±2.43	2.47 ±0.80	7.27 ±2.04	6.34 ±1.93
parathion methyl	3.94 ±1.18	4.33 ±0.91	1.75 ±1.08	3.01 ±1.15	1.83 ±1.13	3.11 ±1.12	1.81 ±0.83	6.64 ±1.65	5.76 ±1.79
pirimicalb	3.05 ±1.25	5.12 ±1.40	2.51 ±1.49	2.92 ±1.66	4.03 ±1.60	3.70 ±0.86	1.48 ±1.04	9.01 ±2.07	7.54 ±2.04
demeton-s- methyl	3.01 ±1.51	3.74 ±1.34	0.71 ±0.61	2.03 ±0.98	1.92 ±0.94	3.56 ±1.04	1.76 ±0.94	5.22 ±2.44	6.81 ±2.14
cypermethrin	5.03 ±1.78	3.12 ±1.68	0.71 ±0.51	1.22 ±0.71	0.69 ±0.56	2.00 ±0.63	0.17 ±1.09	1.24 ±0.78	3.10 ±1.47

Appendix 5: Sittingbourne 1982 Early experiment, Aphid data.

a) Mean number of *S.avenae* and *M.dirhodum* per 50 plants by visual counting  
( with 95% confidence limits )

<i>S.avenae</i>	+12	+19	+32
visual count			
control	27.67 ±0.22	64.66 ±32.69	39.08 ±11.21
parathion methyl	19.00 ±4.50	61.66 ±21.31	136.50 ±100.50
pirimicarb	17.60 ±4.05	60.22 ±20.14	58.00 ±10.00
demeton-s-methyl	27.66 ±4.05	47.66 ±3.22	101.50 ±5.61
cypermethrin	16.00 ±11.93	66.33 ±46.46	62.50 ±41.70
<i>M.dirhodum</i>			
control	38.33 ±37.68	22.00 ±5.88	15.50 ±0.69
parathion methyl	24.00 ±7.07	5.66 ±4.71	28.50 ±9.19
pirimicarb	16.66 ±8.64	26.66 ±24.17	29.00 ±4.64
demeton-s-methyl	7.30 ±3.27	12.33 ±3.97	58.50 ±17.54
cypermethrin	8.30 ±1.53	38.66 ±24.44	70.50 ±55.21

b) Mean numbers of *S.avenae* and *M.dirhodum* per D-Vac sample  
( with 95% confidence limits )

	+14(11.6.82)	+18(15.6.82)	+35(2.7.82)
<i>S.avenae</i>			
control	19.49 ±5.35	31.97 ±8.11	30.79 ±10.97
parathion methyl	19.57 ±5.56	39.66 ±13.12	52.96 ±12.30
pirimicarb	19.13 ±5.36	32.79 ±7.09	28.89 ±9.09
demeton-s-methyl	22.57 ±6.48	35.13 ±11.06	61.31 ±19.43
cypermethrin	11.21 ±3.47	18.62 ±3.80	29.03 ±1.00
<i>M.dirhodum</i>			
control	18.31 ±5.79	7.68 ±4.04	4.85 ±1.82
parathion methyl	6.05 ±1.78	5.95 ±3.37	4.48 ±2.31
pirimicarb	5.91 ±3.69	12.52 ±3.99	2.80 ±2.19
demeton-s-methyl	9.14 ±5.07	4.57 ±2.89	17.52 ±9.26
cypermethrin	6.40 ±2.71	16.14 ±6.82	10.71 ±5.39



Appendix 6 : Sittingbourne 1982 Late Experiment Data. Mean number of Predators  
per pitfall trap (95 % confidence limits)

(a) Carabidae

	-8	-2	+3	+8	+15	+27
control	1.98 ± 1.91	1.22 ± 0.71	1.98 ± 0.91	2.60 ± 1.46	3.44 ± 1.50	2.95 ± 1.16
parathion-methyl	1.88 ± 0.96	1.35 ± 0.83	1.39 ± 0.89	2.53 ± 1.80	1.46 ± 0.86	2.05 ± 1.16
pirimicarb	1.74 ± 0.77	1.77 ± 0.82	0.99 ± 0.78	1.81 ± 1.01	1.17 ± 0.83	2.58 ± 1.66
demeton-s-methyl	1.29 ± 0.77	2.16 ± 1.10	1.20 ± 0.80	2.27 ± 1.53	3.31 ± 1.37	3.25 ± 1.57
cypermethrin	2.84 ± 1.18	2.63 ± 0.94	0.82 ± 0.56	3.39 ± 1.49	5.14 ± 0.78	2.16 ± 1.29

(b) Staphylinidae

	-8	-2	+3	+8	+15	+27
control	7.39 ± 3.19	4.62 ± 1.71	1.64 ± 1.08	2.18 ± 1.43	1.81 ± 1.07	1.94 ± 0.94
parathion-methyl	4.39 ± 1.79	2.29 ± 1.27	0.42 ± 0.35	1.86 ± 0.62	1.47 ± 0.86	1.33 ± 0.95
pirimicarb	4.87 ± 2.25	2.01 ± 0.90	1.22 ± 0.71	3.45 ± 1.40	1.38 ± 0.90	1.35 ± 0.90
demeton-s-methyl	5.05 ± 2.34	3.06 ± 1.27	0.82 ± 0.56	2.17 ± 1.18	1.59 ± 0.84	0.42 ± 0.41
cypermethrin	7.66 ± 3.05	4.89 ± 1.43	0.70 ± 0.61	1.47 ± 0.93	2.65 ± 0.73	1.41 ± 0.95

(c) Linyphiidae

	-8	-2	+3	+8	+15	+27
control	11.41 ± 1.84	14.77 ± 2.66	15.36 ± 4.27	7.48 ± 4.26	17.12 ± 3.53	19.25 ± 3.09
parathion-methyl	11.34 ± 2.45	11.53 ± 3.13	13.26 ± 3.12	13.57 ± 2.94	14.09 ± 3.70	14.69 ± 3.98
pirimicarb	8.93 ± 2.35	15.17 ± 4.96	17.13 ± 4.51	10.04 ± 3.31	14.10 ± 5.11	14.93 ± 3.79
demeton-s-methyl	9.25 ± 2.75	17.94 ± 2.75	3.21 ± 1.18	7.99 ± 2.27	13.70 ± 3.09	9.30 ± 5.70
cypermethrin	9.22 ± 1.14	15.23 ± 2.90	3.75 ± 1.13	1.09 ± 0.87	12.11 ± 2.89	12.89 ± 3.42

Appendix 7 : Sittingbourne 1982 Late Experiment Data.

Numbers of S.avenae and M.dirhodum in

D-Vac samples with 95% confidence limits

Days post-treatment

<u>S.avenae</u>	-2(6.7.82)	+5 (13.7.82)
control	27.89 ±14.41	35.22 ±11.61
parathion -methyl	22.55 ±13.04	11.66 ±7.33
pirimicarb	26.11 ±18.00	8.22 ±6.17
demeton-s -methyl	22.22 ± 9.15	9.00 ±5.96
cypermethrin	32.44 ±21.35	19.89 ±9.77

<u>M.dirhodum</u>		
control	11.78 ±6.83	20.78 ±11.78
parathion- methyl	11.44 ±8.82	1.89 ± 3.93
pirimicarb	7.66 ±7.57	0.89 ± 0.88
demeton-s methyl	7.44 ±4.57	1.33 ± 0.80
cypermethrin	13.11 ±11.9	12.89 ±13.14

Appendix 8 (a) Sittingbourne 1981 Experiment 2. Probability values from one way analysis of covariance of pitfall trap data at each post-treatment sampling date. (Data were transformed as  $\ln(n+1)$  before analysis, with pretreatment catches and blocks as covariates)

Date	Days posttreatment	Carabidae	Staphylinidae	Linyphiidae
2.7.81	+2	0.024*	0.024*	0.002*
4.7.81	+4	0.003*	(0.009*)	0.002*
6.7.81	+6	0.429	0.001*	0.001*
8.7.81	+8	0.373	0.159	0.001*
10.7.81	+10	0.710	0.322	0.003*

\* signifies values of  $P < 0.05$

Significant results , except bracketed entry for Staphylinidae signify reduced catches of these groups.

Appendix 8 (b) Sittingbourne 1981 Experiment 2 . Values of "t" from t-test on adjusted means to pinpoint significant treatment effects.

Sample date	Days post-treatment	Carabidae			Staphylinidae			Linyphiidae		
		PIR	CYP	MEP	PIR	CYP	MEP	PIR	CYP	MEP
2.7.81	+2	0.77	1.39	3.16**	2.16*	0.47	2.00	0.12	3.88**	1.64
4.7.81	+4	0.84	0.49	3.12**	0.56	2.13*	1.47	2.63	4.15***	3.19
6.7.81	+6	—	—	—	2.11	0.66	3.10**	1.19	6.92***	6.41***
8.7.81	+8	—	—	—	—	—	—	0.41	4.37***	1.53
10.7.81	+10	—	—	—	—	—	—	1.11	3.96***	2.72*

Values of t with 30 degrees of freedom

probability. t denoted by in table above

0.05            2.042    \*  
 0.01           2.75       \*\*  
 0.001          3.65       \*\*\*

PIR = pirimicarb

CYP = cypmethrin

MEP = parathion- methyl

Appendix 9 (a) Herne Bay Experiment . Probability values from one way analysis of covariance of  $\ln(n+1)$  of pitfall trap data at each post-treatment sampling date. Pre-treatment catches were covariates.

Date	days post-treatment	Carabidae	Staphylinidae	Linyphiidae
16.6.81	+4	0.399	0.686	0.001*
21.6.81	+9	0.648	0.198	0.064
2.7.81	+20	0.558	0.006*	0.025*
9.7.81	+27	0.869	0.251	1.00

\*signifies significantly reduced catches of these groups  
on the date in question

Appendix 9 (b) Herne Bay Experiment. t-test on adjusted means  
to pinpoint significant treatment effects

date	days post-treatment	Carabidae		Staphylinidae		Linyphiidae	
		DEM	CYP	DEM	CYP	DEM	CYP
16.6.81	+4	—	—	—	—	2.86	5.27
21.6.81	+9	—	—	—	—	—	—
2.7.81	+20	—	—	4.94*	2.63	0.65	2.71
7.7.81	+27	—	—	—	—	—	—

\* = significantly fewer than control

Appendix 10 : Taxa caught in pitfall traps at Sittingbourne  
in 1981 and 1982

ARANEAE

LINYPHIIDAE

Bathyphantes spp. Menge  
Erigone spp. Audouin  
Lepthyphantes spp. Menge  
Meioneta spp. Hull  
Micragus subaequalis (Westring)  
Milleriana inerrans (Cambridge)  
Oedothorax spp. Bertkau

COLEOPTERA

CARABIDAE

Agonum dorsale (Pontppiddan)  
Amara familiaris (Duftschmid)  
Bembidion lampros (Herbst.)  
Harpalus affinis (Schrank.)  
Harpalus rufipes (Degeer)  
Nebria brevicollis (F.)  
Notiophilus biguttatus (F.)  
Pterostichus madidus (F.)  
Pterostichus melanarius (Illiger)  
Trechus quadristriatus (Schrank)

CRYPTOPHAGIDAE

Anthicus antherinus L.  
Atomaria spp. Stephens

ELATERIDAE

Agriotes spp. Eschscholtz  
Dalopius spp. Eschsholtz

HEMIPTERA

APHIDIDAE

Sitobion avenae (F.)  
Metopolophium dirhodum (Walker)  
Rhopalosiphum padi

DIPLOPODA

CHILOPODA

LYCOSIDAE

Lycosa spp. Latrielle  
Trochosa spp. Koch

STAPHYLINIDAE

Aleochara spp. Gravenhorst  
Aloconota spp. Thomson  
Anotylus spp. Thomson  
Atheta spp. Thomson  
Bolitobius spp. Samouelle  
Drusilla spp. Samouelle  
Othius spp. Stephens  
Oxypoda spp. Mannerheim  
Quedius spp. Stephens  
Sepedophilus spp. L.  
Staphylinus spp. L.  
Tachyporus chrysomelinus (L.)  
Tachyporus hypnorum F.  
Tachyporus obtusus L.  
Xantholinus spp. Dejean

CICADELLIDAE

CIXIDAE