

Project ECLO/SEN/003/NET

## ***PROJECT REPORT***

# **Environmental effects of chemical locust and grasshopper control**

**A pilot study**



**Food and Agriculture Organization  
of the United Nations**

Project Report

Project ECLO/SEN/003/NET

**ENVIRONMENTAL EFFECTS OF CHEMICAL  
LOCUST AND GRASSHOPPER CONTROL**

**A Pilot Study**

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The views and opinions expressed in this report are those of the authors and do not necessarily reflect the opinion of the Food and Agriculture Organization.



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**NOTE:** All annexes, containing raw field data as referred to in the respective chapters, are printed as a separate document, which is available from FAO upon request.

## PREFACE

The underlying report is based on a three months' field study by a group of fourteen scientists belonging to five nationalities, representing five organisations and nine scientific disciplines. It has, therefore, been an example of good international and interdisciplinary cooperation. The main reason for this success was the Senegalese setting with its good infrastructure, highly qualified national scientists and highly cooperative local and national administration.

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## Summary

In recent years large quantities of chemical insecticides have been applied in the Sahel, for the control of locust and grasshoppers. Although alternative methods are being developed chemical control is at present the only operational solution at hand. Campaigns with chemicals against grasshoppers which, in contrast to locusts are of an endemic nature, are expected to continue at a considerably large scale. The environmental impact of these measures is virtually unknown, mainly due to the fact that the ecotoxicological effort made thus far in this field of interest, has been of a fractional, local and temporary, short-term character.

The purpose of the present pilot-study is by means of a one-season field test to provide a set of key parameters for an integrated long-term and large scale monitoring programme and to recommend techniques for pre-application risk-assessment.

The following disciplines were represented:

1. Environmental Chemistry
2. Biochemical Toxicology
3. Soil Ecology
4. Entomology
5. Ornithology
6. Hydrobiology
7. Ichthyology
8. Application Technology

The study was designed following the Before-After-Control-Impact principle. Three insecticides were tested: the organophosphates fenitrothion and chlorpyrifos and the insect growth regulator diflubenzuron, applied at two dosages: the nominal recommended dose for locust control and the double dose. The latter was used to simulate overdosing and to allow for a worst-case analysis. Treatments were carried out on 2x2 and 2x3 km blocks of savannah and on artificial lakes (single dosages only), by aircraft using a ULV drift spray technique. The calculated insecticide deposits were 485 and 825 g ai/ha fenitrothion, 270 and 387 g ai/ha chlorpyrifos and 38 and 83 g ai/ha diflubenzuron on the savannah plots. Deposit on the lakes was 550, 257 and 40 g ai/ha respectively. The following observations were made:

### 1. Residues

Residues of the pesticides were analysed from the sprayed vegetation. The highest concentrations found immediately after spraying were fenitrothion: 160 mg/kg dry vegetation; chlorpyrifos: 115 mg/kg; and diflubenzuron: 51 mg/kg. Estimated half-lives were less than 48 hrs for the organophosphates and 7-15 days for diflubenzuron.

### 2. Functional Soil Processes

Neither soil respiration, nitrification or chlorophyll were affected by the chemicals.

### 3. Entomofauna

Effects on orthopterans were measured by means of surface counts and light traps, determining population density and demographic structure. Shortly after spraying of both fenitrothion and chlorpyrifos, less than 10% of the adults and larvae survived, irrespective of the dose. Recovery of larval stages, however, was considerably slower in the fenitrothion plots. Diflubenzuron showed a reduction of 95% and 70% of the larvae after single and double dose treatment, respectively.

Of the beneficial arthropods three groups were distinguished: natural enemies of orthopterans and other pests, pollinators and soil improving arthropods. A variety of monitoring methods were applied (trapping, counting). It appeared that fenitrothion affected the beneficials more than the other compounds. Specifically some tenebrionids, Asilidae, ants, Sphecidae and Ichneumonidae proved sensitive. The latter family was also affected by diflubenzuron. Indications were found for an effect of fenitrothion on epigeal termites. Many populations did not recover completely before the end of the rainy season.

### 4. Birds

Effects on birds were monitored by transect counts, breeding observations, carcass searches, food habit analysis and Cholinesterase (ChE) analysis. Fenitrothion caused a decrease in three of the most abundant species, mostly by emigration as a reaction to a reduction in arthropod food supplies. Reproduction was affected in Singing Bush Lark by direct poisoning of fledglings and indications were obtained for an effect on Buffalo Weavers by food deprivation.

### 5. Aquatic Invertebrates

Aquatic invertebrates were monitored by handcatching and *in situ* bio-assays. Chlorpyrifos was harmful to shrimps, free-swimming insects and sediment inhabiting insect larvae; fenitrothion affected shrimps and free-swimming insects only, and diflubenzuron application was only followed by a strong reduction in zooplankton.

### 6. Fish

Fish were caught by gill nets and scoop nets. One species appeared to be affected by the treatments: chlorpyrifos spraying caused the virtual disappearance of *Porogobius schlegelii*

## Recommendations

The recommendations concern the general approach of future activities. Details and recommendations for improvements in methods and avoidance of mistakes made in this study are given in the separate chapters

- 1 Ecotoxicological surveys for chemical locust and grasshopper control should include:
  - avian reproductive performance; movements and survival of immatures
  - small fish species (such as *Porogobius schlegelii*)
  - macrocrustaceans, such as *Caridina africana*, *Triops sp.* and *Palaemonetes africanus*
  - various coleopteran and hymenopteran species, mentioned in Chapter IX
  - above ground foraging termites
- 2 Field tests should include replication whenever possible, either in the same test or by repeated observations elsewhere
- 3 Laboratory toxicity tests should be developed/applied for
  - macrocrustaceans
  - termites
  - carabids
  - several hymenopterans
- 4 Apart from the compounds tested in the pilot study more tests should be carried out with other insecticides for locust control, in comparable and other habitat types, in Senegal and elsewhere (e.g. Mali, Mauritania)
- 5 Large scale spraying operations such as treatments against Senegalese Grasshopper should be monitored in Senegal and elsewhere
- 6 The approach of integration of several disciplines (environmental chemistry; toxicology and ecology) realized in the pilot study should be continued
- 7 The cooperation with local and foreign institutes and the training started in the pilot study should be enhanced

## Sommaire

Au cours des récentes années, d'importantes quantités d'insecticides chimiques ont été appliqués dans le Sahel pour le contrôle du criquet pèlerin et des sautériaux. Bien que d'autres méthodes aient été développées, le contrôle chimique est à ce moment la seule solution opérationnelle à portée de main. Les campagnes faites avec des produits chimiques contre les sautériaux qui, contrairement au criquet pèlerin, sont de nature endémique, semblent devoir continuer à plus grande échelle qu'avant les récentes éclosions.

L'impact environnemental de ces mesures est virtuellement inconnu, principalement du fait que l'effort écotoxicologique fait jusqu'ici dans ce domaine a eu un caractère fractionnel, local et temporaire. L'objet de cette présente étude pilote est, par le moyen d'une saison de test de terrain, de pourvoir un ensemble de paramètres de terrain pour un programme intégré de surveillance à long terme à grande échelle, et de recommander des techniques de pré-évaluation des risques après traitement.

A cet effet les disciplines suivantes sont représentées:

1. Chimie environnementale
2. Toxicologie biochimique
3. Ecologie du sol
4. Entomologie
5. Ornithologie
6. Hydrobiologie
7. Ichthyologie
8. Technologie d'application

L'étude a été désignée selon le principe "Avant-Après-Contrôle-Impact" (en anglais: Before-After-Control-Impact, ou BACI). Trois insecticides ont été testés: les organophosphorés chlorpyrifos et fénitrothion et le diflubenzuron régulateur de croissance, appliqués en deux doses nominales: la dose recommandée pour le contrôle du criquet pèlerin et la double dose. Cette dernière a été utilisée pour simuler une surdosage et pour permettre l'analyse du plus mauvais cas ("worst case analysis"). Les doses calculées étaient les suivantes: 485 et 825 g ma/ha pour le fénitrothion; 275 et 387 g ma/ha pour le chlorpyrifos et 38 et 83 g ma/ha pour le diflubenzuron. Les doses appliquées aux lacs étaient de 550, 257 et 40 g ma/ha pour les trois produits. Les traitements sont effectués en 4 blocks de 2x3 et en 2 blocks de 2x3 km de savane et sur des lacs artificiels (dosage unique seulement), par avion, en appliquant la technique de dérive ULV. Les observations suivantes ont été faites:

### 1. Les résidus

Les résidus de pesticides ont été analysés à partir de la végétation traitée. Les concentrations les plus grandes qui ont été trouvées le premier jour après le traitement étaient pour le fénitrothion: 160 mg/kg végétation sèche; pour le chlorpyrifos: 115 mg/kg; et pour le diflubenzuron: 51 mg/kg. Les demi-vies estimées étaient moins de 48 hrs pour les organophosphorés et 7-15 jours pour le diflubenzuron.

## 2. Processus fonctionels du sol

Ni la respiration du sol, ni la nitrification ou la chlorophylle sont touchées par les produits chimiques.

## 3. l'Entomofaune

Les effets sur les orthoptères ont été mesurés par l'intermédiaire de comptages en surface et de piègeages lumineux, la détermination de la densité des populations et de la structure démographique. Féntrothion et chlorpyrifos ont tous les deux causé plus de 90% de mortalité, peu après la pulvérisation chez les adultes et les larves, indépendamment des doses. Cependant, la récupération des stades larvaires est considérablement plus faible dans les plots traités au féntrothion. Le diflubenzuron montre une réduction des larves de 95% et 60%, respectivement après les traitements à dose unique et à bouble dose.

Pour les arthropodes utiles, 3 groupes ont été distingués: les ennemis naturels des orthoptères et autres insectes nuisibles, les pollinateurs et les arthropodes améliorant le sol. Un nombre de méthodes d'observation ont été appliqués (piégeage, comptage ...). Il est apparu que le féntrothion a plus affecté les insectes utiles que les autres produits. Quelques tenebrionidae, les Asilidae, fourmis, Sphecidae et Ichneuminidae s'avèrent spécialement plus sensibles. Des indications furent obtenues pour une sensibilité des termites aux féntrothion. Les Ichneuminidae ont été affectés par le diflubenzuron. Plusieurs populations se sont peu rétablies avant la fin de la saison pluvieuse.

## 4. Oiseaux

Les effets sur les oiseaux ont été observés par des comptages en transects, des observations sur la reproduction, les recherches des carcasses, analyses des habitudes alimentaires et des analyses de l'activité de l'acetyl-cholinestérase (indicateur pour une intoxication). Le féntrothion a causé une décroissance dans trois des plus abondantes espèces, principalement par le mouvement en réaction à la réduction des réserves alimentaires en arthropodes. La reproduction a été affectée chez l' Alouette Chanteuse par empoisonnement direct des oisillons. Des indications furent obtenues pour un effet chez l' Alecto à Bec Blanc par la privation alimentaire.

## 5. Les invertébrés aquatiques

Les invertébrés aquatiques ont été obtenus par capture et des bio-essais *in situ*. Le chlorpyrifos a été nuisible pour les crevettes, les insectes et les larves d'insectes du sediment. Le féntrothion a été nuisible pour les crevettes et les insectes et l'application du diflubenzuron a été suivi par une forte réduction du zooplankton seulement.

## 6. Poissons

Les poissons ont été capturés avec des filets à branchies et des épuisets. Sur les espèces qui ont paru être affectées par les traitements la pulvérisation du chlorpyrifos a causé une virtuelle disparition de *Porogobius schlegelii*.

## Recommandations

Les recommandations concernent l'approche générale des activités futures. Les détails et les recommandations pour l'amélioration des méthodes et l'élimination des erreurs dans cette étude sont donnés par chapitre.

- 1 Les enquêtes écotoxicologiques pour le contrôle chimique du criquet pèlerin et des sauterelles devraient inclure:
  - performance de la reproduction aviaire; les mouvements et la suivie des immatures
  - les petites espèces de poissons (tel que *Porogobius schlegelii*)
  - des macrocrustacées tels que *Caridina africana*, *Triops sp* et *Palaemonetes africanus*.
  - des variétés de coléoptères et des espèces d'hyménoptères observées en Chapitre IX
  - termites fourageurs de la strate herbacée
- 2 Les tests de terrain devraient faire l'objet de répétition chaque fois que possible, soit dans le même test ou par observations répétées ailleurs.
- 3 Les tests de toxicité au laboratoire devraient être développés et appliqués pour:
  - les macrocrustacées
  - les termites
  - les carabides
  - plusieurs hyménoptères
- 4 A côté des composés testés dans l'étude pilote, plusieurs tests devraient être exécutés avec d'autres insecticides pour la lutte antiacridienne dans des types d'habitat comparables et différents au Sénégal et ailleurs (par exemple Mali, Mauritanie)
- 5 Les opérations à grande échelle tels que les traitements contre le criquet sénégalais devraient être suivies au Sénégal et ailleurs
- 6 L'Approche relative à l'intégration de plusieurs disciplines (Chimie environnementale, Toxicologie et Ecologie) réalisée dans cette étude pilote devrait être continuée
- 7 La coopération avec les instituts locaux et étrangers et la formation débutées dans cette étude devraient être développées



## **PART 1**

## **INTRODUCTION**

## CHAPTER I

## INTRODUCTION

James W. Everts

### General introduction

The Sahelian countries have experienced long years of grasshopper infestations. These pests have become a real threat to the crops since the beginning of the drought in the Sahel (late sixties early seventies). In addition to grasshoppers, the Desert Locust *Schistocerca gregaria* threatened the Sahel for the last three years.

To this present day, insecticide spraying is the only operational control method available against locust and grasshoppers in Africa. As a consequence, the quantities of chemicals used during a campaign are considerable. In Table I.1 the amount of insecticide applied in 1988/89 is given.

Although the development of alternative methods has been accelerated considerably after the recent outbreaks, chemicals will continue to be used, for the following reasons: 1. alternatives will not be available for general use in the near future (5 - 10 years); 2. alternative methods will not be applicable under all circumstances and 3. biological methods are often applied in an integrated system, i.e. in combinations with insecticides. A purely practical, but nonetheless important factor is that in many cases insecticides are easier to purchase and handle than alternatives. This holds specifically for pests with a highly irregular character, such as locusts. The risk related to the use of these toxic products, therefore, will require constant attention.

### Ecotoxicology of Locust and Grasshopper campaigns

The ecotoxicological risk of the use of pesticides in arid areas is virtually unknown. Over 90% of our knowledge of the hazard of insecticides concerns temperate climatic zones, both with respect to the fate and behavior of chemical compounds and with respect to ecological impact. A good example is the case of dieldrin. Although one of the oldest and best studied insecticides, its ecological impact in arid zones still cannot be predicted at an acceptable level of certainty (Van der Valk 1988).

There are a number of aspects which make anti-locust and grasshopper campaigns different from ordinary plant protection measures and which are of importance for planning monitoring activities.

### *Properties of the insecticides used*

The risk of the compounds to the environment depends on a number of factors, related to the characteristics of both the insecticide and the environment concerned (the sahara, sahel and northern savannah zone).

**Table I.1:** Desert Locust control measures in Africa, 1986/1990. Source: FAO Desert Locust Control Committee

<u>country</u>	<u>estimated area treated (ha)</u> september 1986 - august 1990
Morocco	4 652 000
Algeria	1 772 000
Lybia	100 000
Tunisia	286 000
Mauritania	987 000
Senegal	2 039 000
Cape Verde	37 000
Gambia	177 000
Guinee Bissau	2 000
Mali	504 000
Niger	1 097 000
Chad	163 000
Sudan	1 530 000
Ethiopia	117 000
Egypt	306 000
<hr/>	
Total	1 376 900

In general, the hazard of a chemical compound to a certain organism depends on its intrinsic toxicity, the amount absorbed and the duration of the exposure. If one of these factors is very small, a toxic effect will be limited or non-existent. On the other hand, a long-lived exposure to high concentrations of a relatively non-toxic chemical may induce serious effects. The duration of the exposure depends on the application technique (single vs. repeated treatment) and on the persistence of the compound. The latter is affected by biotic and abiotic factors: i.e. in general a compound is readily degraded in a warm, wet and highly irradiated environment with high microbial activity. In the areas concerned one or more of these conditions are present. In contrast to regular agricultural treatments locust control operations are of a local and temporary nature. The risk of long-term exposure, therefore, is reduced.

Another important factor is the availability of the compound to living organisms. Some insecticides, pyrethroids for example, when applied to natural waters, adsorb rapidly to solid particles. This reduces their bioavailability to aquatic organisms and henceforth their toxic effect. Although highly toxic in the laboratory, such products may not cause serious side-effects in the field, when applied at recommended dosages. Sorption to soil particles and solubility in water determine the mobility in soil and the probability of leaching into surface water. Propoxur, for example, is more mobile in the soil than fenitrothion.

Some products may be stored in body-tissues (especially fat) where they may form a hazardous reservoir for the individual as well as for his consumer/predator. Dieldrin is the only anti-locust pesticide which is known for its high capacity to accumulate in living organisms. All other compounds (organophosphates, carbamates) do so to a much lesser extent because of quick degradation in living organisms. However, when consumption of a contaminated prey, such as sprayed orthopterans is heavy the uptake of even readily degradable products may represent a serious threat to the consumer. It is, therefore, to be expected that insectivorous animals (mainly birds) provided with abundant and easy available (toxic) food directly after spraying, are at risk during the campaigns.

#### *Scale of application*

Treatments against desert locust and grasshoppers generally cover a large surface; in the first case up to 10km<sup>2</sup> and in the latter 100km<sup>2</sup> or more. Large treated areas reduce the chance of recovery of affected populations of non-targets within the same season, giving rise to long-term damage.

The use of equipment for large scale operations, i.e. fixed wing aircraft, increases the risk of indiscriminate spraying. Even the most skilled pilot cannot avoid contamination of small water bodies which, during the wet season, are often found in the areas to be sprayed. When treatments are directed at the protection of arable land (which is the case in many grasshopper campaigns) the risk of water contamination (streams, canals, irrigation basins) is very high. During the large scale grasshopper operations of 1986 in Senegal, side-effects in waterfauna following aerial spraying operations were repeatedly recorded (Fredrickson et al. 1986).

#### *Ecosystems at risk*

Anti-locust spraying almost always, and grasshopper treatments very often, are conducted in non-cultivated areas, i.e. (semi-)natural land. Although conservation areas are generally spared, wildlife in unprotected areas (mainly birds) may be at risk.

In spite of their high adaptation to extreme physical conditions (drought, temperature), the functioning of these ecosystems depends heavily on a limited number of processes that are sensitive to disturbance by pesticides. Examples are the activity of termites, ants, dung beetles and blue-green algae with respect to soil fertility. Ephemeral and poorly migrating populations in isolated pools or bush formations are vulnerable to local extinction.

The physico/chemical properties and the application method of the chemicals used determine whether certain groups of organisms are at risk. It depends on the composition and the functioning of the ecosystem exposed to the chemicals if the effect is limited to mortality in a few populations, hardly distinguishable from natural variation, or extended to many species, disrupting important interactions over a long period. In the Sahel the natural environment suffers from over-exploitation and climatic stress. Despite the remarkable capacity of most ecosystems to recover from disturbance, the increased isolation of biologically rich areas involves an increased risk of irreversible damage.

#### *Dosages*

The dosages used for locust control are among the highest dosages applied in crop protection campaigns. Given the pressure on many applicators to be successful, in practice these dosages are often doubled or even tripled. Recent observations (Ottesen, pers. comm.) not only demonstrated the ineffectiveness of overdosing but also showed that reductions in recommended dose may lead to acceptable results.

#### *Ecological role of locusts and grasshoppers*

Orthopterans are an important source of food for many vertebrates. Swarms and hopper bands of desert locust are often followed by rollers, buzzards, shrikes, thrushes, kites, eagles and storks (Smith & Popov 1953), which gives rise to a risk of secondary poisoning and of the effect of sudden food deprivation after treatment.

Natural enemies of orthopterans are numerous. TAMS (1988) lists 26 bird species and over 100 insect taxa that are known antagonists (predators and parasites). From early field observations (e.g. Stortenbeker 1967) it is known that at the local scale certain locust populations may be regulated by these organisms. In 1987, in certain areas in Mali up to 80% of the eggpods of *Oedaleus senegalensis* appeared to be parasitized (Popov pers. comm.).

#### *Sequence of treatments*

Many populations which show no adverse effect after one treatment do so after a series of applications (e.g. Everts et al. 1983). Recovery of affected non-target populations may be delayed seriously by repeated spraying. In locust control, however, consecutive campaigns at the same place are rare but in grasshopper control operations they are more common. Unnecessary, repeated spraying took place recently at several occasions in West Africa, primarily due to poor co-ordination.

#### **Methodology**

It was mentioned earlier that the ecological risk of chemicals is generally estimated by combining the use pattern and physico/chemical characteristics of a compound with its toxicological properties. The first set of data determines the likelihood of exposure of certain species (communities, trophic groups) and the second determines their chance of being

affected. The fate and behavior of many compounds can be predicted with the help of existing mathematical models. Toxic effects, however, are far less predictable, due to our poor knowledge of relevant processes in natural biota. Because of the innumerable richness of most ecosystems concerned and the complexity of the underlying processes, in general a limited number of *indicators* is selected for prediction and monitoring of ecotoxicological impact.

Indicators are either species or processes, which by virtue of their sensitivity for changing environmental conditions can be used as signals for change. When it is known that a certain species is relatively sensitive to a particular pesticide, such a species can be used to monitor possible effects of that pesticide under field conditions. One of the aims of ecotoxicology is to identify indicators which can be used to protect the environment against the possible undesirable effects of a wide range of chemicals. Preferably the same indicator species should also be suitable model organisms for predictive testing of chemicals under laboratory conditions. Presently standard tests with algae, daphnids and certain fish are used to predict possible negative side-effects on aquatic ecosystems; earthworms represent the soil fauna, a few birds the avifauna and data from rats, mice, dogs and rabbits are extrapolated to man and other mammals. A main limitation of the use of such predictive indicators is, that the sensitivity generally is restricted to a limited number of chemicals. Likewise universal field indicators do not exist. A further complication in the selection of ecotoxicological indicators is, that the sensitivity of a species is not only determined by the intrinsic vulnerability for a certain chemical but also by the likelihood of exposure, which is a function of auto-ecological characteristics (Jepson 1988) and the environmental fate of the chemical.

In the field, the hazard of chemicals has to be distinguished from the constant changes within ecosystems due to natural processes. Since evaluation of test data in the field lacks internationally adopted protocols it is not surprising that the results are not always consistent (e.g. Basedow 1973, Sunderland 1987) and sometimes even contradictory (e.g. Koeman et al. 1978 and Müller and Nagel 1980).

For the design of a monitoring programme not only indicator selection requires attention but also test and monitoring site selection, the establishment of causality instead of correlation, the sampling techniques, and statistics.

The establishment of a causal relationship between the emission or presence of a chemical compound and observed changes is the primary goal for ecotoxicological field work. In many cases the possibilities for classical latin-square or randomized field design are restricted, mainly due to the minimum field size imposed by the spatial scale of the events to be measured. The problem of the trade-off between plot size and replication is discussed by Sotherton et al. (1988). Because of this limitation, circumstantial evidence for causality between exposure and observed changes is often needed. In non-replicated tests strong evidence is provided by a dose related response. Examples are given by Crossland (1988) and Everts et al. (1989). Another important observation is the recovery of disturbed populations or processes after disappearance of the compound or its toxic metabolites. In virtually all communities recovery will occur, in one way or another, when the stressor has been removed. If the emission is repeated, in time or space, the multiple subsequent changes observed should be of the same character (e.g. Everts et al. 1983). Evidence for an effect is further supported by observations of individuals exposed in *in situ* bioassays and, most overlooked, in the field itself. Descriptions of acute or subacute effects shown by individual organisms

in the field are rare, despite their relevance for an understanding of the events recorded by other methods (Takken et al. 1978, Smies et al. 1980, Everts and Koeman 1987). Both categories of observations however, although important, have to be classified as early warning indications with a high chance of false positives. The same holds for chemical techniques. Both residue analysis and measurement of biochemical response to exposure, without an ecological framework, are irrelevant.

There are numerous ecological sampling techniques and strategies which can be used for ecotoxicological field work (Southwood 1978, Grant 1989). An important choice to be made before starting is whether active or passive methods will be applied. The most important difference for ecotoxicology is the fact that passive methods (trapping) measuring both activity and abundance integrate often unknown events over a certain period of time. Trapping at weekly or even daily intervals masks the very short-lived acute effects some chemicals may bring about. An example is the hyperactivity shown by many organisms after exposure to some insecticides which interferes with the measurement of a possible reduction in abundance. Active methods, such as hand catching or visual observation may also be biased by changes in behavior, but these changes can be recorded during the sampling activity. These techniques, however, are extremely time consuming and depend much on personal effort. They are, therefore, only applicable on a limited scale.

If the purpose of an ecotoxicological field test is to observe effects in time (that is, the onset of an effect, the intensity, the time-lag for recovery and the moment of full recovery (Everts 1983), the baseline data have to be handled as (short) time series. This implies that when the events are expressed in terms of changes from a pre-exposure situation this situation should have the form of a time series as well (for instance: the difference in time between numbers of an organism in a (to be) treated and a control plot (Stewart-Oaten et al. 1986). It also has to be demonstrated that the characteristics of this time series would remain the same over the period of observation if left undisturbed. If this is not the case, conclusions on the impact of the exposure should be formulated in qualitative terms.

### **Monitoring side-effects of acridicides**

A number of field studies on the side-effects of locust and grasshopper campaigns has been conducted (reviewed by McEwen 1981 and TAMS 1989, and the recent studies: Ottesen & Sømme 1987; Dynamac Corp 1988, 1989). A few reports exist for Senegal (Huddleston & Edwards 1986, Niassy & Diatta 1987) where the regions of Thiès, Louga and Saint-Louis were subject to large scale spraying programs from 1985-1989.

The results from Africa, as far as they have been reported to date, indicate:

1. A strong effect on terrestrial invertebrates, such as bees, ants, beetles, dipterans
2. Mortality in aquatic invertebrates (crabs)
3. Toxic effects on birds (Trecu, ORSTOM Dakar, pers. comm.)

None of the studies, however, met the requirements for correct monitoring mentioned above. The main reasons are the following:

1. Lack of time. No study exceeded more than two weeks after spraying. As a consequence, possible long-term effects were merely speculation
2. Lack of ecological knowledge. All studies started with a vague conception of the indicator parameters to be monitored and their relevance to the ecosystems concerned
3. Small surfaces. While campaigns were carried out over hundreds of thousands of hectares, the studies were limited to plots of 100 ha maximum
4. Lack of skilled personnel. Even in situations where funds were not the limiting factor, sufficiently sound studies could not be conducted because trained personnel were not available. This applied not only scientists but also technical field and laboratory personnel

On top of these shortcomings, the studies were not coordinated and, due to the lack of support from laboratory data, the results were often difficult to interpret and extrapolate.

### **The present study**

The plan for the present study was prepared during meeting on environmental impact of locust control held at FAO, Rome, in February 1989 (FAO, 1989). Decisions were made on the following issues: the pesticides to be tested, the dosages and application method, the test area, the ecosystems/landscape elements to be monitored and the selection of indicators, plot design, international cooperation and the time schedule.

#### *Pesticides*

Fenitrothion, chlorpyrifos and diflubenzuron were selected for this study, for the following reasons. The first compound, an organophosphate, is the most widely used insecticide in locust and grasshopper campaigns. The second, also an organophosphate, is a promising alternative to fenitrothion and the last one, an insect growth regulator, is a promising new compound (Hofman 1988), with expected favorable environmental properties. Relevant basic information for these three insecticides is shown in table I.2.

The dosages used were those recommended by FAO for locust control (applied in the terrestrial and in the aquatic test) and the double dose (only applied in the terrestrial test, to simulate overdosing and to create a 'worst case' situation).

The pesticides were applied by aircraft with micronair equipment by drift spraying. Details are given in Chapter II.

**Table I.2. Data on the insecticides used**

**1. CHLORPYRIFOS**

Common name:	chlorpyrifos
Trade name:	Dursban
Chemical group:	organophosphates
Formulation:	450 g/l ULV
Solubility:	In water practically non-soluble (at 35°C ca. 2 mg/l); soluble in most organic solvents
Vapour pressure:	$2.4/1.2 \times 10^{-4}$ mbar at 25/35°C, readily volatilized from soil and water
Sorption:	90% in sediment after 5 days, highly sorptive to soil particles, slightly mobile in dry soils
Degradation:	half-life in freshwater: 1.7 - 4.0 days. in soil 80 - 100 days (in temperate climates),
Mode of action:	non-systemic contact, stomach and respiratory action, cholinesterase inhibitor
Ecotoxicity:	hazardous to fish, crustaceans, aquatic insects (LC <sub>50</sub> 96h resp 0.13-520 µg/l; 0.1-5.0 µg/l; 0.035-10 µg/l), terrestrial insects, birds (Odenkirchen & Eisler 1988), bioconcentration factor (BCF) in water 410 - 1000; biomagnification: poor

**2. DIFLUBENZURON**

Common name:	diflubenzuron
Trade name:	Dimitin
Chemical group:	benzoylurea
Formulation:	450 g/l ODC
Solubility:	water: 0.1 mg/l, acetone 6.5 g/l, 104 g/l dimethylformamide, apolar solvents: poor
Vapour pressure:	very low: $< 1.3 \times 10^{-7}$ mbar at 50°C
Sorption:	rapidly adsorbed by soil particles (90% in 5 min) and in sediment
Degradation:	100% in 5 days in water; 100% in 4 days in forest litter (Booth et al. 1986)
Mode of action:	chitin synthesis inhibitor
Ecotoxicity:	non-hazardous to vertebrates, relatively non-hazardous to bees and predatory insects; hazardous to aquatic insects and zooplankton. Bioaccumulation: poor

**3. FENITROTHION**

Common name:	fenitrothion
Trade name:	Sumithion
Chemical group:	organophosphate
Formulation:	500 g/l ULV
Solubility:	practically insoluble in water but soluble in most organic solvents
Vapour pressure:	low: $8 \times 10^{-6}$ mbar at 20°C
Sorption:	readily adsorbed to soil particles (except sand), suspended solids and sediment;
Degradation:	persistent on foliage (detectable after 1 year), 100% degraded in soil after 15 -64 d.; 100% in water after 4 days.
Mode of action:	contact, stomach and respiratory action, cholinesterase inhibitor
Ecotoxicity:	hazardous to aquatic and terrestrial insects (bees), crustaceans; slightly hazardous to fish, birds, slightly phytotoxic. Bioaccumulation: poor

### *The study area*

Since temporarily flooded areas are among the richest and most vulnerable ecosystems in the Sahelian zone, it was decided to situate the test area in one of the three main wetlands: either the Chari system, the inner Niger delta or the Senegal valley and delta. The latter was selected for the following reasons:

1. Relatively well known ecology (Bourlière 1972, Van Lavieren & Van Wetten 1988, le Houérou 1989)
2. Good infrastructure (buildings available, roads, good telecommunication) and short distances to major centres
3. Good existing relations between the Department of Toxicology at Wageningen and the major national services (Plant Protection Service, Institute of Agronomic Research, OCLALAV Headquarters)
4. Availability of skilled personnel: former ORSTOM and OCLALAV technicians with a good knowledge of the bird fauna and observation techniques

The project was based at Richard Toll (Fig. I.1). The terrestrial plots were situated in savannah 15km South of the town (Fig. I.2) and the aquatic tests were carried out in semi-natural irrigation basins of a sugar plantation of the *Compagnie Sucrière Sénégalaise* (CSS) in the near vicinity (Fig. I.1). The savannah area selected was the most homogenous and least disturbed part of the area East of Lake Guièrs. The natural waters, however, appeared too dynamic or too vulnerable (Lake Guièrs) for our purpose. Irrigation ponds at the sugar plant, though limited in representativeness, appeared to provide the best testing conditions available.

### *Subjects for monitoring*

The following groups of organisms and processes were monitored:

- a. Orthopterans
- b. Soil ecosystem functional processes
- c. Terrestrial invertebrates other than orthopterans
- d. Aquatic invertebrates
- e. Fish
- f. Birds

### ORTHOPTERANS

In order to weigh the cost of a campaign (including the environmental damage) against its benefit, data will be required from the target as well as from the non-target populations. Since desert locust was not present in the area during the time of the study, pesticide efficacy assessments were carried out on grasshoppers.

#### SOIL PARAMETERS

According to Grant (1989) soil microbial processes important for the maintenance of soil fertility (the break-down of organic matter and other processes) may be at risk from insecticides applied at levels above the recommended rate.

The author stresses that the large open areas between the sparse savannah vegetation are not necessarily 'sterile'. Algae, lichens and bryophytes grow on the sand/soil surface, stabilizing it and contributing to the organic material production and biological nitrogen production. Processes such as nitrogen-fixation (free-living and associative) can be critical for the balance of nitrogen in poor soils. The positive temperature coefficients of toxicity for organophosphate may enhance the risk of disturbing these processes.

The part of the study concerning toxic effects on these processes is described in Chapter VI.

#### TERRESTRIAL NON-TARGET INVERTEBRATES

All studies hitherto carried out indicate that serious effects are to be expected in terrestrial invertebrates, i.e. ground dwelling species as well as inhabitants of herbs and higher vegetation (see the literature review in Chapter IX). Among these invertebrates there are a number of organisms which, by virtue of their ecological role, should be considered as beneficial; either for the functioning of the ecosystem, or in regulating of the target species (antagonists) or both. Indicators of side-effects were selected from these taxa (Chapter IX).

##### *Functional groups*

The functional groups considered most relevant for this study are the soil burrowing insects, such as termites, ants and dung-beetles and the pollinators.

The soil-burrowing insects play a primary role in the remineralization of organic material, the bioturbation and the aeration of the soil. Their activity provides both the necessary minerals as well as the structural soil conditions upon which many plant species depend. Pollinators play a key-role of comparable importance. A long-term effect on both groups may alter the composition and structure of the vegetation and, as a consequence, primary or biomass production.

The termites of the area selected for this study are relatively well known (Lepage 1972, Gueye 1987). The study on this group is presented in Chapter XI.

##### *Antagonists of Orthopterans and other insect pests*

Populations of predators and parasites of herbivorous and saprophagous insects are generally more sensitive to toxic compounds than their prey. This is caused by differences in population dynamics between the two groups, the recovery of the former being dependent on the second. Twenty-two species of the antagonists of orthopterans listed by TAMS (1988) are known from the Western Sahel (Mali, Mauritania, Senegal). However, because the majority of ground dwelling predator species is omnivorous (the consumption of orthopterans depending on size rather than specific preference) this number is expected to be considerably higher. The survey on the antagonists is presented in Chapter IX.

Groundspiders, though not major predators of large orthopterans, are important indicators of the side-effects of pesticides. The study on groundspiders is presented in Chapter X.

#### AQUATIC INVERTEBRATES

All insecticides used for locust and grasshopper control are known for their toxicity to aquatic invertebrates. The toxic effects of fenitrothion have been studied extensively during large scale operations in Canada (e.g. Varty 1980 and authors referred to in Chapter IV). In the sahelian waters, however, the composition of taxonomic groups differs in one major aspect from the temperate and continental zones, i.e. in the abundance of crustaceans. "Decapod crustacea which form part of the macrobentos community, are a particularly important element of tropical river fauna. Ecologically they may be considered together with fish on the basis of their size, position in the food chain, behaviour and economic importance, as food organisms." (FAO 1985). Everts et al. (1983) demonstrated that recovery of shrimps from local depletion by pesticides, even in waters with an open connection with non-polluted areas, may take several years.

The part of the study concerning aquatic invertebrates is presented in Chapter IV.

#### FISH

Sahelian wetlands (floodplains and marshes) are liable to become contaminated during large scale spray operations. The littoral zone of these plains is usually colonized by young fish. These are almost entirely cichlids of the genera *Tilapia*, *Sarotherodon*, *Oreochromis* and cyprinodonts which have specific tolerance for the elevated temperature found there (FAO 1985).

Fish may become affected directly by the toxicity of the compound, and indirectly by food deprivation resulting from the effect on invertebrate prey. Chlorpyrifos is known to cause mortality in fish under field conditions at application rates used for grasshopper control (Marshall & Roberts 1978; Odenkirchen & Eisler 1988). Fenitrothion and diflubenzuron are less hazardous (Gordon 1981, Kingsbury et al. 1987) but shifts in community structure may be induced by food shortage and sublethal behavioural effects (Gordon 1981). Although the gills are the main route of uptake for these chemicals the toxic effects may, in part, be related to the consumption of contaminated prey (floating and drifting insects)(Chapter V).

#### BIRDS

The area selected for this study, the Senegal valley, the lakes and the marshes are of great importance for both sedentary and migratory birds (Van Lavieren & Van Wetten 1988). In a classical study Morel and Morel (1972) identified 108 species on a 1 km<sup>2</sup> savannah plot in one year, 40% of which were migrants and the same authors (1988) report 354 species between 16° and 17° N and 15° and 16° W. Many of the species are known or potential predators of large orthopterans (TAMS 1988). The importance of birds as a subject for monitoring, therefore, is two-fold: wildlife conservation and preservation of natural enemies of grasshoppers and locusts.

The hazard induced by the pesticides is a combination of the effect of direct exposure to the spray, the uptake via food and the secondary effect of food deprivation. In a given situation, all three effects may occur, depending on the pesticide used. Both fenitrothion and chlorpyrifos are known to be hazardous to birds at rates used for grasshopper control (McEwen 1981, Odenkirchen & Eisler 1988). Diflubenzuron is virtually non-toxic to birds. An effect of this compound is only to be expected through food deprivation. The bird study, therefore, was limited to the organophosphate tests (Chapter XII).

### *Plot design and spray programme*

For the design of the trial plots the following aspects were taken into consideration.

- a. The plots have to represent a realistic spray situation; desert locust treatments rarely exceed 10km<sup>2</sup> per spray block.
- b. The plots must be sufficiently large to allow for observations on the scale of daily ranges of a large number of species, vertebrates as well as invertebrates and to reduce edge-effects, i.e. immigration from the unsprayed area before the effect of the test compound can be established.
- c. The cost of aerial treatment and the limited availability of sufficiently skilled personnel for large scale censusing (birds, fish) are limiting factors.
- d. If good control areas can be found the BACI method (Before-After-Control-Incident, Stewart-Oaten 1986) which does not require repetition in space can be applied. A prerequisite, however, is that the time-series of observations should be long (depending on the quality of the control).
- e. In the trade-off between an extra dose and one repetition with the same dose, the former option was adopted, which offers the possibility of 'worst case analysis' combined with dose-related responses.

Seven blocks were chosen within a 48,300 ha zone located between the edge of the forest of Keur MBaye and the villages of Sam-Sam, Keur S.ould Ibrahim, Keur Ibra Souilen and Bougar (Fig. I.1, I.2): 5 plots of 2x3km (coded A to E) for bird and invertebrate monitoring, to be treated with the organophosphates and two plots of 2x2km (G and H) for invertebrates only, to be treated with diflubenzuron. Sites were selected for homogeneity and absence of inhabitants (camps, villages). The spraying programme is presented in Table I.3.

The aquatic study sites were irrigation basins of the CSS sugar plant. After an extensive inventory of the fauna in the irrigation system, four lakes were selected for their richness, representativeness of the surrounding natural waters and absence of disturbing influences (villages). Three lakes were sprayed with the test compounds at recommended dose.

### *International co-operation and personnel*

The different tasks were divided as follows:

1. Aerial applications: FAO/ECLO
2. Chemical monitoring: University of Dakar
3. Acridology: National Plant Protection Service (Dakar) and PRIFAS (France)
4. Soil ecosystem functions: ODNRI (UK)
5. Beneficial Arthropods: FAO/ECLO, with some help from University of Wageningen (Spiders) and the Senegalese Ministry of Forestry and Natural Waters (Termites)
6. Aquatic invertebrates: University of Wageningen (Netherlands)
7. Fish: ODNRI
8. Birds: Denver Wildlife Research Center (USA) and FAO/ECLO
9. General Management: University of Wageningen

**Table I.3: Treatment schedule**

Plot	Product	Nominal Dose (g ai/ha)	Treatment Code	Date 1989
Block A	fenitrothion	500	1F	8 Sept
Block B	fenitrothion	1000	2F	12 Sept
Block C	untreated control		C0	
Block D	chlorpyrifos	225	1C	5 Sept
Block E	chlorpyrifos	450	2C	7 Sept
Block F	diflubenzuron	90	2D	9 Sept
Block G	diflubenzuron	45	1D	10 Sept
Lake 1	untreated control		L0	
Lake 2	diflubenzuron	45	LD	9 Sept
Lake 3	chlorpyrifos	225	LC	5 Sept
Lake 4	fenitrothion	500	LF	7 Sept

The personnel involved is listed at the beginning of the report. Temporary assistance was provided by senegalese specialists and technicians. The services of an entomologist (for training of staff), an ornithologist (technician) and a safety officer (a nurse) were hired.

#### *Time schedule*

The time schedule (Table I.4) covered one whole rainy season and allowed for equal sampling periods before and after treatments. Despite a 2 week delay in the treatments, the terrestrial invertebrate and the bird sampling programmes achieved this goal. The aquatic studies started later, due to the necessary extensive inventory studies required.

**Table I.4: Time schedule**

Date/Period	Activity
1989	
14 - 16 February	Working Group Meeting, Rome
15 - 30 March	Preparatory visit to Senegal (Van der Valk)
April	Literature research (BIOSIS, CAB, Duphar)
19 June	Briefing teamleader in Rome, arrival in Dakar
28 June	Installing laboratory and camp in Richard Toll
	Site selection
17 July	Start observations on birds, orthopterans,
1 August	Start observations on terrestrial invertebrates
11 August	Start observations on aquatic invertebrates
14 August	Start observations on fish
17 August	Start preparations soil function tests
2 September	Start chemical monitoring
5 - 12 September	Aerial treatments
13 September	End soil function observations
9 October	End observations on birds, fish, aquatic and terrestrial invertebrates, orthopterans, chemical monitoring
10 October	Presentation preliminary results for national audience
12 - 14 October	Observations on termites
23 October	Debriefing in Rome

**THE STUDY AREA**

The area selected for the study is situated between 15° 50' - 15° 70'W and 17° 50' - 17° 70'E. The climate is semi-arid. Rainfall during the rainy season of 1989 was 235 mm. The mean temperature was 26.4°C and the mean air humidity 70.2% (Fig. I.3).

Soils in the area are brown-red and weakly evolved on silicious sands. South of the river valley the landscape is slightly sloping with small depressions, situated at distances of 0.2 - 1 km. The landscape is classified by Bille et al. (1972) as "small non-oriented dune systems". During the rainy season waterholes are formed covering about 5% of the total surface (le Houérou 1989). The waterholes are not necessarily linked to the depressions and most depressions remain dry throughout the year. The soil which mainly consists of coarse sand (90 - 95%) is slightly acidic (pH 5.8 - 7.2), contains little organic material (1 - 4%) and is deficient in N and P (max. 0.4 and 0.15% respectively).

**Figure L1: Map of the study area.**

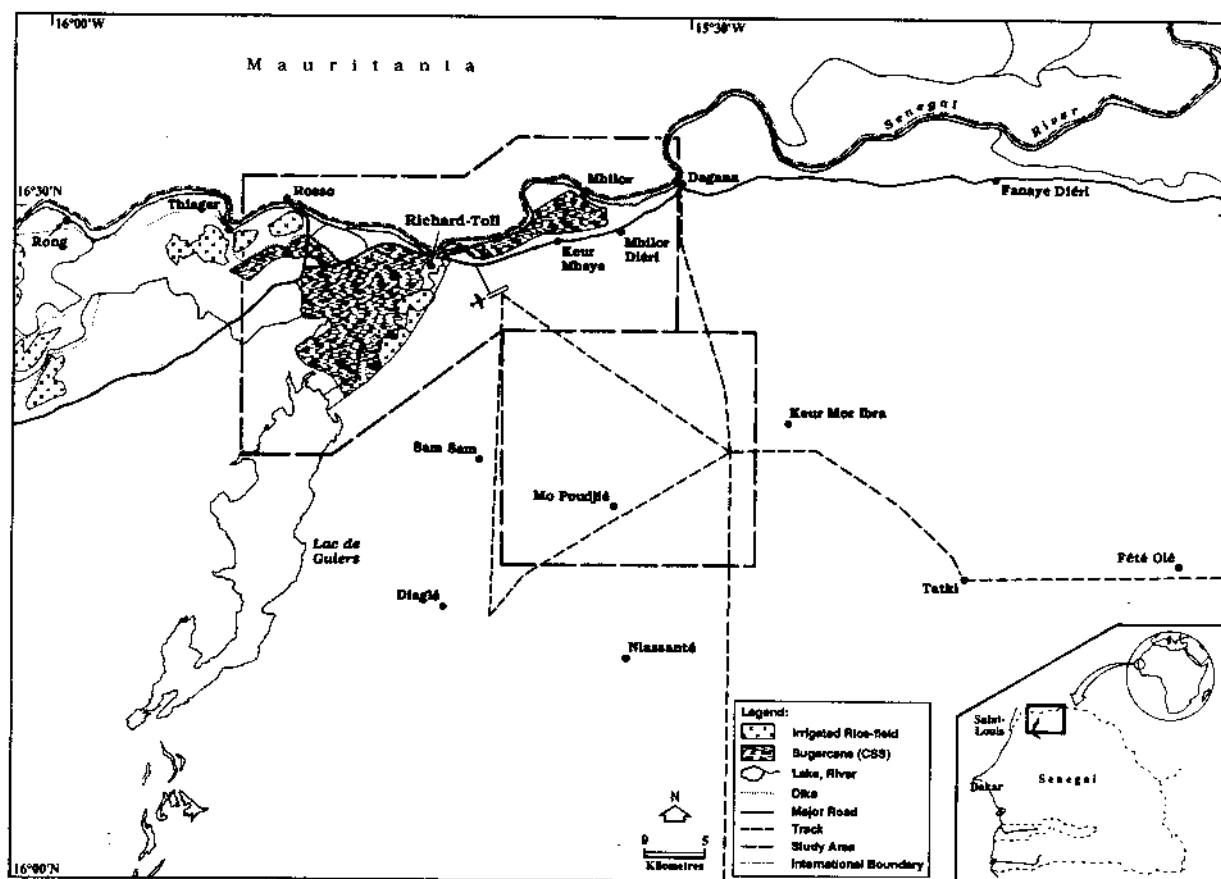


Figure I.2: Lay-out of the experimental plots.

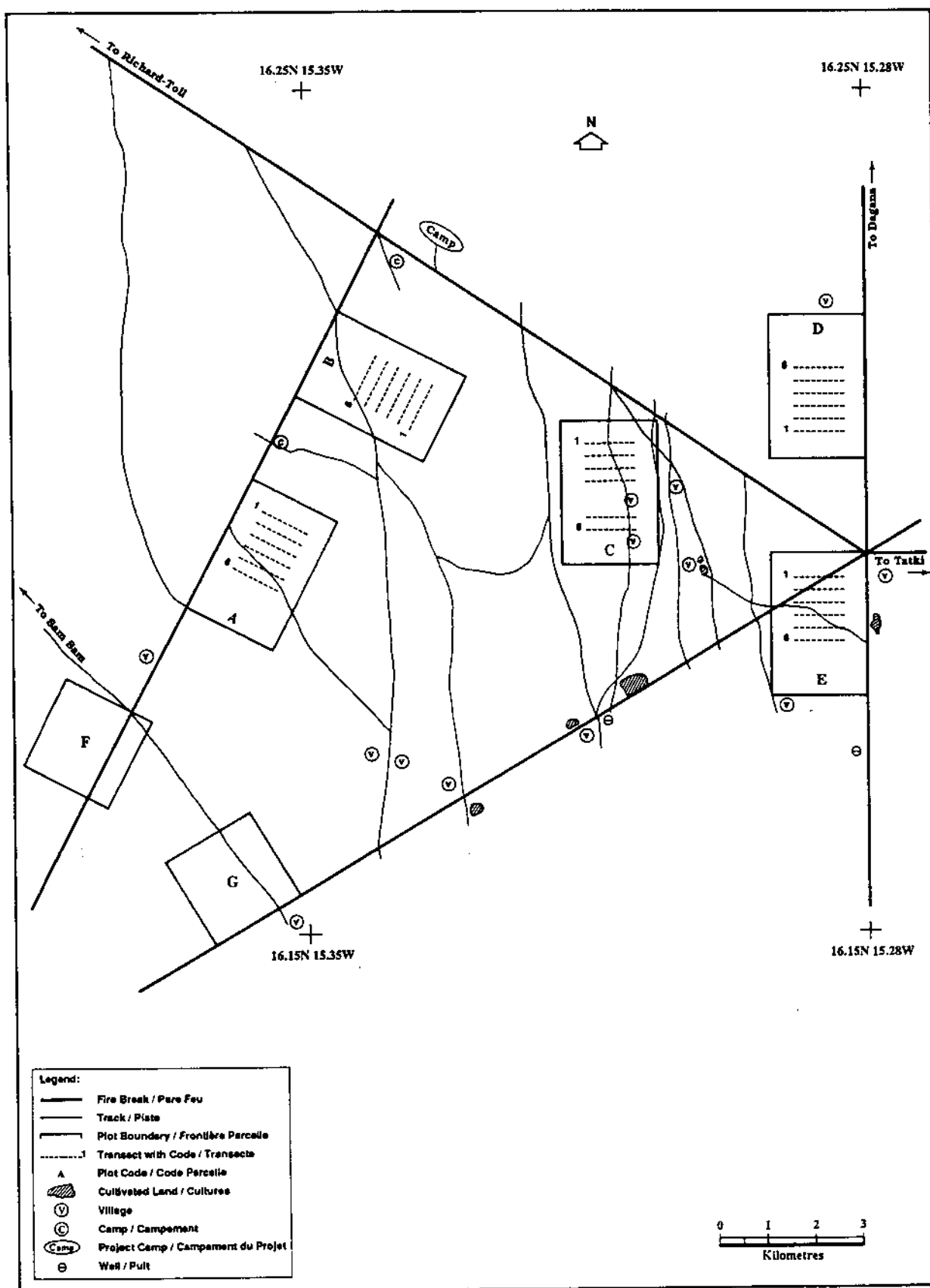
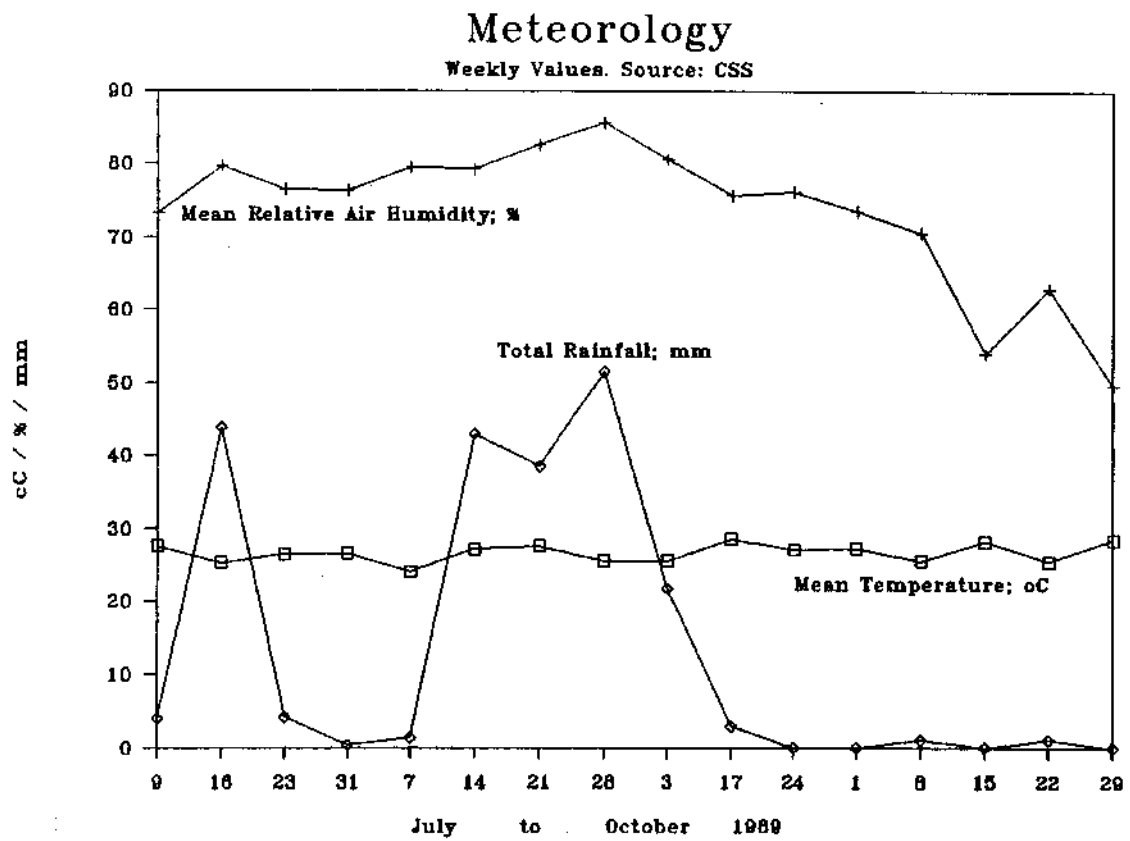


Figure I.3: Meteorology.



The vegetation (semiarid thornbush) varies according to the microtopography, especially in relation to the location of depressions. Overall cover by trees and shrubs is 10 - 20% (le Houérou 1989), 60 - 100% is not covered by vegetation. The most important trees are *Balanites aegyptiaca*, *Boscia senegalensis*, *Salvadora persica*, *Acacia senegal*, *A. raddiana*, *Grewia bicolor*, *Adansonia digitata*, *Calotropis procera* and *Guiera senegalensis* (Diallo 1987, Bille & Poupon 1972). The total tree density within the study plots ranged from 51 to 84 trees per ha, 57 % of which are below 2.5m in height (Table I.5). The main herbs on the higher sites are: *Cenchrus spp*, *Eragrostis tremula*, *Ctenium elegans*, *Aristida spp*, *Cyperaceae*, *Tribulus terrestris*. In the depressions the following herbs can be found: *Cassia mimosoides*, *Triumfetta pentandra*, *Echinichloa calona*, *Andropogon spp*, *Pennisetum pedicellatum*, *Zornia glochidiata*, *Diheteropogon hagerupii*. Furthermore, the grasses *Dactyloctenium aegyptium*, *Tragus berteronianus*, *Chloris prieuri*, *C. virgata*, *Panicum laetum*, and the perennial plants *Pancratium trianthum*, *Mormodica charantia*, *Cucumis melo*, *Heliotropium ramosissimum* and *Alyscarpus ovalifolius* were found in abundance in the area. After the rains begin forbs in the depressions respond immediately and grow tall and dense, in striking contrast to the shorter grasses in the savannah. The type of vegetation has been referred to as "wooded steppe with abundant acacias and commiphoras" by Keay (1959) and Moreau (1966), it is also present in parts of east and southern Africa.

The vertebrate richness is mainly restricted to birds. During this study, in which the main bird concentration areas were only superficially censused, over 240 different species were identified (annex XIII-31). Of the larger mammalian fauna, however, only 15 species are left, the most important being Warthog, Dama-gazelle and Jackal. The invertebrate fauna is rich.

**Table I.5:** Tree densities (number per hectare) counted in 4 to 10 ha areas within study plots.

Species	PLOT				
	A	B	C	D	E
<i>Balanites aegyptiaca</i>	29.6	7.6	26.2	11.0	29.0
<i>Boscia senegalensis</i>	43.4	28.6	23.6	29.0	15.4
<i>Acacia spp.</i>	5.2	16.2	11.2	23.8	5.4
<i>Salvadora persica</i>	2.6	-	-	-	-
<i>Combretum glutinosum</i>	0.4	0.4	0.2	0.8	1.0
<i>Grewia bicolor</i>	1.4	-	-	-	-
<i>Cadaba farinosa</i>	0.4	0.1	-	-	-
<i>Commiphora africana</i>	0.4	0.3	-	-	-
<i>Zizyphus mauritiaca</i>	0.6	0.7	-	-	-
<i>Adansonia digitata</i> <sup>1</sup>	-	-	-	0.5	-
Total	84.0	53.9	61.2	65.1	50.8

<sup>1</sup> This species is widely, but thinly, distributed and occurred on all study plots; estimated density: 5 - 10 trees per 1.000 ha

The Senegal River flows through a broad valley which covered, at peak floods, 5000 km<sup>2</sup>. Most of these inundations do not occur anymore, however, due to the flood control of the Manantali dam and dams alongside the river. After the drought of the early eighties fish populations were decimated. The loss of wetlands has partly been compensated by the creation of irrigation schemes. The aquatic fauna is further described in Chapters IV and V.

The human population in the area is mainly Wolof (farmers) with minorities of Fulani (semi-nomadic) and Mauritians (fully nomadic). Crops in the savannah area are millet, cowpea, coudges and groundnuts; on the lower lands near to the river vegetables, sorghum, irrigated rice (20.000 ha) and sugar (7.500 ha) are cultivated. During the rainy season non-moving herds of zebu are present all over the savannah area (1 unit per 12 ha). During the dry season the area is an important transhumance zone.

## References

Basedow Th (1973) Der Einfluss epigäischer Raubathropoden auf die Abunbanz phytophager Insekten in der Agrarlandschaft. *Pedobiol* 13: 410-422

Bille JC, Lepage M, Morel G & Poupon H (1972) Recherches écologiques sur une savane sahéenne du Ferlo Septentrional, Sénégal. *Présentation de la région. Terre et Vie* 26:332-350

Bille JC & Poupon H (1972) Recherches écologiques sur une savane sahéenne du Ferlo Septentrional, Sénégal. *Description de la végétation. Terre et Vie* 26:351-365

Bourlière F (Ed) (1972) Recherches écologiques sur une savane sahéenne du Ferlo Septentrional, Sénégal. *Terre et Vie* 26:325-472

Crossland NO (1988) Experimental design of pond studies. In: Greaves MP, Greig-Smith PW and Smith BD: Field methods for the study of environmental effects of pesticides. BCPC Mono. 40:231-236

DYNAMAC Corp (1988) Results of the Mali pesticide testing trials against the Senegalese Grasshopper. Final Technical Report. Dynamac Corp, 11140 Rockville Pike, Rockville, MD 20852, USA

DYNAMAC Corp (1988) Results of the locust pesticide trials in Sudan. Technical Report. Dynamac Corp, 11140 Rockville Pike, Rockville, MD 20852, USA

Edwards CR & Huddleston EW (1986) Efficacy and environmental effects of large plane and small plane operations in Senegal and proposed plan for gathering information for 1987 environmental assessment. Prepared for USAID, supported by CACP

Everts JW (1983) Animal indicators for side-effects of chemical vector control. *Environ Monitor Assess* 3:229-236

Everts JW, van Frankenhuyzen K, Román B and Koeman JH (1983) Side-effects of experimental pyrethroid applications for the control of tsetseflies in a riverine forest habitat (Africa). Arch Environ Contam Toxicol 12:91-97

Everts JW and Koeman JH (1987) The ecological impact of insecticides in connection to the control of tsetse flies in Africa: a review. In: Cavalloro R(Ed): Integrated tse-tse fly control: methods and strategies. Rotterdam. pp. 49-56

Everts JW, B Aukema, R Hengeveld and JH Koeman (1989) Side-effects on ground-dwelling predatory arthropods in arable ecosystems. Env Poll 59:203

FAO (1985) River Fisheries. FAO Fisheries Techn Pap. 262:330pp

FAO (1989) Report of the working group on environmental side-effects of desert locust control; 14-16 February 1989. FAO, Rome

Frederickson CJ, M Balmat, PA Oomen & W Overholt (1986) Project joint FAO/donor review of the 1986 grasshopper campaign in the Sahel. Team report for Senegal. FAO Rome.

Gordon K (1981) The fate of fenitrothion in the environment and its effects on organisms. Australian Plague Locust Commission Techn. Rep. # 3

Grant IF (1989) Environmental effects of desert locust control. FAO Plant Prot Bull 37:27-35

Hofman T (1988) Application of diflubenzuron (Dimilin ODC-45) for control of desert locust in Senegal. Duphar BV DOC. # 56647/06/88

Jepson PC (1988) Ecological characteristics and the susceptibility of non-target invertebrates to long-term pesticide side-effects. In: Greaves MP *et al.*(Eds) Field methods for the study of environmental effects of pesticides. BCPC Mono. 40:191

Keay RWJ (1959) Vegetation map of Africa. Oxford University Press, London

Koeman JH, Den Boer WMJ, Feith AF, De Iongh HH and Spliethoff PC (1978) Three years' observations on side-effects of helicopter applications of insecticides used to exterminate Glossina species in Nigeria. Environ Pollut 15:31-59

Le Houérou HN (1989) The grazing land ecosystems of the African Sahel. Ecological Studies # 75, Springer, Heidelberg, New York.

Lepage M (1972) Recherches écologiques sur une savane sahélienne du Ferlo Septentrional, Sénégal. Données préliminaires sur l'écologie des termites. Terre et Vie 26:383-409

Marshall WK & Roberts JR (1978) Ecotoxicology of Chlorpyrifos. NRCC Publ. # 16079, 126pp

McEwen LC (1981) Review of grasshopper pesticides vs. rangeland wildlife and habitat. In: Proc Wildlife-Livestock Relationships Symposium, Coeur d'Alene, Idaho US April 20-22,

1981

Moreau RE (1966) The bird fauna of Africa and its islands. Academic Press, New York

Morel G & Morel MY (1972) Recherches écologiques sur une savane sahélienne du Ferlo Septentrional, Sénégal. L'avifaune et son cycle annuel. Terre et Vie 26:410-439

Morel G & Morel MY (1988) Oiseaux de Sénégal. Liste de présence par degré-carré. ORSTOM, Station d'Écologie, Richard Toll, Sénégal

Müller P and Nagel P (1980) Oekologischer Einfluss von Tsetsefliegen bekämpfung mit Dieldrin im Hochland von Adamaoua (Kamerun). Amazonia 7:31-48

Niassy A & Diatta F (1987) Rapport d'évaluation du traitement aérien contre les sautériaux effectué dans la région de Kaolack (NGanda et Nioro) du 23 au 25 Juillet 1987. Rapport DPV, Dakar, Senegal

Odenkirchen EW & Eisler R (1988) Chlorpyrifos hazards to fish, wildlife and invertebrates. A synoptic review. USDI Fish & Wildl. Serv., Contaminant Hazard Rev. #13, 34pp

Ottesen P & Sømme L (1987) Environmental effects of insecticides against grasshoppers and locusts. Rep. to Roy. Norw. Min. Dev. Coop., Univ. of Oslo, 44pp

Smies M, Evers RHJ, Peynenburg FHM and Koeman JH (1980) Environmental aspects of field trials with pyrethroids to eradicate tsetse fly in Nigeria. Ecotox Environ Safe 4:114-128

Smith KD & Popov GB (1953) On birds attacking desert locust swarms in Eritrea. Entomol 86:3-7

Sotherton NW, Jepson JP and Pullen AJ (1988) Criteria for the design, execution and analysis of terrestrial, non-target invertebrate field tests. In: Greaves MP, Greig-Smith PW and Smith BD: Field methods for the study of environmental effects of pesticides. BCPC Mono. 40:183-190

Southwood TRE (1978) Ecological methods, with particular reference to the study of insect populations. London, 524 pp

Stewart-Oaten A, Murdoch WW, Parker KR (1986) Environmental impact assessment: "pseudoreplication" in time? Ecology 67(4):929-940

Stortenbeker CW (1967) Observations on the population dynamics of Red Locust *Nomadacris septemfasciata* (Serville) in its outbreak area. PUDOC Afr. Res. Rep. 694:110pp

Sunderland KD (1987) Spiders and cereal aphids in Europe. Bull IOBC/WPRS X:82-102

Takken W, Balk F, Jansen R and Koeman JH (1978) The experimental application of insecticides from a helicopter for the control of riverine populations of Glossina tachinoides in West Africa. VI. Observations on side-effects. Pest Agr News Summary 24:455-466

TAMS Consultants Inc & CICP (1989) Locust and Grasshopper control in Africa/Asia. A Programmatic Environmental Assessment. New York/Washington DC

Van der Valk HCHG (1988) Environmental impact of dieldrin applications in locust control; a hazard assessment. Working paper meeting FAO/ECLO Rome 21 Oct 1988. FAO, Rome

Van Lavieren B & Van Wetten JCJ (1988) Profil de l'environnement de la vallee du Fleuve Senegal. Euroconsult/RIN, Arnhem 159pp

Varty IW (ed)(1980) Environmental surveillance in New Brunswick, 1978-1979. Effects of spray operations for forest protection against Spruce Budworm. Depr. Forest Resources, Univ, Nw Brunswick Fredericton, N.B., Canada 76pp



## **PART 2**

## **PESTICIDE APPLICATION**

## CHAPTER II

## PESTICIDE APPLICATION

Richard J. Courshee

### Objective

The purpose of the work was to ensure that the three chemicals (fenitrothion, chlorpyrifos and diflubenzuron at standard rates to land and water and at double rates also to land) were applied correctly and in a manner characteristic of locust control operations, so that any environmental effects that they might show in the test could be expected to occur similarly in practice.

### Treatments and Plots

Plot sizes were 3x2 km for the organophosphates and 2x2 km for the insect growth regulator. For these a spacing between aircraft runs of 100 m was chosen with a flying height of 10-15 m usually but up to 25 m where tall trees needed to be evaded.

Table II.1: Products and formulations

Products	Nominal Dose g ai/ha		Formulation	Quantity l/ha
Fenitrothion	500	1000	500 g/l ULV	1 and 2
Chlorpyrifos	225	450	450 g/l ULV	0.5 and 1
Diflubenzuron	45	90	90 g/l in diesel	0.5 and 1

The treatments of water were made on lakes with surface areas of 16 to 30 ha and a track spacing of 50 m was chosen together with a flying height of 5 m (atomizer to water surface) to reduce drift of spray onto the surrounding banks.

At a nominal flying speed of 50 m/s the corresponding spray outputs for the treatments are given in Table II.2.

**Table II.2.** Flow rate required (l/s)

Application Rate l/ha	Track Spacing (m)	
	50	100
0,5	0,125	0,25
1	0,25	0,5
2	0,5	1

Thus we had to calibrate in principle for four flow rates and three viscosities and compensate approximately for corresponding changes in atomizer speed even at one aircraft speed.

### Equipment and Settings

A Britten Norman Islander aircraft fitted with electric pumps, two under-wing pesticide tanks and two AU4000 Micronair rotary atomisers with short twisted blades was hired from the Plant Protection Service of Mali. Flow control was ensured by a multiple hole disc and a pump bypass. In view of the need to change flow rates daily, it was decided that we could not use the uncalibrated bypass valve.

Accordingly we were restricted to using the holes in the disc numbered 7, 11 and 13 which at full pump pressure (with small changes due to different viscosities of the three formulations) gave flow rates of 3.5, 9.2 and 15.5 l/min per atomizer (instead of the required 3.75, 7.5 and 15 l/min per atomizer).

It was not practicable to alter the pre-determined track spacing, once all the trees indicating the ends of the runs were premarked, so the aircraft was flown at a range of speeds 45 m/s to 52 m/s to provide the required application rates at the fixed output rates. Because a 2 l/ha volume application rate with a run spacing of 100 m is not possible with this equipment two consecutive 1 l/ha applications were made when fenitrothion was applied at double dose.

An attempt was made to retain rotational speed of the short twisted blades at between 7,500 and 10,000 rpm to give a drop size of 90 - 100 $\mu$ m vmd (based on data manufacturer), by altering the blade angle over the range 40 to 50 degrees.

### Calibration

The output of the aircraft was calibrated in three independent ways to ensure that no mistakes were made on the single available plots. Three people: the pumping supervisor, the pilot and the person responsible for flagging kept independent records of all operating parameters to which they had access, to provide cross checks.

Calibration of output was done:

- 1) by operating the electric pumps and measuring the output per minute on the ground
- 2) by recording the instantaneous flow rate and total flow through each Micronair on the built-in flow meters in flight
- 3) by measuring the amount of liquid put into the aircraft and withdrawn from it after application. The discrepancy between the several measures was less than 10% (Table II.3).

Operating settings were as follows:

Wind speed > 2 m/s at 1.5 m height

Wind direction within 30 degrees from perpendicular to plane's path

Flying height 10-15 m (to 25 m) over ground, 5 m over the lakes

Track spacing 100 m over the ground, 50 m over the lakes

Blade angle 40-45 degrees over the ground, 50 degrees over the lakes

Micronair speed 7,500-10,300 rpm

Flow Disc settings 7, 11 and 13

Pump pressure Maximum, no measurement

The known Micronair speed and flow rate ensured that the drop spectrum was typical of routine operations. This spectrum coupled with known flying height and sufficient wind speed to generate turbulence, in turn assured a typical downwind distribution of droplets.

### **Plot Location, Track Marking and Flagging**

The plot corners were marked by a survey team from the CSS Sugar Company, and their distances from particular points - usually where tracks crossed - was recorded.

To make track guidance rapid and sure, trees were marked with white paint every 100 m on four sides (560 trees). Flags 1 m<sup>2</sup> on white vehicles were moved from one marked tree to another to guide the airplane in each pass. A red flag indicated that the plot was being entered and, at a white flag, the airplane left the plot.

The treatment data are given in Table II.3

## Discussion

Only the short twisted blades were available for the Micronairs. These absorb inadequate power from the slipstream to maintain a constant rotational speed, at a fixed blade angle, when the flow rate varies from 3.5 to 15.5 l/min and the flying speed varies by 18%. Long twisted blades should be available in future.

Atomization, recovery and distribution across the swath could not be measured, given the limits on time and manpower, with sufficient precision to justify making the measurements. We could only have obtained limited readings which, in view of the variability of Micronair speed, wind speed, tree cover (0.1-10%) and vegetation density (estimated 1.0-10 tons/ha) would have a very low chance of representing the average for each plot. Accordingly such limited measurements without precisely determined confidence limits might have been unrepresentative and uninformative. Rudimentary measurement of the distribution in one tiny part of the plots would not increase our substantial knowledge of where the droplets fell. Spray recovery and deposit density on the vegetation are likely to be dependent on the form and density of the trees and grass cover. Neither was measured however. The task again was beyond our resources and would be unduly large and expensive for the purposes of this preliminary trial of pesticide effects on wildlife.

Despite the preparatory work by CSS surveyors, the plot boundaries were difficult to locate on the ground during the first week. And in the absence of air to ground radios it was also laborious and slow for the pilot sometimes to find the 4 or 6 km<sup>2</sup> plots, 10 to 20 km apart. Because of the tree cover and undulating ground levels, the flags were sometimes not visible either to the pilot or to his navigator (deemed essential for safety and allowing the pilot to fly without having to search). For lack of radios we could not guide the pilot from the ground; one signalling mirror gave the pilot some guidance during his turn at the far end of the plot on most days.

This part of the work was successful but very time consuming and quicker ways of navigating and marking and surer ways of guiding the aircraft are needed.

## Conclusion and Future Improvements

The different applications were carried out satisfactorily. In future however we need:

- 1) better marking and guidance (mirrors)
- 2) radios with approved frequencies
- 3) 4 Micronairs fitted with long twisted blades
- 4) calibrated pump by-pass valve
- 5) mechanized loading
- 6) backup plane and pilot
- 7) square blocks
- 8) planning of treatments to increase the number of application variables which can be left unchanged between sprays.

**Table II.3: Treatment data**

Plot	Time	Date	Product	Rate l/ha	Treated Area ha	Volume Used l	Dose g/ha	Applied l/ha	Micronair Speed rpm x 10 <sup>3</sup>	Flow Meter Reading <sup>1</sup> l/min
D	09.40- 10.30	5/9	Chlorpyrifos	0,5	530	320	270	0,60	8	8.7;9.7
3 <sup>2</sup>	17.40- 18.15	5/9	„	0,5	30	17	257	0,57	7.5	3.0;4.0
4 <sup>2</sup>	15.55- 16.25	7/9	Fenitrothion	1,0	18	20	550	1,1	9.5	8.0;9.0
E	09.25- 10.40	7/9	Chlorpyrifos	1,0	600	513	387	0,86	9	15.3;16.7
A	09.35- 11.17	8/9	Fenitrothion	1,0	600	585	485	0,97	9-10	15.5;16.6
F	10.55- 12.45	9/9	Diflubenzuron	1,0	400	385	82,8	0,92	9.2-10.3	14.5;15.5
2 <sup>2</sup>	16.10- 16.40	9/9	„	0,5	16	15	39,6	0,44	n.r. <sup>3</sup>	n.r.
G	09.40- 11.15	10/9	„	0,5	400	170	37,8	0,42	n.r.	8,4;9,5
B	09.10- 12.00	12/9	Fenitrothion	2,0	600	990	825	1,65	7.6-9.0	15.5;16.9; 15.3;17.1

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<sup>1</sup> per flow meter

<sup>2</sup> lake numbers

<sup>3</sup> not recorded

## **PART III**

## **CHEMICAL MONITORING**

### Introduction

Le projet ECLO/SEN/003/NET intitulé "Effet sur l'environnement de la lutte antiacridienne" a consisté en une expérimentation de plein champ classique, caractérisée essentiellement par l'importance des surfaces traitées et par l'intervention d'une équipe pluridisciplinaire. Le Laboratoire de Chimie Analytique et Toxicologie (LCAT) de la Faculté de Médecine et Pharmacie de l'Université Cheick Anta Diop (UCAD) a représenté l'Institut des Sciences de l'Environnement (ISE) de la Faculté des Sciences pour s'occuper de l'analyse chimique pour la recherche et le dosage des résidus de pesticides et pour l'analyse d'un paramètre biochimique: la détermination de l'activité cholinestérasique.

Les analyses toxicologiques, complétées par d'autres consistant en des études de toxicité directe et de toxicité indirecte sont indispensables pour une évaluation correcte des risques.

En effet, si les analyses des résidus des pesticides s'imposent d'elles-mêmes pour comprendre les résultats des évaluations de la mortalité pendant et après les traitements, elles ne suffisent pas pour expliquer l'importance de l'effet toxique sur l'environnement et les possibilités de récupération des organismes vivants sensibles aux pesticides.

Le choix de l'activité cholinestérasique comme paramètre biochimique va dans ce sens et se justifie par l'utilisation d'insecticides organophosphorés dans cette étude.

### A. Analyses des résidus

#### Materiel, Méthodes et Programmes

##### Analyse chimique

##### *Les pesticides*

Au nombre de trois, les pesticides sont utilisés à deux concentrations (données de Chapitre II):

Fénitrothion pour les parcelles A et B aux doses de:

- 485 g ma/ha
- 825 g ma/ha

Chlorpyrifos pour les parcelles D et E aux doses de:

- 270 g ma/ha
- 387 g ma/ha

Diflubenzuron pour les parcelles G et F aux doses de:

- 37.8 g ma/ha
- 82.8 g ma/ha

La parcelle C a servi de témoin. De plus amples informations sur les traitements appliqués, les situations des parcelles et leurs caractéristiques sont fournies par J.W. Everts et R.J. Courshee dans leurs rapports (Chapitres I et II).

### *Les prélèvements*

Les prélèvements constitue une étape fondamentale puisqu'il conditionne les résultats de l'analyse toxicologique. Les seuls prélèvements concernés pour le dosage de résidus de pesticides ont été de l'herbe. Ils ont été effectués sur chacune des parcelles le jour du traitement et les jours suivants; la parcelle C servant de témoin non traité.

Le principe retenu a consisté, pour chaque dose de pesticide et tous les jours de prélèvement, à prélever de l'herbe tous les cent mètres à partir de la médiane de chaque parcelle sur une distance de 1,5 kilomètre.

Chaque prélèvement est homogénéisé au laboratoire situé à une douzaine de kilomètres et réparti en sachets de poids connu dans du papier d'aluminium. Tout contact avec des matières plastiques a été évité. La conservation est assurée dans un congélateur à

-20°C. Le problème qui s'est posé a été de pouvoir tenir compte de toute dégradation éventuelle des pesticides avant analyse. Il a été retenu le principe de la constitution de lots contenant des quantités connues de pesticides et conservés dans les mêmes conditions afin que, le cas échéant, il soit possible de suivre la courbe d'évolution de la dégradation de chaque produit. Cette précaution a l'avantage de permettre de s'assurer de la fiabilité des résultats qui seront obtenus pour l'analyse des échantillons.

C'est ainsi que, pour chaque dose de pesticide, nous avons eu à procéder de la manière suivante:

#### **1. Prélèvement d'échantillons témoins a partir de la parcelle C**

Un certain nombre de ces échantillons témoins a été surchargé avec des quantités connues de pesticides. Ces échantillons ont été conditionnés en plusieurs sachets de 20 grammes et un grand sachet d'environ 200 grammes.

#### **2. Prélèvement d'échantillons sur chaque parcelle**

Un certain nombre d'entre eux a été également surchargé avec des quantités connues de pesticides. Ces échantillons ont été conditionnés en plusieurs sachets de 20 grammes et un sachet d'environ 200 grammes (voir Annex III.3 à III.5).

### *L'Analyse des échantillons*

Les analyses ont été effectuées par:

- le Département de Chimie Organique de l'Université Agronomique de Wageningen, Pays Bas, pour le Chlorpyrifos et le Fénitrothion;
- les laboratoires Duphar aux Pays Bas pour le Diflubenzuron.

### *Méthodes de dosage*

Le Chlorpyrifos et le Fénitrothion, pesticides organophosphorés, ont été dosés par chromatographie en phase gazeuse avec détecteur à capture d'électrons, selon la méthode donnée en Annexe III.1.

Pour le Diflubenzuron, la méthode utilisée a été la Chromatographie Liquide Haute Performace suivant la technique appliquée pour les pommes et les poires (Annexe III.2).

### *Résultats*

Les résultats des dosages de résidus de Chlorpyrifos et de Fénitrothion figurent aux Tableaux III.1 et III.2.

Les résultats des dosages de résidus de Diflubenzuron sont reportés au tableau 3 ci-dessous.

**Tableau III.1:** Résultats des analyses des échantillons d'herbe. Les numéros H et Z sont les codes des prélèvements. Concentrations en mg/kg d'herbe sèche et extraïée.

D,5/9,270	4 heures	1 jour	2 jours	4 jours
chlorpyrifos	H62 31	H64 12	H66 12	H68 3
	H63 35	H65 14	H67 11	H69 5
	Y1 34	Y2 13	Y3 12	Y4 4
E,7/9,387	2 heures	1 jour	2 jours	4 jours
chlorpyrifos	H70 67	H72 20	H74 28	H76 12
	H71 64	H73 23	H75 25	H77 20
	Y5 60	Y6 27	Y7 20	Y8 10
A,8/9,485	2 heures	1 jour	2 jours	4 jours
fénitrothion	H78 86	H80 46	H82 29	H84 31
	H79 143	H81 57	H83 36	H85 41
	Z1 63	Z2 34	Z3 15	Z4 26
B,12/9,825	5 heures	1 jour	2 jours	4 jours
fénitrothion	H102 130	H104 94	H106 55	H108 12
	H103 125	H105 68	H107 37	H109 12
	Z5 51	Z6 32	Z7 26	Z8 7

**Tableau III.2:** Résultats des analyses des échantillons surchargés d'herbe.

Chlorpyrifos code	conc. <sup>1)</sup>	Fénitrothion code	conc.
J	-		4.11
H1	-		7.76
H12	-		6.75
H13	2		
H14	7	H3	12
H15	81	H4	163
H16	69	H5	160
H17	17	H6	98
H18	17	H7	86
H19	20	H8	57
H20	20	H9	53
H21	10	H10	29
H22	13	H11	43
H23	106	H31	131
H24	108	H32	77
H25	46	H33	46
H26	41	H34	57
H27	34	H35	59
H28	35	H36	51
H29	19	H37	24
H30	21	H38	22

<sup>1)</sup> en mg/kg d'herbe sèche et extraquée

**Tableau III.3: Dosages du Diflubenzuron par la Société Duphar.**

Parcelle	Echantillon	Teneur/Temps g ma/ha	Concentrations éch.humide	(mg/kg) sec
F	X		0.08	0.18
F	X1	82.8 / 2H	14.3	51.0
F	X2	82.8 / 3J	11.8	42.2
F	X3	82.8 / 7J	7.1	25.4
F	H92	82.8 / 15J	2.7	7.4
F	H50	82.8 / 32J	2.9	4.2
G	X4	37.8 / 1J	2.8	10.3
G	X5	37.8 / 3J	3.6	12.4
G	X6	37.8 / 7J	2.7	8.9
G	X100	37.8 / 14J	1.8	4.4
G	X60	37.8 / 30J	0.9	1.8
C *	H40		0.38	
C *	H41		0.85	

Parcelle F: 80 g ma/ha

Parcelle G: 37.8 g ma/ha

\* Témoins surchargés

### Discussion des résultats

L'analyse des résidus de pesticides avait un double objectif:

1. évaluer les quantités réelles de pesticides appliquées et les rémanences dans les conditions de l'expérimentation;
2. évaluer l'influence des conditions de conservation sur les teneurs réelles en résidus de pesticides.

Ce souci majeur nous a conduit à présenter les résultats obtenus avec le Fénitrothion et le Chlorpyriphos sous forme de tableaux par parcelles.

Tableau III.4: Parcelle A

Tableau III.5: Parcelle B

Tableau III.6: Parcelle D

Tableau III.7: Parcelle E

Cette présentation a permis pour le chlorpyriphos et le fénitrothion de tracer la dégradation dans le temps (Figure III.2).

**Tableau III.4:** Comparaison des résultats de la Parcelle A:  
Fénitrothion 485 g ma/ha

1. Echantillons ayant la même concentration

Temps après traitement	Echantillon	Poids (g)	Code	Concentration (mg/kg)
2 H.	H78	20	C1	86
2 H.	H79	20	C1	143
2 H.	Z1	210	C1	63
24 H.	H80	20	C2	46
24 H.	H81	20	C2	57
24 H.	Z2	210	C2	34
48 H.	H82	20	C3	29
48 H.	H83	20	C3	36
48 H.	Z3	315	C3	15
4 J.	H84	20	C4	31
4 J.	H85	20	C4	41
4 J.	Z4	220	C4	26

2. Témoins surchargés

Echantillons	Concentration théorique (mg/kg)	Concentration mesurée (mg/kg)
H 1      0 mg/kg	0	7,76
H 2 = H1 + 2 mg/kg	2	
H 3 = H1 + 5 mg/kg	5	12

3. Echantillons surchargés

Echantillon	Concentration théoriques (mg/kg)	Concentration mesurée (mg/kg)
H 4 = H78 + 2 mg/kg	88	163
H 5 = H79 + 5 mg/kg	148	160
H 6 = H80 + 2 mg/kg	48	98
H 7 = H81 + 5 mg/kg	62	86
H 8 = H82 + 5 mg/kg	33	57
H 9 = H83 + 5 mg/kg	41	53
H10 = H84 + 2 mg/kg	33	29
H11 = H85 + 5 mg/kg	46	43

Nb. \* aucun résultat

H1 (20 g) provient de la Parcelle C qui est la parcelle témoin.

**Tableau III.5:** Comparaison des résultats de la parcelle B:  
Fénitrothion 825 g ma/ha

**1. Echantillons ayant la même concentration**

Temps après Traitement	Echantillon	Poids (g)	Code	Concentration (mg/kg)
5 H.	H102	20	C5	130
5 H.	H103	20	C5	125
5 H.	Z5	190	C5	51
24 H.	H104	20	C6	94
24 H.	H105	20	C6	68
24 H.	Z6	192	C6	32
48 H.	H106	20	C7	55
48 H.	H107	20	C7	37
48 H.	Z7	255	C7	26
4 J.	H108	20	C8	12
4 J.	H109	20	C8	12
4 J.	Z8	185	C8	7

**2. Témoins surchargés**

Echantillon	Concentration théorique (mg/kg)	Concentration mesurée (mg/kg)
H1	0 mg/kg	7,76
H2 = H1 +	2 mg/kg	*
H3 = H1 +	5 mg/kg	12

**3. Echantillons surchargés**

Echantillon	Concentration théorique (mg/kg)	Concentration mesurée (mg/kg)
H31 = H102 +	2 mg/kg	131
H32 = H103 +	5 mg/kg	77
H33 = H104 +	2 mg/kg	46
H34 = H105 +	5 mg/kg	57
H35 = H106 +	5 mg/kg	59
H36 = H107 +	2 mg/kg	51
H37 = H108 +	2 mg/kg	24
H38 = H109 +	5 mg/kg	22

Nb. \* aucun résultat

H1 (20 g) provient de la parcelle C qui est la parcelle témoin.

**Tableau III.6:** Comparaison des résultats de la parcelle D:  
Chlorpyriphos 270 g ma/ha

1. Echantillons ayant la même concentration

Temps après traitement	Echantillon	Poids (g)	Code	Concentration (mg/kg)
4 H.	H62	20	C9	31
4 H.	H63	20	C9	35
4 H.	Y1	260	C9	34
24 H.	H64	20	C10	12
24 H.	H65	20	C10	14
24 H.	Y2	240	C10	13
48 H.	H66	20	C11	12
48 H.	H67	20	C11	11
48 H.	Y3	20	C11	12
4 J.	H68	20	C12	3
4 J.	H69	20	C12	5
4 J.	Y4	170	C12	4

2. Témoins surchargés

Echantillons	Concentration théorique (mg/kg)	Concentration mesurée (mg/kg)
H12	0 mg/kg	6,75
H13 = H12 +	2 mg/kg	2
H14 = H12 +	5 mg/kg	7

3. Echantillons surchargés

Echantillons	Concentration théorique (mg/kg)	Concentration mesurée (mg/kg)
H15 = H62 +	2 mg/kg	81
H16 = H63 +	5 mg/kg	69
H17 = H64 +	2 mg/kg	17
H18 = H65 +	5 mg/kg	17
H19 = H66 +	2 mg/kg	20
H20 = H67 +	5 mg/kg	20
H21 = H68 +	2 mg/kg	10
H22 = H69 +	5 mg/kg	13

Nb. H12 (20 g) provient de la parcelle C qui est la parcelle témoin.

**Tableau III.7:** Comparaison des résultats de la Parcelle E:  
Chlorpyriphos 387 g ma/ha

1. Echantillons ayant la même concentration

Temps après traitement	Echantillon	Poids (g)	Code	Concentration (mg/kg)
2 H.	H70	20	C13	67
2 H.	H71	20	C13	64
2 H.	Y5	210	C13	60
24 H.	H72	20	C14	20
24 H.	H73	20	C14	23
24 H.	Y6	237.8	C14	27
48 H.	H74	20	C15	28
48 H.	H75	20	C15	25
48 H.	Y7	180	C15	20
4 J.	H76	20	C16	12
4 J.	H77	20	C16	20
4 J.	Y8	275	C16	10

2. Témoins surchargés

Echantillon	Concentration théorique (mg/kg)	Concentration mesurée (mg/kg)
H12	0 mg/kg	6,75
H13 = H12 +	2 mg/kg	2
H14 = H12 +	5 mg/kg	7

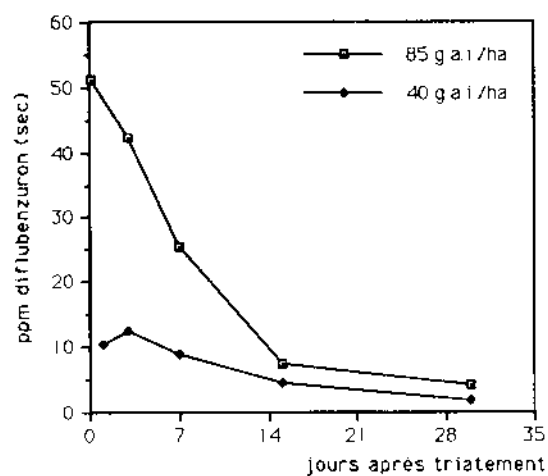
3. Echantillons surchargés

Echantillon	Concentration théorique (mg/kg)	Concentration mesurée (mg/kg)
H23 = H70 +	2 mg/kg	106
H24 = H71 +	5 mg/kg	108
H25 = H72 +	2 mg/kg	46
H26 = H73 +	5 mg/kg	41
H27 = H74 +	2 mg/kg	34
H28 = H75 +	5 mg/kg	35
H29 = H76 +	2 mg/kg	19
H30 = H77 +	5 mg/kg	21

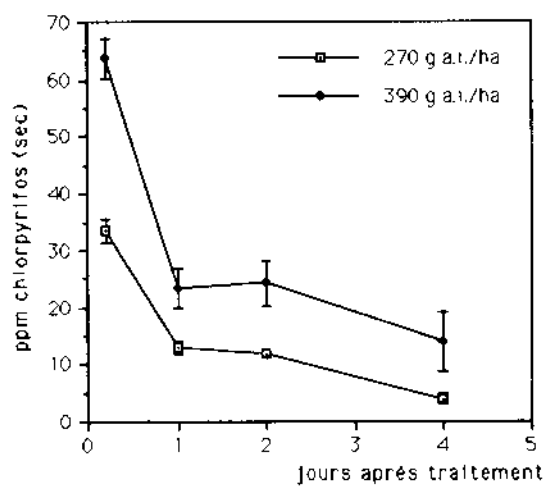
Nb. H12 (20 g) provient de la parcelle C qui est la parcelle témoin.

**Figure III.1:** La dégradation dans le temps du fénitrothion, du chlorpyrifos et du diflubenzuron.

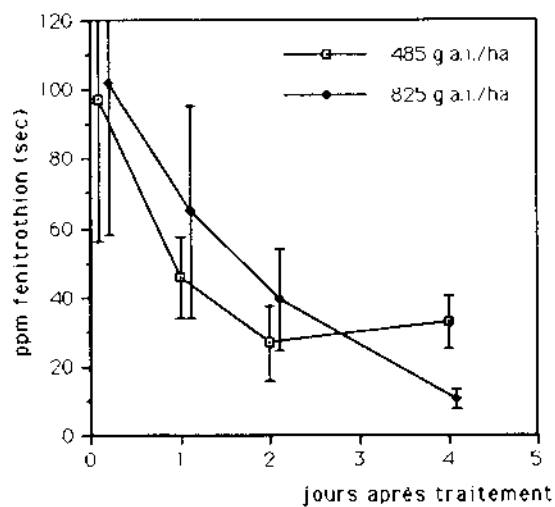
a: Dégradation des résidues de diflubenzuron sur herbe



b: Dégradation des résidues de chlorpyrifos sur herbe



c: Dégradation des résidues de fenitrothion sur herbe



Discussion des résultats obtenus avec le Fénitrothion et le Chlorpyrifos  
L'Etude des tableaux et des graphiques (fig. III.1 et III.2) permet de noter:

A. Pour des échantillons identiques mais répartis en deux sachets de 20 grammes et un sachet d'environ 200 grammes, les résultats obtenus sont parfois très différents. Par exemple:

Pour le Fénitrothion dosé à 485 g ma/ha (Parcelle A)

C1 a trois valeurs	:	86,	143	et	63
C2 a trois valeurs	:	46,	57	et	34
C3 a trois valeurs	:	29,	36	et	15
C4 a trois valeurs	:	31,	41	et	26

Pour le Fénitrothion dosé à 825 g ma/ha (Parcelle B)

C5 a trois valeurs	:	31,	35	et	34
C6 a trois valeurs	:	12,	14	et	13
C7 a trois valeurs	:	12,	11	et	12
C8 a trois valeurs	:	3,	5	et	4

Pour le Chlorpyrifos dosé à 387 g ma/ha (Parcelle E)

C9 a trois valeurs	:	67,	64	et	60
C10 a trois valeurs	:	20,	23	et	27
C11 a trois valeurs	:	28,	25	et	20
C12 a trois valeurs	:	12,	20	et	10

Ainsi donc, il apparaît que les résultats obtenus avec le chlorpyrifos sont beaucoup plus reproductibles, avec une excellente précision. Ce n'est malheureusement pas le cas pour le Fénitrothion.

Par ailleurs, il est intéressant de noter que pour les deux pesticides, la biodégradation est nette. Quatre jours après le traitement, les quantités moyennes de pesticides retrouvées dans l'herbe sont respectivement de:

Parcelle A: (Fénitrothion 485 g ma/ha): 32 mg/kg  
Parcelle B: (Fénitrothion 825 g ma/ha): 10 mg/kg  
Parcelle D: (Chlorpyrifos 270 g ma/ha): 4 mg/kg  
Parcelle E: (Chlorpyrifos 387 g ma/ha): 14 mg/kg

Les chiffres du Chlorpyrifos sont cependant plus crédibles que ceux du Fénitrothion. En effet, la parcelle B qui reçoit une dose de pesticide deux fois plus élevée que celle de la parcelle A, présente après quatre jours, un taux de résidus nettement plus faible (10 mg/kg contre 32 mg/kg).

B. Pour les témoins surchargés:

1. Les résultats obtenus avec le Fénitrothion montrent une nette différence entre les valeurs théoriques et les valeurs trouvées:

	H1	H2	H3
Concentration théorique (mg/kg)	0	2	5
Résultats du laboratoire (mg/kg)	7,76	*	12

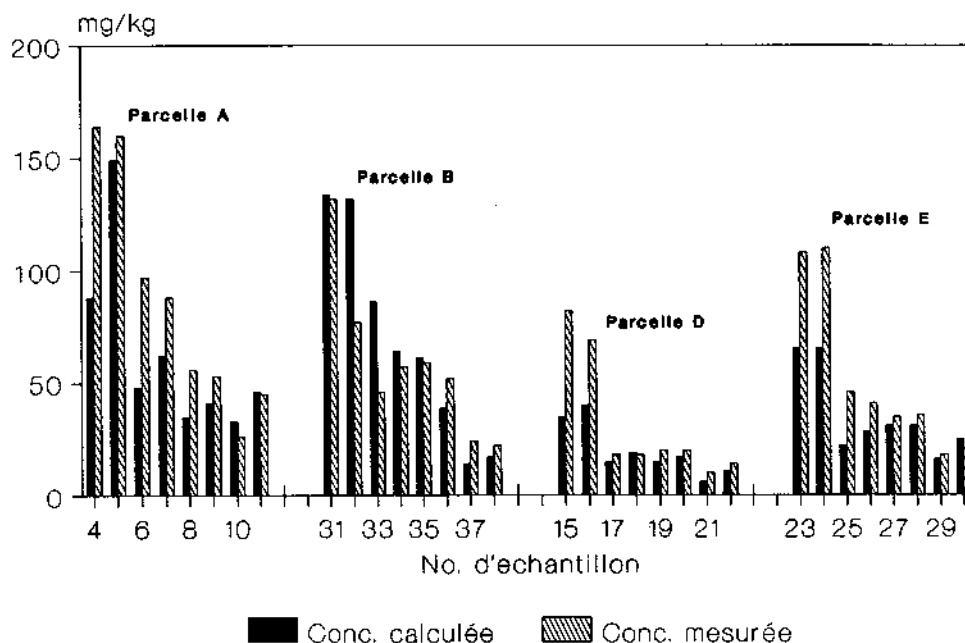
\* aucun résultat

Il est à noter que les témoins surchargés sont les mêmes pour les parcelles A et B.

2. Les résultats obtenus avec le chlorpyrifos sont encore une fois d'une très grande précision, sauf pour une mesure:

	H12	H13	H14
Concentration théorique (mg/kg)	0	2	5
Résultats du laboratoire (mg/kg)	6,75	2	7

**Figure III.2:** Comparaison des mesures dans échantillons surchargés H4 à H38



C. Pour les échantillons des parcelles, il y a, là aussi, de grandes différences entre les valeurs théoriques et les valeurs trouvées:

Parcelle A: (Fénitrothion 485 g ma/ha)

Echantillon	Concentration théorique (mg/kg)	Concentration trouvée (mg/kg)
H4	88	163
H5	148	160
H6	48	98
H7	62	86
H8	34	57
H9	41	53
H10	33	29
H11	46	43

Parcelle B: (Fénitrothion 825 g ma/ha)

Echantillon	Concentration théorique (mg/kg)	Concentration trouvée (mg/kg)
H31	132	131
H32	130	77
H33	96	46
H34	73	57
H35	60	59
H36	39	51
H37	14	24
H38	17	22

Parcelle D: (Chlorpyriphos 270 g ma/ha)

Echantillon	Concentration théorique (mg/kg)	Concentration trouvée (mg/kg)
H15	33	81
H16	40	69
H17	14	17
H18	19	17
H19	14	20
H20	16	20
H21	5	10
H22	10	13

Parcelle E: (Chlorpyrifos 387 g ma/ha)

Echantillon	Concentration théorique (mg/kg)	Concentration trouvée (mg/kg)
H23	69	106
H24	69	108
H25	22	46
H26	28	41
H27	30	34
H28	30	35
H29	14	19
H30	25	21

Ainsi, les différences constatées sont très importantes dans la grande majorité des cas. Il se pose là probablement le problème de la représentativité de la prise d'essai à partir de l'échantillon à analyser. Il en est de même pour la méthode de surcharge qui doit tenir compte de l'importance du volume de l'échantillon à surcharger. En effet, plus le volume est important, moins la répartition sera homogène. Il y a donc des possibilités d'améliorer la méthode de préparation des échantillons à surcharger.

#### Discussion des résultats obtenus pour le dosage des résidus de Diflubenzuron

Ces résultats figurent au tableau III.3. Aussi bien pour la parcelle G recevant un traitement de 37.8 g ma/ha que pour la parcelle F recevant 82.8 g ma/ha, on note une dégradation régulière du diflubenzuron au fil des jours. Pour la parcelle G, les chiffres passent de 2,8 mg/kg 1 jour après traitement, à 0,9 mg/kg 30 jours après traitement. Pour la parcelle F, ces chiffres vont de 14,3 mg/kg 2 heures après traitement, à 2,9 mg/kg 32 jours après traitement.

Il faut constater en effet qu'il n'y a que treize échantillons qui ont été analysés, dont deux témoins surchargés, sur les trente huit échantillons prévus. Il y a de très grandes différences entre les quantités de diflubenzuron ajoutées dans les échantillons H40 et H41 et les quantités trouvées après analyse:

	H40	H41
Concentrations ajoutées en mg/kg	2	5
Concentrations trouvées après analyse	0,38	0,85

Le nombre trop insuffisant d'analyses effectuées par rapport à celui prévu est autant un argument qui fait que ces résultats doivent être considérés avec précaution.

## **B. Détermination de l'activité cholinestérasique**

### **Materiel et Méthodes**

#### *Les pesticides*

Les pesticides sont les mêmes que pour l'analyse chimique.

#### *Les prélèvements*

Ils ont été exécutés par les experts concernés conformément à un protocole qui a été retenu par l'équipe. Il y a eu comme prélèvements:

- des cerveaux d'oiseaux
- des insectes (criquets, scorpions)
- des poissons
- des crevettes.

#### *Le matériel et les méthodes d'analyse*

##### **A. Principe de la méthode**

De nombreuses méthodes de détermination de l'activité acétylcholinestérasique ont été mises au point. Citons la méthode de Hestrin (1949), modifiée par Weiss (1958, 1959, 1961), Holland (1967), Williams (1966), Gras et Coll. (1968, 1982). La méthode de Elman (1961) présente l'avantage d'être très sensible, précise et spécifique. C'est la méthode que nous avons utilisée.

La baisse de l'activité acétylcholinestérasique d'un tissu montre une atteinte du système enzymatique. On hydrolyse donc de l'acétylthiocholine par l'enzyme contenue dans un homogénat du tissu à étudier. Il se forme de l'acide acétique et de la thiocholine, qui réagit avec le DTNB (ion dithiobisnitrobenzoïque), en donnant une coloration jaune. La variation de l'absorbance est mesurée avec un spectrophotomètre à 412 nm en fonction du temps. Les résultats sont exprimés en activité spécifique correspondant au nombre de moles d'acétylthiocholine hydrolysée par minute et par gramme de tissu.

##### **B. Réactifs et matériel**

- Iodure d'acétylthiocholine en solution à 108,35 mg pour 5 ml.d'eau, (conservation au réfrigérateur, une semaine)
- Acide dithiobisnitrobenzoïque (DTNB) en solution à 39,6 mg. pour 10 ml. de tampon à pH=7, additionnée de 15 mg. de bicarbonate de sodium.
- Solution A: 23,9 g. de  $\text{Na}_2\text{HPO}_4$ , 12  $\text{H}_2\text{O}$  par litre.
- Solution B: 9,08 g. de  $\text{KH}_2\text{PO}_4$  par litre.
- Tampon pH=8: 94,5 ml solution A pour 5,5 ml solution B.
- Tampon pH=7: 60,8 ml solution A pour 39,2 ml solution B.
- Spectrophotomètre BECKMANN.
- Broyeur de Potter.
- Micropipettes Eppendorf.
- Agitateur Vortex.
- Chronomètre.
- Propipettes et pipettes.

- Balance de précision au 1/100e de mg.
- Trébuchet au 1/10e de g.
- Matériel de dissection.
- Récipient DEWAR de 20 litres.
- Flacons et étiquettes utilisables dans l'azote liquide.
- Congélateur et réfrigérateur.

### C. Technique de la mesure de l'activité cholinestérasique

Immédiatement après prélèvement, ou après décongélation, le tissu est broyé au broyeur de Potter avec 2 ml. du tampon pH=8. On ajoute alors la quantité de tampon nécessaire pour avoir une concentration de 20 mg. de tissu par ml. de tampon.

Dans une cuve du spectrophotomètre, on introduit un blanc contenant 3 ml de tampon pH=8 et 100 µl de la solution de DTNB.

Dans l'autre cuve, on verse 3 ml de tampon pH=8, 20 µl de l'homogénat de tissu et 100 µl de DTNB.

L'absorbance est mesurée à 412 nm contre le blanc.

On ajoute alors dans les deux cuves 20 µl de la solution d'acétylthiocholine, que l'on agite.

L'absorbance est à nouveau mesurée après six minutes exactement.

### D. Calculs

L'activité cholinestérasique du tissu est calculée à partir de la relation d'Ellmann (1).

$$R = \frac{\delta \odot}{1,36.10^4}$$

R: moles de substrat (iodure d'acétylcholine) hydrolysé par litre et par minute, et  $\delta \odot$  variation d'absorbance par minute.

Si on appelle:

- $m_o$  la masse de tissu analysé (en mg)
- $V'$  le volume de tampon utilisé pour homogénéiser le tissu
- $v$  le volume d'homogénéisat introduit dans la cuve
- $V$  le volume total de solutions introduits dans la cuve  
( $v + \text{DTNB} + \text{tampon} + \text{substrat}$ )

La relation d'Ellmann devient:

$$R = \frac{\delta \odot}{1,36.10^4} \times \frac{1}{\frac{v}{V} \times \frac{m_o}{V'}}$$

Compte tenu de nos conditions expérimentales, où  $v=20 \mu\text{l}$ ,  $V= 3140 \mu\text{l}$  et  $V'= 10 \text{ ml}$ , il vient:

$R = 115.440 \cdot 10^{-6} \cdot \delta \gamma / m_0$   
 $R$  : moles de substrat hydrolysées par minute et  
 par gramme de tissu  
 $\delta \gamma$  : variation d'absorbance par minute  
 $m_0$  : masse de tissus analysées (en mg)

## Résultats

Les valeurs de  $R$  mesurées sont regroupées en Annexe III.6 en fonction de l'espèce, du sexe et du poids de l'animal capturé, de la nature du traitement (parcelles) et de la durée d'exposition après traitement, exprimée en heures.

Considérons successivement chaque espèce, puis l'évolution de son activité cholinestérasique en fonction de son temps d'exposition à un produit donné. On prendra pour origine la valeur obtenue dans la parcelle témoin (parcelle C, Fig. III.2) en l'absence de traitement.

Pour certaines espèces, les prélèvements ont été trop peu nombreux pour permettre l'établissement d'un graphique. C'est le cas notamment de *Amonanes deserti* (Amonane du Désert), *Aquila rapax* (Aigle Ravisser), de *Passer luteus* (Moineau Doré), *Upupa epops* (Huppe), *Lamprolornis chalybaeus* (Merle Métallique Commun), *Lanius senator* (Pie-Grèche à Tête Rousse), *Lophoceros erythrorhynchus* (Petit Calao à Bec Rouge), *Streptopelia roseogrisea* (Tourterelle Rieuse), *Turnix sylvatica* (Turnix d'Afrique) et des crevettes.

Les données des espèces les plus nombreuses ont été présentées par parcelle, en forme de graphes donnant les valeurs moyens par espèce et par date de prélèvement.

### *Oedaleus senegalensis* (Crique Sénégalais)

Il semble que l'activité cholinestérasique de ces criquets passe par un maximum après 6 heures de traitement au chlorpyrifos (4387 g ma/ha, parcelle E Fig III.1), tandis qu'elle chute fortement après traitement au fénitrothion à la dose de 825 g ma/ha (parcelle B).

### *Cataloipus cymbiferus*

On distingue une tendance à la diminution de  $R$  sans restauration ultérieure par traitement avec 485 g ma/ha de fénitrothion, tandis que le traitement au chlorpyrifos (387 g ma/ha) paraît sans effet (Fig. III.2). On notera cependant que cette observation ne repose que sur une seule mesure.

### *Scorpiones spp*

Très forte baisse de l'activité cholinestérasique des scorpions dès le premier jour de traitement aux deux doses de chlorpyrifos (270 et 387 g ma/ha, parcelles D et E, Fig. III.2). Le nombre d'échantillons est trop faible et la durée de l'étude trop brève pour permettre de déceler une éventuelle restauration de cette activité.

### *Alestes sp.* (Poisson insectivore)

On constate une décroissance de l'activité d'environ 40% après traitement avec 270 g ma/ha

de chlorpyrifos, sans récupération Fig III.2). Après traitement au fénitrothion, il apparaît une décroissance du même ordre les 20 premiers jours, et une restauration de l'activité initiale par la suite. L'étude a été limitée à trente jours.

*Hydrocinus sp* (Poisson piscivore)

Diminution peu significative de l'activité après 1 jour de traitement au chlorpyrifos 270 g ma/ha Fig III.2. Restauration apparente de cette activité après 21 jours d'exposition au fénitrothion à 485 g ma/ha. (Nombre de mesures trop faible, vérification souhaitable.)

*Coracias abyssinica* (Rollier d'Abyssinie)

Etant donnée la dispersion des résultats (Annexe III.6), on ne peut noter que des tendances. Après traitement avec 485 g ma/ha de fénitrothion (parcelle A Fig. III.4), l'activité diminue d'environ 50% les 10 premiers jours, puis revient à son état initial après 20 jours. Avec 825 g m.a. de fénitrothion à l'hectare (parcelle B, Fig. III.5), la tendance est la même, mais la restauration paraît plus aléatoire, compte tenu de la très forte dispersion des valeurs de R mesurées après 19 jours de traitement. Après traitement avec 387 g ma/ha de chlorpyrifos (parcelle E, Fig. III.8), on retrouve une valeur sensiblement équivalente à l'activité initiale au bout de 20 jours.

On notera une dispersion anormale des valeurs de R dans la zone témoin (Annexe III.6).

*Bubalornis albirostris* (Alecto à Bec Blanc)

L'activité cholinestérasique passe par un minimum après environ 10 jours d'exposition au fénitrothion à la dose de 485 g ma/ha (parcelle A, Fig. III.4), puis remonte fortement au delà de sa valeur initiale au bout de 20 jours. Augmentation de l'activité cholinestérasique entre le 1er et le 5e jour après traitement avec 387 g ma/ha de Chlorpyrifos (parcelle E, Fig. III.8). Tendance moins marquée après traitement avec 270 g ma/ha de Chlorpyrifos (parcelle D Fig. III.7) en raison de la forte dispersion des résultats.

*Mirafra javanica* (Alouette Chanteuse)

On remarquera en premier lieu une forte dispersion des valeurs de R pour les témoins non traités, ce qui ne facilite pas l'interprétation. On note une tendance à la diminution de l'activité cholinestérasique après 2 ou 3 jours de traitement au chlorpyrifos 270 g ma/ha (parcelle D, Fig. III.7) ou au chlorpyrifos 387 g ma/ha (parcelle E, Fig. III.8), suivie d'une restauration dès le 5e ou 6e jour. Forte sensibilité de cette espèce au fénitrothion. Pour le traitement avec 825 g ma/ha de fénitrothion (Fig III.5), la tendance à la baisse de l'activité est très nette dès le lendemain du traitement. Reprise significative dès le 6e jour.

Figure III.2

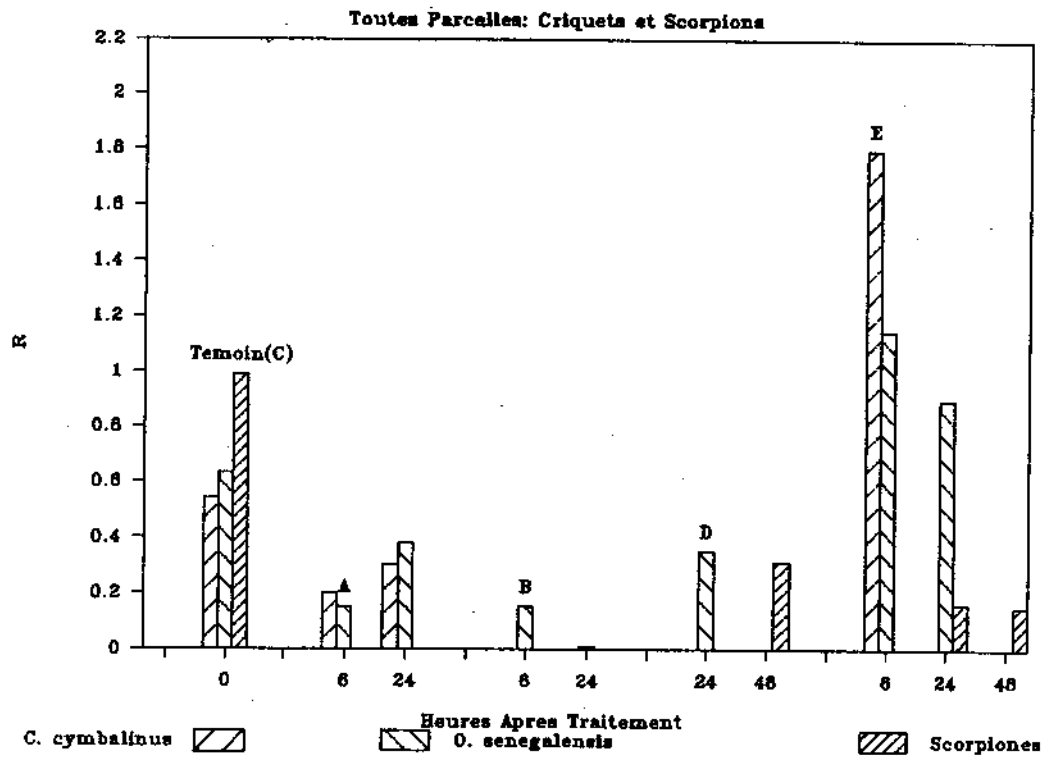


Figure III.3

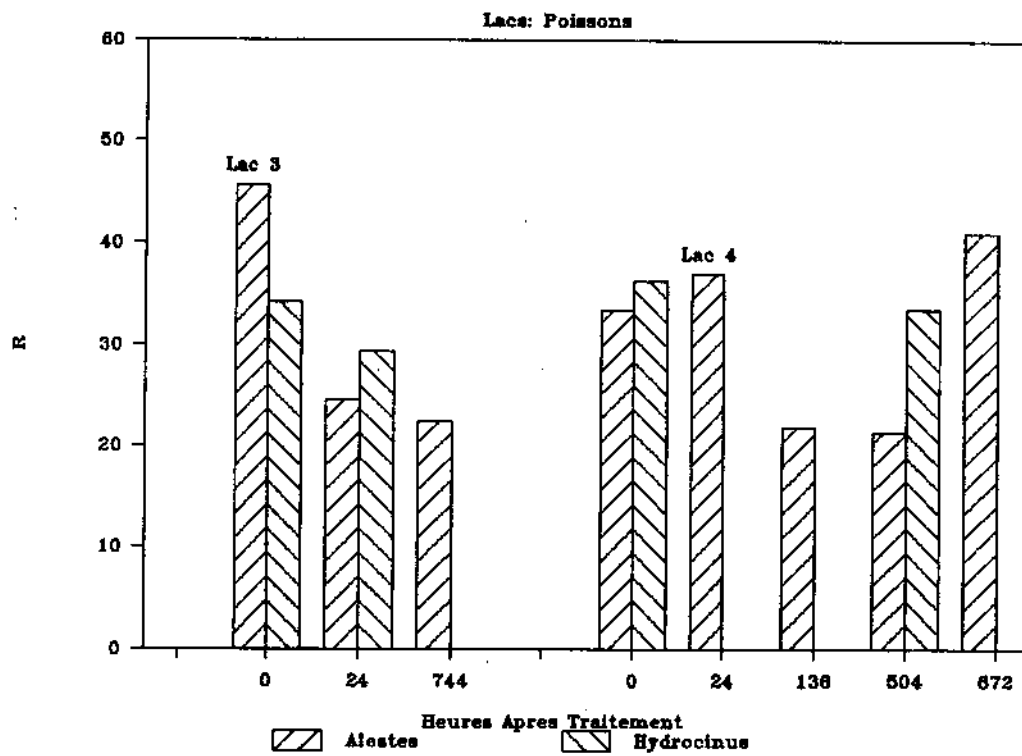


Figure III.4

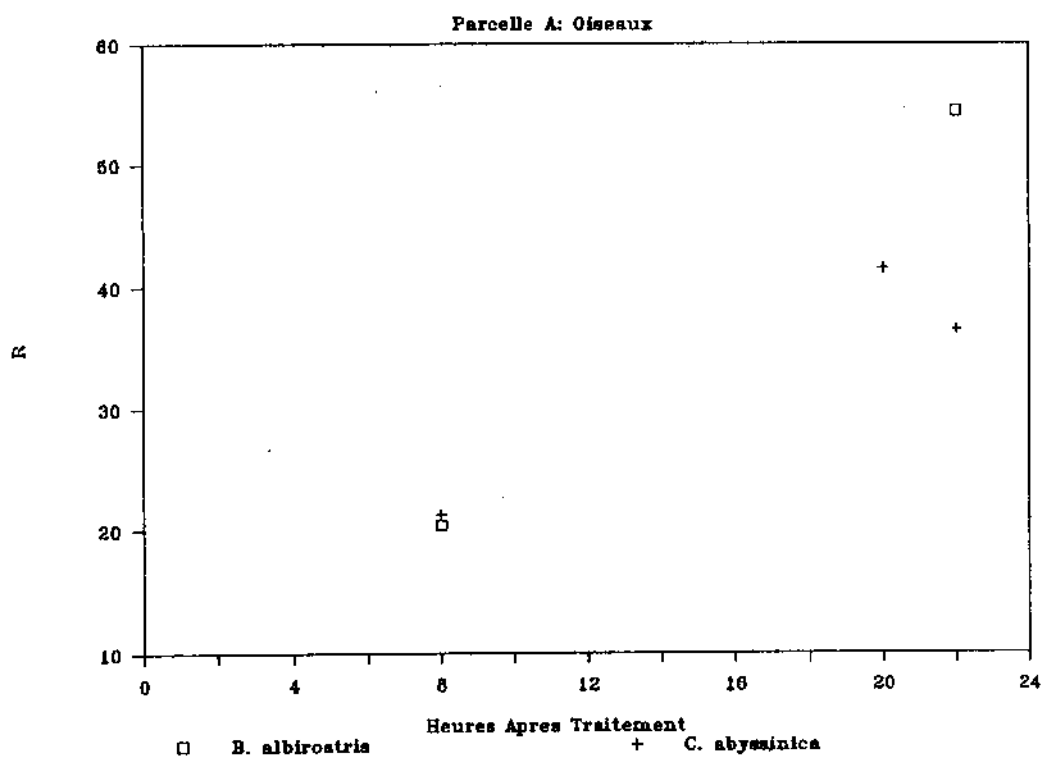


Figure III.5

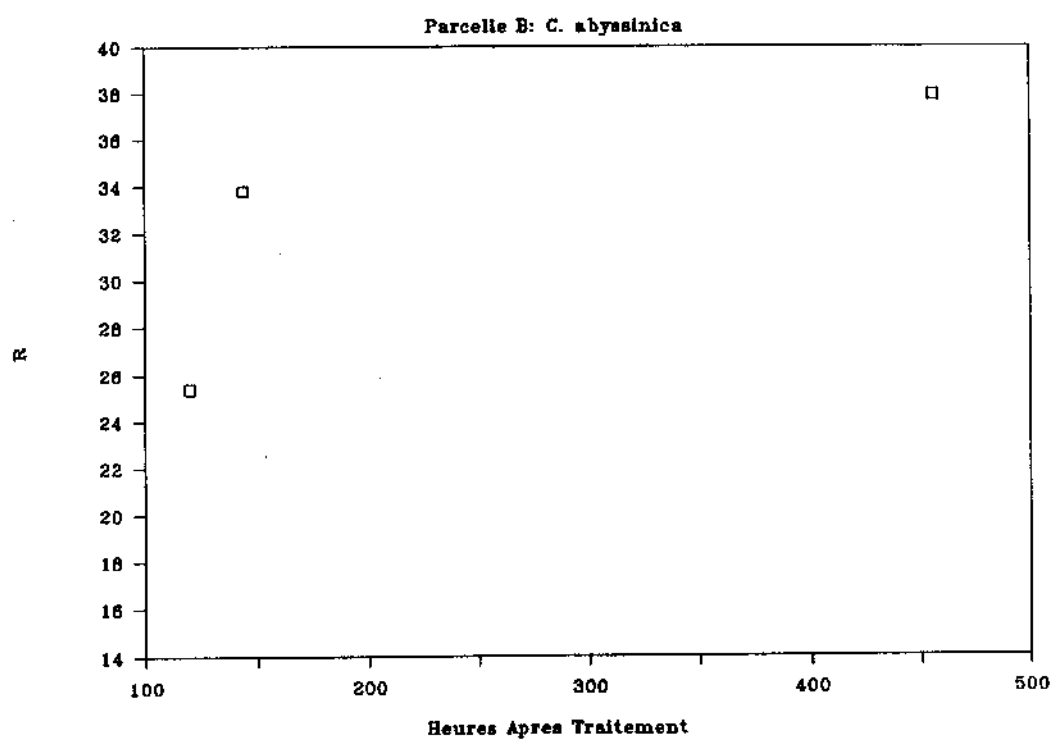


Figure III.6

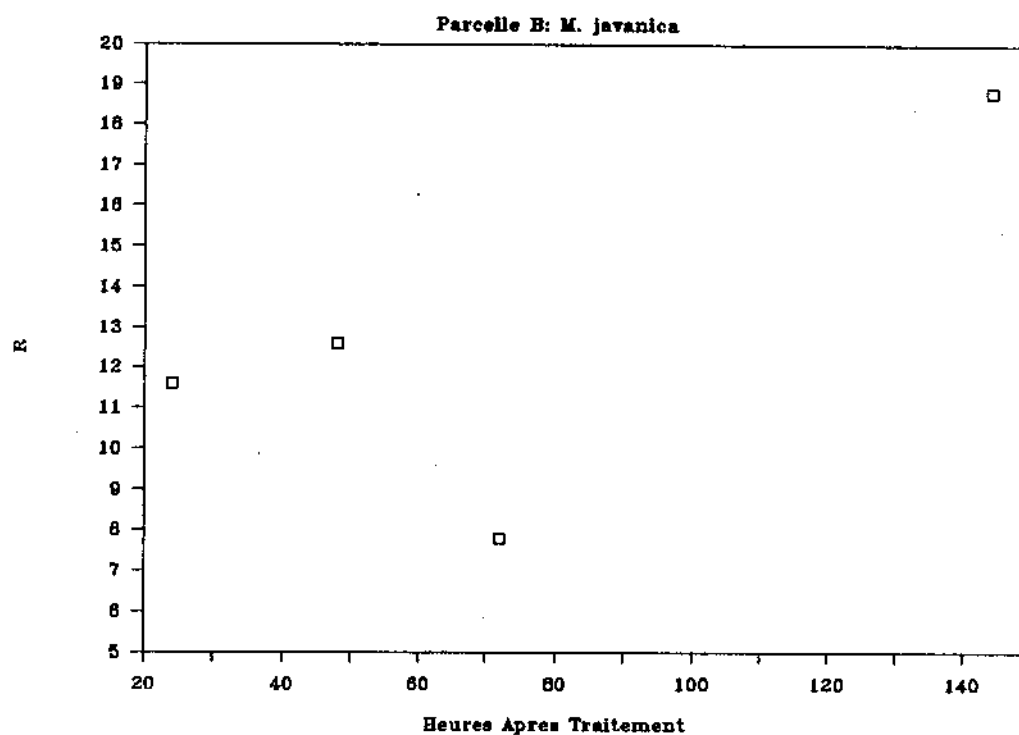


Figure III.7

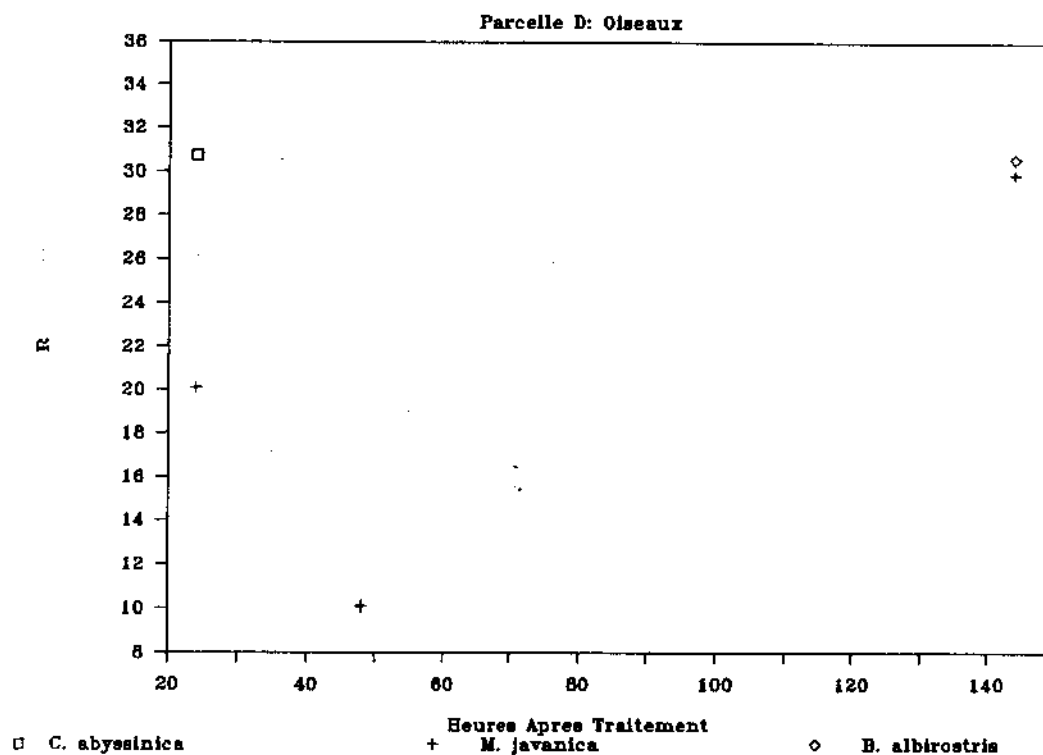


Figure III.8

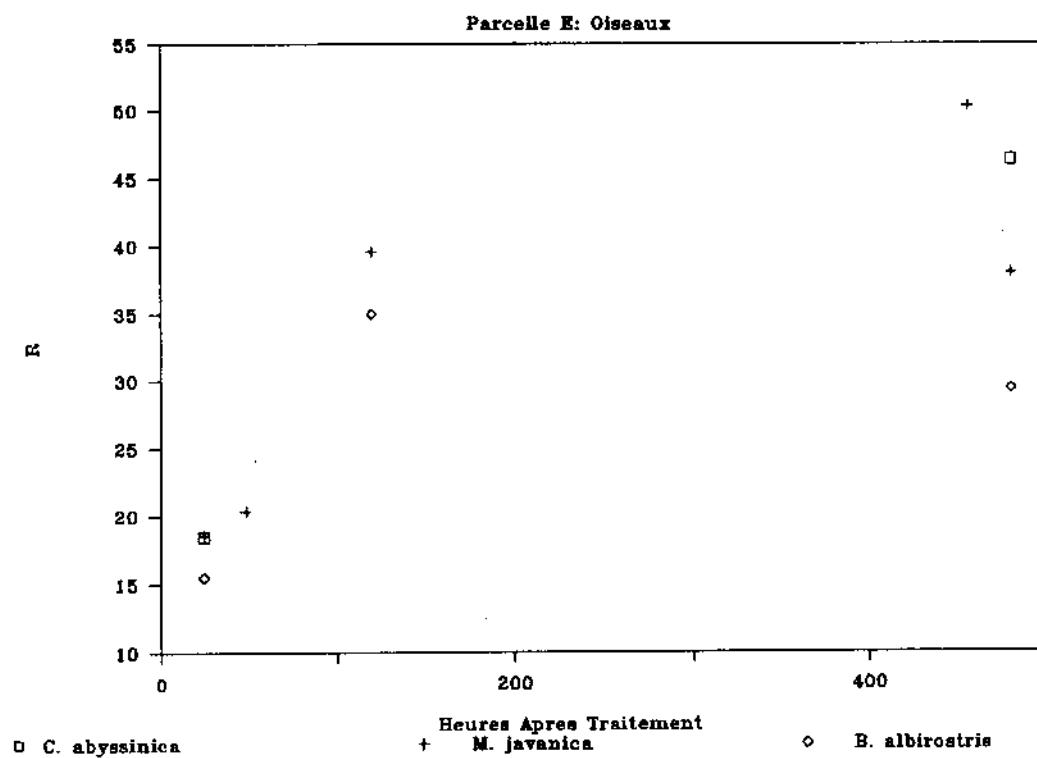
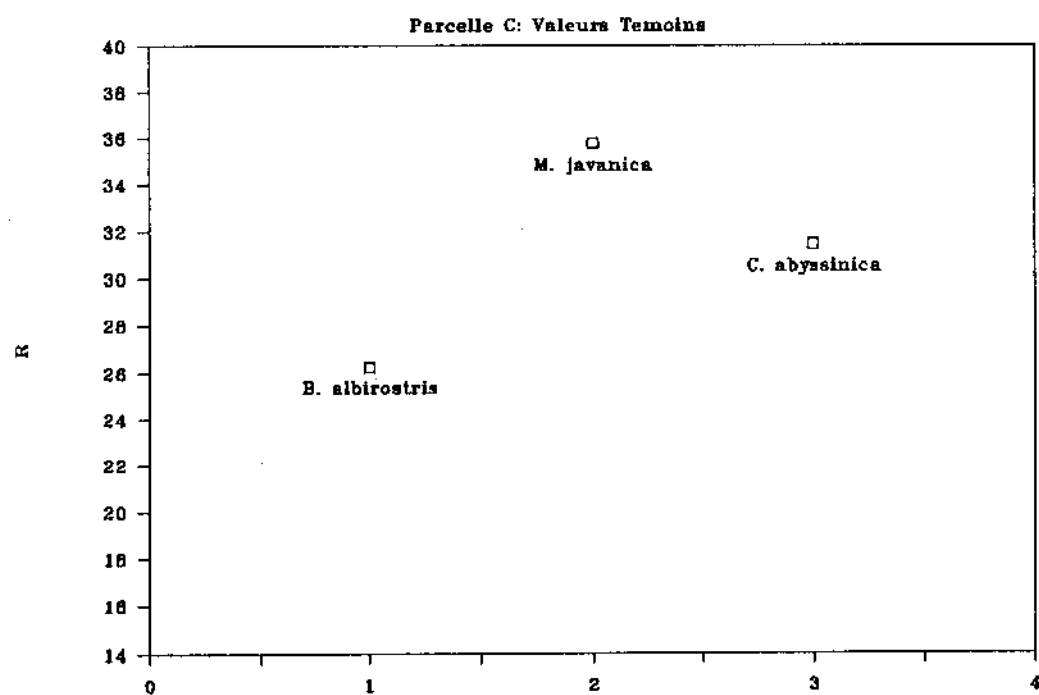


Figure III.9



## **Discussion et conclusions**

L'exploitation des résultats obtenus dans notre Laboratoire a permis de constater, pour la quasi-totalité des espèces et pour tous les types de traitements, une tendance très marquée à la baisse de l'activité cholinestérasique, suivie d'une remontée plus ou moins rapide vers l'état initial.

On peut déplorer malheureusement qu'une analyse plus fine n'ait pu être réalisée, pour plusieurs raisons (Etiquetage insuffisante, prélèvements insuffisants, échantillonnages très groupés à certains moments, et inexistant à d'autres)

Une telle imprécision ne constitue pas en fait un obstacle majeur et pourrait facilement être levée à l'avenir grâce à une meilleure organisation qui tiendrait compte des spécificités de l'expérimentation.

## **Remerciements**

Nous tenons à remercier le Dr. D.A. de BIE, du Laboratoire de Chimie Organique de l'Agricultural University de Wageningen, pour ses analyses de résidus de Fénitrothion et de Chlorpyrifos, ainsi que les Laboratoires DUPHAR pour leurs analyses de résidus de Diflubenzuron.

## Références bibliographiques

Ellmann GL, Courtney KD, Andres Jr. V, Featherstone RM (1961) A new and rapid colorimetric determination of acetylcholinesterase activity. *Biochem Pharmacol* 7: 88-95

Gras G, Rioux JA, Conty M (1968) Effets des concentrations infralétales de Fénitrothion sur l'activité cholinestérasique du cerveau de l'anguille. *Ann Pharm Fr* 26 (12): 759-766

Gras G, Pellissier C, Leung Tack D (1982) Etude expérimentale de l'action du Temephos sur l'activité cholinestérasique du cerveau de *Tilapia guineensis*. *WHO/VBC/82.868*: 1-13

Hestrin S (1949) The reaction of acetylcholine and other carboxylic acid derivatives with hydroxylamine and its analytical application. *J Biol Chem* 180: 249-261

Holland HT, Coppage DL, Buttler PA (1967) Use of fish brain acetylcholinesterase to monitor pollution of organophosphorus pesticides. *Bull environm contam Toxicol* 2 (3): 156-162

Weiss Ch (1958) The determination of cholinesterase in the brain tissue of three species of fresh water fish and its inactivation in vivo. *Ecology* 39 (2): 190-199

Weiss Ch (1959) Response of fish to sub-lethal exposures of organic phosphorous insecticides. *Sewage and industrial wastes* 31 (5): 580-592

Weiss Ch (1961) Physiological effect of organic phosphorous insecticides on several species of fish. *Trans Amer Fish Soc* 90: 143-153

Williams AK & Sova CR (1966) Acetylcholinesterase levels in brain of fishes from polluted waters. *Bull environm contam Toxicology* 1 (5): 198-203



## **PART 4**

## **AQUATIC MONITORING**

Joost Lahr

### Introduction

Since locust control operations are mainly carried out in inland areas, it is not very likely that aquatic environments will be directly affected. However, when pesticides are used to protect crops in agricultural regions, there is a chance that drift from these treatments will deposit on nearby water bodies such as rivers, flood plains, irrigation systems or pools. Accidental spraying of smaller wetlands might also occur. Among the regions in West Africa that are situated close to water systems and that have been treated in the past with pesticides for locust control, are the Senegal river basin (Senegal and Mauritania), the inner Niger delta (Mali) and the Sine Saloum area (Senegal). Areas like these are rare in the Sahel region and have an important function for agriculture, fisheries and as natural resources.

Aquatic invertebrates, with the general exception of molluscs, are known to be sensitive to carbamates, organophosphates, pyrethroids and benzoyl-ureas. Apart from the control of blackfly larvae (Levêque 1989) and tsetse flies (Everts and Koeman 1986), very little is known about the effects of the pesticides on the aquatic fauna of West Africa. Therefore, special attention has to be paid to the possible effects on the aquatic environment of insecticides currently used in locust control.

It was decided that the research should focus on the most important and sensitive groups of organisms among the aquatic invertebrates. Some experience existed from work on macrocrustaceans (Lahr and Everts 1989). They were found to be suitable for use in *in situ* bioassays and their relative densities can easily be measured in the field. Additionally, it was decided to pay attention to the zooplankton, as this serves as a food source for larger invertebrates and small fish and controls algal populations. Most macro- and microcrustaceans are very sensitive to insecticides. Insect larvae were studied as well. These are important as a source of food and some bottom dwelling species have a function in the bioturbation of the sediment.

Several parameters were selected to monitor the possible adverse effects of the applications on the invertebrates. Macrocrustaceans, zooplankton and aquatic insects were sampled quantitatively on a weekly basis, before and after the treatments, to investigate any possible effects on the population densities. *In situ* bioassays were carried out with the shrimp *Palaemonetes africanus*, to determine and compare the acute toxicity of the different insecticides to decapods under field conditions. After the treatment with chlorpyrifos, surviving specimens of *P. africanus* were collected to measure changes in cholinesterase activity after the chlorpyrifos treatment. Chemical parameters of the water were measured weekly.

## Material and Methods

### Study Area

At the beginning of the project, several surveys were undertaken in the area around Richard-Toll to find suitable aquatic study sites. The sites had to fit a number of different requirements. Both economically important fishes and aquatic invertebrates, especially macrocrustaceans, had to be present in sufficient numbers to be sampled quantitatively. Secondly, the aquatic fauna had to be representative of the Senegal river system. Other requirements dealt with the accessibility of the sites. Several aquatic habitats in the Richard-Toll area were monitored during surveys. These included the Senegal river, floodplains connected to the Senegal river, the area around Lake Guiers and the irrigation systems of the sugar cane and rice plantations.

The Senegal river seemed suitable because of its abundance of fish and macrocrustaceans, but was rejected for security reasons since it is an international border.

The connecting floodplains of the Senegal river were also rejected. Only low densities of aquatic organisms were found and there was uncertainty as to where and when flooding of the plains would exactly occur.

As dykes have been built around Lake Guiers to improve its function as a reservoir (it supplies drinking water for Dakar and water for agriculture), only a few smaller wetlands are left around it. These were found to be too small or too far away from Richard-Toll to be suitable for research.

The irrigation system of the sugar cane plantation contained an aquatic fauna that was very similar to that of the Senegal river and Lake Guiers. The larger ponds in the system contained two species of macrocrustaceans, *Palaemonetes africanus* (Balss 1916) and *Caridina africana* (Kingsley 1882), as well as large fish (see Chapter V). Different species of aquatic insects and insect larvae were abundant too. There were several of these reservoirs located in the plantation of the Compagnie Sucrière Sénégalaise (CSS) near Richard-Toll. After approval from the CSS, four of these were selected for experimental pesticide applications (Figure IV.1a). Some characteristics of the lakes are shown in Table IV.1.

Figure IV.1a: Situation of monitored irrigation ponds.

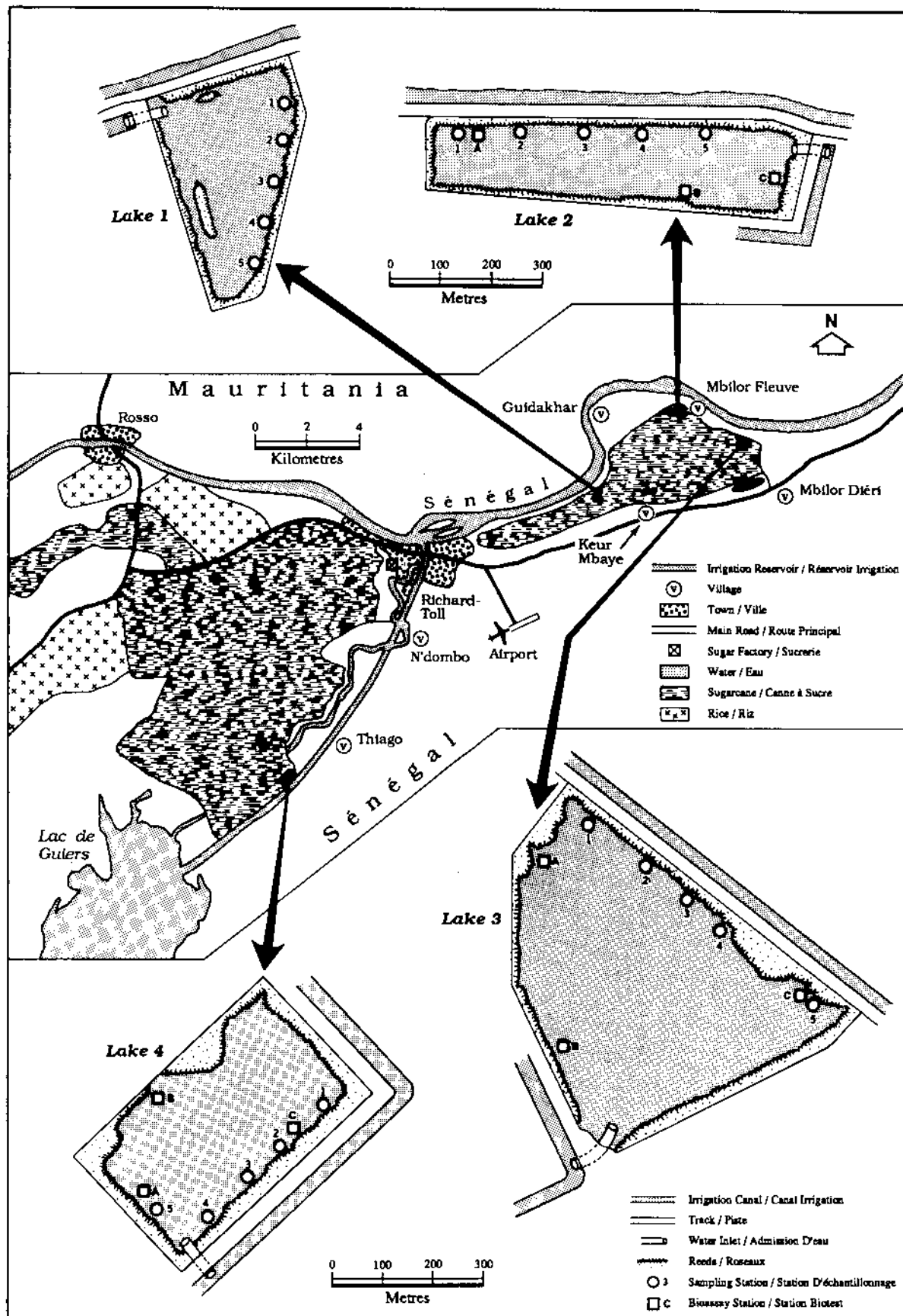


Figure IV.1b: Waterbodies in north-western Senegal.

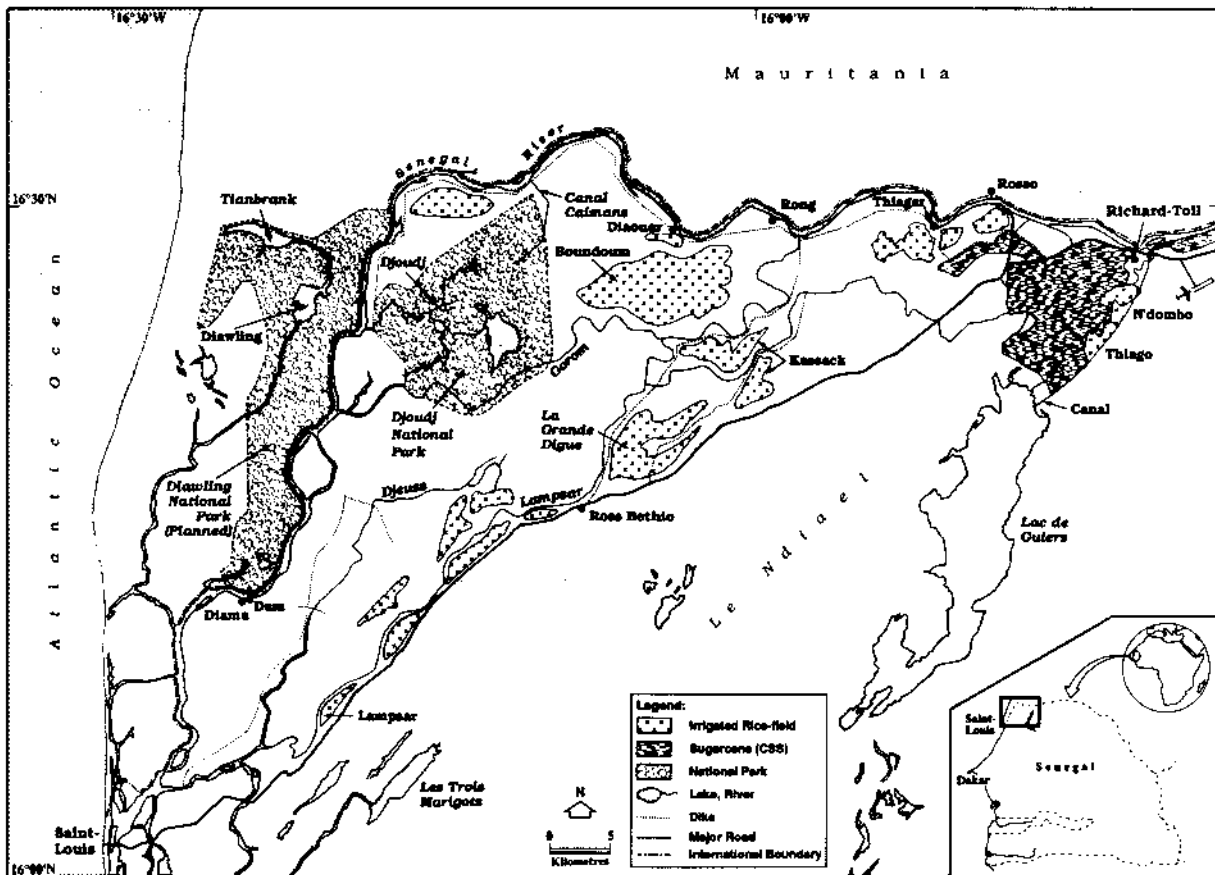


Table IV.1: Characteristics of irrigation ponds selected for aquatic research.

Lake	Surface ha	Depth		Vegetation
		Center m	Edge m	
1	±10	> 2	0.5	reeds and water plants
2	±16	0.5-1	0.5	high reeds and water plants, floating water plants all over the surface
3	±30	1.5	0.5	reeds and water plants
4	±18	2	0.5	very high reeds and water plants

### Treatments with Insecticides

Since Lake 1 was used by the CSS for the water supply of an experimental shrimp hatchery, it was decided to use it as the control. This lake was used intensively for the water supply of the plantation during September and October. This resulted in fast, daily changes in the water level of the lake. Frequently, the water plant vegetation on the lake sides, was found to be dry.

The treatments of the lakes are listed in Table IV.2. As with Lake 1, Lake 2 was also used for the water supply of the plantation when the pumps started to malfunction. One week after the treatment with diflubenzuron, the water level was especially low.

**Table IV.2:** Treatments of irrigation ponds with insecticides used for locust control.

Lake	Insecticide	Applied Dose g ai/ha	Date 1989	Time
1	control			
2	diflubenzuron	35.2	9/9	16.30
3	chlorpyrifos	337.5	5/9	17.15
4	fenitrothion	550.0	7/9	16.00

### Quantitative Sampling of Densities

#### *Macrocrustaceans and aquatic insects*

The quantitative sampling of macrocrustaceans and aquatic insects was done by scoop-netting. Therefore five sampling stations were chosen along the eastern side of each lake (Figure IV.1a). The minimal distance between two sampling stations was 100 m. At all stations, a 10 m stretch was labelled with markers. Three samples were taken on these stretches. The first sample was taken from the vegetation itself to capture the fauna around the stems of water plants; for example mayfly and dragonfly larvae and some free swimming waterbugs and beetles. A second sample was taken by dragging the net along the sides of the vegetation close to the sediment. Most of the shrimps were captured this way. These two samples were taken with a circular shaped scoop-net (diameter 30 cm, mesh width 1 mm). The third sample was taken by dragging a square scoop-net (30 x 30 cm, mesh width 1 mm) through the upper 5 cm of the sediment, at a minimum distance of 1 m from the side of the vegetation. These samples contained merely insects living in the sediment or on its surface, such as midge larvae and caddis-fly larvae. Special care was taken to avoid sampling the same stretch of sediment more than once a month. This was done by taking the samples at different distances from the vegetation in subsequent weeks.

The collected specimens were sorted in the field and taken to the laboratory in a 5% formol solution. There they were washed and stored in 70% ethanol until identified.

To discover whether intensive sampling of the sites would or would not interfere with the densities of the fauna, Lake 1 was sampled twice in three days when the sampling began. Because the densities of all the important groups of invertebrates were found to be higher on the second occasion, it was concluded that weekly sampling during the experiments would not cause a major disturbance.

Population density samples were taken once a week in each lake, four weeks before and five weeks after the treatments. The number of animals found in the three samples at each station were summed and presented as the total number captured per station (Annex IV.3 ,raw data). The figures show the total numbers captured per lake.

### *Zooplankton*

The zooplankton was sampled by hauling a zooplankton net (mesh width 250  $\mu$ m, diameter 30 cm) through the surface water over a distance of 50 m (content of each sample equalled 3.5 m<sup>3</sup> water). At each lake, three replicates were taken at the same place, each time the lake was sampled. Sampling was done between 11 pm and 1 am.

Sampling of the zooplankton started one week before the treatments of the lakes. Samples were taken on the day of the treatments, 3 and 7 days later and then weekly until the end of the project.

The samples were fixed in 20 ml of a 5% formol solution and taken for identification to the Agricultural University of Wageningen, the Netherlands. The numbers of Cladocera, Cyclopoida, Calanoida and Ostracoda in each sample were counted. The numbers are presented as the number per sample (Annex IV.3) or the total of these three samples (10.5 m<sup>3</sup> water). The latter will be referred to as the total number captured per lake (figures).

### *Bioassays with Shrimps*

*In situ* bioassays were carried out with the shrimp *Palaemonetes africanus*, the most abundant arthropod in the lakes. Three bioassay stations (A,B and C, Figure IV.1a) were selected at different sides of each of the sprayed lakes.

At each station, 5 floating cages (20 x 20 cm, depth 40 cm, mesh width 1 mm), were attached to stakes, all at a minimum distance of 2 m from the shore. 10 shrimps were placed in each cage. These had been captured by scoop-netting on the same sites. The shrimps were not sorted, so that they reflected the differences in size of the natural populations in the lakes (size between 1.5 and 2.5 cm). After 24 hours the number of surviving specimens was counted.

Control data were obtained by doing a series of bioassays on the day before the applications on the lakes. All tests were started at 12.00 pm. In the case of the control in lake 4 (fenitrothion), tests were only carried out at station B, because very few specimens of *P. africanus* could be found on that day.

### Cholinesterase Activity Analyses

Before and after treatment of Lake 3 with chlorpyrifos specimens of *Palaemonetes africanus* were collected for cholinesterase activity measurements. Three 20 g samples of shrimps were collected three days before the treatment. One day after the treatment, only one 20 g sample could be collected in the northern part of the lake, the only part where shrimps were still found alive (see results). After this time, living shrimps were no longer observed. The method of analysis is explained in Chapter III.

### Post-treatment Searches

The sides of the lakes were searched for any dead, floating invertebrates, one hour and one morning after each treatment. Each search lasted for approximately one hour.

### Chemical parameters

Chemical parameters of the water in the lakes were measured weekly with portable equipment. This was done from the first day of treatment of the lakes, until the end of the project. The measurements included water temperature, dissolved oxygen (and percentage saturation), pH and the Secchi depth (turbidity). On one occasion the salinity of the lakes was measured. Therefore two 11 water samples were taken in each lake and sent to the ORSTOM laboratory in Dakar. Analyses were done with a digital salinometer.

### Inventarization of Savannah Pools

The members of the research team thought it important to undertake a limited inventory of the aquatic fauna of temporary pools in the savannah area. Very little is known about the ecological functions of and fauna in these pools. They might be important for local wildlife as drinking reservoirs during the rainy season. Therefore they are of special interest for future research.

On two occasions several pools were monitored for aquatic invertebrates with scoop-nets and plankton nets in a non quantitative way. The pools were located in blocks F and G, near the village of Mopudji and near the Richard-Toll airstrip (Figure I.2)

## **Results**

The raw data are given in Annex IV. It contains the chemical data (Annex IV.1), the data of the *in situ* bioassays with *Palaemonetes africanus* (Annex IV.2) and the data of the quantitative sampling of macrocrustaceans, zooplankton and aquatic insects (Annex IV.3).

### Chemical parameters

The minimum and maximum values of the chemical parameters measured in the lakes are presented in Table IV.3. In general, the chemical properties of all four ponds were quite comparable. The only exception was Lake 4. Here the water was much less opaque than in the other three lakes. The oxygen content of the water in the lakes was never found to be of less than 60-70 % saturation. The pH values were normal for a freshwater environment.

**Table IV.3:** Minimal and maximal values of the chemical parameters in four monitored irrigation ponds.

Lake	Temperature °C, at noon	pH	O2 mg/l	O2 % sat.	Secchi depth cm
1					
min.	26.0	7.20	5.8	81	7
max.	31.2	7.82	7.6	92	12
2					
min.	26.2	7.22	5.6	72	9
max.	31.8	8.30	7.6	106	15
3					
min.	28.5	7.55	4.9	63	7
max.	29.9	8.23	7.9	103	10
4					
min.	28.5	7.30	5.7	77	15
max.	31.7	7.89	6.5	88	40

The salinity of all four lakes was measured between September 25 and 29. The salt content of the water was low in all lakes (Table IV.4).

**Table IV.4:** Salinity of four monitored irrigation ponds.

Lake	average salt content ‰
1	0.025
2	0.053
3	0.044
4	0.058

### Macrocrustaceans

Several species of decapods were found in the area around Richard-Toll during preparative surveys undertaken at the start of the project. The most numerous was *Palaemonetes africanus*, which was found in large numbers in all waterbodies connected to the Senegal river. For example, Lake Guiers, the floodplains near Rosso, Thiagar and Rong, the river branches Djeuss and Kassack, the water-inlet of the Djoudj natural reserve (Canal Caimans) and in the irrigation system of the CSS sugar cane plantation (Figure IV.1b). *Caridina africana* was found in Lake Guiers and the irrigation system. The larger *Macrobrachium felicinum* was also found on several occasions in the irrigation system. Local fisherman were seen to catch large species of *Macrobrachium macrobrachion* in the Senegal river itself.

The results of *in situ* bioassays with *P. africanus* are shown in Table IV.5 (raw data in Annex IV.2). As depicted, diflubenzuron has no short-term impact on the shrimps. However, chlorpyrifos and fenitrothion caused an almost complete mortality in the shrimps. The mortality of the specimens at station A in Lake 3 was only 29 % after the chlorpyrifos treatment. One explanation for this might be that the north-western corner of the lake was not treated effectively. In fact, this was already observed during the treatment. Station A was the only place in the lake where living shrimps were still found the morning following the treatment. However, on the second day when the wind had turned towards the direction of this corner of the lake, all shrimps had disappeared.

Dead *P. africanus* were not found directly following the treatment with chlorpyrifos but dead specimens were seen floating on the water the next morning. Dead shrimps on the water surface were not observed following the application with fenitrothion in Lake 4. After the diflubenzuron treatment on Lake 2, no dead invertebrates were found.

Three days before the chlorpyrifos treatment in Lake 3, three 20 g samples of *P. africanus* were taken near station A for analysis of the cholinesterase activity (Chapter III). The average value for R in these samples was  $9.75 \pm 0.55 \mu\text{g/g/min}$  ( $n=3$ ). R was  $8.78 \mu\text{g/g/min}$  for a single 20 g sample taken the morning after the treatment at the same site. This 9.9% reduction is not very dramatic.

**Table IV.5:** The mortality of *Palaemonetes africanus* after 24 hours in *in situ* bioassays in irrigation ponds sprayed with insecticides (at each station 5 cages with 10 shrimps each).

Lake	Treatment	Station	Mortality Control.		Mortality Treated	
			%	SD	%	SD
2	diflubenzuron	A	2 ± 4		10 ± 12	
		B	6 ± 5		2 ± 4	
		C	6 ± 13		2 ± 4	
3	chlorpyrifos	A	2 ± 4		28 ± 19	
		B	0 ± 0		94 ± 9	
		C	0 ± 0		100 ± 0	
4	fenitrothion	A	-		100 ± 0	
		B	4 ± 5		100 ± 0	
		C	-		100 ± 0	

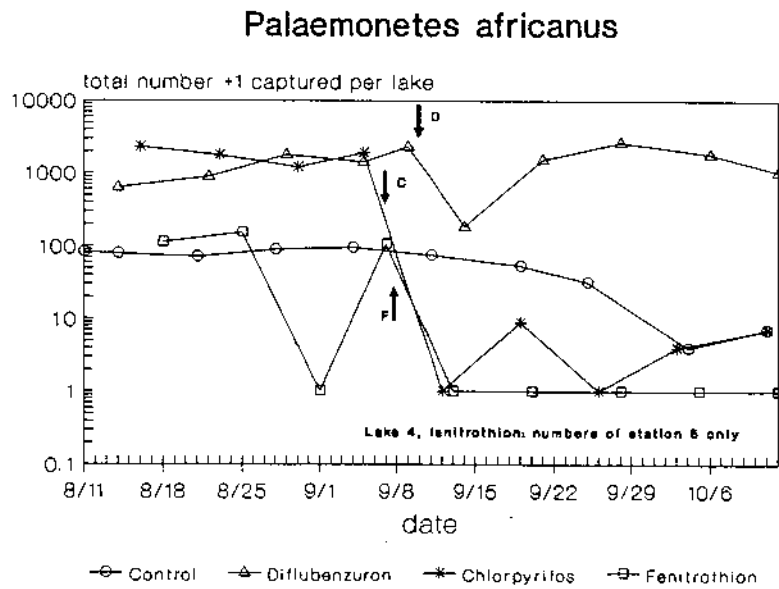
The development of the densities of *Palaemonetes africanus* and *Caridina africana* is given in Figure IV.2a and 2b. The first species was very numerous, especially in Lake 2 and 3. In Lake 4, shrimps were only abundant in significant numbers at sampling station 5. Therefore only the data of this station are shown in the graphs. Both species decreased in the control lake, probably caused by the constant emptying and refilling of this lake for irrigation practices.

One week after the chlorpyrifos treatment in Lake 3, no shrimps could be found. While a decline in the densities of the shrimps also took place in the control lake, this was much slower and less sudden. A complete disappearance of both species was also observed in Lake 4 after the application of fenitrothion. On a few occasions some shrimps were captured again in Lake 3, but in both lakes no recovery took place within five weeks after the treatments.

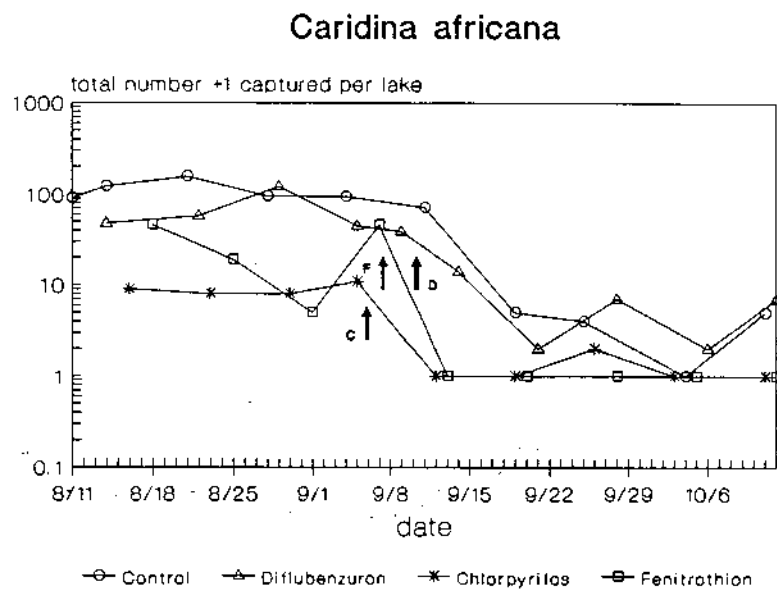
One week after the diflubenzuron treatment in Lake 2, the populations of *P. africanus* and *C. africana* had decreased. Two weeks later, the number of *P. africanus* in the lake was again at the same level as before the diflubenzuron treatment while the number in Lake 1 decreased continuously. The density of *C. africana* continued to decrease, but at the same rate as in Lake 1. Lake 2 was emptied and refilled several times during the week after the treatment. The number of *C. africana*, however, did not recover after the diflubenzuron application, but the decrease of the numbers was of similar pattern to that of Lake 1.

**Figure IV.2:** The numbers of *Palaemonetes africanus* (a) and *Caridina africana* (b) in four irrigation ponds before and after treatments with different insecticides. Arrows indicate the treatments.

**A**



**B**



### Zooplankton

The numbers of Cladocera, Cyclopoida, Calanoida and Ostracoda in the lakes are shown in Figure IV.3a, b, c and d. Because of the late availability of the appropriate materials, the pre-treatment sampling period was unfortunately very short.

The number of Cyclopoida and Ostracoda in lake 1 remained very low during the whole monitoring period. The initial numbers of Cladocera and Calanoida were low, but increased towards the end of the project.

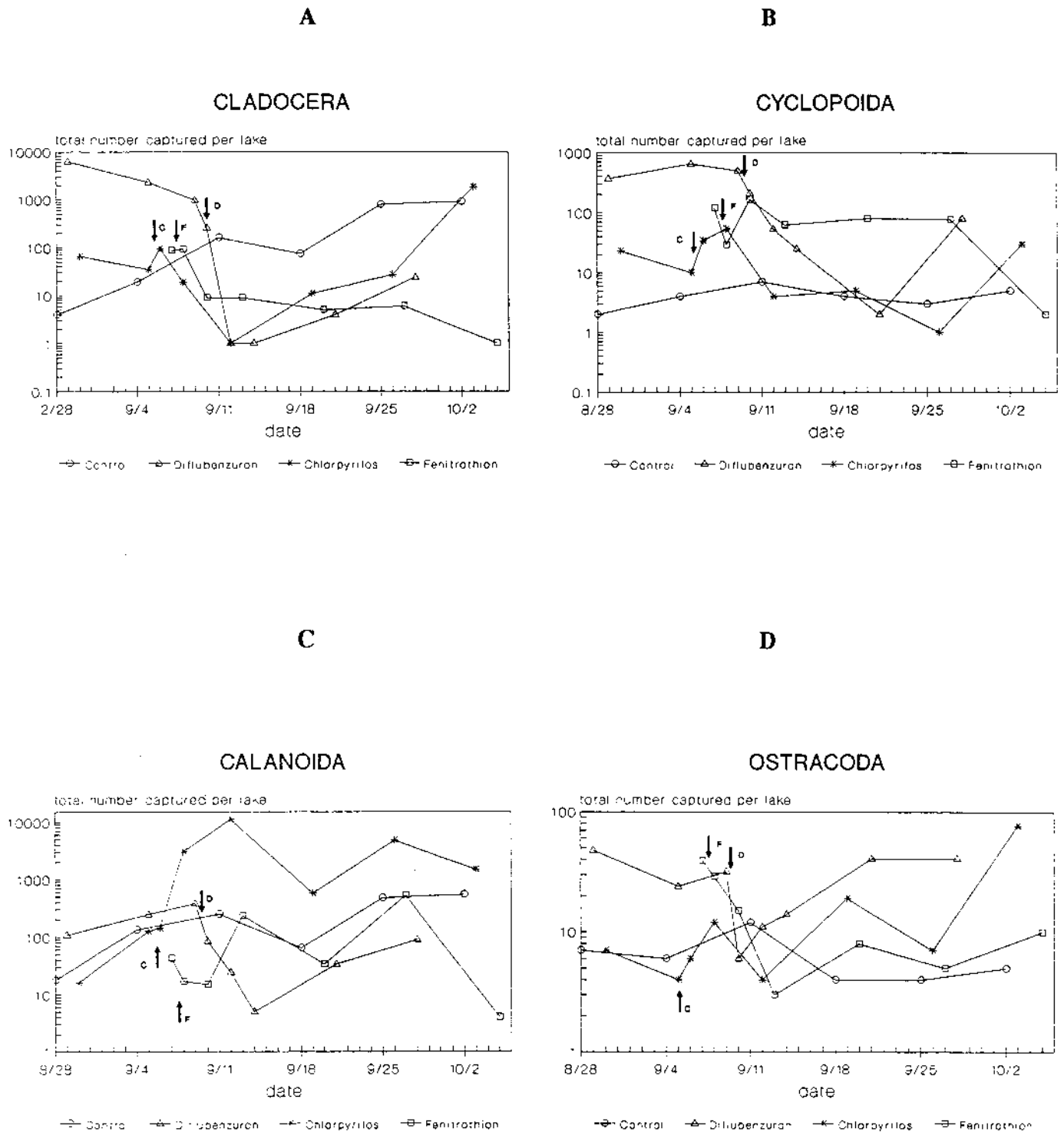
The densities of zooplankton species in Lake 3 were not high before the application with chlorpyrifos. After the treatment, the number of all groups increased. The densities of Calanoida and Ostracoda seemed to be unaffected by the treatment.

The numbers of Cladocera and Cyclopoida decreased one week after the treatment, but recovered within one month.

The numbers of the above orders in Lake 4 were also low. The densities of all monitored groups more or less decreased on the day following the fenitrothion treatment. The densities of Cladocera and Ostracoda remained low in the five following weeks, while the densities of Cyclopoida and Calanoida recovered within four and seven days respectively.

All groups of zooplankton species were abundant in large numbers before the diflubenzuron treatment in Lake 2. The densities of all groups decreased dramatically after the treatment. The number of Cladocera was reduced from 1000 to 1 per lake in three days. They hardly recovered during the following three weeks. The density of Cyclopoida decreased less rapidly, but only two specimens were found after two weeks. Some recovery was observed in the third week following the treatment. Calanoida were almost completely eliminated within one week, but slowly recovered. The number of Ostracoda was reduced some 85% on the day after the treatment, although a complete recovery was observed within two weeks.

**Figure IV.3:** The densities of Cladocera (a), Cyclopoida (b), Calanoida (c) and Ostracoda (d) in four irrigation ponds before and after treatments with different insecticides. Arrows indicate the treatments.



### Insects

Only five groups of insect larvae were captured in sufficient numbers to determine any possible effects. The densities of Baetidae, Coenagrionidae and Libellulidae in the different lakes during the monitoring period are shown in Figure IV.4a, b and c. The larvae of Baetidae and Coenagrionidae were captured around the stems of water plants, while the Libellulidae were found on top of the sediment. The numbers of the sediment inhabiting larvae of Chironomidae and Trichoptera are shown in Figure IV.5a and b.

The densities of all insect larvae in the lakes started to decrease before the treatments, most probably due to seasonal influences. Occasionally other sites in the lakes were checked to see if any disappearing species were still abundant there. This was not the case. The decrease in numbers made it extremely difficult to monitor any effects of the treatments on population densities of this group of invertebrates.

After the chlorpyrifos treatment on Lake 3 many dead insects were found on the water surface, among them many terrestrial insects. Groups and species of aquatic insects found are listed in Table IV.6. Most of the aquatic specimens found are known to live on or close to the water surface. Surprisingly, also dead sediment inhabiting larvae of Chironomidae and Trichoptera were found floating on the water surface after the treatment.

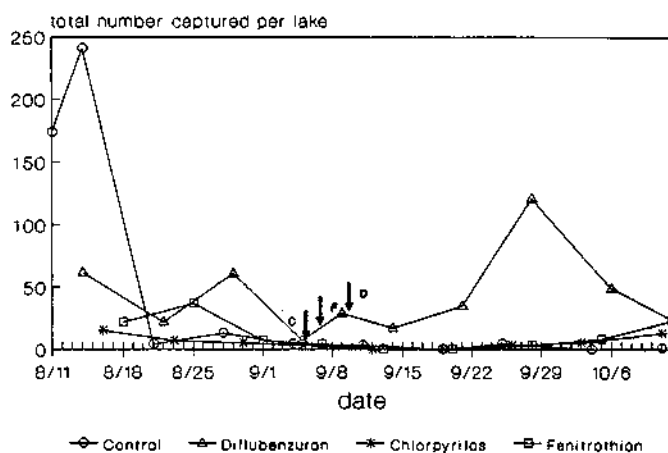
**Table IV.6:** Groups and species of aquatic insects found dead after a treatment with chlorpyrifos on an irrigation pond (Lake 3).

Ephemeroptera:	Baetidae larvae	
	Caenidae larvae	
	Polymitarcidae larvae	
Diptera:	Chironomidae larvae	
Trichoptera:	larvae	
Coleoptera:	Gyrinidae	
	Dytiscidae:	<i>Laccophilus cf evanescens</i>
		<i>Canthydrus cf koppi</i>
		other not identified
Hemiptera:	Gerridae	
	Vellidae:	<i>Rhagovelia sp.</i>
	Notonectidae	
	Corixidae:	<i>Micronectus sp.</i>
	Hydrometridae:	<i>Hydrometra sp.</i>

**Figure IV.4:** Densities of larvae of Baetidae (a), Coenagrionidae (b) and Libellulidae (c) in irrigation ponds during four weeks before and five after applications with different insecticides. Arrows indicate the treatments.

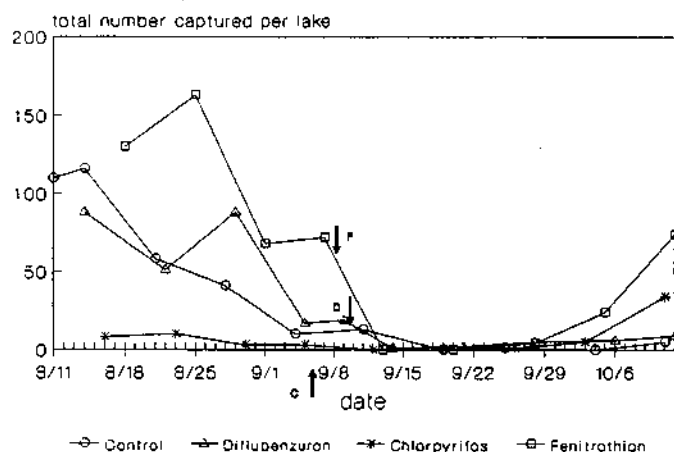
**A**

**Baetidae larvae (Ephemeroptera)**



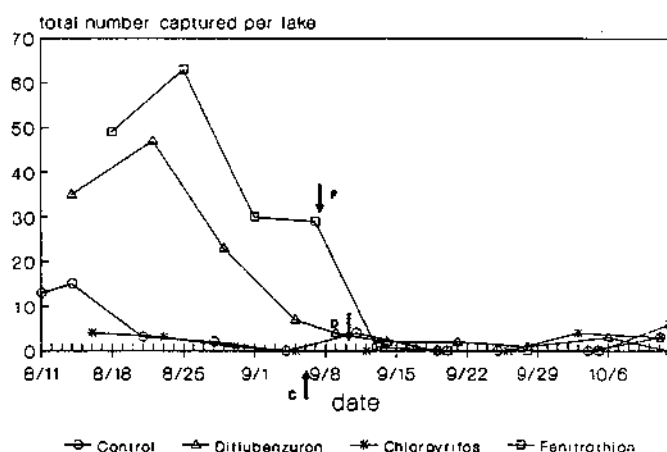
**B**

**Coenagrionidae larvae (Odonata)**



**C**

**Libellulidae larvae (Odonata)**



In Lake 3 which was sprayed with chlorpyrifos, hardly any aquatic insects were captured by scoop-netting, as can be seen in Figure IV.4 and 5. Therefore any effects of the treatment on the densities of these groups could not be determined.

The results of post-treatment searches for dead aquatic insects after the fenitrothion treatment on Lake 4 are presented in Table IV.7. Almost all of the same families and species of Coleoptera and Hemiptera were found as after the chlorpyrifos treatment. However, dead Chironomidae and Trichoptera larvae were not found after the fenitrothion treatment, even though they were quite numerous in the lake. Baetidae were hardly abundant in Lake 4 (Figure IV.4a).

**Table IV.7:** Groups and species of aquatic insects found dead after a treatment with fenitrothion on an irrigation pond (Lake 4).

Diptera:	Culcidae larvae	
Coleoptera:	Gyrinidae	
	Dytiscidae:	<i>Laccophilus cf evanescens</i> <i>Canthydrus cf koppi</i>
Hemiptera:	Gerridae	
	Mesovellidae	
	Notonectidae	
	Corixidae larvae	
	Hydrometridae:	<i>Hydrometra sp.</i>
	Naucoridae	

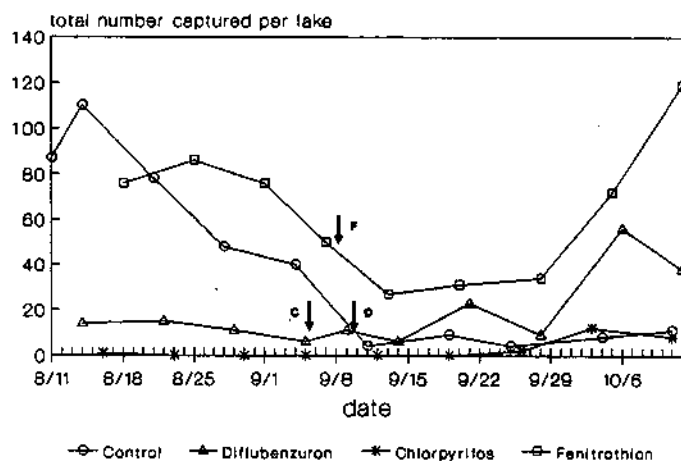
The densities of the free-swimming larvae of Coenagrionidae and the bottom-dwelling Libellulidae larvae (both Odonata) were considerably reduced after the application of fenitrothion (Figure IV.4a and b). However, in Lake 1 (the control), they had already disappeared. This made it very hard to draw any conclusions in relation to these groups. Although Lake 1 was used intensively for irrigation practices during this time, this was not the case with Lake 4. A rapid and almost complete eradication as observed, was not likely to have been caused by seasonal influence only, although this possibility can not be excluded. Larvae of Coenagrionidae and to a lesser degree those of Libellulidae returned after 4 to 5 weeks.

Chironomidae and Trichoptera larvae in the sediment of Lake 4 were not affected by the fenitrothion treatment. They remained abundant during the whole monitoring period and even increased in number shortly after the application of the insecticide. In the control, their number declined rapidly during the first weeks the lakes were monitored. Therefore it can be concluded that the application of fenitrothion had no significant effect on these groups of larvae.

**Figure IV.5:** Densities of larvae of Chironomidae (a) and Trichoptera (b) in irrigation ponds during the four weeks before and five weeks after applications with different insecticides. Arrows indicate the treatments.

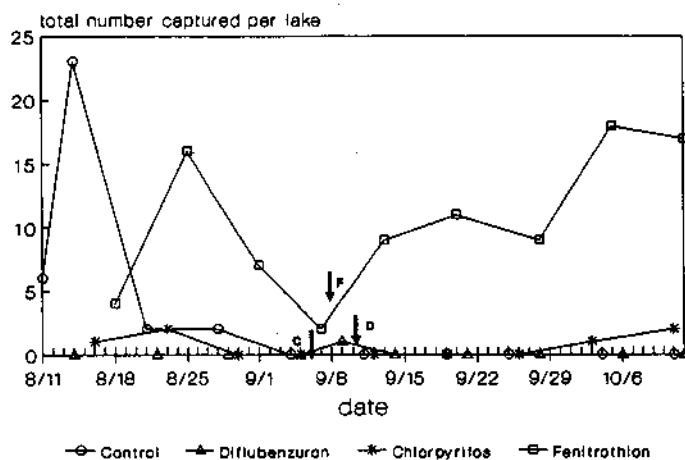
**A**

### Chironomidae larvae (Diptera)



**B**

### Trichoptera larvae



No dead aquatic insects were found on the surface of Lake 2 after the application of diflubenzuron. This product was not acutely toxic to the aquatic insect fauna.

In Figure IV.4a it can be seen that the number of Baetidae larvae increased in Lake 2 after the diflubenzuron treatment. They had already disappeared completely from the control lake. By the time of the treatment the larvae of Coenagrionidae and Libellulidae were no longer abundant. Therefore the only conclusion in relation to the free-swimming insect larvae is that the Baetidae were not affected.

Some larvae of Chironomidae remained present in Lake 2 during the whole monitoring period. Their density changed little up until the last two weeks, when it increased. Trichoptera larvae were seldom found in Lake 2.

#### Temporary Savannah Pools

During the sampling in temporary pools near the Richard-Toll airport at the beginning of the rainy season, large numbers of the branchiopods *Triops sp.* and *Branchinella chudeaui* were found. While the latter were still abundant two weeks later, *Triops* had disappeared, very probably after completing their life cycle. Their carapaces were found on the sides of the pools.

The pools that were monitored at the end of the rainy season all contained many Notonectidae, adult specimens of *Eretes sticticus* (Coleoptera), larvae of Chironomidae and a smaller branchiopod, *Streptocephalus cf. vitreus*. In most of the pools, large species of *Hydrophilus cf. senegalensis* (Coleoptera) and *Nepa sp.* (Hemiptera) were found. One pool in Plot G contained many relatively large ostracods. This survey was not set up to answer any questions in relation to the possible effects of the experimental pesticide treatments in the area.

### **Discussion**

#### Chlorpyrifos

In general, chlorpyrifos is known to have a highly toxic effect on aquatic fauna, especially on arthropods (Mulla *et al.* 1979; U.S. EPA 1987; Madder 1977). This high toxicity was also observed after the application of chlorpyrifos on Lake 3 at 337.5 g ai/ha, when all abundant larger arthropods disappeared for a minimum of at least one week. The nominal concentration of chlorpyrifos in Lake 3 directly after the treatment was estimated to be between 17 and 70 µg/l.

#### Macrocrustaceans

The 24h-LC50 of chlorpyrifos for the grass shrimp, *Palaemonetes pugio*, determined by Hansen *et al.* (1973), was 3.2 µg/l. The 100% mortality rates observed for *Palaemonetes africanus* and *Caridina africana* are in agreement with the sensitivity of this related species.

Ludwig *et al.* found no effects on grass shrimps and brown shrimps *Penaeus aztecus* when a salt marsh was treated with chlorpyrifos at a dosage of 28 g ai/ha. However, at 56 g ai/ha the numbers of both shrimps were reduced.

Other macrocrustaceans such as amphipods are also very sensitive to chlorpyrifos. The 48h-LC50 for *Hyaella azteca* is less than 0.5 µg/l (U.S. EPA, 1987). The 24h- and 96h-TL50 for *Gammarus fasciatus* were 5.6 and 0.32 µg/l respectively (Sanders 1972). *Gammarus pulex* exposed to 0.05-0.1 µg/l chlorpyrifos during one hour, experienced 90-95% mortality after 24 hours (Muirhead-Thomson 1978a). This same species was also the most sensitive invertebrate during experimental chlorpyrifos applications on streams (Muirhead-Thomson 1978b).

#### *Zooplankton*

The chlorpyrifos treatment on Lake 3 did not seem to have a severe impact on the zooplankton. A possible temporary decrease of the populations was only observed for Cladocera and Cyclopoida.

Hughes *et al.* (1980) exposed zooplankton in artificial ponds to chlorpyrifos, at an initial concentration of 10 µg/l. Cladoceran and cyclopoid copepod populations were almost reduced to zero and remained suppressed over more than 20 days.

Ali and Mulla (1978a) observed large reductions of cladocerans after the application of 220 g ai/ha chlorpyrifos to fingers of natural lakes but did not observe any effects on cyclopoid copepods. Some species of cladocerans recovered within a span of two weeks, others did not recover at all.

Hurlbert *et al.* (1970) studied the effects of different treatments with chlorpyrifos on natural ponds. *Moina micrura* (a cladoceran) and *Cyclops vernalis* (a cyclopoid copepod) were affected by treatments at 11.2 g ai/ha and higher dose rates. At dosages of 112 g a.i. and higher, no recovery was observed for these species within one month. *Diaptomus pallidus*, a calanoid copepod, was unaffected by dosages of 112 g ai/ha and lower. The same species of *Moina* and *Cyclops* experienced high mortalities after treatments at 28 and 280 g ai/ha in natural ponds (Hurlbert *et al.* 1972). Recovery in these ponds varied from 1-3 weeks for the low-dose, to 3-6 weeks for the high dose ponds.

The effects of chlorpyrifos on the zooplankton in Lake 3 were less severe than could be expected from literature data. A possible explanation for this might be that chlorpyrifos is degraded and eliminated more rapidly under tropical conditions (e.g. higher temperature and light intensity). Tropical species might also have a different sensitivity to chlorpyrifos.

#### *Aquatic insects*

The chlorpyrifos treatment on Lake 3 caused acute mortality in many different aquatic insects. They were found dead on the water surface shortly following the application. However, the densities that were measured by scoop-netting were too low to investigate the long-term effect.

The side-effects of chlorpyrifos were tested in the U.S.A., where it was used as a mosquito control agent (Mulla *et al.* 1971; Mulla *et al.* 1973; Ali and Mulla 1977). The recommended dosage against mosquitos is 28 to 112 g ai/ha (Mulla *et al.* 1979). The dosage of 337.5 g ai/ha applied on Lake 3 killed chironomid larvae in the sediment. The dead specimens floated to the surface.

Hurlbert *et al.* (1972) sprayed freshwater ponds with chlorpyrifos at 28 and 280 g ai/ha. The treatments showed greater reductions of predaceous (Notonectidae, Dytiscidae, Coenagrionidae, larval Hydrophilidae), than herbivorous (Corixidae, Baetidae, adult Hydrophilidae) insect populations. Predaceous insect populations generally recovered at a slower pace (more than 5 weeks), than herbivorous populations (less than 5 weeks). On another occasion when chlorpyrifos was applied to a salt marsh at 28 g ai/ha, chlorpyrifos did not alter the densities of the dominant aquatic insects (Campbell and Denno, 1976).

#### Fenitrothion

Applied at 550 g ai/ha on Lake 4, fenitrothion concentrations were estimated to be between 25.5 and 110 µg/l immediately after spraying.

#### *Macrocrustaceans*

The treatment completely eradicated the populations of the shrimps *Palaemonetes africanus* and *Caridina africana*. This result agrees with the known 96h-LC50 for a related grass shrimp *Palaemon paucidens* (2.2 µg/l; Takimoto *et al.* 1987). This value is much lower than the nominal concentration in the lake. The 96h-LC50 for the amphipod *Gammarus pseudolimneus* was also very low (4.3-8.8 µg/l; Woodward and Mauck 1980). The same value for a larger shrimp, *Macrobrachium lamerii*, was ±40 µg/l (Sarojini *et al.* 1986).

#### *Zooplankton*

The application on Lake 4 possibly had 1), a short-term effect on all abundant groups of zooplankton and 2), a medium-term effect on cladocerans and ostracods. The only references to compare these results with, are the 96h-LC50 and 24h-EC50 for *Daphnia magna* (Cladocera) given by LeBlanc (1984) and Takimoto *et al.* (1987), which are 11 and 1.6 µg/l respectively. These values are considerably lower than the nominal concentrations in Lake 4.

#### *Aquatic insects*

The application on Lake 4 affected surface dwelling insects and possibly densities of Coenagrionidae and Libellulidae larvae. The sediment inhabiting larvae of Chironomidae and Trichoptera were unaffected. There is little information on the effects of fenitrothion on aquatic insects in stagnant waters. Applications on streams had effects on the drift and standing crops of different insect species (Eidt 1981; Morrison and Wells 1981).

#### Diflubenzuron

The insect growth regulator diflubenzuron was applied to Lake 2 at 35.2 g ai/ha. This was estimated to have resulted in initial concentrations of 3.5 to 7.0 µg/l.

The side-effects of diflubenzuron on aquatic fauna have been evaluated extensively by Gijswijt (1979); Mulla *et al.* (1979); Raven (1987) and Cunningham (1986). In general, diflubenzuron was found to be less toxic than other compounds such as carbamates, organophosphates and pyrethroids.

#### *Macrocrustaceans*

In *in situ* bioassays in Lake 2, *Palaemonetes africanus* did not experience any acute mortality. Their density was lower one week after treatment, but this was more probably due to rapid changes in the lake's water level.

The 96h-LC50 for adult *Palaemonetes pugio* in laboratory tests was 640 µg/l (Petrocelli 1975), much higher than the nominal concentrations in the lake. However, Touart and Ranga Rao (1987) showed that certain phases of premolt adult *P. pugio* were affected at concentrations as low as 1.1 µg/l. Lethal effects on *P. pugio* larvae are also known to occur at concentrations around 1 µg/l (Wilson and Costlow 1986). The photo-response reaction of *P. pugio* larvae was affected at concentrations as low as 0.3 µg/l (Wilson and Costlow 1985). During experimental applications on small ponds, *P. pugio* showed high mortalities at diflubenzuron dose rates of 44.8, 112 and 224 g ai/ha (McAlonan 1976).

The mortality of the amphipod *Hyaella azteca* under laboratory circumstances was significant at 2.0 µg/l (Nebeker *et al.* 1983). In the field, populations of this species were affected at dose rates of 28, 220 and 280 g ai/ha (Farlow *et al.* 1978; Ali and Mulla 1978a and b).

#### Zooplankton

The zooplankton was the only group of aquatic organisms that appeared to be affected considerably after the diflubenzuron treatment on Lake 2. Cladocera and Cyclopoida populations remained suppressed longer than Calanoida and Ostracoda.

In the laboratory, juvenile *Daphnia magna* (Cladocera) showed significant mortality after exposure for 48 hours to 2.0 µg/l diflubenzuron (Nebeker *et al.* 1983). In other tests the 48h-LC50 for *Daphnia sp.* and *Moina sp.* was 1.5 µg/l (Miura and Takahashi 1974).

In outdoor aquaria, Miura and Takahashi (1974) observed a decline in the populations of *Daphnia sp.* and *Moina sp.* (Cladocera), *Cyclops sp.* (Cyclopoida) and *Diaptomus sp.* (Calanoida), at a concentration of 5 µg/l diflubenzuron. The first two species recovered slower (21 days) than the latter two.

Ali and Mulla (1978a) sprayed diflubenzuron on natural lakes at 110 and 220 g ai/ha. The populations of two species of *Daphnia* (Cladocera) and a calanoid copepod, *Diaptomus sp.*, were reduced, although another cladoceran, *Bosmina longirostris*, and the cyclopoid copepod *Cyclops sp.* tolerated the diflubenzuron. Recovery of most of the affected species occurred within 1 to 4 weeks. More severe effects on zooplankton were observed by Ali and Mulla (1978b) when they sprayed a lake with 156 g ai/ha. All groups were eliminated within one week and recovery was very slow (11 weeks to 6 months for different groups). Kingsbury *et al.* (1987) treated two ponds with diflubenzuron. The initial concentrations in the water of these ponds were 5.9 and 13.8 µg/l. Both treatments reduced the densities of cladocerans and copepods considerably in one week. Recovery occurred within 3 weeks to 2 months, copepods recovering faster than cladocerans.

#### Aquatic insects

The populations of abundant aquatic insects (Baetidae and Chironomidae larvae) in Lake 2 were not affected by the diflubenzuron treatment.

Under laboratory conditions larvae of aquatic insects were more sensitive to diflubenzuron than adult insects (Miura and Takahashi 1974; Nebeker *et al.* 1983). Ali and Mulla (1977) applied diflubenzuron to the waters of a lake for mosquito control at 110 and 220 g ai/ha. The emergence of various mosquito larvae was suppressed for 3-5 weeks by the treatments.

Populations of *Caenis* sp. were reduced 99% by applications at 156 g ai/ha, although they recovered in four to six weeks (Ali and Mulla 1978a). Subsequent diflubenzuron applications on a marsh at 28 mg ai/ha, reduced the populations of Corixidae and Notonectidae nymphs, Coenagrionidae naiads and Hydrophilidae adults, but had no effect on adult species of Dytiscidae, Mesovellidae, Corixidae, naiads of Baetidae and Caenidae and larvae of Dytiscidae and Chironomidae (Farlow *et al.* 1978).

In general, zooplankton is the group of aquatic organisms which is most sensitive to diflubenzuron. This was confirmed by the effects observed in Lake 2. Existing literature shows that, adverse effects on other groups of aquatic organisms are usually due to the use of higher dose rates than those used on Lake 2.

#### Implications of the Results

The observed effects of the three insecticides are summarized in Table IV.8.

It can be concluded from the results that chlorpyrifos and fenitrothion have a considerable impact on aquatic invertebrates when used at operational dosages for locust control. Therefore, these compounds should not be used where larger water bodies are present, especially if they contain macrocrustaceans. Also, when chlorpyrifos and fenitrothion are applied next to smaller wetlands, special care should be taken to avoid contaminating these, although the effects on marshes and temporary savannah pools have not yet been investigated.

Although diflubenzuron treatments cause less damage to aquatic macroinvertebrates, they still have a considerable adverse effect on zooplankton populations. When applied near water bodies, however, diflubenzuron should be the preferred choice before chlorpyrifos and fenitrothion. However, special care should still be taken because a long-term reduction of zooplankton could result in algal blooms.

**Table IV.8:** Summary of the effects of three insecticides after experimental treatments on irrigation ponds.

Effect:	CHLORPYRIFOS		FENTROTHION		DIFLUBENZURON	
	ST	MT	ST	MT	ST	MT
<b>MACROCRUSTACEANS</b>						
Decapoda:						
<i>Palaemonetes africanus</i>	+	+	+	+	-	-
<i>Caridina africana</i>	+	+	+	+	-	-
<b>ZOOPLANKTON</b>						
Branchiopoda:						
Cladocera	(+)	(+)	(+)	(+)	(+)	(+)
Copepoda:						
Cyclopoida	(+)	(+)	(+)	-	(+)	(+)
Calanoida	-	-	(+)	-	(+)	(+)
Ostracoda	-	-	(+)	(+)	(+)	-
<b>AQUATIC INSECTS</b>						
Ephemeroptera:						
Baetidae larvae	+	0	0	0	-	-
Caenidae larvae	+	0	0	0	0	0
Polymitarcidae l.	+	0	0	0	0	0

+ = adverse effect  
 - = no adverse effect  
 (+)= indication of adv. eff.  
 0 = no data

ST= short-term effect (0-1 week)  
 MT= medium-term effect (1-5 weeks)

Table IV.8: Continued.

Effect:	CHLORPYRIFOS		FENITROTHION		DIFLUBENZURON	
	ST	MT	ST	MT	ST	MT
<b>AQUATIC INSECTS</b>						
<b>Odonata:</b>						
Coenagrionidae l.	0	0	(+)	(+)	0	0
Libellulidae larvae	0	0	(+)	(+)	0	0
<b>Diptera:</b>						
Chironomidae l.	+	0	-	-	-	-
Culcidae larvae	0	0	+	0	0	0
<b>Trichoptera:</b>						
larvae	+	0	-	-	0	0
<b>Coleoptera:</b>						
Gyrinidae	+	0	+	0	0	0
<b>Dytiscidae:</b>						
<i>Laccophilus</i>	+	0	+	0	0	0
cf <i>evanescens</i>						
<i>Canthydrus</i>	+	0	+	0	0	0
cf <i>koppi</i>						

+ = adverse effect  
 - = no adverse effect  
 (+)= indication of adv. eff.  
 0 = no data

ST= short-term effect (0-1 week)  
 MT= medium-term effect (1-5 weeks)

Table IV.8: Continued.

Effect:	CHLORPYRIFOS		FENITROTHION		DIFLUBENZURON	
	ST	MT	ST	MT	ST	MT
AQUATIC INSECTS						
Hemiptera:						
Gerridae	+	0	+	0	0	0
Vellidae:						
<i>Rhagovelia sp.</i>	+	0	0	0	0	0
Mesovellidae	0	0	+	0	0	0
Notonectidae	+	0	+	0	0	0
Naucoridae	0	0	+	0	0	0
Corixidae:						
larvae	0	0	+	0	0	0
<i>Micronectus sp.</i>	+	0	0	0	0	0
Hydrometridae:						
<i>Hydrometra sp.</i>	+	0	+	0	0	0

+ = adverse effect  
 - = no adverse effect  
 0 = no data

ST= short-term effect (0-1 week)  
 MT= medium-term effect (1-5 weeks)

## Recommendations

Subjects for future research are:

- 1- Selection of suitable aquatic organisms for field monitoring programmes (indicators)
- 2- Extension of the research to other types of aquatic habitats which are at risk during locust control operations
- 3- Monitoring of effects during locust control campaigns
- 4- Development of laboratory bioassays with aquatic organisms to screen the toxicity of different insecticides used in locust control

ad 1)

Monitoring all abundant aquatic species in large field studies is extremely time consuming. Therefore indicator-species should be selected. These species should be sensitive to insecticides and representative of the Sahel region and different trophic levels in the aquatic ecosystems concerned.

ad 2)

To date the effects of locust control operations have only been studied in riverine systems. However, in the Sahel area, different types of aquatic habitats can be found.

Since the applications of insecticides against locusts are usually carried out in drier savannah-type areas during the rainy season, it is of importance to investigate the impact of the operations on temporary savannah pools. During a short survey, a rich fauna of invertebrates was found in these pools. This fauna consisted of species other than those found in the irrigation ponds. The sensitivity of these organisms might differ. *Triops* sp., for instance, is 1000 times more sensitive to diflubenzuron than the shrimp *Palaemonetes pugio* (Miura and Takahashi 1974; Petrocelli 1975). Ephemeral branchiopods such as *Triops*, have very short reproduction cycles which are induced by the presence of water and after a (sometimes multi-annual) diapause. Pesticides, applied at a sensitive stage in the cycle, could eliminate these isolated populations.

Very little is known about the ecological functions of these pools, but the aquatic species in them could serve as an important source of food for several predatory savannah animals, especially birds.

Other biotopes of particular interest are marshes (Inner Niger Delta, Mali), mangrove forests (Sine Saloum, Senegal), and flood plains connected to larger rivers.

ad 3)

The validity of results obtained during experimental field trials should be verified for operational locust control operations. This can be done by monitoring aquatic environments when treatments for the control of locusts take place.

ad 4)

Laboratory bioassays are a suitable and easy method for preliminary screening of the relative toxicity of new insecticides to aquatic organisms. The resulting data could help with the selection of insecticides to be used in further research under field or semi-field circumstances. The tests should be conducted using aquatic species found to be the most vulnerable in the experimental field trials (indicator-species).

A species of possible interest for use in bioassays is the freshwater shrimp *Caridina africana* (Atyidae). This decapod is abundant in many different aquatic habitats throughout the whole African intertropical zone. It proved to be very sensitive to different types of insecticides. The development of a standard bioassay with this species would not only be useful for locust control, but also for other control programmes where aquatic ecosystems are at risk (e.g. the WHO Onchocerciasis Control and WHO Tsetse Control Programmes).

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### References

- Ali A & MS Mulla (1977) The IGR diflubenzuron and organophosphorus insecticides against nuisance midges in man-made residential recreational lakes. *J Econ Entom* 70 (5): 571-577
- Ali A & MS Mulla (1978a) Impact of the insect growth regulator diflubenzuron on invertebrates in a residential-recreational lake. *Arch Environm Contam Toxicol* 7: 483-491
- Ali A & MS Mulla (1978b) Effects of chironomid larvicides and diflubenzuron on nontarget invertebrates in residential-recreational lakes. *Ann Entom Soc America* 71 (1): 21-27
- Campbell BC & RF Denno (1976) The effect of temephos and chlorpyrifos on the aquatic insect community of a New Jersey salt marsh. *Environm Entom* 5 (3): 477-483
- Cunningham PA (1986) A review of toxicity testing and degradation studies used to predict the effects of diflubenzuron (Dimilin) on estuarine crustaceans. *Environm Poll (Series A)* 40: 63-86

Eidt DC (1981) Recovery of aquatic arthropod populations in a woodland stream after depletion by fenitrothion treatment. *The Canadian Entomologist* 113: 303-313

Everts JW & JH Koeman (1987) The ecological impact of insecticides in connection to the control of tsetse flies in Africa: a review. In: *Proc of the CEC Int Symp/Ispra 4-6 March 1986*, R Cavalloro (ed), AA Balkema/ Rotterdam/ Brookfield

Farlow JE, TP Breaud, CD Steelman & PE Schilling (1978) Effects of the insect growth regulator diflubenzuron on non-target aquatic populations in a Louisiana intermediate marsh. *Environm Entom* 7 (2): 199-204

Gijswijt MJ (1979) Side effects of diflubenzuron on aquatic organisms. A review of reports and publications. Philips-Duphar BV, Amsterdam, The Netherlands, Rep.nr. 56635/8/1979/MJG/ybz

Hansen DJ, SC Schimmel & JM Keltner jr (1973) Avoidance of pesticides by grass shrimp (*Palaemonetes pugio*) *Bull Environm Contam Toxicol* 9 (3): 129-133

Hughes DN, MG Boyer, MH Papst & CD Boyle (1980) Persistence of three organophosphorus insecticides in artificial ponds and some biological implications. *Arch Environm Contam Toxicol* 9: 269-279

Hurlbert SH, MS Mulla, JO Keith, WE Westlake and ME Düsck (1970) Biological effects and persistence of Dursban in freshwater ponds. *J Econ Entom* 63 (1): 43-53

Hurlbert SH, MS Mulla & HR Willson (1972) Effects of an organophosphorus insecticide on the phytoplankton, zooplankton and insect populations of fresh-water ponds. *Ecol Monogr* 42 (2): 269-299

Kingsbury P, KMS Sundaram, S Holmes, R Nott & D Kreutzweiser (1987) Aquatic fate and impact studies with Dimilin. Forest Pest Managem. Inst., Can. Forestry Service, Sault Ste. Marie, Ontario, Canada. File rep. nr. 78

Lahr J & JW Everts (1989) Evaluation of the short- and medium-term effects of weekly permethrin and carbosulfan larviciding on *Caridina africana* (Atyidae) in the Kan river, Ivory Coast. WHO ref. 08/181/115.

LeBlanc GA (1984) Interspecies relationships in acute toxicity of chemicals to aquatic organisms. *Environm Toxicol Chem* 3: 47-60

Levêque C (1989) The use of insecticides In th Onchocerciasis Control Programme and aquatic monitoring in West Africa. In: *Ecotoxicology and climate*, Bourdeau *et al.* (eds), Scope 38, Wiley and sons Ltd, New York

Ludwig PD, HJ Dishburger, JC McNeill IV, WO Miller & JR Rice (1968) Biological effects and persistence of Dursban insecticide in a salt-marsh habitat. *J Econ Entom* 61 (3): 626-633

Madder DJ (1977) The disappearance from, efficacy in and effect on non-target organisms of diflubezuron, methoprene and chlorpyrifos in a lentic ecosystem. MSc Thesis, Dept of Entom, University of Manitoba, Canada.

McAlonan WG (1976) Effects of two insect growth regulators on some selected saltmarsh non-target organisms. MSc Thesis, University of Delaware, USA.

Miura T & RM Takahashi (1974) Insect developmental inhibitors. Effects of candidate mosquito control agents on nontarget aquatic organisms. Environm Entom 3 (4): 631-636

Morrison BRS & DE Wells (1981) The fate of fenitrothion in a stream environment and its effect on the fauna, following aerial spraying of a Scottish forest. Sci Tot Environm 19: 233-252

Muirhead-Thomson RC (1978a) Relative susceptibility of stream macroinvertebrates to temephos and chlorpyrifos, determined in laboratory continuous-flow systems. Arch Environm Contam Toxicol 7: 129-137

Muirhead-Thomson RC (1978b) Lethal and behavioral impact of chlorpyrifos methyl and temephos on select stream macroinvertebrates: experimental studies on downstream drift. Arch Environm Contam Toxicol 7: 139-147

Mulla MS, RL Norland, DM Fanara, HA Darwazeh & DW McKean (1971) Control of chironomid midges in Recreational lakes. J Econ Entom 64 (1): 300-307

Mulla MS, RL Norland, WE Westlake, B Dell & J St. Amant (1973) Aquatic midge larvicides, Their efficacy and residues in water, soil, and fish in a warm-water lake. Environm Entom 2 (1): 58-65

Mulla MS, G Majori & AA Arata (1979) Impact of biological and chemical mosquito control agents on nontarget biota in aquatic ecosystems. Res Rev 71: 121-173

Nebeker AV, Ph McKinney & MA Cairns (1983) Acute and chronic effects of diflubenzuron (Dimilin) on freshwater fish and invertebrates. Environm Toxicol Chem 2: 329-336

Petrocelli SR (1975) The acute and subchronic toxicity of R-20458, Altosid and TH-6040 to the grass shrimp *Palaemonetes pugio*. Rep. EG & G Bionomics, Pensacola, Florida, USA

Raven CW (1987) Dimilin in forestry. Summaries on non-target aquatic invertebrates and residues. Philips-Duphar BV, Amsterdam, The Netherlands, Rep.nr. 56683/02/1987.

Sanders HO (1972) Toxicity of some insecticides to four species of malacostracan crustaceans. US Dept. of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Washington DC, USA, Technical Paper nr. 66.

Sarojini RR Nagabushanam & Sr A Mary (1986) Effect of fenitrothion on reproduction of the freshwater prawn *Macrobrachium lamerii*. Ecotoxicol Environm Safety 11: 243-250

Takimoto Y, M Oshima & J Miyamoto (1987) Comparative metabolism of fenitrothion in aquatic organisms. III. Metabolism in the crustaceans *Daphnia pulex* and *Palaemon paucidens*. *Ecotoxicol Environm Safety* 13: 126-134

Touart LW & KR Rao (1987) Influence of diflubenzuron on survival, molting, and limb generation in the grass shrimp, *Palaemonetes pugio*. In: Pollution ecology of estuarine organisms. WB Vernberg, A Calabrese, FP Thurberg and FJ Vernberg (eds), Univ of South Carolina Press

US EPA (1987) The effects of chlorpyrifos on a natural aquatic system: A research design for littoral Enclosure Studies and preliminary data report. Rep US EPA Environm Res Lab Duluth, Pesticide Res Branch

Wilson JE, RB Forward jr & JD Costlow (1985) Effects of embryonic exposure to sublethal concentrations of Dimilin on the photobehavior of grass shrimp larvae. In: Marine Pollution and Physiology: Recent Advances. FJ Vernberg, FP Thurberg, A Calabrese and W Vernberg (eds), The Belle W. Baruch Library in Marine Science nr.13, Univ of South Carolina Press

Wilson JEH & JD Costlow (1986) Comparative toxicity of two Dimilin formulations to the grass shrimp, *Palaemonetes pugio*. *Bull Environm Contam Toxicol* 36: 858-865

Woodward DF & WL Mauck (1980) Toxicity of five forest insecticides to cutthroat trout and two species of aquatic invertebrates. *Bull Environm Contam Toxicol* 25: 846-853

**Introduction**

The objectives of this study were:

1. To select suitable fish monitoring sites in the delta.  
Attention should be given to both flowing and static water bodies. Temporary and permanent water bodies should be distinguished and suitable control sites should also be identified. Monitoring areas should fit in with other team members' plans as far as possible because of transport considerations.
2. To draw up a suitable work programme to investigate the side effects of spraying on selected fish species. Important economic or recreational species, sensitive species or age classes and representatives of different trophic levels (especially bottom feeders and predators) should be criteria for the selection, especially if abundant.
3. To make qualitative and, if possible, semi-quantitative assessments (standing crop) of selected fish populations. Identify the short-term effects of spraying on fish mortality, pathological indications, obvious changes in behaviour, gut contents etc.. Note longevity of toxic effects.
4. To take a small number of fish tissues for residue analysis with due respect for the storage conditions.
5. To gather common information to facilitate the interpretation of field and residue results e.g. spray dates, physico-chemical parameters of water bodies, relevant data from aquatic invertebrate ecologist, meteorological information etc..

**Site Selection**

As the project laboratory was at Richard Toll and the bird camp already established in the savannah some 12 km south of Richard Toll, the sites chosen had to be within all weather driving reach of this predetermined region. The northern border of Senegal with Mauritania is defined by the Senegal river. During the period of the project a border dispute was in progress and the opposing troops on each river bank precluded the use of the river as a field trial location. To the west of Richard Toll, near Rosso, there were some regions that were likely to be inundated if the river flooded sufficiently. It was, however, impossible to reach them by road during the rainy season and travel by river was prohibited.

Temporary pools that formed on the savannah were discrete, isolated and devoid of fish life.

The only other region with water bodies containing fish was the sugar cane plantation. Thanks to the kindness of the Compagnie Sucrier Sénégalais (CSS) we were given permission to use four of their irrigation reservoirs as test sites. For various reasons, only single dosage treatments were allowed.

From a biological point of view the irrigation basins were not ideal. They were artificial and the oldest only some eight years old. The water levels changed substantially and rapidly as they were used for the purpose for which they were constructed. The faunal assemblage (see below) was most unusual and poor. The only fishes living in the basins were those which had accidentally come in with replacement water and were able to survive there. Some species were found to have been capable of reproducing under these conditions but only three species seemed to have the seasonal reproduction shown by the same species under natural conditions.

Nonetheless, results were obtained from these unnatural trial sites that were useful in establishing the short term effects of the insecticides. Details on the situation of the lakes and their treatments are given in Chapter IV.

Running water sites were not available because the CSS did not want any insecticides applied to their irrigation ditches. Their attitude was understandable as a part of the irrigation system fed their experimental shrimp rearing programme. As has been seen from the previous section, two of the three insecticides used were extremely harmful to the shrimp populations in the lakes.

Fish have no recreational purpose in Senegal, but they are a vital source of protein. Tiebou dienne, a dish of rice, fish and sauce, has been described as the Senegalese national dish. Effectively, in this part of the Sahel region it is the main and often only dish of the day for the great majority of the people throughout the year. All fish are eaten, but cichlids are preferred. Fishes of this family were rarely caught in the lakes fished, but great attention must be paid to the effects of insecticides on these species.

Any substantial diminution of the fish supply would have almost the same effect on the human population as a plague of locusts.

## **Materials and Methods**

The equipment available consisted of a 50 m beach seine and six 50 m gill nets, two with 2" mesh, two with 3" mesh and two with 4" mesh. The latter two were of monofilament nylon, those with the smallest mesh were of braided nylon. The beach seine could not be used at the trial localities because the banks and submerged vegetation were inconducive to its fish entrapping capabilities.

The gill nets were used to catch the middle sized and large fish. The exact combination of nets and the length of time in the water was calculated after prespray trials yielded information on the species composition and population structure in each lake.

The small fish (both species of small adult size and juveniles of larger species) were caught along with the aquatic invertebrates at five 3 x 10 m stretches in each lake (see the preceeding section for details).

Bearing in mind the inherent bias in the size of fish caught by each of the two fishing techniques available, the hypothesis determined was to see if the absolute abundance in the segment of the population sampled changed after the insecticide treatment. However, two

difficulties presented themselves.

Firstly, the fish population density of each lake was finite and unknown. If that population were small, then later samples could be much smaller than earlier, due not to the effect of the insecticides but to the effect of the fishing itself. This fishing effect would be even more marked if shoaling species were involved. To minimize this effect, which would be greater with the gill nets, only two prespray gill net samples were taken from each lake.

The second difficulty that affected the results in a way that statistical techniques could not validly allow for was the removal of fish by local fishermen. Before our sampling started there was no evidence that three of the lakes had been fished by the local population; their activities were confined to the irrigation canals. In the fourth lake (Lake 2) a local, very wide mesh, fixed gill net was seen once before our sampling programme started. When our programme was under way the number of foreign nets increased dramatically in all the lakes. On one occasion, in the control lake, there were so many fixed gill nets, stretched completely across the lake, that our nets could not be set on the sample day. To minimize further the reliance that can be placed on the gill net yield, on at least two occasions some fish (presumably the most comestible) were known to have been removed from my nets. On one occasion (in Lake 3) the nets had been stripped entirely. Interference with the project's nets was suspected much more frequently but could not be proven, so only a few aspects of the gill net yields can be used and then only at a general level.

The combination of the above two factors means that the results from the gill net fishing are unreliable and at best are only a general indicator of population changes and then only if it is assumed that the number of fish taken from each lake by the extraneous nets is of the same order of magnitude in each case. Consequently it would be specious to treat and interpret the results in a sophisticated way (Backiel & Welcomme 1980).

The small fishes (their upper size limit being that at which they had the mobility to escape the dip nets) are more reliable indicators in changes in that segment of the population. It can be safely assumed that, if the population is evenly distributed around all the shallow waters of the lakes (and there was no evidence to the contrary), then each sample did not significantly deplete the total population.

Furthermore, there was evidence of recruitment to the sampled stock at the lower end of the size range; the fish started to be caught when about 7 mm SL. The small fish population also escaped the attentions of the local fishermen.

From the beginning, the small fish were sampled weekly before spraying. After spraying it was the intention to sample all the fishes; one, three or four and seven days after spraying and weekly thereafter. Transport difficulties led to changes in this schedule reflected in the graphs below.

Financial and other constraints dictated that the only chemical analysis possible on fish tissue was the determination of cholinesterase levels. The analyses were to be carried out by Professor Ciss of Dakar University. It was decided that the most useful results might be obtained from the brains of *Hydrocynus* (a piscivore) and *Alestes* (an aquatic invertebrate - mostly insect larvae - feeder).

Accordingly, the brains were taken from four fresh *Alestes* and four fresh *Hydrocynus* from each post spray sample from Lakes 3 (chlorpyrifos treated) and 4 (fenitrothion treated). The total body weight of each sample was noted and a code number was given to it. The brains were then wrapped in aluminium foil, placed in a deep freeze and kept therein until their delivery to Dakar University at the end of the project. At the time of writing, the analysis of the samples has not been completed.

### Bioassays

In Lakes 2 and 4 the surface shoaling cyprinodont *Aplocheilichthys normani* was abundant. Its small size and zooplanktonic or insectivorous habit suggested it would be a good subject for bioassays. Accordingly floating cubic cages, each edge 50 cms long, were constructed and samples of the *Aplocheilichthys* placed therein. In Lake 4, sixty four *Aplocheilichthys* 5 - 18 mm SL were caught and transferred immediately to the cages. Fifty of these (5 - 12 mm SL) were dead in three minutes. A second sample of twenty five larger specimens 10 - 23 mm SL was placed in a cage. After ten minutes sixteen were dead and the remaining nine were obviously suffering.

In another experiment on Lake 3, ten large *Aplocheilichthys* (all circa 20 mm SL) were caught in the centre of the lake at a depth of circa 1 m and placed in a floating cage. Eight died within three minutes. It was later found that the surface temperature of the lake was 32°C whereas at 1 m down it was only 24°C. Similar afternoon temperatures were recorded in Lake 4 (34°C, 24°C) in the top metre of water.

The significance of afternoon temperatures was that the afternoon was the predetermined spray time. It is worth noting that *Aplocheilichthys* were rarely seen at the surface during this period. Because of the fishes' inability to cope with the thermal shock bioassays were abandoned. The shrimps used in similar experiments were unaffected by the heat (see above).

### **Results**

A total of 23 species were recorded from the lakes and the faunal composition of each lake is listed below. The arrangement is alphabetical under each family.

### Lake 1 (control)

- Bagridae
  - Chrysichthys nigrodigitatus*
- Centropomidae
  - Lates niloticus*
- Characidae
  - Alestes baremose*
  - Hydrocynus forskhalii*
- Clupeidae
  - Pellonula vorax*
- Cyprinidae
  - Barbus leonensis*
  - Labeo combie*
  - Labeo senegalensis*
- Cyprinodontidae
  - Aplocheilichthys normani*
- Gobiidae
  - Porogobius schlegelii*
- Mochokidae
  - Hemisynodontis membranaceus*
- Syngnathidae
  - Syngnathus ansorgii*

### Lake 2 (diflubenzuron)

- Bagridae
  - Chrysichthys nigrodigitatus*
  - Clarotes laticeps*
- Clariidae
  - Clarias anguillaris*
- Characidae
  - Alestes baremose*
  - Hydrocynus forskhalii*
- Cichlidae
  - Hemichromis fasciatus*
- Cyprinidae
  - Barbus leonensis*
  - Labeo coubie*
  - Labeo senegalensis*
- Cyprinodontidae
  - Aplocheilichthys normani*
- Gobiidae
  - Porogobius schlegelii*
- Mochokidae
  - Hemisynodontis membranaceus*
  - Synodontis clarias*
  - Synodontis schall*

### Lake 3 (chlorpyrifos)

- Bagridae
  - Chrysichthys nigrodigitatus*
- Centropomidae
  - Lates niloticus*
- Characidae
  - Alestes baremose*
  - Hydrocynus forskhalii*
- Cichlidae
  - Hemichromis fasciatus*
  - Sarotherodon melanotheron*
  - Tilapia dageti*
- Cyprinidae
  - Labeo coubie*
  - Labeo senegalensis*
- Cyprinodontidae
  - Aplocheilichthys normani*
- Distichodontidae
  - Distichodus brevipinnis*
- Gobiidae
  - Porogobius schlegelii*
- Mochokidae
  - Synodontis ocellifer*
  - Synodontis schall*
- Schilbeidae
  - Eutropius niloticus*

### Lake 4 (fenitrothion)

- Bagridae
  - Bagrus bayad*
  - Chrysichthys nigrodigitatus*
  - Clarotes laticeps*
- Centropomidae
  - Lates niloticus*
- Characidae
  - Alestes baremose*
  - Hydrocynus forskhalii*
- Cichlidae
  - Hemichromis fasciatus*
- Clariidae
  - Clarias anguillaris*
- Cyprinidae
  - Barbus leonensis*
  - Labeo coubie*
  - Labeo senegalensis*

Cyprinodontidae  
     *Aplocheilichthys normani*  
 Distichodontidae  
     *Distichodus brevipinnis*  
 Gobiidae  
     *Porogobius schlegelii*  
 Mochokidae  
     *Synodontis ocellifer*  
     *Synodontis schall*

Some comments are necessary on the identifications. The most significant fish, in the sense that it was most affected by one of the insecticides, was the goby. It was the only member of its family in the area and was present in all four lakes. This species has been tentatively identified as *Porogobius schlegelii*, but I must stress this identification is tentative until I can confirm it by examination of the holotype. In the rest of the text it will just be called "goby". No similar examples occur in British collections and the search will have to be extended abroad.

Although seven species were present in all the lakes, the relative abundance of some varied widely. For example, hundreds of *Aplocheilichthys normani* were caught in lakes 2 and 4 but only thirty seven were caught in nine samples in Lake 3.

Only two gobies appeared in the nine Lake 1 samples compared with three hundred and two in the three prespray samples in Lake 3. The two species of *Labeo* and *Chrysichthys nigrodigitatus* were caught neither in sufficient numbers nor reliably enough to use for the cholinesterase assays. Only *Alestes baremose* and *Hydrocynus forskhalii* were regularly caught in sufficient numbers to use for these analyses.

The numbers of *Hydrocynus forskhalii* successively caught in each lake showed an interesting pattern. In the first samples obtained from each lake, *Hydrocynus* was a much more prominent feature of the catch than would have been expected for a predator at the top of the food chain and would be unlikely to reflect the relative abundance of the species in the lakes (see Table V.1).

Table V.1

Lake	Number of <i>Hydrocynus</i>	Number of <i>Alestes</i>	Total number of fish in catch	% <i>Hydrocynus</i>
1	3	2	6	50%
2	26	13	59	44%
3	18	16	61	29%
4	21	21	62	33%

Probably coincidentally, the number of *Alestes* caught was equal in magnitude to the number of *Hydrocynus*. After these first samples the proportion of the catch comprising *Hydrocynus* diminished rapidly, whereas the numbers of *Alestes* did not show such a dramatic change (except for the D1 catch in Lake 3 - see below). Considering Lakes 3 and 4, for which the post spray samples are the most complete, the contribution of *Hydrocynus* to each catch is shown in Table V.2.

The interpretation of this decline in *Hydrocynus* caught is that in the early catches the *Hydrocynus* were attracted to the struggles of the other fishes in the net and a higher proportion than that naturally occurring in the lake became entrapped. There is no evidence that their numbers fell because of the insecticide application. The *Alestes* were chosen for comparison because they are of a similar size and body shape. The gradual decline in numbers caught is thought to be due to the overall diminution of numbers in the lakes as a result of fishing (the fishing factor - see below under the sections on lakes 3 and 4).

**Table V.2**

	Number of <i>Hydrocynus</i>	Number of <i>Alestes</i>	Total catch	% <i>Hydrocynus</i>
<b>Lake 3</b>				
D 1	4	7	15	26%
D 3 & 4	4	1	26	15%
D 7	1	2	13	8%
D 21	2	5	13	15%
<b>Lake 4</b>				
D-1	1	35	43	2%
D 1	0	22	37	0%
D 3	4	9	36	11%
D 14	2	13	29	7%
D 21	6	16	36	17%

The population changes in each lake will be described separately.

#### Lake 1 (control)

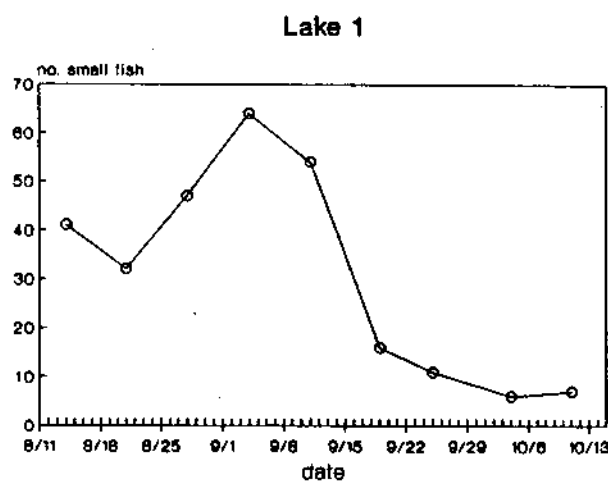
The weekly small fish samples in this, the untreated lake, are tabulated in Table V.3 and expressed graphically in Figure V.1. The fluctuations and gradual reduction in numbers is a result of changes in water level. Towards the end of the period of observation some of the fixed sample stations were barely covered with water.

Apart from the prespray sample discussed above, the other gill net samples are valueless because of local interference with my nets when set and the irregularity of sampling when prevented from setting nets. The number of fish caught by later gill net settings was very low as intensive fishing by local people had severely depleted the stock.

**Table V.3 small fish population in control lake**

DATE	14 08 89	21 08 89	28 08 89	04 09 89	11 09 89	19 09 89	25 09 89	04 10 89	11 10 89
<i>Barbus leonensis</i>	11	15	17	18	33	1	-	1	-
<i>Aplocheilichtys</i>	13	8	23	39	13	9	5	4	1
<i>Syngnathus</i>	6	5	-	-	-	1	1	1	-
<i>Pellonula</i>	5	4	6	3	7	1	-	-	-
juv. <i>Chrysichthys</i>	-	-	1	-	-	-	-	-	1
Goby	-	-	-	1	1	-	-	-	-
juv. cichlids	-	-	-	2	-	-	-	-	-
juv. <i>Lates</i>	-	-	-	-	-	4	-	-	-
juv. <i>Synodontis</i>	-	-	-	-	-	-	1	-	-
juv. <i>Alestes</i>	-	-	-	-	-	-	6	-	5
<b>TOTAL</b>	<b>41</b>	<b>32</b>	<b>47</b>	<b>64</b>	<b>54</b>	<b>16</b>	<b>11</b>	<b>6</b>	<b>7</b>

**Figure V.1**



## Lake 2 (diflubenzuron)

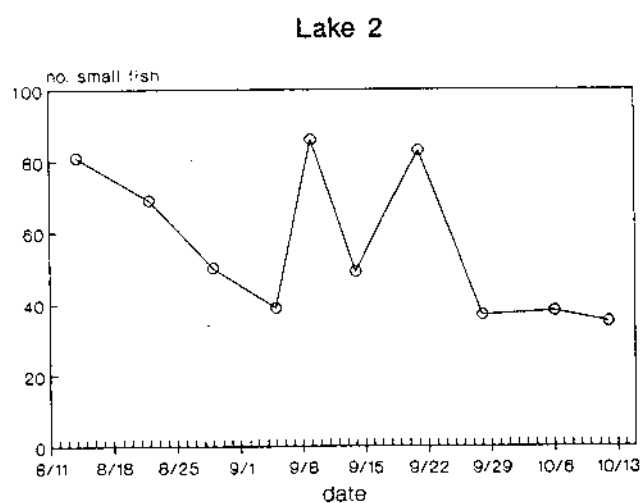
**Table V.4 small fish population in diflubenzuron lake**

DATE	15 08 89	21 08 89	29 08 89	05 09 89	09 09 89	14 09 89	21 09 89	28 09 89	06 10 89	12 10 89
<i>Aplocheilichthys</i>	46	48	37	27	80	39	69	11	10	25
Goby	31	19	13	11	6	10	13	26	14	10
<i>Barbus leonensis</i>	-	-	-	1	-	-	1	-	-	-
juv. cichlids	4	2	-	-	-	-	-	-	14	-
TOTAL	81	69	50	39	86	49	83	37	38	35

These figures are expressed graphically in Figure V.2. The samples were all taken in the morning. The lake was sprayed on the afternoon of September 9. The small fish returns do not suggest that diflubenzuron had any effect on the fish populations in the lake.

As with Lake 1, the gill net data are not included here because of its incompleteness. As well as the reasons given for Lake 1, later samples were impossible because the lake became too shallow for the nets as the water was channelled into the irrigation system.

**Figure V.2**



### Lake 3 (chlorpyrifos)

**Table V.5 small fish population in chlorpyrifos lake**

DATE	15 08 89	22 08 89	30 08 89	05 09 89	12 09 89	19 09 89	26 09 89	03 10 89	11 10 89
Goby	87	92	64	148	-	-	-	-	-
<i>Aplocheilichthys</i>	5	1	6	4	3	5	5	1	8
juv. cichlids	1	1	-	-	1	-	-	-	-
juv. <i>Chrysichthys</i>	-	1	-	1	-	-	-	-	-
juv. <i>Alestes</i>	-	-	-	-	1	4	10	14	20
juv. <i>Lates</i>	-	-	-	-	-	-	1	-	1
TOTAL	93	95	70	153	5	9	16	15	29

These data are expressed graphically in Figure V.3.

The lake was sprayed with chlorpyrifos on the afternoon of September 5. After this date no live gobies were found. On the morning of September 6, some sixteen hours after treatment, dead gobies were floating on the surface of the lake. At one part of the shoreline, near one of the stations, one hundred and four dead gobies from 9 - 27 mm SL were collected, along with two juvenile catfish (either *Clarotes* or *Chrysichthys*) 16 and 14 mm SL and one juvenile cichlid 16 mm SL. No corpses of larger fish were found.

Prior to the treatment with chlorpyrifos, the diet of the *Alestes* in the lake (as in the other lakes) consisted of aquatic insects and gastropod molluscs mixed with (probably inadvertently ingested) filamentous algae. The stomach contents of Day 1 *Alestes* consisted entirely of dead gobies. Previously no fish remains had ever been found in an *Alestes* stomach. Concomitant with this was a sharp drop in the absolute numbers of *Alestes* caught in all the postspray samples (see Tables V.1 and V.2).

In the absence of corpses it seemed unlikely that the decline in *Alestes* caught was a result of the consumption of the gobies killed by chlorpyrifos. A comparison of the gill net yields in Lake 4, where no mortality was observed, showed that a similar sharp drop in yield occurred there after the first two samples (figures V.4 and V.6). The y axis in both cases is the fishing factor, a standardization of the fishing effort involved expressed as the number of fish caught x 100 divided by the number of metres of net x number of hours fished. Mesh size was not considered in this expression of number of fish per metre of net per hour.

The similarity of the fishing factor graphs for both lakes suggests that the number of fish available to be caught diminished rapidly after the first samples. The speed of the appearance of this reduction in numbers suggests in turn that the original standing stock was low.

Chlorpyrifos had no detectable immediate effect on the larger fishes in this lake. Despite the drop in *Alestes* numbers caught in the gill nets, enough were present and had unaffected reproductive potential for juvenile *Alestes* to appear in the small fish samples from early September onwards when their numbers increased steadily. Juvenile *Lates* appeared in samples during the same period.

From the erratic evidence available, there was no evidence of reproductive seasonality in other species and the presence of dead bagrid catfish young and a dead juvenile cichlid in the postspray sample is noted. It therefore seems fair to conclude that chlorpyrifos is very dangerous to very young fishes and is selectively lethal to species of small adult size. Future work will have to determine why it is lethal to the bottom and weed living gobies but not to the equal sized surface living *Aplocheilichthys*.

Figure V.3

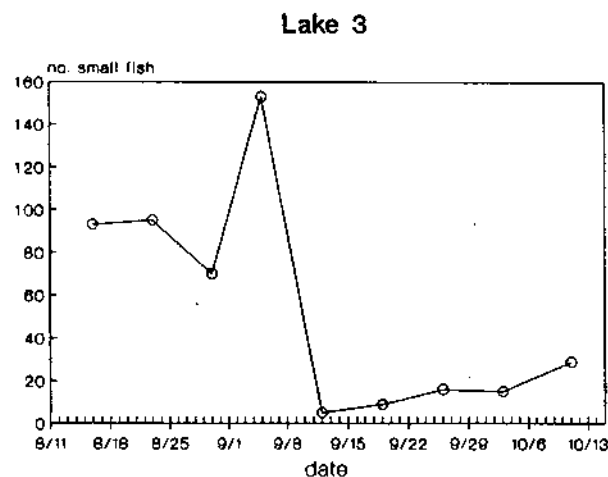
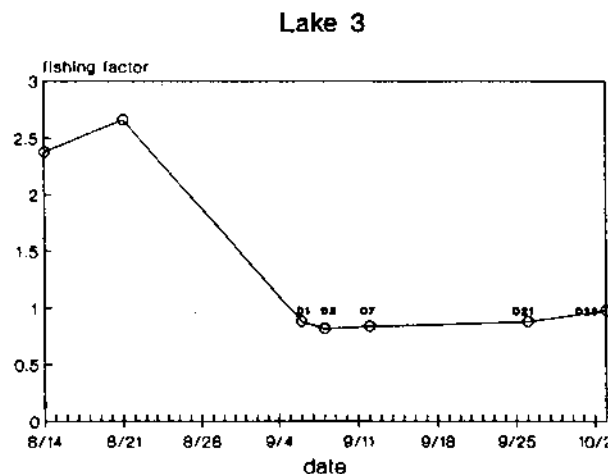


Figure V.4



Lake 4 (fenitrothion)

**Table V.6 small fish population in fenitrothion lake**

DATE	16 08 89	23 08 89	01 09 89	07 09 89	13 09 89	20 09 89	27 09 89	05 10 89	12 10 89
<i>Aplocheilichthys</i>	90	93	133	71	32	35	14	14	52
<i>Barbus leonensis</i>	5	4	3	5	9	6	1	-	-
Goby	-	-	1	-	-	-	2	-	1
juv. <i>Hemichromis</i>	-	-	-	-	1	-	-	-	-
TOTAL	95	97	137	76	42	41	17	14	53

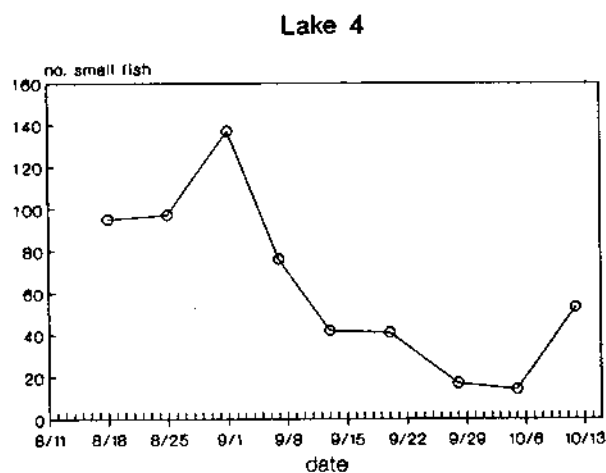
These data are presented graphically in Figure V.5.

The lake was sprayed with fenitrothion on the afternoon of September 7. No mortalities were subsequently observed among the fishes. The fluctuations in the gill net yield (Figure V.5) are discussed above. Only in *Alestes* did the diet change after spraying. Prior to the treatment their diet was as in the other lakes, a mixture of aquatic insects and gastropod molluscs. The day after spraying, the stomach contents were *circa* 70% terrestrial insect remains and 30% gastropod molluscs. Dead insects were seen floating on the lake surface. Three days after spraying, the *Alestes* had reverted to the prespraying diet. No other species showed any dietary changes.

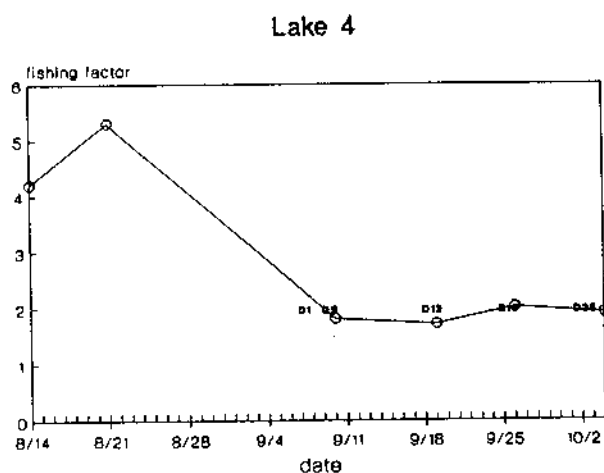
The only two gobies caught were large: 52 mm and 56 mm SL. Small gobies were never caught and none were found dead after the application of fenitrothion. It is tempting to speculate that the gobies did not breed in that lake.

The fluctuations in *Aplocheilichthys* abundance, as shown by the numbers caught, do not reflect population density changes. During the sampling programme in this lake (but not in the others) the *Aplocheilichthys* left the reed-fringed shores and formed large shoals in the open waters among floating weed clumps. Hence, they did not figure in the returns from the shallows sampling stations. In the last two samples, the *Aplocheilichthys* caught were juveniles and very small. It is presumed that the adults left the shore-line to breed elsewhere in the lake and the shallows formed a nursery area for the young. Certainly, the *Aplocheilichthys* movements were not related to the changes in lake level in this instance.

**Figure V.5**



**Figure V.6**



## Discussion and Recommendations

The observations and their interpretations particular to each lake are described above.

With such a narrow and skimpy database acquired in biologically unusual conditions, it would be unsound to make extrapolations and comparisons with other studies. This was only a pilot project but the results were interesting and may offer some indications towards more widely applicable lines of research. It is suggested that future research be conducted in areas where the only changes to the environment are natural and that any effects are monitored over at least three seasons to see if the reproduction or recruitment rates to the fish population are affected by the insecticide applications.

The time span of this project was too short to reveal any effects save that in Lake 3 juvenile *Alestes* appeared in the samples towards the end of the project. Such slight evidence as exists suggests that the reproductive cycle of all the species in the lakes investigated does not follow that of the fishes in the river system when the rainy season is popularly supposed to stimulate breeding. Even the latter statement needs verifying for the area studied. Consequently, the long term effects of insecticides on fish need to be studied in an area with a wide range of habitats, free from human interference.

To this end, I recommend the Podor-Ndioum region. It offers a wide variety of habitats including a large river (the Doué) with both banks well within Senegal, small streams, pools, creeks and, most importantly, large inundation zones. Already the nursery areas for the young of many species have been discovered. The significance of these areas is that they afford a ready source of the young fishes, suspected of being most sensitive, for laboratory experiments. Many young fish do not travel well and it is important to have a reliable source close at hand to provide the subjects for the much needed laboratory experiments. In the wild mortality on very small fish is hard to detect; the bodies are fragile, decay very rapidly or are eaten. Hence determination of sensitivity is next to impossible except under controlled laboratory conditions.

Furthermore, the region I advocate has a much more extensive fish fauna, although the species present would have to be identified as a prerequisite for future work. This would make the research more meaningful as, at best, the irrigation basins at Richard Toll afford only a random selection of twenty three species, some of which do not appear to behave as they reportedly do in the wild. Also, unlike Richard Toll, there are areas free from the attentions of local fishermen.

The western end of the region is only some 120 km from Richard Toll. There is some infrastructure in the presence of the Département des Eaux et Forêts in Podor and, on a pragmatic note, government accommodation is available close to Podor.

I feel that if that area were selected as the main base for the continuation of the aquatic studies, the results gathered would be of great and widespread significance. Such results would certainly be directly valid for a large part of Africa because the fish fauna of the Senegal is the western end of the Nilo-Soudanian fauna, a coast-to-coast ancient zoogeographical regime, now rendered discontinuous by desertification. Any results from Senegal are thus applicable to almost the whole of the Sahel.

One line of research that may well be a profitable venture is to investigate the effect that electrofishing has on cholinesterase levels. Under normal circumstances, the techniques used for fish collecting are adequate, but in using such techniques in Lakes with a low population level many more fish are removed from the lake than are necessary to provide the brain tissue samples. This reduces the reliability of using catch returns for populations studies. What seems to be unknown is how electrofishing, which would enable one to take just enough fish for the sample, affects the cholinesterase.

## Conclusions

1. Fish are an extremely important food source for the people of northern Senegal and much of the Sahel region. Therefore, the use of any anti-locust insecticides that reduces the number of fishes effectively reduces the point of using the insecticides.
2. Although all fish are eaten, those most favoured and most easily caught were poorly represented in the fauna of the artificial lakes investigated.

3. In the short term, no mortalities to fishes resulted from the use of standard doses of fenitrothion (at 500 g ai/ha) nor diflubenzuron (at 40 g ai/ha). The time span of the project was too short to detect any long term effects. It was noted that one species of comestible importance, *Alestes baremose*, eagerly consumed animals killed by these insecticides. Any effects of this adventitious feeding on the *Alestes* populations must be monitored.
4. Chlorpyrifos, at a standard dosage of 240 g ai/ha exterminated completely a species of goby (tentatively identified as *Porogobius schlegelii*) and killed some juvenile bagrid catfishes and a juvenile cichlid. The danger of this insecticide must be investigated most rigorously. The intimations that fish reproduction is not affected by chlorpyrifos must be confirmed.
5. It is suggested that the hydrobiological research would be more efficaciously and profitably conducted in the Podor-Ndioum region some 120 km to the east of Richard Toll.
6. The effect of electrofishing on cholinesterase levels needs to be investigated.

## References

Backiel T & Welcomme RL (eds) (1980) Guidelines for sampling fish in inland waters. EIFAC Technical paper 30:i - ix, 1 - 176



## **PART 5**

## **TERRESTRIAL MONITORING**

Ian F. Grant

### Introduction

Soils of the sahelian zone fall within three or four soil orders. The Aridisols of the annual prairies are characteristic of desert locust invasion areas, where, for less than three months a year, soils are warm and moist enough to support plant growth and summer breeding of locusts. The nutrient status of the soil is generally low but the overriding constraint on all biotic activity in arid and semi-arid biomes is water, such that annual production (dry matter) is often a linear function of precipitation.

In moister regions, and where soils can retain water, there are seasonal opportunities for low intensity cropping (e.g. *Pennisetum* sp.) and grazing of herdsman's animals. These large mammalian herbivores may have an important role in recycling of nutrients stored in above-ground biomass, but the spectacular primary production of annual grasses and forbs during the short wet season relies heavily upon mechanical nutrient release (comminution and wash-out) and microbial mineralisation of organic material accumulated during the dry period. Mineralisation of soil organic matter is microbially driven and therefore rapid once the rains begin, so that in a short space of time (2-3 months or more) most carbon, nitrogen and other nutrients largely held in the standing biomass pass through soil microbial biomass.

Populations and processes instrumental in the cycling of nutrients and maintenance of soil fertility are vulnerable to perturbations by pesticides. The sandy Aridisols possess little soil organic matter (1-4%), and have low clay contents and cation exchange capacities. Indeed, they lack the attributes which could attenuate the immediate toxicity of pesticides by adsorption onto large or charged surfaces. Acridicides will therefore be more active and biologically available under these conditions, subjecting microbial processes to considerable stress while moisture is available.

The organophosphates chlorpyrifos and fenitrothion are slightly soluble in water (2 and 14 mg l<sup>-1</sup> @ 22°C, Table I.2) but partition quite strongly into non-polar solvents. The benzoylurea insecticide diflubenzuron, an insect growth regulator, is not water soluble. The activity of the soil microbial biomass is a convenient indicator of the mineralisation of organic matter, and it is readily measured in the field as carbon dioxide release (*respiration*). The oxidation of ammonia to nitrate (*nitrification*) is an important step in the nitrogen cycle, the NO<sub>3</sub> ion being the preferred form of N for plant uptake. As the process is dependent upon a few species of slow-growing chemoautotrophs that are known to be sensitive to biocides, it can bioindicate for adverse microbial reactions to acridicides.

The short-term monitoring of acridicide impact on these two soil processes was undertaken using techniques specifically developed for field evaluations. Only soils sprayed at double rates were studied i.e. 1000g fenitrothion, 480g chlorpyrifos and 80g diflubenzuron ha<sup>-1</sup> nominal, on the assumption that the higher concentrations were more likely to show side-effects.

{Intentions of estimating biological N<sub>2</sub> fixation based on the C<sub>2</sub>H<sub>2</sub> reduction technique were abandoned. The two species of Cyanophyta (*Lyngbya* and *Oscillatoria*) found to be abundant have little or no ability to fix N<sub>2</sub>, and ethylene levels in the local acetylene, although small, would have masked weak nitrogenase activity. Incidental measurements of soil chlorophyll were made for area characterisation and did not form part of the impact monitoring exercise. Field estimates of associative N<sub>2</sub>-fixation in grasses are unreliable and were never anticipated)

## Materials and Methods

### Soil Respiration

Respiration was measured:

- i) in prepared soils exposed to acridicides
- ii) *in situ*, on soils immediately before and after spraying.

Soils for amendment were taken from a moist and well vegetated area referred to as a "depression". There was no history of pesticide use in this area. Fig. VI.1 shows the dominant vegetation and soil characteristics along a transect running from open savanna to the depression. Soil particle-size analyses were not available at time of writing the report.

Bulk density (1.35g cm<sup>-3</sup>) and field capacity (31% moisture) were estimated using field methods: the former by volumetric cylinder, the later gravimetrically after applying a vacuum of 25mm Hg to saturated soil. The soil was air dried and passed through a 2mm sieve before weighing 100g portions into plastic food containers. An organic amendment (0.5% dried grass passed through 1mm sieve) was dispersed in the soil before bringing the soil to c.60% FC with distilled water and incubation in aluminium trunks at ambient temperatures. Soil water losses were replenished every few days. Evolution of CO<sub>2</sub> was measured at intervals by affixing a modified lid to the containers and passing air from a mass flow pump over the surface of the soil and into an infra red gas analyser (IRGA). The difference in CO<sub>2</sub> concentrations (vpm) between incoming and outgoing air at the end of a 5 min. period was used to calculate respiration rate at standard temperature and pressure. Twenty replicates were used to estimate pre-spray respiration; five of these containers were exposed to each acridicide and respiratory activity monitored for as long as possible thereafter. The surface area of soil presented for exposure was 110cm<sup>2</sup>; container lids were removed 10-15 minutes before spraying and replaced within 1 h. Control soils were also positioned in the spray block to retain temperature parity, but their lids remained in place.

Evolution of CO<sub>2</sub> from soils in fenitrothion and chlorpyrifos treated areas (Blocks B and

E) was measured *in situ*. A known surface area of soil was isolated with an open ended coffee can pushed into the soil to a depth of 3cm. The proximal (closed) end of the can was fitted with input and output ports through which air was pumped from a height of 1.5m (mass flow) and then removed to an IRGA after flushing out the CO<sub>2</sub> evolved over a known time period. The headspace was cleared twice before measuring the difference in CO<sub>2</sub> concentration (vpm) in incoming and outgoing air. Pump rates were chosen to allow measurement of respiration within 4 minutes, thereby reducing the heating effect of the enclosure on the soil. *In situ* measurements were taken on transects running along moisture gradients - from open ground to the centre of a "depression" (Fig. VI.1). Field estimates of respiration include CO<sub>2</sub> produced by microbial, root and animal activity and it is difficult to allocate the amounts contributed to their respective compartments. However, in open savanna areas where plant cover is sparse, the contribution from root and animal respiration is minimal, and CO<sub>2</sub> evolution has been considered as microbial in origin. Areas with algal growths were generally avoided. Logging of air temperature, soil temperature and %RH of air over the soil accompanied all respiration measurements.

#### Nitrification

The soil used for nitrification measurement was described and prepared as above, but the organic amendment was replaced by ammonium sulphate [100µg NH<sub>4</sub>-N g<sup>-1</sup> soil]. Soils were wetted to c.60% of FC with a solution of the substrate and incubated as above. They were exposed to chlorpyrifos, fenitrothion and diflubenzuron as and when spraying occurred.

Elapsed time: wetting to spraying (days)

chlorpyrifos (387)	fenitrothion (825)	diflubenzuron (82.8g.ha <sup>-1</sup> )
7	12	9

Nitrate was extracted by shaking 50g (wet weight) of soil three times at 0.5h intervals with 50ml distilled water. After settling, a sample of supernatant was mixed with an equal volume of 2M (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> (ionic buffer) and NO<sub>3</sub>-N determined with a double junction reference and ion-specific nitrate electrodes calibrated against standard solutions. Standards and unknowns were always at ambient temperature for ionic measurements, which were made at zero time, 7, 15 and 20 days after wetting. [Delays caused by aircraft and insecticide availability severely shortened the length of the post-spray incubation period]

#### Soil chlorophyll

The chlorophyll complex was estimated by stratified sampling of algal crusts within 1m<sup>2</sup> quadrats thrown at random in open savanna and in depressions. Soil cores of 14mm diameter were extruded from the corer, the surface 2-3mm cut with a blade and the crusts placed in a glass vial. Ten ml. of acetone was pipetted onto the crust and the vials refrigerated for 24h. Absorbance of extracted chlorophylls was measured at 665nm in a portable spectrophotometer and reported as a chlorophyll a equivalent. Extracted pigments from sources other than viable algae (decayed plant material etc.) were unknown, but sand with no obvious growth of algae or other organic material produced little or no absorbance

after extraction. Some soil cores were flooded to promote the growth of algae for identification.

### Spraying Statistics

Aerosol generators were calibrated to produce 100µm vmd droplets (diflubenzuron was a droplet suspension). Only the volume of insecticide loaded, sprayed and respective run numbers were noted. Sedimented mass of insecticides was not measured during trials and the only guide to the distribution of drifted spray was given by oil sensitive papers (chlorpyrifos and fenitrothion). Papers were placed facing the wind at a 45° angle near the containers of soil and also at sites selected for *in situ* CO<sub>2</sub> measurements. Droplet distribution was gauged visually i.e. small, large or average droplet size; approximate dose, 50% dose etc. [Containers of soil were covered during this period to prevent water loss]

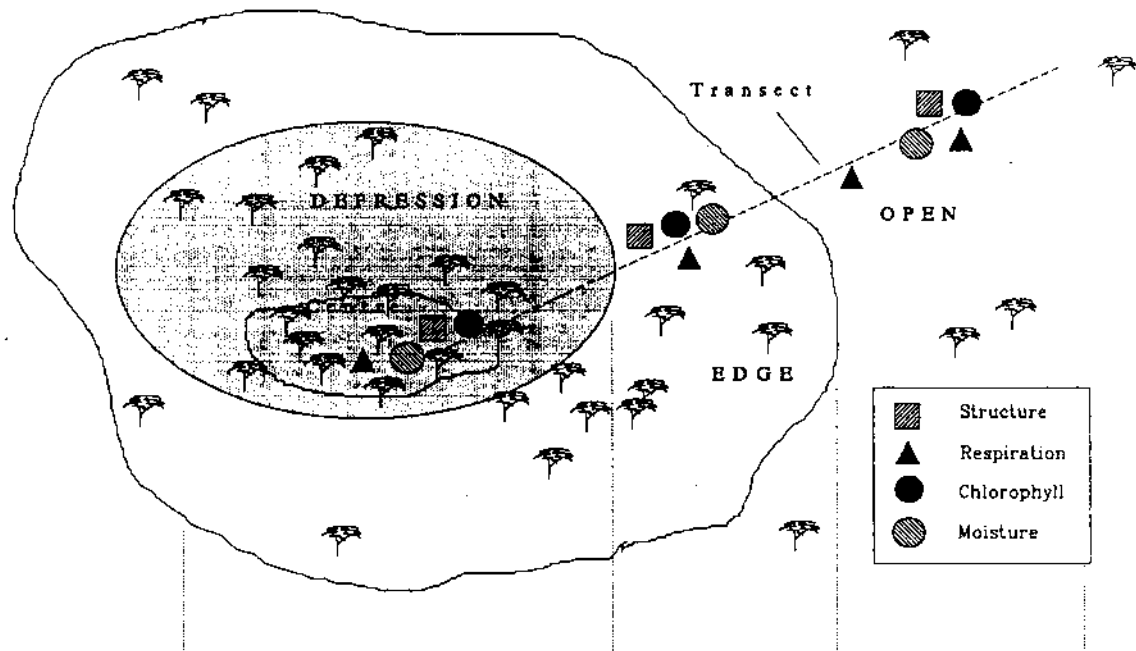
**Table VI.1:** Summary of Acridicide Impact Assessment

	chloropyrifos	fenitrothion	diflubenzuron
Dose nominal	450g.l <sup>-1</sup>	1000g.l <sup>-1</sup>	80g.l <sup>-1</sup>
Dose actual	387	825	82.8
Sedimented Mass	25-30%	50-100%	n.d.
Date	7.9.89	12.9.89	9.9.89
Block	E	B	F
Nitrification	x	x	x
Respiration			
<i>in situ</i>	x	x	
incubated	x	x	x

\* approximation by oil-sensitive paper. n.d = not determined

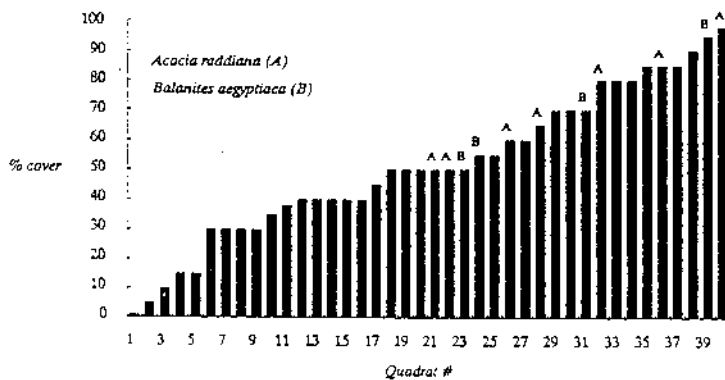
Figure VI.1

SCHEMA OF SITE TRANSECT AND SOIL CHARACTERISTICS

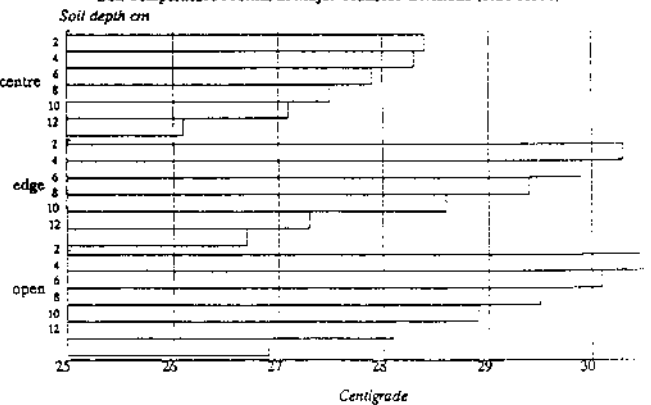


Soil moisture %	3.8-10.24	2.27-5.8	1.1-1.31
Soil chlorophyll (mg chl a/m <sup>2</sup> )	17.5-179.0	11.6-65.0	0.08-21.0
Soil structure			
Soil temps (0800h)	28-29	30-31	31-32
Dominant vegetation	<i>Balanites aegyptiaca</i> <i>Acacia Senegal</i> <i>Acacia raddiana</i> <i>Cassia Tora</i>	<i>Boscia senegalensis</i> <i>Latipes senegalensis</i> <i>Salvadors persics</i> <i>Dactyloctenium sp.</i>	<i>Latipes senegalensis</i> <i>Tribulus terrestris</i> <i>Boscia senegalensis</i> <i>Dactyloctenium sp.</i> <i>Centrus biflorus</i>
Soil pH	8.1	8.3	8.0
CEC	0.08	0.07	0.08
Total N %	0.06	0.04	0.05
Total Organic C%	0.67	0.47	0.83
C:N	11.1	11.75	12.6
CO <sub>2</sub> release (mg CO <sub>2</sub> /m <sup>2</sup> /h) (max at camp site)	750 +/-45		197+/-24
%OM	1.34	0.94	1.26

Estimated Grass Cover: Open and shaded areas



Soil Temperature Profiles at Major Transect Divisions (0730-0830h)



## Results

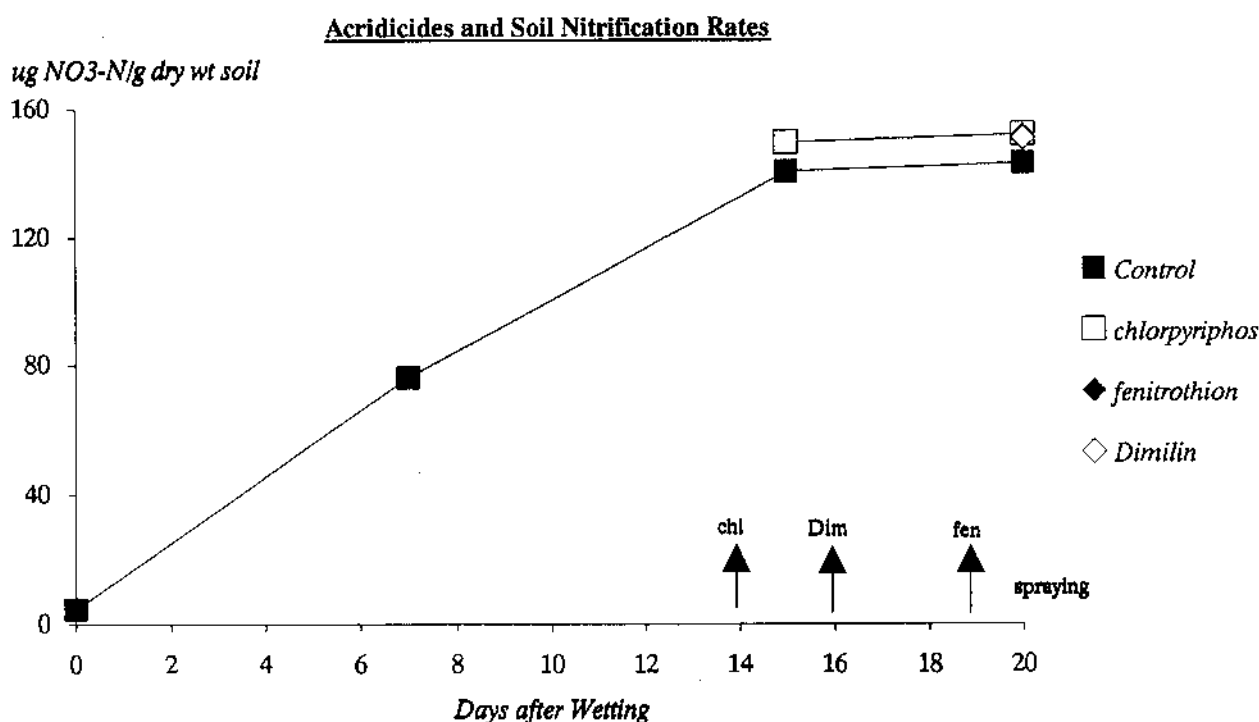
### Spraying Statistics

Oil sensitive papers indicated that 4 out of 5 soil containers (nitrification - Block E) were in a spray shadow; soils prepared for respiration measurements and those measured *in situ* received c.25-30% of the target dose. In Block B, droplet sedimentation of fenitrothion near samplers and transects was c.100 and 50% of target dosage for two sorties respectively. See Table VI.1 for spraying statistics.

### Nitrification

Over the 20 day period of incubation (Fig. VI.2), the accumulation of  $\text{NO}_3\text{-N}$  from the oxidation of  $\text{NH}_4\text{-N}$  was in excess of the ammonium amendment (100ppm-N). The oxidation of additional reduced N-compounds derived from the soil obviously occurred: the onset of wet season stimulating their rapid production through ammonification<sup>1</sup>. [soil analysis =  $400\mu\text{g}$  total N  $\text{g}^{-1}$  d.w.soil] The absence of a logarithmic phase to the oxidation of the  $\text{NH}_4$  amendment suggests that the upper extremes of diurnal temperature ( $39^\circ\text{C}$ ) may have significantly affected the growth of nitrifiers - nitrification proceeds very slowly at  $40^\circ\text{C}$ . Nitrification proceeded at same rates in control and pre-sprayed soil (graph-lines omitted: SEM = to or < size of point).

Figure VI.2



<sup>1</sup> Insecticides frequently stimulate ammonification

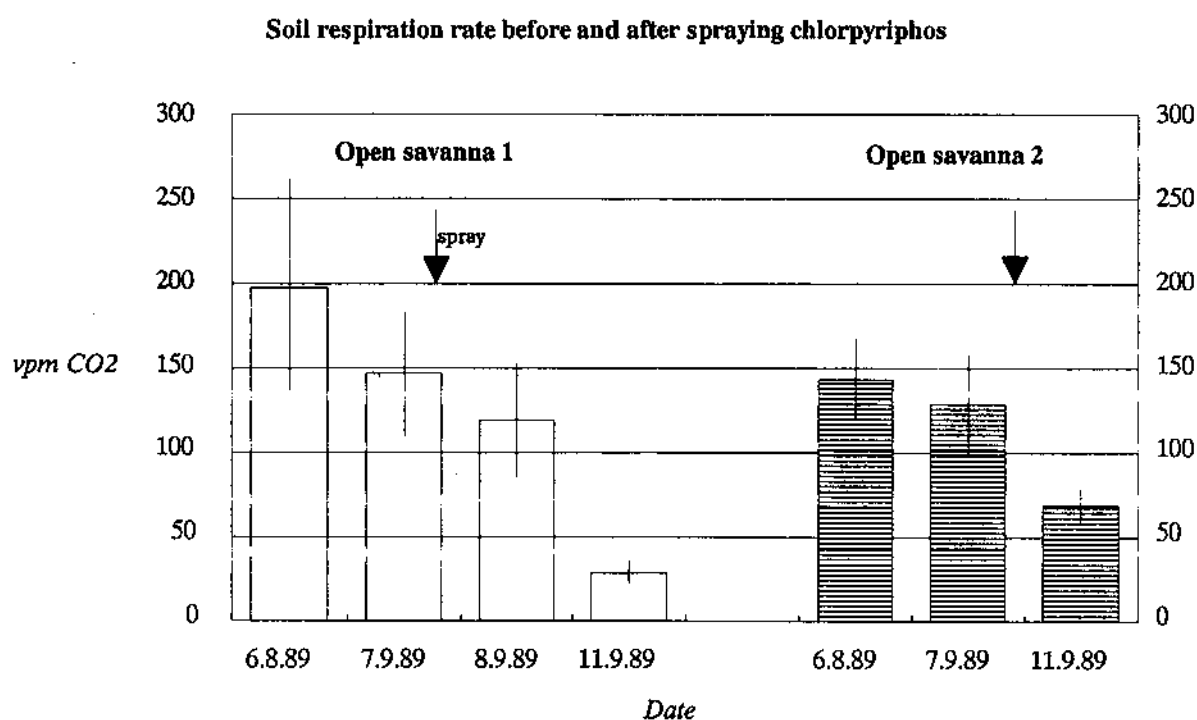
The delays in spraying reduced the number of post-spray  $\text{NO}_3$  determinations to two (chlorpyrifos) and one each for diflubenzuron and fenitrothion. All were exposed at a time when nitrification rates were becoming asymptotic. During this period, neither chlorpyrifos (15-20 DAW) nor diflubenzuron (16-20 DAW) affected nitrification. No conclusion about the impact of fenitrothion (sprayed one day before the nitrification trial terminated) could be drawn.

## Respiration

### *In situ*

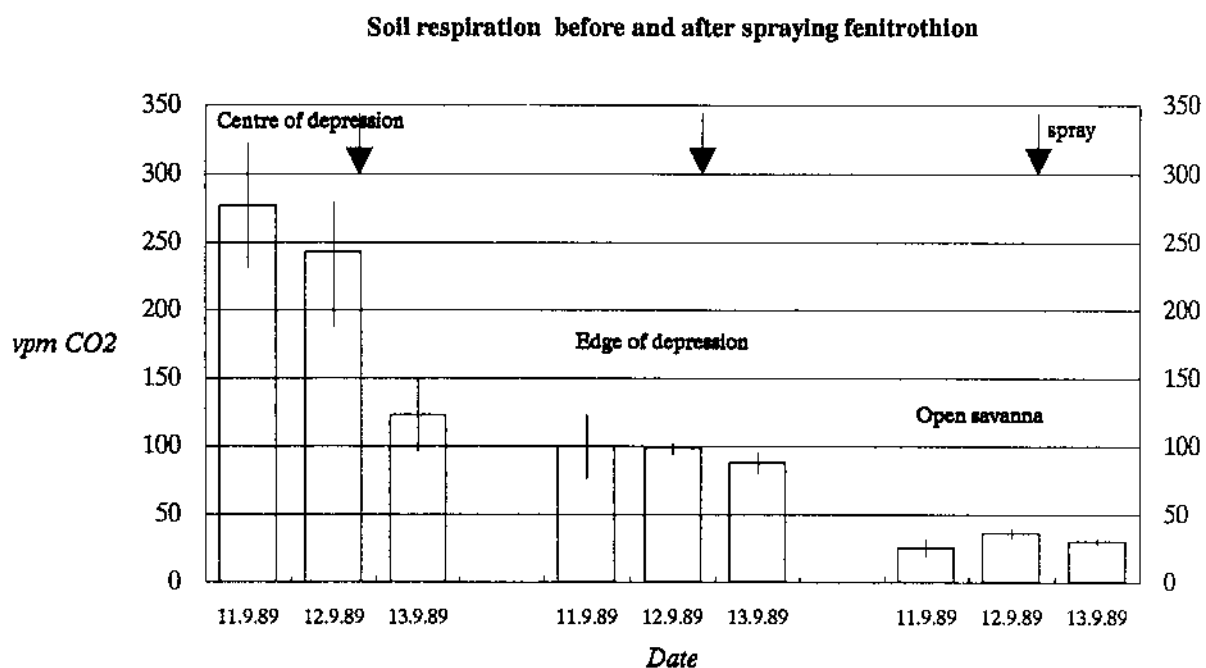
Soil respiration rates of two areas of open savanna were measured shortly before and after spraying chlorpyrifos (Block E; Fig. VI.3). Maximum respiration was recorded on 6.8.89, after heavy rain the previous day: readings of  $260 \text{ vpm} = 800 \text{ mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$  ( $20 \text{ g m}^{-2} \text{ day}^{-1}$ ), indicate that it was a period of intense microbial activity. In both areas of open savanna, the linear<sup>2</sup> decline in the concentrations of  $\text{CO}_2$  evolved was attributed to diminishing soil moisture, as no rain had fallen since 5.8.89. Chlorpyrifos did not significantly affect soil respiration, although minor effects would have been masked by the critical influence of moisture on respiration.

**Figure VI.3**



<sup>2</sup> n.b. scale of X axis

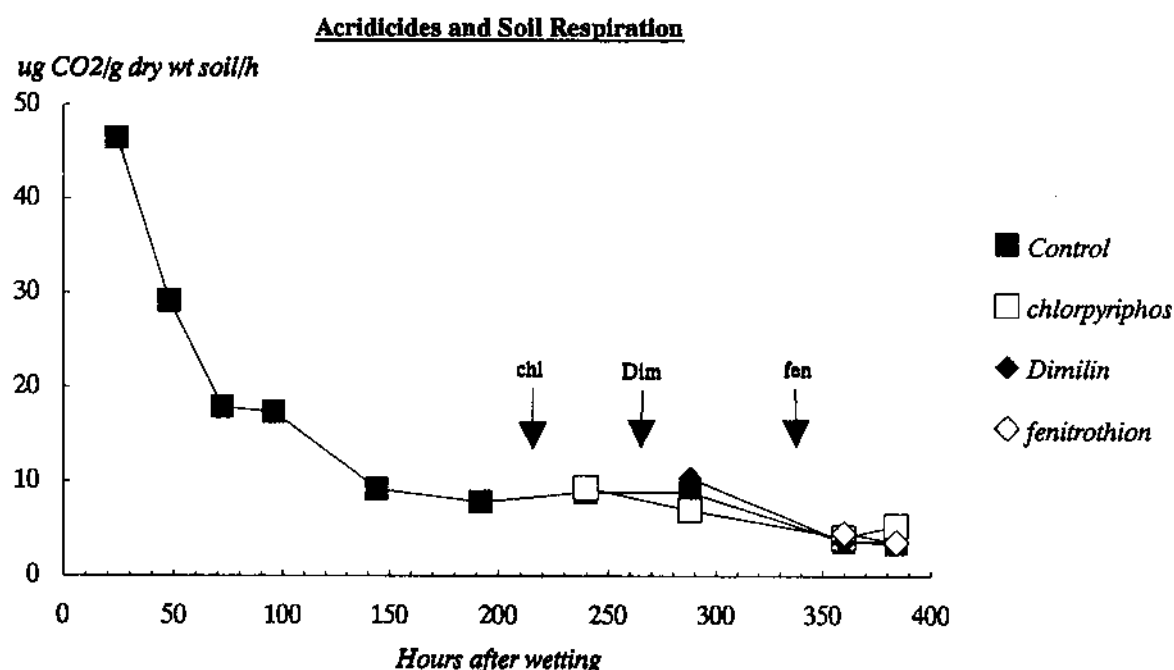
Figure VI.4



In contrast to Block E, the soils of Block B were drier when fenitrothion was sprayed (Fig. VI.4). As a result, the variation in microbial activity (over time) was reduced in the open savanna area and at the edge of the depression. But carbon dioxide production in the centre of the depression was more variable, and probably a drying effect as the heavier textured and shaded soil dried out more slowly.

Marked differences in respiration between soils of the open savanna, the edge and centre of the depression were demonstrated along the transect crossing the three habitats. The increasing clay, TOC content and WHC of soils down the gradient towards the depression offered the best explanation for the differences. Respiration in the depression was as high as  $23\text{g CO}_2 \text{ m}^{-2} \text{ day}^{-1}$ . The lower temperatures in the depressions also retard evaporation and evapotranspiration rates (Fig. VI.1 - temperature profile).

Figure VL5



In areas where spray deposition on the soil would be greatest, i.e. open areas and edge of depression, fenitrothion produced no marked effect on soil respiration the day after spraying. In the depression centre, where virtually no spray makes direct contact with the soil, a decline in  $\text{CO}_2$  evolution 24h after spraying was evident, although of no statistical significance. No *in situ* study of respiration was made in diflubenzuron treated areas.

#### Amended soils

The release of  $\text{CO}_2$  from the decomposition of soil organic matter was measured at various intervals after wetting of soils (Fig. VI.5). The influence of acridicides on the process was examined after the initial flush of  $\text{CO}_2$  was over. The burst of microbial activity, produced by wetting and utilisation of readily available soil C, subsided after 150h, when soil respiration stabilised around  $5\text{--}10\mu\text{g CO}_2 \text{ g d.w.soil}^{-1}$ . The influence of diurnal temperature on microbial activity was moderated by estimating respiration at similar times of day, yet small temperature differences at different dates (Fig. VI.6) showed up as noise on the decay curve. However, control and treated soils were measured at the same temperature. The  $\text{CO}_2$  release from 150h onwards is in good agreement with *in situ* measurements made in depressions i.e. those with adequate soil moisture (Fig. VI.7).

Respiration rates of soils exposed to chlorpyrifos, fenitrothion and diflubenzuron did not differ significantly from those of their control. It was concluded that there was no immediate impairment of microbial decomposition. [Ideally, decomposition would have been studied for longer, about 30days; this was precluded by delays in spraying]

Figure VI.6

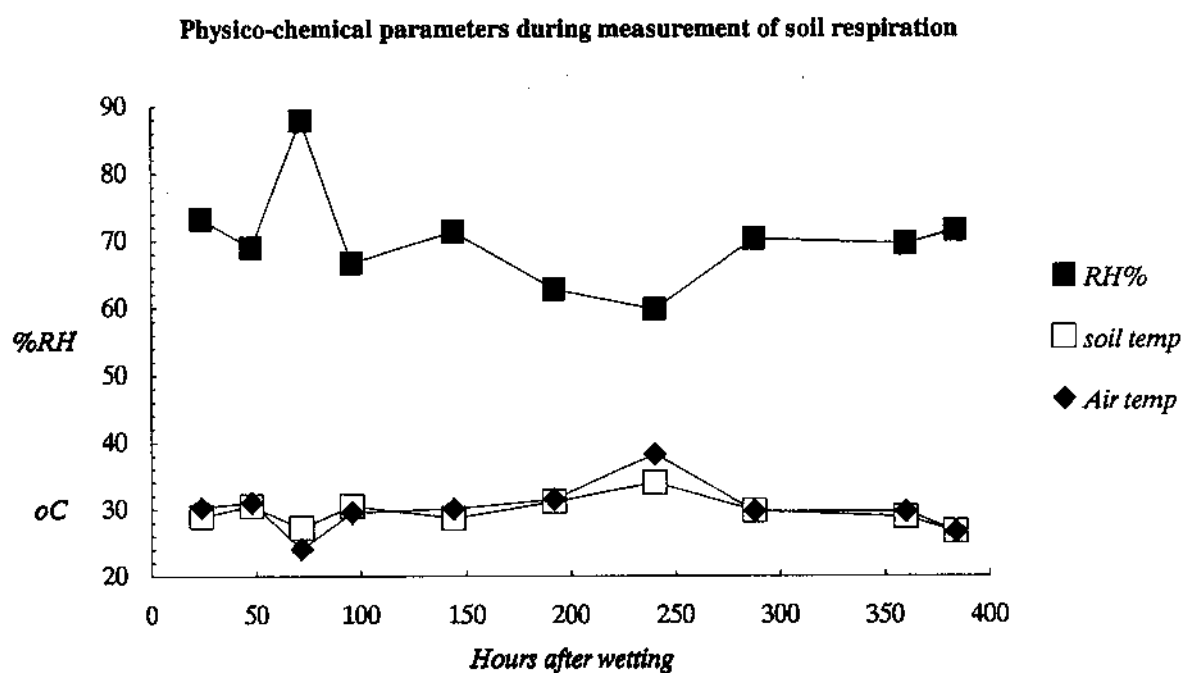
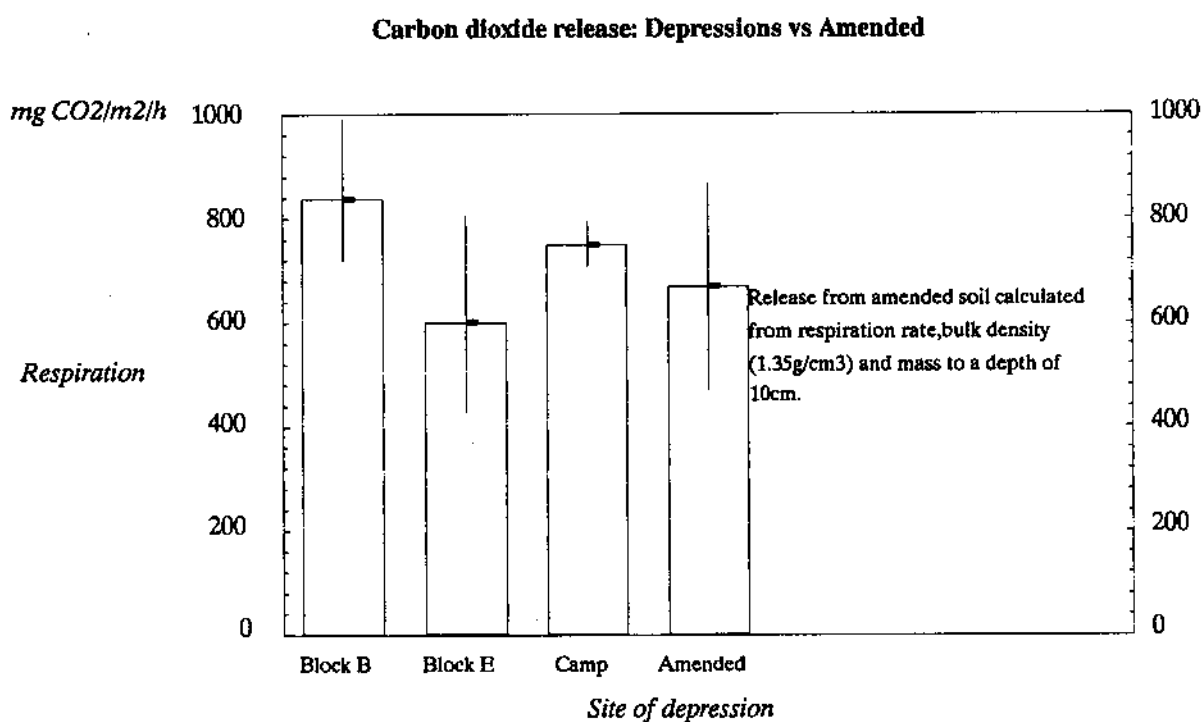


Figure VI.7



### Soil Chlorophyll

Thick surface crusts of algae were associated with moist shaded areas early in the wet season - before grasses and forbs limited the penetration of light. Concentrations of chlorophyll in such crusts reached  $179 \text{ mg chl} a \text{ m}^{-2}$  soil. Soil chlorophyll decreased along transects running from the centre of a depression to the open savanna (Fig. VI.1). Algae in the open savanna grew below the surface of the soil, colouring the sand a light to dark brown, and changing its reflective properties. The chlorophyll content of these sands ranged from  $11.6 \text{ mg chl} a \text{ m}^{-2}$  (dark brown) to  $0.08 \text{ mg m}^{-2}$  (light brown), yet small amounts of shade could increase chlorophyll to  $17.5 \text{ mg m}^{-2}$ . Soil chlorophyll was not monitored for potential effects of acridicides.

The algal crusts were dominated by Cyanophyceae of the genera *Lyngbya* and *Oscillatoria* (unbranched Nostocales) and the green algae were represented by Chlorophyceae and Bacillariophyceae (diatoms); the green algae were far less abundant. The heterogeneous mix prohibited estimations of standing biomass from the chl *a* concentrations.

### Discussion

The OPs, chlorpyrifos and fenitrothion, and the IGR diflubenzuron have moderate to low persistence in soils, and wet season use provides almost optimal conditions for their swift detoxification and degradation by physical and biochemical action. In open savanna, the mobility of all three acridicides will be greater than in the depressions, where clay content is slightly higher. Partition coefficients suggest that chlorpyrifos (Log  $P=5.2$  n-octanol:water partition) and fenitrothion (4.4) are non-polar and easily sorbed. Diflubenzuron also absorbs strongly to sediment but its degradation is dependent more on its particle size than soil characteristics. By the time annual grasses and forbs are incorporated in the soil, <1 year, the acridicide residues would neither be appreciable nor detrimental to microbial activity.

Concentrations of the organophosphates used in this pilot study were equivalent to 3.6ppm chlorpyrifos and 6.6ppm fenitrothion [bulk density 1.35 and 1cm soil depth<sup>3</sup>]. Under stable laboratory conditions, chlorpyrifos has depressed nitrification of soil organic nitrogen and  $(\text{NH}_4)_2\text{SO}_4$  in a sandy loam (pH8.1) and a loamy sand (pH7.4) at 10 and 100ppm for up to 2 weeks, but recovery of nitrifiers (and oxidation) was seen within 3 weeks. Lower dosages (0.5 - 5ppm) had no such effects in a sandy loam (pH 7.6) (Tu 1969, 1970). Fenitrothion was reported to affect nitrification at very high application rates (10-50kg ha<sup>-1</sup>), but initial inhibition was subsequently followed by stimulation (Dhanaraj 1988, Ross 1974). Used as acridicides, chlorpyrifos and fenitrothion were just under the threshold of where effects are manifest under laboratory conditions.

Unlike the nitrifiers, that are physiologically similar, the microbial groups involved in the decomposition of OM are physiologically diverse, and while perturbations by insecticides may suppress sensitive populations, the overall process may not be unduly disrupted. Cellulose degraders and soil respiration have been shown to increase in a clay loam

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<sup>3</sup>a soil depth of 10cm would mean 0.36 and 0.66ppm

following chlorpyrifos treatment at field rates ( $100-10^4$  g ha<sup>-1</sup>) (Tu 1969, Sivasitharampam 1970) and in other laboratory studies, a stimulation of respiratory activity in three soils treated with the equivalent of 112kg fenitrothion ha<sup>-1</sup> were demonstrated (Anderson 1978). Diflubenzuron has not been shown to affect decomposition processes. In contrast to nitrification, the concentrations of acridicides used were more than one order of magnitude below those where laboratory effects are seen on soil respiration.

The environmental influences of soil moisture and temperature on carbon mineralisation and ammonium oxidation are critical in the savanna, as these microbially mediated processes are subjected to extremes of both during the wet season. Therefore it was evident that temperature fluctuations and changes in soil moisture exerted a far greater effect on soil respiration than any of the acridicides sprayed to control locust. The linear conversion of ammonium to nitrate was also considered to be linked to temperature extremes. There remain some doubts about the actual dose of chlorpyrifos received by N-amended soils and the effect of the delays in spraying on nitrifiers. That soils were subsequently and unconventionally exposed when nitrifying populations were already established has probably greater relevance to field circumstances at the time of control operations than the usual convention of toxicity testing from stationary phase. More post-spray observations on soil nitrification and respiration would have been desirable.

At the start of wet season algae quickly colonise bare areas in the open (and forested) savanna, where they contribute fixed carbon and sometimes nitrogen to an often hostile environment. At the same time, they improve soil structure and increase the tensile strength of the upper layer of soil, protecting it from mechanical disruption by wind, rain and grazing (i.e. agencies of erosion). Organophosphorus compounds are relatively non-toxic to algae, although small concentrations of chlorpyrifos (1.2ppb) have reduced growth of phytoplankton and stimulated growth of cyanophytes (2.4ppb) (Hurlbert *et al.* 1972). Diflubenzuron stimulated the N<sub>2</sub>-fixing activity of *Azotobacter* grown on medium (Martinez-Toledo *et al.* 1988).

The stability of soil in an area where overgrazing is prevalent is a critical factor in reducing soil erosion and the risks of desertification. As vegetative cover is the best defence against erosion, direct or indirect effects of acridicides on soil fertility or algal growth should be of great concern in desert locust biomes. Where regular spraying is not anticipated, as in desert locust habitats, these acridicides cannot be conceived as being detrimental to soil fertility and primary production through microbial pathways.

## Recommendations

The role of mammalian herbivores in nutrient turnover may be underestimated in annual prairie. Indirect effects of acaricides on incorporation and breakdown of OM in faeces via scarabids and dung living invertebrates might be of biological significance to plant production. Similarly, a reduction of predation on invertebrate grazers could influence algal growth indirectly with consequences for de novo C and N fixation and soil stability. Future studies might invest some effort in these areas.

## References

- Anderson JR (1978) Pesticide effects on non-target soil microorganisms. In: Hill R & Wright SJL (Eds) *Pesticide Microbiology*, pp 313-533 Ac Press, London
- Dhanaraj PS (1988) Effects of pesticides on nitrification and denitrification. In: Lal R & Lal S (Eds) *Pesticides and Nitrogen Cycle Vol II* pp 48-118 CRC Press, Florida, USA
- Hurlbert S, Mulla MS & Wilson H (1972) Effects of an organophosphorous insecticide on phytoplankton, zooplankton and insect populations of fresh-water ponds. *Ecol Monogr* 42:269-299
- Martinez-Toledo MV, Gonzales-Lopez J, De La Rubia T, Moreno J & Ramos-Cormenzana A (1988) Diflubenzuron and the acetylene-reduction activity of *Azotobacter vinelandii*. *Soil Biol Biochem* 20:255-256
- Ross DJ (1974) Influence of four pesticide formulations on microbial processes in a New Zealand pasture soil. II Nitrogen mineralization. *NZ J Agric Res* 17:9-17
- Sivasithamparam K (1970) Some effects of an insecticide (Dursban) and a weed killer (Linuron) on the microflora of a submerged soil. *Riso* 19:339-346
- Tu CM (1969) Effects of four organophosphorous insecticides on the activity of microorganisms in soil. *Bact Proc* 9:3
- Tu CM (1970) Effects of four organophosphorous insecticides on microbial activities in soil. *Appl Microbiol* 19:479

Abdoulaye Niassy

### **Introduction**

In Senegal fenitrothion and malathion are the most widely used insecticides because of their advantages (quick kill, short persistence in the environment). There is, however, a need for the Senegalese Crop Protection to diversify their insecticides and to reduce the related application costs and possible environmental problems. This is partly why chlorpyrifos and diflubenzuron (a growth regulator) were added to the list for this experiment.

### **Objectives**

1. To evaluate short and long term effects of fenitrothion, chlorpyrifos and diflubenzuron on the grasshopper complex in the area; the first insecticide being currently used, whereas the last two will be so in the near future.
2. To establish whether higher than recommended rates would increase mortality despite the possible threat to the environment.
3. To compare the effects of the three insecticides on the grasshopper populations.
4. Give recommendations as far as the use of these insecticides is concerned.

### **Materials and Methods**

#### **The design**

Within each block, one observation site was chosen such that it was representative of the block. Observations were made at each site on a weekly basis. They concerned essentially density counts, light trapping and sweep net sampling. Because of differences in vegetation between blocks C, F and G, an additional control area, CFG, was selected near block F (Chapter I, Figure I.2: asterisk near Block F).

#### **Density counts**

Plastic tubings provided by the National Crop Protection Laboratory of Entomology were cut into pieces equivalent to the circumference of a 0.1 m<sup>2</sup> circle or ring. Hundreds of rings were manufactured this way and used for counting insect densities. Such counts were done following a method developed by Huddleston & Edwards (1986). Twenty-five rings were deposited following a 250 m transect (running uphill to downhill to cover all habitats) on a site 24 hours prior to density reading.

This time was enough to allow disturbed insects to redistribute themselves naturally throughout the site. Early in the morning readings were taken in the following manner:

- an operator comes to the head of the transect with a rod long enough to allow him to reach the centre of the ring from a distance. The piece rod is directed into the ring and only those hoppers jumping from it are counted and noted in a form designed for the purpose;
- after all rings were counted the average was calculated for that particular week.

During the counts we separated nymphs from adults, but not larval stages.

#### Light trapping

This was to allow an overall view of the species composition in the area. During the evening following the density counts, the light trap was placed at the same site. The trap used for this experiment was made of metal with a height of 1.69 m. The tank was 57 cm in diameter, 23 cm deep; its conic roof had a diameter of 75 cm at its largest side and was held in position by three 79 cm bars. The bars supporting the roof and the legs were adjustable so that the overall height could be varied at will. The tank had a hole through the bottom for a gaz tube to a lamp placed on top of it. Inside the tank were placed two strains that helped collect the trapped insects. This allowed trapping inside an approximate 500 m radius, thus within the boundaries of an experimental plot.

Before the trap was lit at 7:30 or 8:30 pm a 15 to 18 l solution of water with a detergent was poured in the 25 l tank. Trapping lasted 2 hours per night. At the end of the two hours the trap was covered. The insects were collected the next morning and taken to the laboratory to be sorted out by species. All species and their code numbers were recorded.

#### Sweep net sampling

Since all insects could not be attracted to or trapped by the light trap there was a need to use a sweep net to complete the picture. The sweep net was only complementary to the light trap.

The sweep net sampling was either done just before light trapping or the day after. It consisted of 200 sweeps along the counting transect. The harvest was taken to the laboratory to be sorted out. Results were added to those of the light trap.

## **Results and Discussion**

#### The insect community

As revealed by the light trap and the sweep net catches, the community was very diverse. A total of 69,313 individual insects (all species) were trapped through the trial period, divided as follows (Table VII.1): 14,712 in block A, 6,163 in B, 12,174 in C, 7,279 in D, 5,350 in E, 18,184 in F and 5,451 in G. The average catches were were 1,839, 10,272, 2,029, 1,040, 764, 3,031 and 909 in the respective blocks mentioned above. It appeared therefore, that blocks F, C and A had higher total insect numbers, whereas B, D and G were medium and E the lowest. Overall, at least 1,509 individuals were captured on average per day and throughout the trial zone. The numbers of species obtained were 210, 198, 220, 143, 147, 194, 172 for the respective blocks. In terms of species diversity A, B, C, F, G were most similar on one hand, and D and E on the other hand. Despite the apparent differences in species numbers, all blocks could be considered as fairly similar as far as species composition was

concerned. Of the grasshopper complex a total of 11,557 insects were captured using the two methods. In other words the grasshoppers represented on the average 16.8% of the whole entomofauna of the trial zone (as captured with the above methods)(Annex VII.1) with 22 different species present (Table VII.1 and Annex VII.1). The main grasshopper species found throughout the trial zone were:

*Oedaleus senegalensis* 40%, *Stenohippus epacromioides* 21%, *Stenohippus xanthus* 13%, *Aiolopus simulator* 11%, *Hieroglyphus daganensis* 5% and *Cataloipus cymbiferus* 2%. There were sixteen other species present in low numbers (less than 1%). In all plots, however, *Oedaleus senegalensis* was present in high numbers. For instance: 35.7% in A, 44.3% in B, 59.8% in C, 39.3% in D, 70.8% in E, 16.2% in F and 21.8% in G. *Stenohippus* and *Aiolopus simulator* were also consistently present, but at lower rates. Therefore, *Oedaleus senegalensis* was the first indicator species followed by *S. epacromioides* and *A. simulator*. The numbers in this text mainly refer to these species. *H. daganensis* and *C. cymbiferus* are late season insects with only one generation per year. They appeared in the plots only in mid-September whereas the first three had been there throughout the season.

**Table VII.1:** Total numbers of insects captured throughout the experimental period. Averages were also shown in these tables. July 6 to October 10, 1989. Richard Toll.

Trap- ping week	Blocks							Total	Average
	A	B	C	D	E	F	G		
1	101	160	2225	346	63	5840	1346	10081	1440
2	11139	475	2110	2540	209	10333	251	72057	8865
3	892	997	297	1520	57	46	61	3870	552
4	708	15	4938	465	148	15	163	6592	941
5	313	1804	1610	23	37	1337	3016	8140	1163
6	693	2712	994	549	605	473	614	6640	948
7	513	-	-	1836	4231	-	-	6580	1645
8	353							353	353
Tot.	14712	6163	12174	7279	5350	18184	5451		<u>69313</u>
Aver.	1839	1027	2029	1039	764	3030	9085		<u>1506</u>

### Age composition

*Oedaleus senegalensis* is one of the most, if not the most, dangerous grasshopper species in the Sahel. This is because of its ability to produce more than a generation (1-3) a year, its migratory ability and its voracity. This year in Richard Toll we were able to follow one generation. In fact, it had become evident that early in the sampling period populations were mainly 1st and 2nd instar and a few mature adults. These adults (probably allochtones) disappeared later on to give place to young nymphs which then grew up in the trial zone and became our targets. As can be seen (Table VII.3) fledging commenced the first week of September. The application took place against a mixed population of grasshoppers (L4, L5 and young adults). Fledging was complete by the 20th of September (in blocks F and G) corresponding to sampling n° 8 (Table VII.3). Recolonization of the treated zones was mainly by adult insects immigrating from adjacent areas.

### Insect population dynamics in the trial zone and indications of treatment effects

Each block was separately compared to the control C; blocks F and G were compared to control site CFG. In Table VII.3 and Figs. VII.1 to VII.7 we can see the population trends from August to October.

#### *Block A*

Block A was treated with fenitrothion 500 ULV at the dosage of 485 g ai/ha. During the first three weeks of August, populations were declining. This was also true for the control plot C. The reason for this decline was that allochtone populations formerly present in the area started to move out as the area became drier. However, by the 22nd of the month there was heavy rainfall that allowed heavy hatching of eggpods still quiescent in the soil. This explained the peak observed by the 25-26th of August in blocks A and C. However, the insect population started slowly to decline thereafter. The decline was accelerated by the chemical applied on the 8th of September (Fig. VII.1).

It became evident that 48 hours following application, recolonization had started, but was slow until the 21st of September; about 2 weeks later the insect populations started to increase more rapidly. The effect of the chemical was therefore evident on the insect populations.

#### *Block B*

This block was treated with fenitrothion 500 ULV at the rate of 825 g ai/ha. The drop in populations observed in A was true for B: however, the insects starting picking up by the 2nd week of August, when we had seen some sort of recruitment in the plot, probably due to the hatchings that occurred following a slight rain a few days before. Compared to the control plot, populations in B increased faster until the 25th of the month when they started again to decline slowly. The insecticide application on the 12th caused a drastic drop in the insect densities (Fig. VII.2), much faster than in the control. Again recolonization here started 48 hours after treatment. It was slow in the 1st week following application, but was faster thereafter. The effects of the chemical was also evident in block B, but was similar to block A in intensity and recolonization.

**Table VII.2:** Grasshopper species composition of the trial plots as indicated by the light trap and sweep net sampling. The species *Oedaleus senegalensis* was by far the most important. Only major species (1%) are included.

SPECIES	A	B	C	D	E	F	G	Relative Abundance	Total
<i>Oedaleus senegalensis</i>	589	461	1283	624	1100	452	142	40%	4651
<i>Stenohippus epacromioides</i>	175	28	150	660	161	1042	212	21%	2428
<i>Stenohippus xanthus</i>	277	118	104	109	53	803	82	13%	1546
<i>Aiolopus simulator</i>	297	228	414	65	42	87	96	11%	1229
<i>Hieroglyphus daganensis</i>	125	111	31	16	31	114	124	5%	552
<i>Cataloïpus cymbiferus</i>	83	6	13	6	58	18	7	2%	191
Other* (16 species)	105	88	155	107	109	266	130	8%	960
<b>TOTAL</b>	<b>1651</b>	<b>1040</b>	<b>2150</b>	<b>1587</b>	<b>1554</b>	<b>2782</b>	<b>793</b>	<b>100%</b>	<b>11557</b>

\* *Heteracris annulosus*, *Aiolopus thalassinus*, *Acorypha glaucopsis*, *Pnorisa carinata*, *Pyrgomorpha cognata*, *Pyrgomorpha vigneaudi*, *Acrida bicolor*, *Acrida Acrotylus longipes*, *Acrotyles daveyi*, *Acrotylus blondeli*, *Stenohippus gracilis*, *Stenohippus arabicus*, *Zacompsa festa*, *Locusta migratoria* and *Diabolocatanops axillaris*

#### Block D

This block was treated with chlorpyrifos 450 ULV at the rate of 270 g ai/ha. The population drops observed in the former two cases were also seen in D for the first three weeks (period of drought). Then the rains were followed by hatching and increase in population densities. Application was on the 5th of September after which insect numbers dropped quickly compared to the control. We note that population levels in D stayed consistently higher than in the control C (Fig. VII.3). Recolonization started 24 hours after applications and increased steadily until the 14th, when populations started to increase. We note that this exceptional speed of recolonization could be partly due to rain in the plot 18 hours post treatment.

**Table VII.3:** Age composition of the grasshopper population during the test period. Results are per 1/10m<sup>2</sup>. Numbers are totals for 25 rings

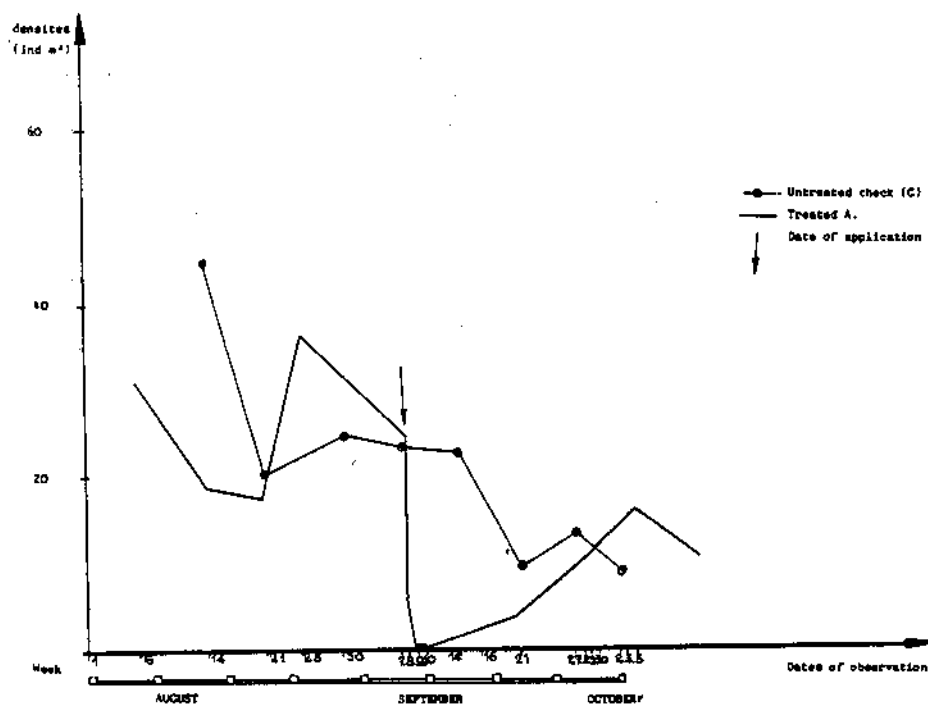
Sam- pling	BLOCK								
	A			B			C		
	T	N	A	T	N	A	T	N	A
1	78	61	17	44	32	12	111	102	9
2	46	46	0	21	20	1	36	30	6
3	43	31	12	42	39	3	61	19	42
4	90	42	48	71	65	6	59	24	35
5	61	51	10	64	25	39	57	29	28
6	7	4	3	57	2	55	24	5	19
7	1	0	1	3	0	3	33	0	33
8	1	0	1	4	0	4	21	0	21
9	5	0	5	1	0	1			
10	7	0	7	5	0	5			
11	26	0	26	29	0	29			
12	40	0	40	24	0	24			

Sam- pling	BLOCK												CFG*
	D			E			F			G			
	T	N	A	T	N	A	T	N	A	T	N	A	
1	53	52	1	64	59	5	63	45	18	22	12	11	0
2	43	26	17	145	145	0	36	24	12	23	22	1	0
3	55	44	11	65	64	1	34	31	3	18	12	6	31
4	31	10	11	66	58	8	44	38	6	17	1	16	38
5	4	4	0	6	6	0	78	74	4	8	8	0	74
6	1	0	1	1	0	1	95	88	7	16	4	12	56
7	6	0	6	8	2	6	44	26	18	25	2	23	80
8	15	0	15	10	4	6	59	31	28	20	1	19	136
9	59	0	59	10	0	10	9	0	9	15	0	15	0
10	87	0	87	64	1	63	25	0	25				5
11							8	0	8				
12													
13													

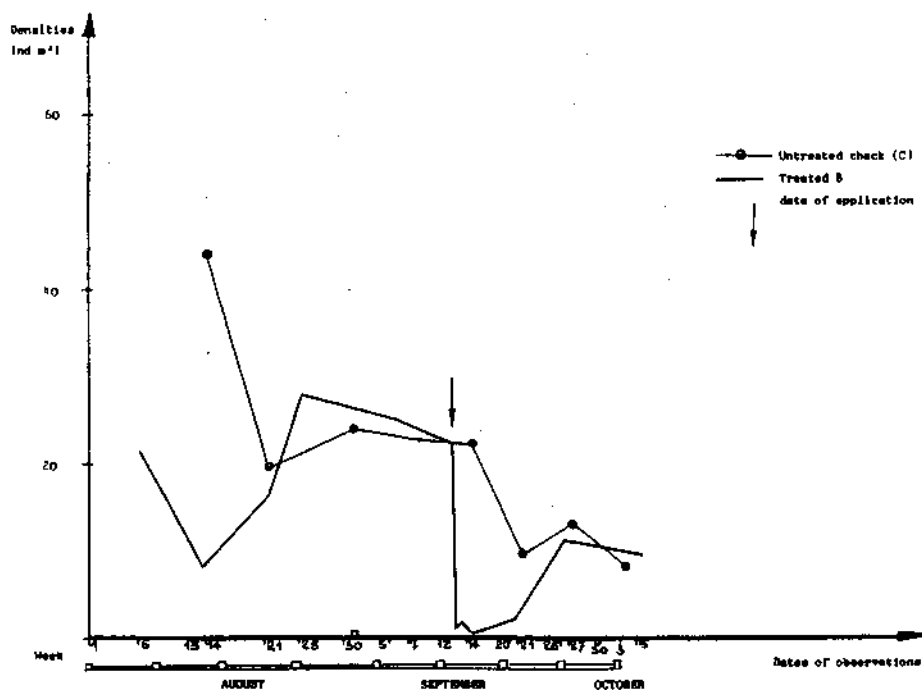
T = Total      N = Nymphs      A = Adults

\* CFG: control for Blocks F and G (Figure I.2: asterisk)

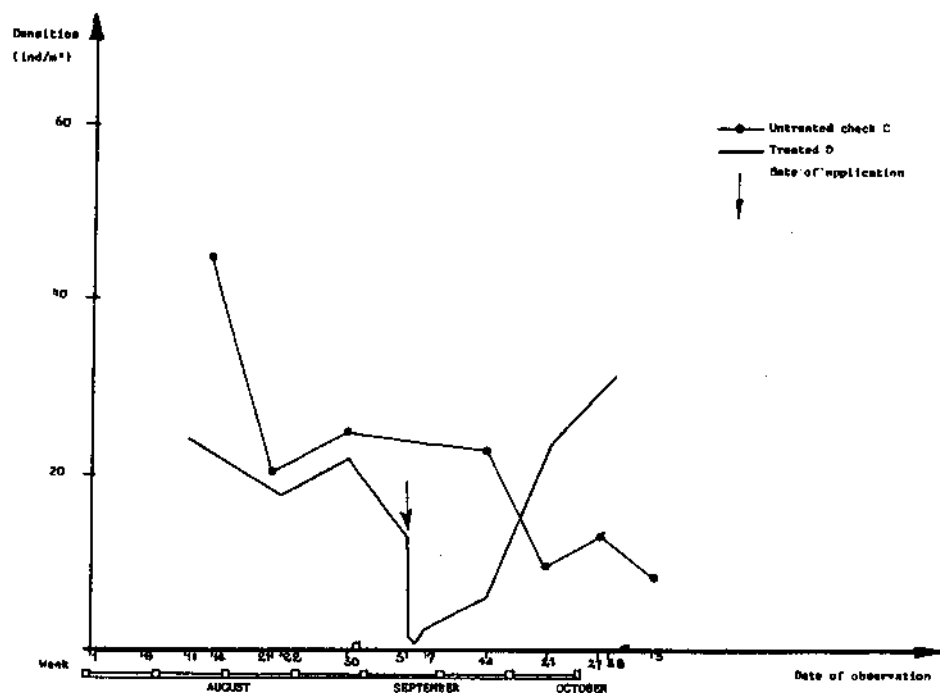
**Figure VII.1:** Population dynamics in blocks A and C. Effects of the Fenitrothion single dose application (485 g ai/ha).



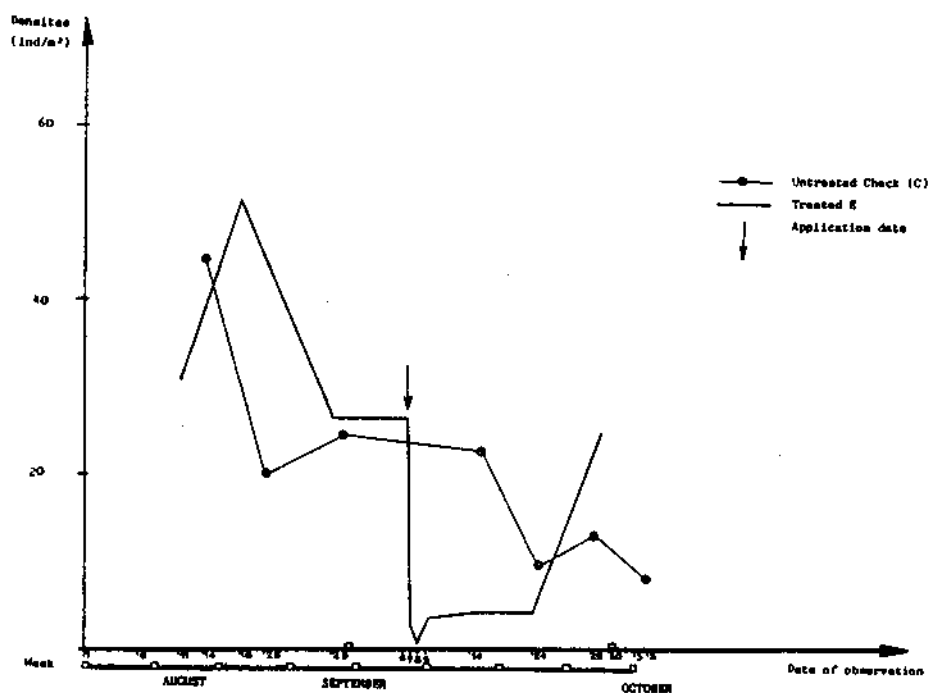
**Figure VII.2:** Population dynamics in blocks B and C. Effects of the Fenitrothion double dose application (825 g ai/ha).



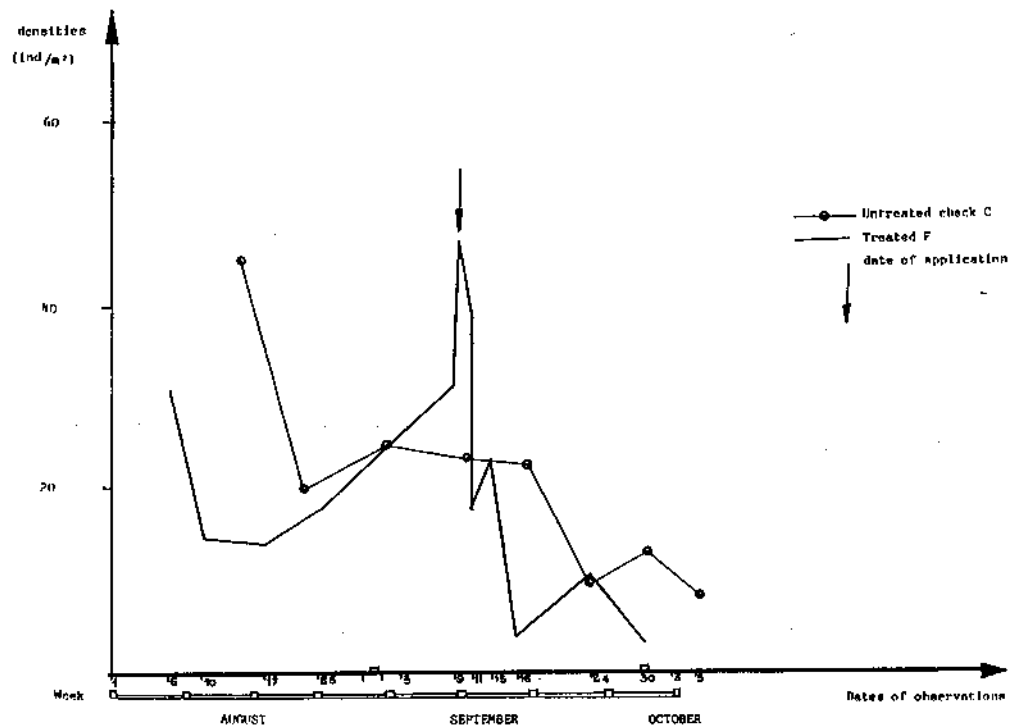
**Figure VII.3:** Population dynamics in blocks D and C. Effects of Chlorpyrifos single dose application (270 g ai/ha).



**Figure VII.4:** Population dynamics in blocks E and C. Effects of Chlorpyrifos double dose application (387 g ai/ha).



**Figure VII.5:** Nymphal Population dynamics in blocks F and CFG. Effects of Diflubenzuron double dose application (83 g ai/ha).



#### *Block E*

This plot received the double dose of Chlorpyrifos 450 ULV: 387 g ai/ha. The sampling started by the 2nd week of July. Populations increased sharply till the 18th after which they started to drop, but stayed higher than in the control plot C. The insect populations were leveling off by the 7th of September when the chemical was applied. Consequently there was a drastic drop in numbers (Fig. VII.4); recolonization started 24 hours post treatment and was rapid during the next 24 hours. The densities stabilised for 2 weeks following treatment; then increased very sharply to reach the original population level.

#### *Block F*

This block was treated with diflubenzuron 450 ULV at the dose of 82.8 g ai/ha. Populations were dropping for the first 3 weeks of July for the same reason as mentioned above; then started to increase, reached their peak when the insecticide was applied. Effects were delayed until the 4th day following application (Fig. VII.5 and 6) when the curve dropped quite sharply compared to the control CFG. The population declined until the end of the season. The effects of diflubenzuron are substantial at the 4th and 7th day. Beyond this period we could not separate the effects of the chemical to those due to migration and natural mortality as the area became drier and drier. However, one can say that up to 3 weeks after application the chemical was active.

#### *Block G*

This block received a single dose of diflubenzuron 450 ULV; that is 37.8 g ai/ha. The data do not indicate any effect. Nevertheless, given some morphological effects on nymphs of *Cataloipus cymbiferus* after treatment we were tempted to conclude that diflubenzuron might have had some impact on grasshoppers in G. This impact could not be evaluated because of so many constraints such as low insect densities, dense vegetation, etc..

#### The effects of the different chemicals on the insect populations

The effects were measured by the percent reduction in insect densities. This parameter was calculated as follows:

$$\%R = \frac{D1 - D2}{D1} \times 100 \text{ where}$$

$$\%R = \text{rate of population reduction}$$

$$D1 = \text{density (ind/m}^2\text{) at least 24 hours before application}$$

$$D2 = \text{density (ind/m}^2\text{) after application.}$$

The percentage density reduction was measured within 48 hours following application. For diflubenzuron we chose 4 days, 7 days, 14 days and 21 days. The densities and respective rates of population reduction are shown in Tables VII.5 and VII.6 for all chemicals.

**Table VII.4:** Estimated densities (ind/m ) obtained by the ring method. This is a summary of all counts through the period from 06-08-1989 to 10-10-1989. The values are averages of 25 ring counts

DATES	TREATMENTS						
	A	B	C	D	E	F	G
AUGUST							
6	31.2	22.0				31.5	10
10						14.4	
11		24	30.50				
13		8.4					
14	18.4		44.4				
17					13.6		
18					58.0		
20						9	
21	17.2	61.8	20				
22				16.8			
25	36.0	38.4				17.6	
29					26.0		
30			24.4	22		7.2	
SEPTEMBER							
5		25.6		12.4			
5 + 6H				1.6			
6				0.4	26.4		
7			23.6	2.4	26.4		
7 + 6H					2.4		
8	24.4				0.4		
8 + 6H	2.8						
9	0.4				3.2	31.2	
9 + 6H						46.8	
10	0.4					38.0	6.8
10 + 6H							3.6
11						17.6	3.2
12		22.8					
12 + 6H	1.2						
13		1.6				23.6	
14		0.4	22.8	6.0	4.0		
16	2.0					3.6	
18							10.0
20		2.0					
21	2.8		9.6	23.6	4.0		8.0
22							
24				10.0			
26		11.6					
27			13.2				
28				34.8			
29	10.4				25.6		
OCTOBER							
1							6.0
2							
3			8.4				
5	16.0	9.6			3.2		

**Table VII.5:** Insect densities (ind/m<sup>2</sup>) before (OH) 6 hours, 24 hours, 48 hours, 4 days, 7 days and 21 days after application with fenitrothion, chlorpyrifos or diflubenuron. Richard Toll, July - October, 1989.

	Time after treatment							
	0	6H	24H	48H	4d	7d	15d	21d
Block								
A	24.4	2.8	0.4	0.4	-	2	2.8	10.4
B	22.8	1.2	1.6	0.4	-	2	11.6	9.6
C	23.6	23.6	23.6	23.6	22.8	9.6	13.2	8.4
D	12.4	1.6	0.4	3.4	-	6	23.6	36.8
E	26.4	2.4	0.4	3.2	-	4	4	25.6
F	31.2	46.8	38.0	17.6	23.6	3.6	10	3.2
G	6.8	3.6	3.2	6.4	8.2*	10	8	6
CFG	16.8	46.8	31.2	58.8	36.4*	33.6*	30.8	7.2

\* Adjusted values to facilitate comparison

**Table VII.6:** Short term effects on the grasshopper populations (% reduction from populations at least 24 H prior to application). The reduction was calculated as the ratio of the difference of population before and after application and before application multiplied by 100

	Time after Treatment						
	6H	24H	48H	4d	7d	15d	21d
Block							
A	88.33	98.33	98.33	-	-	-	-
B	94.74	93.00	98.25	-	-	-	-
C	-	-	-	-	-	-	-
D	87.1	97.8	80.65	-	-	-	-
E	90.91	98.5	87.88	-	-	-	-
F	-	-	43.6	24.36	88.46	68*	89.74*
G	-	-	5.99**	-	-	-	11.8**

\* This reduction could not be solely attributable to the chemical; there may be some migration effect due to the adults leaving the trial zone. This was a general movement observed at this period of the season.

\*\* There was an indication of some diflubenzuron effect at this rate. We have noticed the effects on *Cataloipus cymbiferus* at 15 and 21 days.

## Conclusions

1.The reduction rates were the same ( $P < 0.05$ ) for all chemicals at 24 hours on one hand (for fenitrothion and chlorpyrifos) and at 7 days on the other hand after application (for diflubenzuron). This was true for all doses. Therefore, there was no difference between single and double doses.

2.There was no difference in percent reduction ( $P < 0.05$ ) between 6 and 24 hours in the block treated with single dose of fenitrothion and between 24 hours and 48 hours in the block which received chlorpyrifos single dose. This may be partly true, but one could argue that the first difference was probably due to counting variations whereas the second to the rain at 18 hours post treatment. To stay cautious, we could say that for the evaluation of high rates of quick acting insecticide effects one can evaluate only once between 6 and 48 hours post treatment and obtain the same result; however, for lower doses there may be a need to look at 6,24 and 48 hours to seek for maximum effects.

3.Recolonization in all treated areas for quick acting insecticides was from 24 hours to 48 hours following application. It was complete two weeks after, irrespective of the dose.

4. Even though it was not shown in the data, there was some differential effects of chlorpyrifos and fenitrothion on species. For instance *Cataloipus cymbiferus* and *Anacridium melanorhodon* appeared to be the only main survivors after treatments. This is due to their habitat (under shade) and probably their size as they needed to eat or be exposed to more insecticide to become poisoned. This aspect may be investigated in the future.

5. The action of diflubenzuron could be seen as early as 4 days following a double dose, but may be longer after a single dose application. In fact, research on the effects of diflubenzuron needs to be resumed where possible on younger nymphs in order to establish clearer conclusions.

6. The residual effect of the chemicals was not clear. Therefore further studies on the persistence of these chemicals in the Sahelian environment would be relevant.

In general it was concluded that the chemicals were equally effective on the grasshoppers and chlorpyrifos and diflubenzuron could be used in addition to fenitrothion as insecticides to control these pests. Doubling the dose did not increase the effectiveness of the treatment

### Acknowledgements

Apart from the persons acknowledged in the preface, I am specially grateful to Mme Diouf, accountant at DPV and to my staff Aliou Badji, lab assistant, and Bassirou Djiba, driver, for their courage throughout the experimental period.

### References

Edwards CR & Huddleston EW (1986) Efficacy and environmental effects of large plane and small plane operations in Senegal and proposed plan for gathering information for 1987 environmental assessment. Prepared for USAID, supported by CICP

Niassy A & Diatta F (1987) Rapport d'évaluation du traitement aérien contre les sautériaux effectué dans la région de Kaolack (NGanda et Nioro) du 23 au 25 Juillet 1987. Rapport DPV, Dakar, Senegal

Niassy A & Diatta F (1987) Rapport d'évaluation du traitement antiacridien au Malathion ULV 0.59 l/ha dans la Forêt de Mbegue (Kaffiré, Gossas) du 11 au 17 Aout 1987. Rapport DPV, Dakar, Senegal

Gilles Balança et Marie-Noël de Visscher

*NOTEZ: Dans ce chapitre une codification des parcelles est utilisée qui est différente que celui trouvée dans les autres chapitres: traitement D1=parcelle G; traitement D2=parcelle F; traitement F1=parcelle A; traitement F2=parcelle B; traitement C1=parcelle D; traitement C2=parcelle E; témoin T=parcelle C. (voir aussi tableau 1.3)*

### Introduction

Le présent chapitre reprend les résultats d'une mission d'un mois centrée sur la date des traitements dont l'objectif était prioritairement de suivre les effets de ces derniers sur les populations acridiennes afin de valider ces expériences par rapport aux opérations réelles de lutte.

#### Description des Milieux

Une description de la végétation a été donnée au Chapitre I; quelques indications supplémentaires sont nécessaires à ce stade. Le sol à forte dominance sableuse s'enrichit de limon dans les bas-fonds, son humidité augmente suivant un axe N.E.-S.O. qui traverse le secteur d'étude. C'est ainsi que les parcelles D1 et D2 diffèrent des autres par un tapis herbacé plus dense et plus abondant et un couvert arboré plus régulièrement distribué, constitué essentiellement de *Balanites aegyptiaca*. Dans ces parcelles, les buissons dispersés sont peu à peu remplacés par des formations buissonneuses plus étendues couvertes de plantes grimpantes.

Au cours de la période d'étude, le tapis herbacé a fortement évolué. Il est passé d'une hauteur moyenne comprise entre 15 et 30 cm, à environ 50 cm et parfois plus, dans certains sites plus humides et à l'écart des pâturages. En trois semaines, la majorité des plantes herbacées ont évolué du stade de la floraison à celui de la fructification et de la dissémination des graines. Le recouvrement global du couvert herbacé a sensiblement augmenté de 75 % à 95 % en dépit d'un dessèchement général déjà visible en fin de mission (mi-septembre).

#### Cadre de l'expérience sur le plan acridien

##### *Statut du Criquet pèlerin dans la région*

La simulation de traitements chimiques dirigés contre le Criquet pèlerin (SGR) s'est faite dans ce projet indépendamment de la présence de cette espèce, l'objectif principal étant d'étudier l'impact des insecticides sur la faune et la flore non-cibles. La région choisie est néanmoins incluse dans l'aire d'habitat de SGR en phase grégaire. En période de rémission, quelques signalisations d'imagos ont été réalisées en août et septembre (une année sur dix). En période d'invasion, SGR est signalé tous les mois de l'année dans la région de Richard Toll, avec une fréquence plus élevée d'août à février (moins d'une année sur deux cependant). Des larves ont été signalées de juillet à novembre, plus fréquemment en septembre et octobre. La région a, par exemple, été envahie à la fin de la saison des pluies de 1988.

Bien que n'étant pas située dans une région très régulièrement fréquentée par SGR, l'expérience s'est donc déroulée à une époque où la présence de cet acridien n'est pas exceptionnelle. Elle est donc assez représentative de la lutte chimique contre le Criquet pèlerin.

#### *Situation acridienne dans la zone d'étude*

La période précédant les épandages a été mise à profit pour évaluer la situation acridienne dans la zone d'étude et choisir les stations de comptage nécessaires pour déterminer l'effet des insecticides sur les sauteriaux.

Les densités, juste avant les traitements, sont comprises entre 17 000 et 60 000 individus par hectare, la proportion de larves variant de 33 à 73 % selon les parcelles. Le Criquet sénégalais, *Oedaleus senegalensis* (Krauss, 1877), nom de code OSE, espèce dominante dans la région à cette époque, représente 6 à 87 % des individus selon les stations (Tableau VIII.1).

Plusieurs événements acridiens se sont produits pendant le séjour :

1. maturation des OSE de deuxième génération (G2) dont les premiers imagos sont apparus juste avant notre arrivée (le 22 août selon A. NIASSY, com.pers.) ;
2. migration massive d'OSE du nord vers le sud, en liaison avec le déplacement du front intertropical, qui s'est traduite par d'importantes arrivées et quelques départs d'imagos dans la région. Ces mouvements aboutissent à un quintuplement de la densité des OSE imagos dans les stations témoins entre le 5 et le 16 septembre, et à un triplement de la densité de l'ensemble des criquets présents ;
3. abondance des éclosions de *Stenohippus spp* du 14 au 17 septembre.

Ces phénomènes, tout à fait normaux à cette époque, ne constituent pas une gêne pour l'interprétation des résultats. Bien au contraire, ces injections naturelles quotidiennes de criquets ont permis d'apprécier la rémanence des produits utilisés.

Espèces présentes dans les parcelles au moment des traitements :

Nom de Code	Nom Scientifique
ABI	<i>Acrida bicolor</i> (Thunberg, 1815)
ABL	<i>Acrotylus blondeli</i> (Saussure, 1884)
AGL	<i>Acorypha glaucopsis</i> (Walker, 1870)
AME	<i>Anacridium melanorhodon</i> (Walker, 1870)
ALO	<i>Acrotylus longipes</i> (Charpentier, 1843)
APA	<i>Acrotylus patruelis</i> (Herrich-Schaffer, 1838)
ASI	<i>Aiolopus simulatrix</i> (Walker, 1870)
CCY	<i>Cataloipus cymbiferus</i> (Krauss, 1877)
CHA	<i>Cryptocatantops haemorrhoidalis</i> (Krauss, 1877)
CSE	<i>Chrotogonus senegalensis</i> (Krauss, 1877)
DAX	<i>Diabolocatantops axillaris</i> (Thunberg, 1815)
EBR	<i>Eurysternacris brevipes</i> (Chopard, 1947)
KAN	<i>Kraussaria angulifera</i> (Krauss, 1877)
OSE	<i>Oedaleus senegalensis</i> (Krauss, 1877)
PCO	<i>Pyrgomorpha cognata</i> (Krauss, 1877)
PSA	<i>Pseudosphingonotus savignyi</i> (Saussure, 1884)
SEP	<i>Stenohippus epacromioides</i> (Krauss, 1877)
SXA	<i>Stenohippus xanthus</i> (Karny, 1907)
TCO	<i>Trilophidia conturbata</i> (Walker, 1870)
TJO	<i>Truxalis johnstoni</i> (Dirsh, 1950)

Les espèces les plus abondantes après OSE sont SXA, SEP, ABI et ABL. CCY est abondant dans les zones à strate herbacée non graminéenne dense.

## Méthodes de Travail

### Choix des stations de comptage

Pour estimer les densités de criquets, deux stations de comptage ont été choisies dans chaque parcelle traitée (Figure VIII.1) selon les critères suivants :

- facilité d'accès même après une pluie ;
- représentativité de l'ensemble de la parcelle ;
- localisation à au moins 500 mètres du bord de la parcelle pour éviter tout effet de lisière ;
- densité totale de criquets comprise entre 10 000 et 100 000 par hectare.

Deux stations, initialement placées dans la parcelle témoin utilisée par les ornithologues et les entomologistes du projet, ont été abandonnées. On y a en effet observé une trop forte diminution de la densité des criquets entre le 30 août et le 4 septembre, veille du premier traitement, vraisemblablement à la suite d'un dessèchement prématuré de la végétation dans cette zone trop bien drainée. Deux nouvelles stations témoins ont donc été aussitôt choisies, à proximité immédiate du campement situé entre les deux groupes de parcelles qui ont reçu

les organophosphorés.

En outre, la végétation des deux parcelles destinées à être traitées au diflubenzuron était sensiblement différente de celle des autres et les densités de criquets y étaient faibles. Pour ces raisons, deux stations témoins supplémentaires ont été établies à proximité.

#### Protocole de travail sur le terrain

Pour déterminer l'effet des insecticides sur les sauteriaux, l'évolution de plusieurs paramètres mesurables a été suivie par des approches différentes:

- la densité de l'ensemble des espèces, en distinguant les larves et les imagos. Ces densités sont évaluées grâce à des comptages à vue par mètre carré, à raison de deux séries de trente mètres carrés par station. Chaque série correspond à un secteur particulier de la station et les sauteriaux y ont toujours été dénombrés par la même personne. Les dépressions humides à strate herbacée dense ont été exclues des zones de comptage ;
- la composition du peuplement et la structure des populations. Ces données nécessaires pour interpréter les résultats des comptages sont obtenues à partir des sauteriaux capturés par deux séries de cinquante coups de filet effectués dans chaque station. Après avoir noté l'espèce et le stade de développement, les criquets ont été relâchés sur place. Après les traitements, les densités étant très faibles et les captures beaucoup trop insuffisantes, ces mêmes données proviennent de l'identification à vue d'au moins cinquante criquets vivants.

Dans chaque parcelle traitée, les relevés ont été faits une heure avant le traitement, puis 24 heures, 48 heures et 72 heures après. Il s'agit de déterminer la mortalité maximale, généralement observée un jour après l'épandage, et les modalités d'une éventuelle recolonisation précoce. Passé ce délai, un intervalle de deux jours entre les relevés a semblé suffisant.

#### Méthodes d'analyse des données

Pour chaque station de comptage en parcelle traitée, la densité retenue est calculée à partir de l'ensemble des deux séries de comptage sur trente mètres carrés. Par contre, les quatre séries de relevés sur les stations témoins ont été regroupées.

Les résultats apparaissent sous deux formes : les données brutes et les données corrigées.

Les données brutes sont présentées sous forme de graphiques qui montrent simplement l'évolution des densités mesurées dans les stations des parcelles traitées et dans les stations témoins.

L'effet acridicide des produits ne peut être déduit directement des données brutes car les variations d'effectifs découlent de plusieurs phénomènes simultanés:

- mortalité et/ou départs des criquets sous l'effet des insecticides;
- arrivées ou départs, naissances et mortalité naturelle liées aux conditions éoclimatiques, aux cycles de développement et aux comportements spécifiques des espèces concernées.

L'importance relative de ces phénomènes peut être appréciée en suivant de près les populations acridiennes des stations témoins.

Pour distinguer l'action des insecticides de celle des phénomènes naturels, les variations d'effectifs dans les stations traitées doivent être comparées à celles des stations témoins. Pour ce faire, deux processus arithmétiques sont successivement appliqués aux données:

- toutes les valeurs du témoin sont corrigées de façon à ce que la densité le jour du traitement (J0) soit identique à celle qui est mesurée dans la parcelle à traiter;
- pour chaque comptage, la densité mesurée dans la situation traitée est rapportée à la densité corrigée du témoin. Elle est exprimée en pourcentage de ce témoin fictif dont la densité de départ est semblable à celle de la parcelle traitée et qui est supposé évoluer comme la parcelle expérimentale en l'absence de tout traitement.

Ces corrections reposent sur les deux postulats suivants:

- en cas de baisse d'effectifs dans les stations témoins, un même pourcentage de criquets quitte aussi les parcelles traitées: diminution géométrique;
- en cas de hausse d'effectifs dans les stations témoins, les parcelles traitées ont reçu un nombre semblable de criquets par unité de surface: augmentation arithmétique.

Etant donné qu'un pourcentage des criquets fuient les parcelles traitées, il vaut mieux parler de taux de criquets survivants plutôt que de taux de mortalité. Les graphiques expriment donc des taux de criquets vivants par rapport au témoin corrigé qui représente la référence 100%.

## Résultats

Pour décrire et comparer l'efficacité des traitements, cinq paramètres sont choisis :

- le taux de criquets vivants 24 heures après le traitement ;
- le taux minimal de criquets vivants et le délai d'apparition de ce niveau après le traitement ;
- le temps nécessaire pour que les populations s'accroissent à nouveau (délai de recolonisation) et l'intensité de ce phénomène (vitesse de recolonisation).

Les valeurs de ces paramètres apparaissent dans le Tableau VIII.2.

### Les organophosphorés

#### *Le chlorpyrifos*

A la dose de 270 g de matière active par hectare, le chlorpyrifos-éthyl laisse en moyenne 12,5 % des imagos vivants et 3,7 % des larves 24 heures après le traitement (Figures VIII.2, 3, 10, 11).

Chez les imagos, la recolonisation est visible dès le deuxième jour et devient continue à partir du cinquième.

Chez les larves, l'effet acridicide se maintient jusqu'au cinquième jour après le traitement. En effet, le lendemain du traitement, cinq des douze larves observées sont des larves de *Stenohippus* sp. qui ne seront pas revues par la suite. Les larves plus âgées disparaissent entre le premier et le cinquième jour après le traitement. Le 14 septembre, soit neuf jours après le traitement, toutes les larves observées sont du premier stade (une abondance de ces larves est aussi observée dans les stations témoins). Deux jours après (J11), le nombre de larves a nettement augmenté, certaines ayant mué. Le chlorpyrifos n'a donc plus d'effet acridicide une semaine après le traitement.

Avec une dose de 390 g m.a./ha de chlorpyrifos, une moyenne de 8 % des imagos et de 4,5 % des larves survivent 24 heures après le traitement (Figures VIII.4, 5, 12, 13).

La recolonisation par les imagos commence deux jours après l'épandage dans les deux stations. Au-delà du deuxième jour, les profils de recolonisation diffèrent profondément d'une station à l'autre. Dans la station C2.2, les effets du chlorpyrifos se font sentir jusqu'au cinquième jour et la recolonisation ne reprend que sept jours après le traitement. Dans la station C2.1, les arrivées d'ailés sont beaucoup plus importantes.

Les densités de larves évoluent de la même façon que dans la parcelle traitée avec 270 g m.a./ha. Les densités décroissent pendant cinq ou sept jours puis augmentent le septième ou le neuvième jour selon les stations.

#### *Le fénitrothion*

Vingt-quatre heures après le traitement, il subsiste en moyenne 2,2 % des imagos dans la parcelle traitée avec 485 g m.a./ha. Le produit semble encore agir jusqu'à cinq jours après le traitement mais la recolonisation qui est entamée le septième jour se confirme le neuvième jour (Figures VIII.6 et 7).

Dans le cas de la double dose de produit (825 g m.a./ha), les résultats sont analogues (Figures VIII.8 et 9) : 3,3 % des imagos sont vivants vingt-quatre heures après le traitement. La recolonisation est visible dès le 16 septembre, soit quatre jours après le traitement. Elle est probablement facilitée par les gros apports d'imagos venus du nord ces jours-là.

L'effet sur les larves est semblable pour les deux doses : elles sont toutes tuées dès le lendemain du traitement (une seule larve est vue deux jours après le traitement). Le 17 septembre, soit neuf jours après le traitement à 485 g m.a./ha, et cinq jours après l'application du double de cette dose, aucune larve n'est observée, alors que des éclosions ont lieu dans toutes les autres stations de comptage.

#### LE CAS D'*OEDALEUS SENEGALENSIS* (KRAUSS, 1877)

OSE étant parmi les sauteriaux du Sahel l'espèce nuisible la plus importante, l'évolution de ses populations dans les parcelles traitées et témoins a été déduite des résultats des comptages à vue par mètre carré et des captures (Figures VIII.14 à 25).

Chez les imagos (Figures VIII.14 à 21), les courbes de survie obtenues sont très voisines de celles qui concernent l'ensemble du peuplement acridien. OSE est en effet l'espèce la plus abondante avant les traitements et le principal acteur de la recolonisation. En ce qui concerne les larves (Figures VIII.22 à 25), seule une recolonisation discrète est observée dans le cas

du chlorpyrifos appliqué à raison de 270 g m.a./ha. Elle est presque inexistante dans les autres cas. Les éclosions sont en effet très rares dans tout le secteur d'étude après les traitements et les larves des autres stades ne sont pas assez mobiles pour envahir les parcelles traitées à partir des zones non traitées.

#### LE CAS DE *CATALOIPUS CYMBIFERUS* (KRAUSS, 1877)

Parmi les autres acridiens, le cas de CCY mérite d'être rapporté. Cette espèce est assez abondante (environ 3 individus au mètre carré) avant les traitements sous forme de larves d'avant-dernier stade et surtout de dernier stade, uniquement dans les dépressions humides à strate herbacée dense qui sont bien représentées dans trois des quatre parcelles traitées avec les organophosphorés (C2, F1 et F2).

Dans ces trois parcelles, qui n'ont pas été traitées le même jour, les imagos de CCY ont brusquement fait leur apparition le lendemain des épandages en dehors des bas-fonds humides, constituant de 3 à 21 % de l'acridofaune (Figure VIII.26). Un tel phénomène n'a pas été observé dans les stations témoins qui sont également proches de taches de végétation dense que les CCY imagos ne quittaient pratiquement pas. Il semble donc que les organophosphorés utilisés à des doses sublétales pour les CCY aient perturbé leur comportement au point de leur faire quitter leur milieu habituel.

#### *Le diflubenzuron*

Le diflubenzuron faisant partie du groupe des dérégulateurs de croissance qui tuent les larves en agissant sur la synthèse de leur cuticule, la densité et la structure des populations de larves ont été suivies avec un soin particulier.

L'effet du diflubenzuron sur la densité des larves est important et régulier (Figures VIII.27 à 30) : le 17 septembre (soit 6 ou 8 jours après le traitement selon les parcelles), les densités avaient diminué selon la parcelle de 60 à 97 % par rapport au témoin.

L'observation de l'évolution de la structure des populations larvaires permet de mieux apprécier le pouvoir acridicide du diflubenzuron aux doses appliquées (Figures VIII.31 et 32). Ainsi, l'abondance des larves de premier stade (*Stenohippus* spp) insensibles aux effets des inhibiteurs de croissance évolue de façon analogue dans toutes les parcelles, traitées ou non, prouvant en outre l'absence d'effet du produit sur les éclosions (Figure VIII.31).

Le bouleversement de la structure des populations larvaires est illustré par la Figure VIII.32. L'abondance des larves ayant mué au moins une fois diminue puis augmente beaucoup dans les deux stations témoins tandis qu'elle diminue nettement dans les quatre stations des parcelles traitées. De plus, les deux seules larves (d'OSE) de classe 4 vues le 17 septembre étaient anormales : l'une d'elles se déplaçait très lentement et l'autre présentait une malformation à une patte postérieure (tibia tordu). Il n'y a pas de différence d'efficacité entre la simple (40 g m.a./ha) et la double dose (85 g m.a./ha).

L'effet du diflubenzuron est beaucoup moins net sur les imagos (Figures VIII.33 à 36). On observe une diminution de 10 à 30 % de la densité des imagos dans trois des quatre stations de comptage. Cette baisse de densité peut être attribuée à un effet insecticide du diflubenzuron sur les jeunes imagos à tégument encore mou, qui synthétisent encore de la cuticule. Il faut aussi envisager un éventuel effet répulsif temporaire du gazole utilisé comme solvant dans

cette expérience. A l'avenir, une parcelle témoin traitée avec le seul gazole permettrait de clarifier cette question.

## Discussion

### Efficacité des traitements

Les doses d'insecticides appliquées sont, d'une part, celles qui sont recommandées pour la lutte contre le Criquet pèlerin, d'autre part, des doses doubles pour simuler les applications excessives. Ces doses correspondent respectivement au double et au quadruple des doses recommandées pour la lutte contre les sauteriaux. On pouvait donc s'attendre à une très forte mortalité de sauteriaux.

Le taux de criquets vivants observé vingt-quatre heures après le traitement est très bas dans toutes les parcelles traitées avec un organophosphoré. Dans les parcelles traitées au fénitrothion, ce taux est en moyenne cinq fois plus faible que dans le cas du chlorpyrifos.

Les résultats obtenus avec le fénitrothion au Sénégal sont meilleurs qu'avec la dose préconisée contre les sauteriaux (250 g m.a./ha) testée sur des parcelles de 2 500 mètres carrés : moins de 2 % de survivants au lieu de 13 à 29 % si l'on considère les larves et les imagos ensemble (Launois et al. 1987, Chiffaud et al. 1988). De plus, les larves ont complètement disparu dans toutes les stations des parcelles traitées au fénitrothion, ce qui n'a pas été observé avec la dose classique.

L'effet de choc est excellent dans la plupart des cas puisque la mortalité maximale est observée vingt-quatre heures après le traitement sauf dans le cas des larves qui résistent au chlorpyrifos pendant trois à sept jours. On n'observe pas de différence significative d'effet acridicide (et répulsif ?) entre les deux doses pour les deux organophosphorés. Doubler ou quadrupler la dose permet de tuer davantage de criquets, et même d'éliminer toutes les larves avec le fénitrothion, mais, compte tenu de l'efficacité des doses classiques, le rapport coût/efficacité devient beaucoup moins bon aux doses élevées.

L'examen des effets des épandages de diflubenzuron aboutit à des conclusions analogues. Les traitements ont été très efficaces sur les larves qui muent puisque la densité des larves autres que celles de premier stade tendait vers zéro une semaine après les traitements. Le doublement de la dose n'apporte rien de plus car la dose de 40 g m.a./ha, déjà très élevée, correspond au maximum d'efficacité.

### La rémanence et la recolonisation

Le choix de traiter de vastes parcelles (400 ou 600 ha) est intéressant sur le plan acridologique. Il permet en effet d'observer les modalités de la recolonisation post-traitement dans des conditions proches de celles de la lutte antiacridienne opérationnelle.

Dans ces circonstances, la recolonisation par les larves est pratiquement impossible depuis l'extérieur des parcelles et ne peut se faire que grâce aux naissances *in situ*. L'estimation du temps de rémanence d'un produit dépend donc dans ce cas de l'occurrence d'éclosions dans les jours qui suivent le traitement, donc des pontes qui ont été déposées avant celui-ci. La recolonisation par les imagos par contre peut être faite soit par les populations qui vivent à

proximité des parcelles traitées, soit par immigration de populations allochtones. Les traitements expérimentaux ont été faits pendant une période de migration importante d'OSE, phénomène normal à cette époque de l'année où les imagos de deuxième génération devenus matures refluent vers le sud à la recherche de biotopes favorables à la ponte. Les conditions sont donc idéales pour estimer la durée de l'effet des produits. Cependant, on observe qu'avec les fortes doses de fénitrothion utilisées, les parcelles traitées ne retrouvent pas leur niveau initial de densité, même après neuf jours, comme c'est le cas dans les tests acridicides réalisés sur des parcelles de 2 000 ou 2 500 mètres carrés (Launois *et al.* 1987, Chiffaud *et al.* 1988)

On observe de plus une différence de vitesse de recolonisation entre les deux doses de chlorpyrifos. Elle semble plus élevée dans le cas de la plus faible (240 g m.a./ha), mais cette parcelle a reçu une pluie importante quelques heures après le traitement, de sorte qu'une partie du produit a dû être entraînée dans le sol. En outre, les deux stations de la parcelle traitée avec 390 g m.a./ha de chlorpyrifos présentent des profils de recolonisation différents. Cette différence s'explique par la proximité d'une source de recolonisation importante pour une des stations. En effet, la station C2.1 est située à deux cents mètres d'une zone de plusieurs hectares qui n'a pas été atteinte par l'insecticide et qui renfermait après le traitement des criquets en densité normale. La proximité d'une zone non traitée a moins d'effet sur la recolonisation des larves que sur celle des imagos qui sont beaucoup plus mobiles.

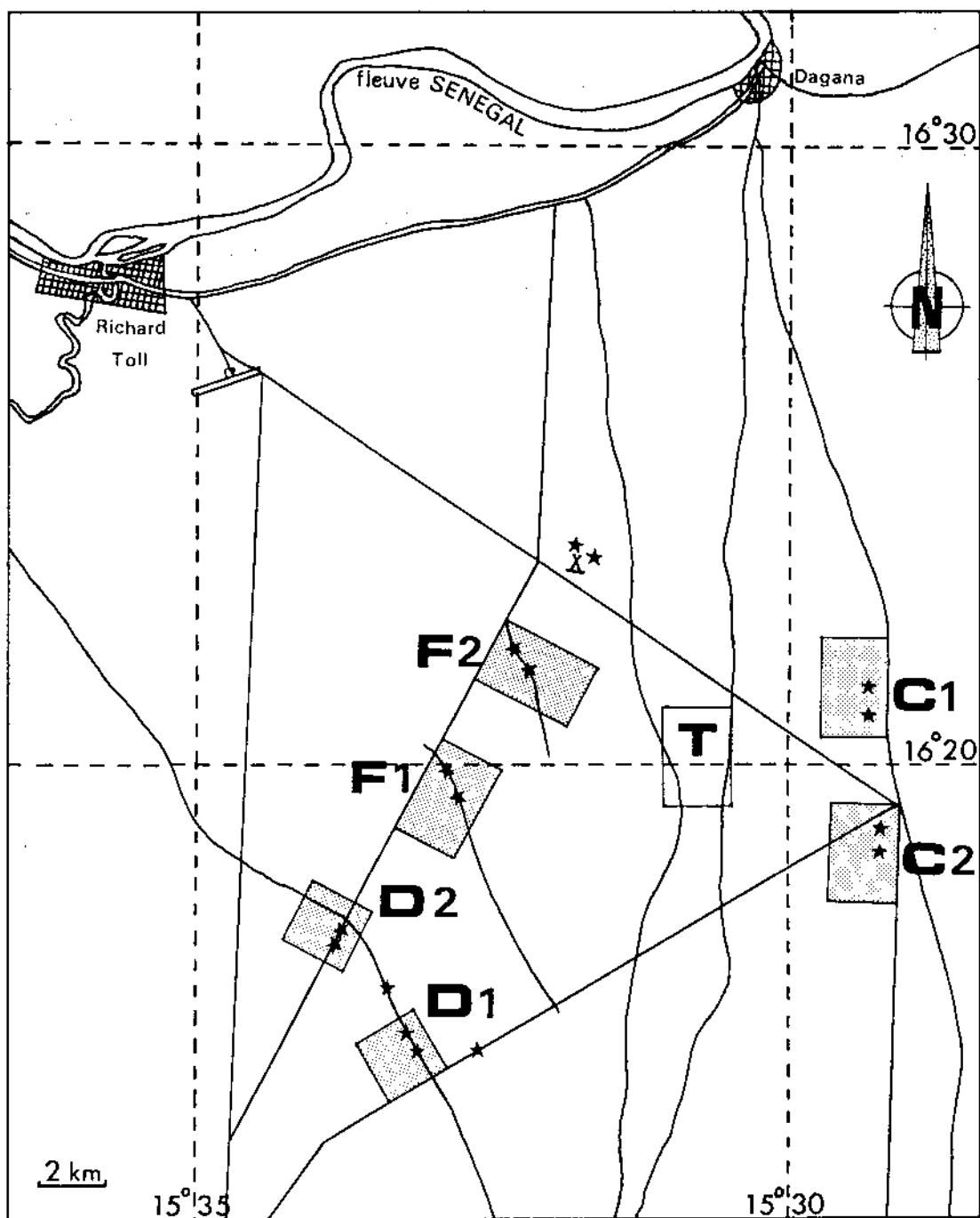
Compte tenu de la taille des parcelles traitées, les profils de recolonisation observés ne peuvent être considérés comme caractéristiques des produits et des doses employés car ils dépendent énormément des immigrations qui se sont produites dans la région après les traitements. Si les traitements avaient eu lieu vers le 15 août, comme prévu initialement, ils auraient eu pour cibles des populations de criquets à très forte densité composées en grande majorité de larves car les premiers imagos de la deuxième génération d'OSE ne sont apparus que le 22 août (A. NIASSY com.pers.). Dans ce cas, la vitesse de recolonisation par les imagos aurait d'abord été faible, car assurée seulement par les mouvements locaux des immatures. Ensuite, elle aurait augmenté à la fin de la première décade de septembre, quand les premiers imagos de la deuxième génération nées en Mauritanie sont arrivés au Sénégal.

En ce qui concerne le diflubenzuron, l'effet acridicide de ce produit ne se manifeste que sur les larves qui muent, ce qui explique que le délai observé entre le traitement et la réduction des populations larvaires dépend de l'occurrence des mues. Mesurer avec précision le temps de rémanence d'un dérégulateur de croissance est donc difficile car cela nécessite des éclosions assez nombreuses et bien réparties pendant la période qui suit le traitement pour maintenir un stock suffisant de larves susceptibles de muer et de subir les effets du produit. En cas de bandes larvaires, on peut aussi envisager un réapprovisionnement artificiel régulier de larves à partir de zones non traitées. Dans le cas de la présente expérience, des éclosions se sont produites pendant la courte période d'observation après l'application du diflubenzuron (6 jours pour la simple dose et 8 jours pour la double dose). Si de nouvelles éclosions le permettent, l'acridologue sénégalais resté sur place pourra déterminer la durée des effets sur six semaines.

## **Bibliographie**

Launois M, Lecoq M & Rachadi T (1987) Tests dynamiques d'insecticides sur les acridiens du Sahel en conditions naturelles. Niger-Tchad. Campagne 1987. CIRAD/PRIFAS, Montpellier, doc.multigr. D.277 : 140 p.

Chiffaud J, Launois-Luong MH, Mestre J & Rachadi T (1988) Tests dynamiques d'insecticides sur les acridiens du Sahel en conditions naturelles. Tchad 1988. CIRAD/PRIFAS, Montpellier, doc. multigr. D.307 : 89 p.



**Fig. VIII.1** - Localisation des parcelles expérimentales et des stations de comptage des acridiens (\*).

Etoiles isolées : stations témoins pour les acridiens.

F1 et F2 : parcelles traitées au fénitrothion (F1 : 485 g m.a./ha, F2 : 825 g m.a./ha).

C1 et C2 : parcelles traitées au chlorpyriphos-éthyl (C1 : 270 g m.a./ha, C2 : 390 g m.a./ha)

D1 et D2 : parcelles traitées au diflubenzuron (D1 : 40 g m.a./ha, D2 : 85 g m.a./ha)

T : parcelle témoin pour l'écotoxicologie

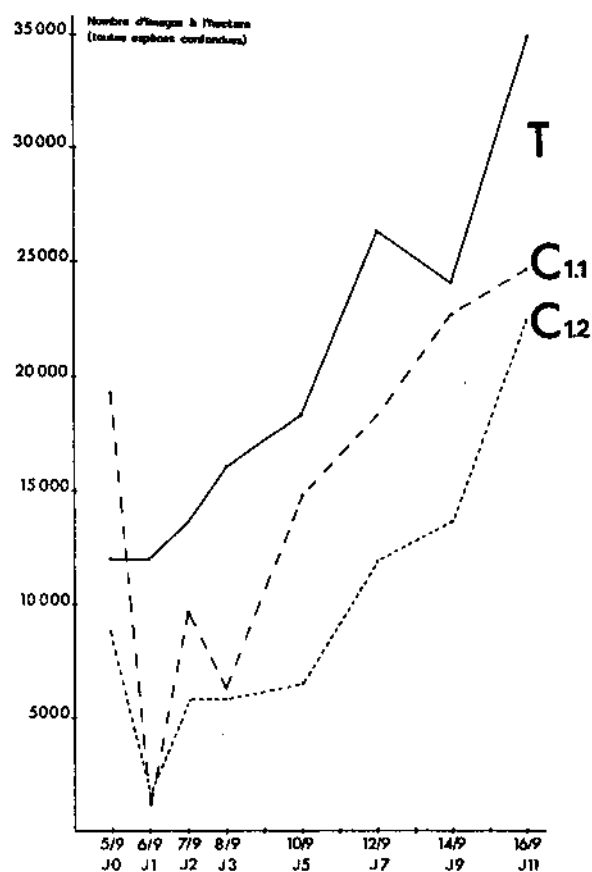


Fig. VIII.2 - Evolution des densités imaginaires brutes de sauteriaux dans les stations de la parcelle C1 traitée au chlorpyriphos-éthyl à 270 g m.a./ha le 5.09.89 et dans les stations témoins T.

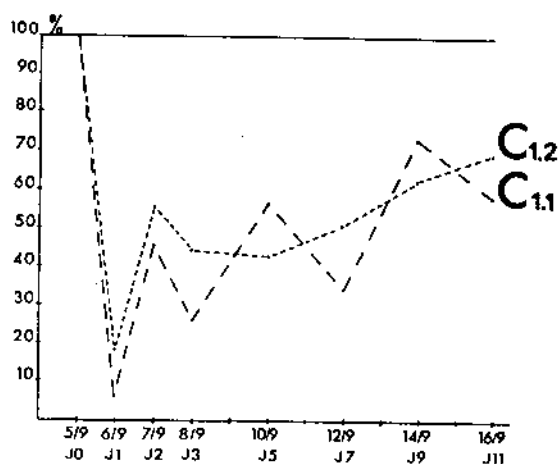
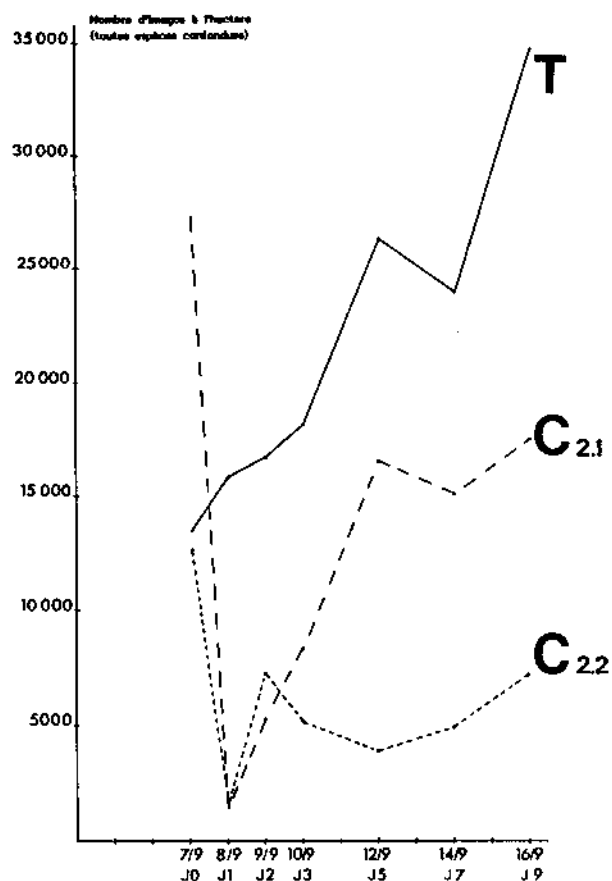
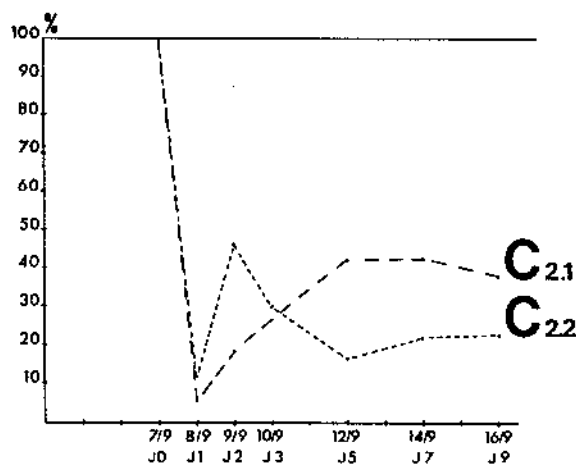


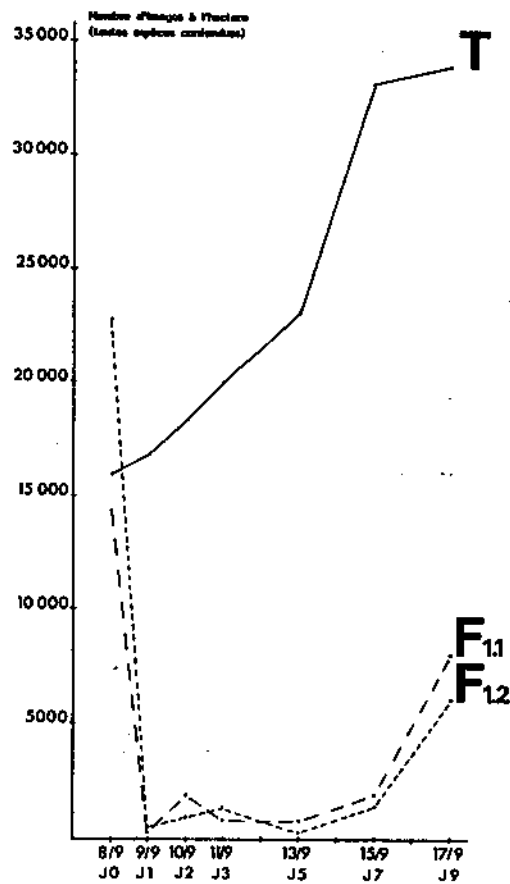
Fig. VIII.3 - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginaires soumises à un épandage de chlorpyriphos-éthyl à 270 g m.a./ha (parcelle C1).



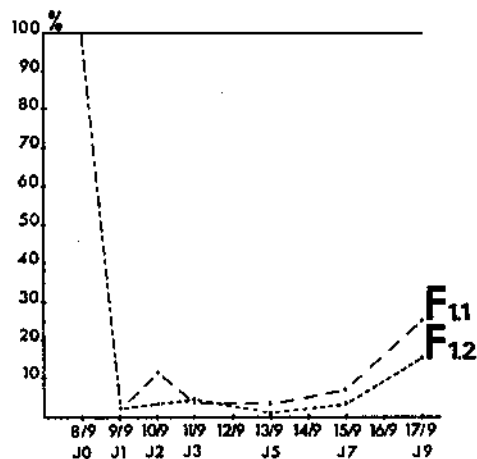
**Fig. VIII.4** - Evolution des densités imaginaires brutes de sauteux dans les stations de la parcelle C2 traitée au chlorpyrifos-éthyl à 390 g m.a./ha le 7.09.89 et dans les stations témoins T.



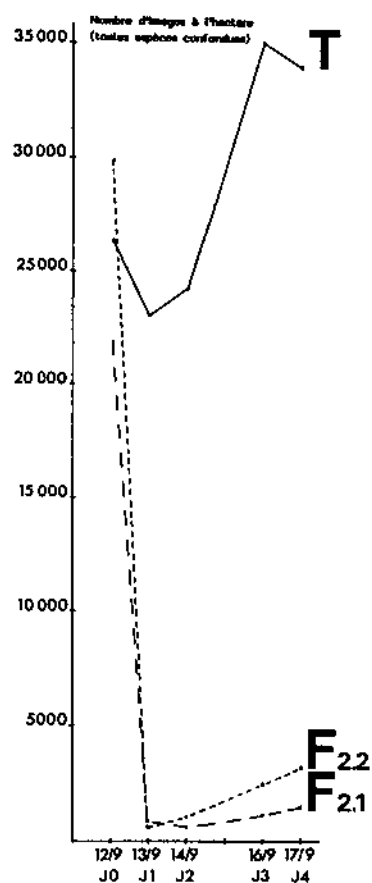
**Fig. VIII.5** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginaires soumises à un épandage de chlorpyrifos à 390 g m.a./ha (parcelle C2).



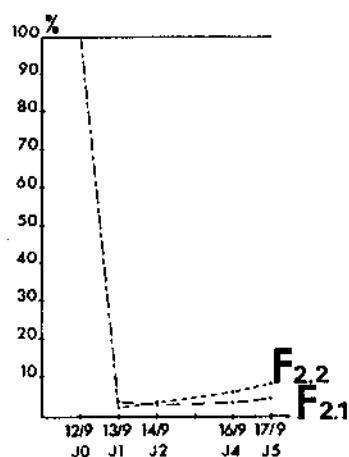
**Fig. VIII.6** - Evolution des densités imaginale brut de sauteriaux dans les stations de la parcelle F1 traitée au fénitrothion à 485 g m.a./ha le 8.09.89 et dans les stations témoins T.



**Fig. VIII.7** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginale soumises à un épandage de fénitrothion à 485 g m.a./ha.



**Fig. VIII.8** - Evolution des densités imaginale brut de sauteriaux dans les stations de la parcelle F2 traitée au fénitrothion à 825 g m.a./ha le 12.09.89 et dans les stations témoins T.



**Fig. VIII.9** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginale soumises à un épandage de fénitrothion à 825 g m.a./ha.

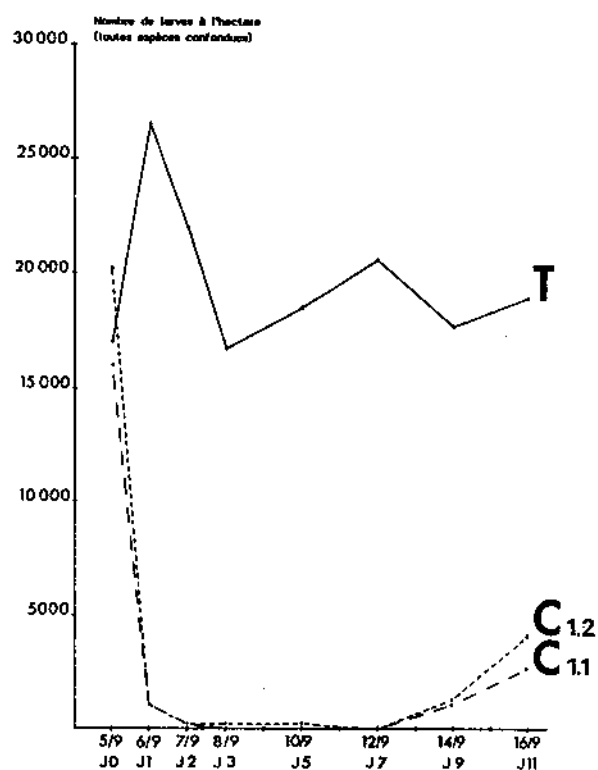


Fig. VIII.10 - Evolution des densités larvaires brutes de sauteriaux dans les stations de la parcelle C1 traitée au chlorpyriphos-éthyl à 270 g m.a./ha le 5.09.89 et dans les stations témoins T.

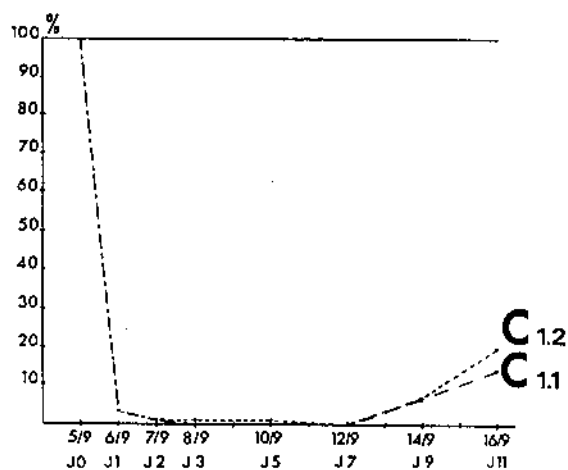


Fig. VIII.11 - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginaires soumises à un épandage de chlorpyriphos-éthyl à 270 g m.a./ha.

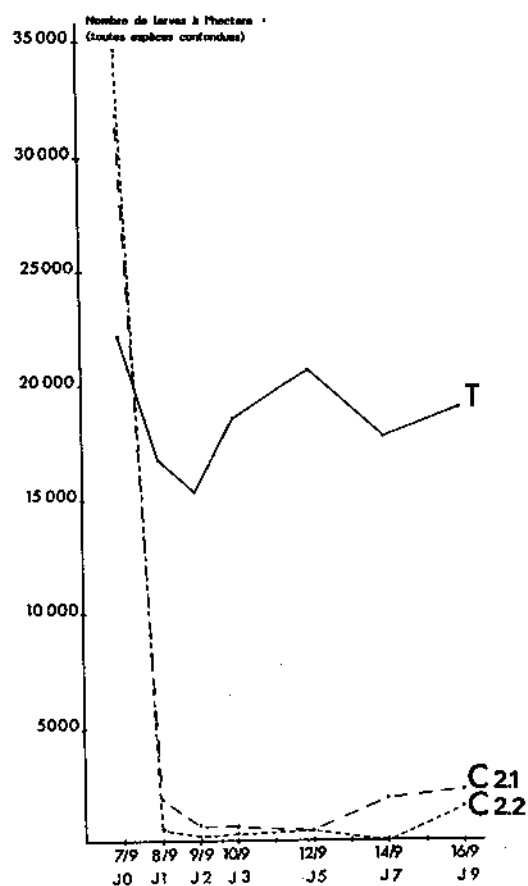


Fig. VIII.12 - Evolution des densités larvaires brutes de sauteriaux dans les stations de la parcelle C2 traitée au chlorpyriphos-éthyl à 390 g m.a./ha le 7.09.89 et dans les stations témoins T.

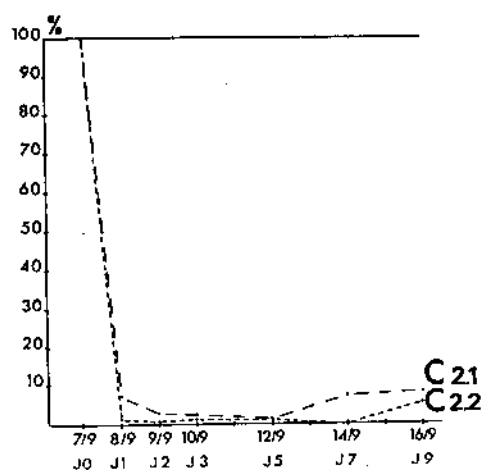
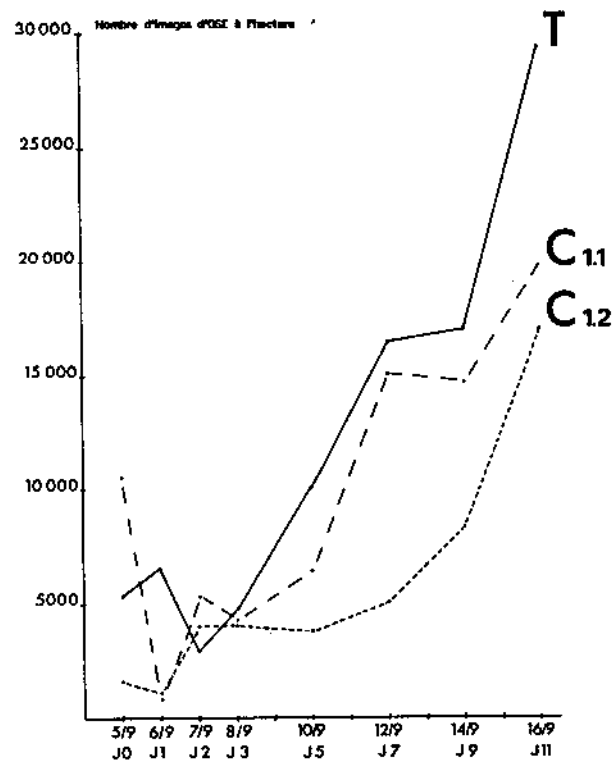
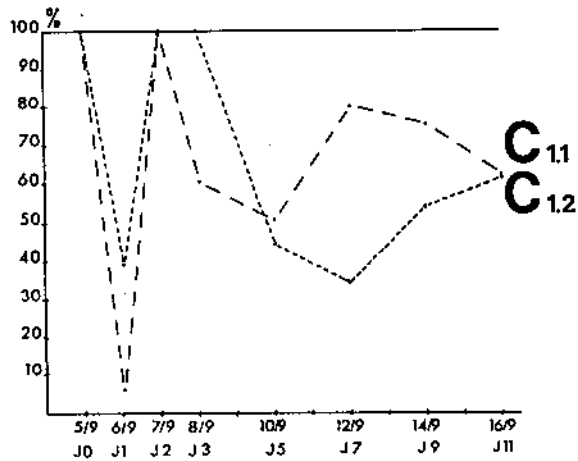


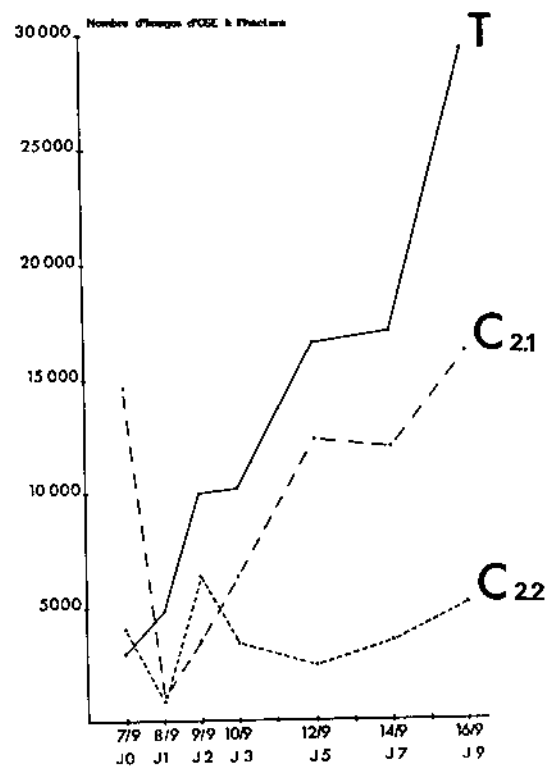
Fig. VIII.13 - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginales soumises à un épandage de chlorpyriphos-éthyl à 390 g m.a./ha.



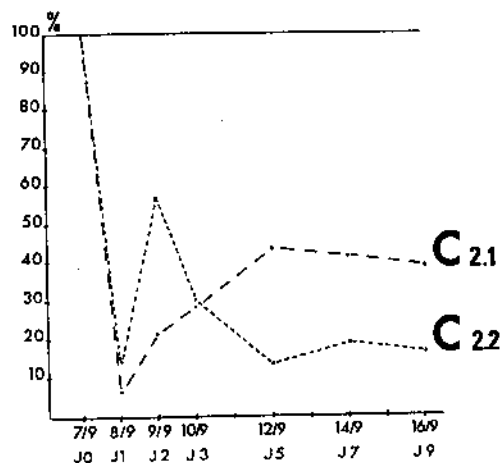
**Fig. VIII.14 -** Evolution des densités imaginale brutes d'OSE dans les stations de la parcelle C1 traitée au chlorpyriphos-éthyl à 270 g m.a./ha le 5.09.89 et dans les stations témoins T.



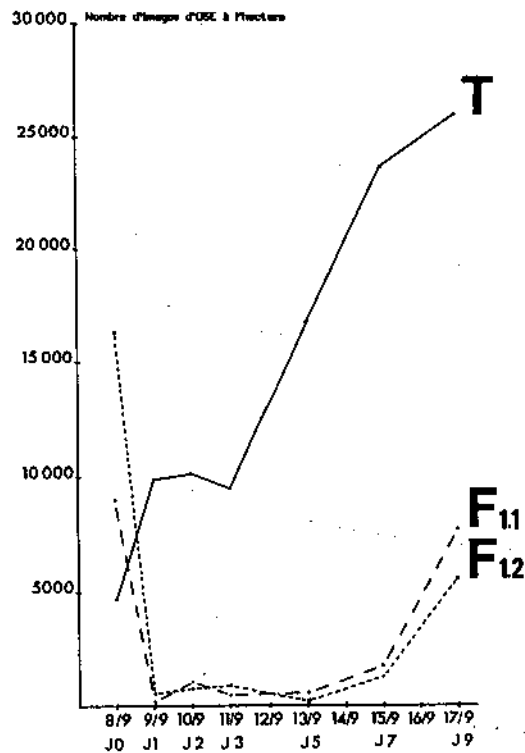
**Fig. VIII.15 -** Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginale d'OSE soumises à un épandage de chlorpyriphos-éthyl à 270 g m.a./ha.



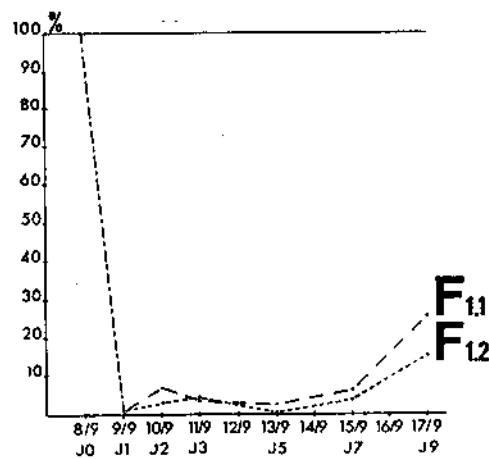
**Fig. VIII.16** - Evolution des densités imaginale brut d'OSE dans les stations de la parcelle C2 traitée au chlorpyrifos-éthyl à 390 g m.a./ha le 7.09.89 et dans les stations témoins T.



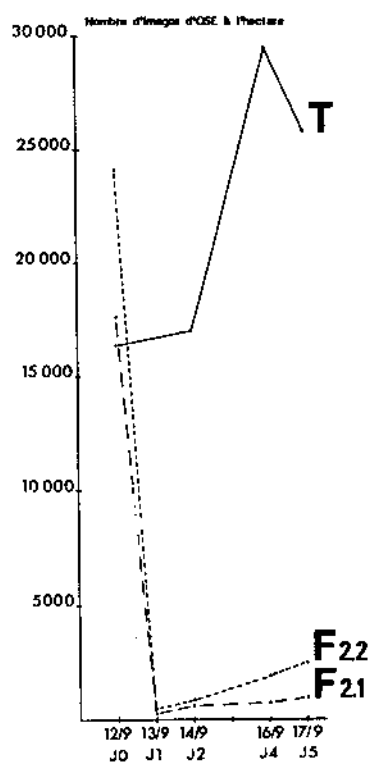
**Fig. VIII.17** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginale d'OSE soumises à un épandage de chlorpyrifos-éthyl à 390 g m.a./ha.



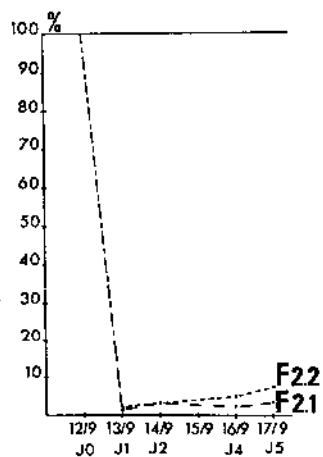
**Fig. VIII.18** - Evolution des densités imaginale brut d'OSE dans les stations de la parcelle F1 traitée au fénitrothion à 485 g m.a./ha le 8.09.89 et dans les stations témoins T.



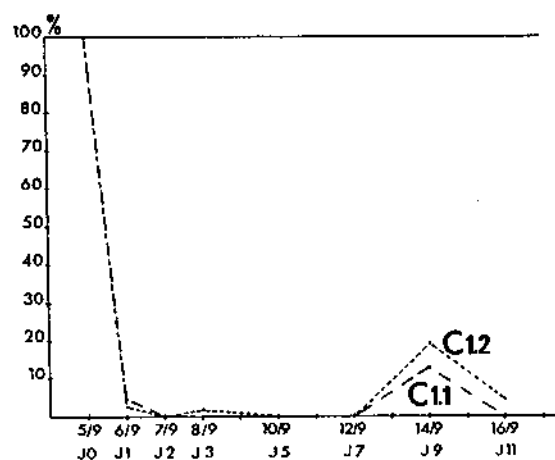
**Fig. VIII.19** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginale d'OSE soumises à un épandage de fénitrothion à 485 g m.a./ha.



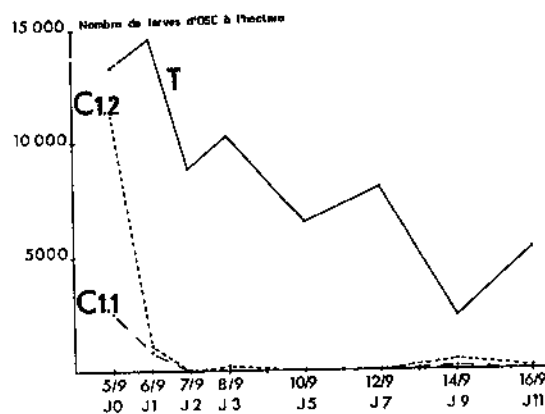
**Fig. VIII.20** - Evolution des densités imaginale brut d'OSE dans les stations de la parcelle F2 traitée au fénitrothion à 825 g m.a./ha le 12.09.89 et dans les stations témoins T.



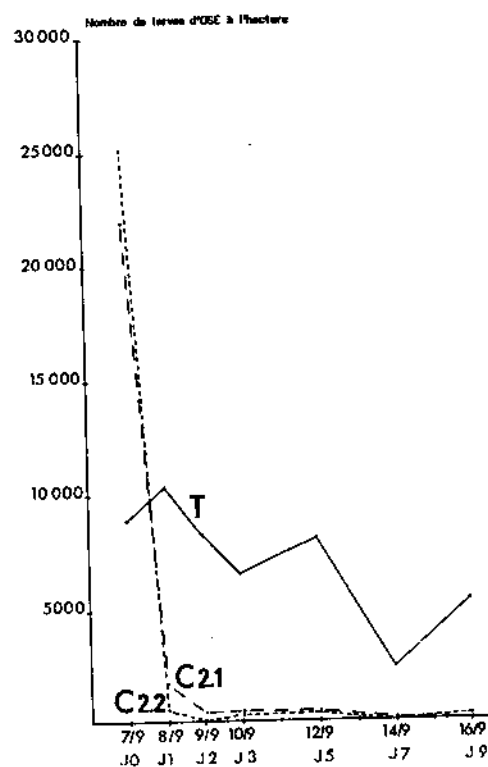
**Fig. VIII.21** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginale d'OSE soumises à un épandage de fénitrothion à 825 g m.a./ha.



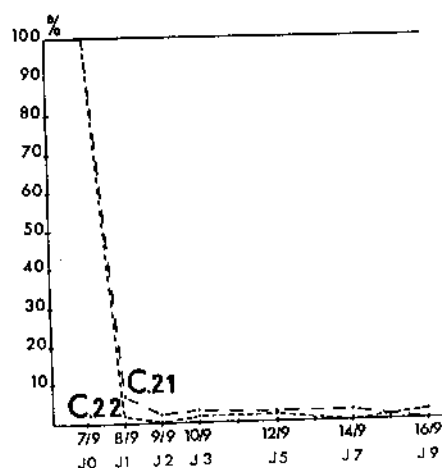
**Fig. VIII.22** - Evolution des densités imaginaires brutes d'OSE dans les stations de la parcelle C1 traitée au chlorpyriphos-éthyl à 270 g m.a./ha le 5.09.89 et dans les stations témoins T.



**Fig. VIII.23** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations larvaires d'OSE soumises à un épandage de chlorpyriphos-éthyl à 270 g m.a./ha.



**Fig. VIII.24** - Evolution des densités larvaires brutes d'OSE dans les stations de la parcelle C2 traitée au chlorpyriphos-éthyl à 390 g m.a./ha le 7.09.89 et dans les stations témoins T.



**Fig. VIII.25** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations larvaires d'OSE soumises à un épandage de chlorpyriphos-éthyl à 390 g m.a./ha.

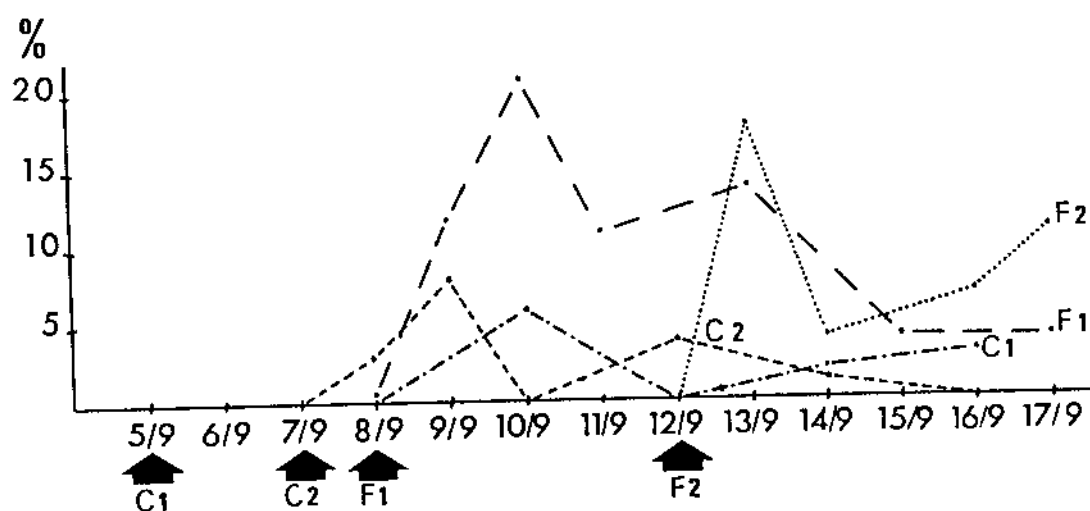
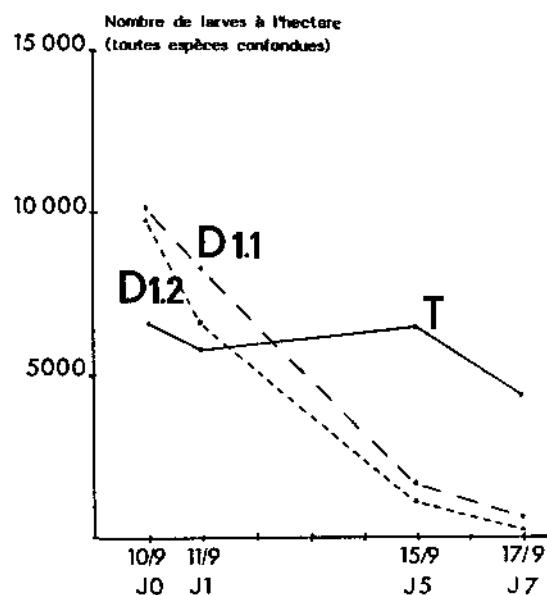
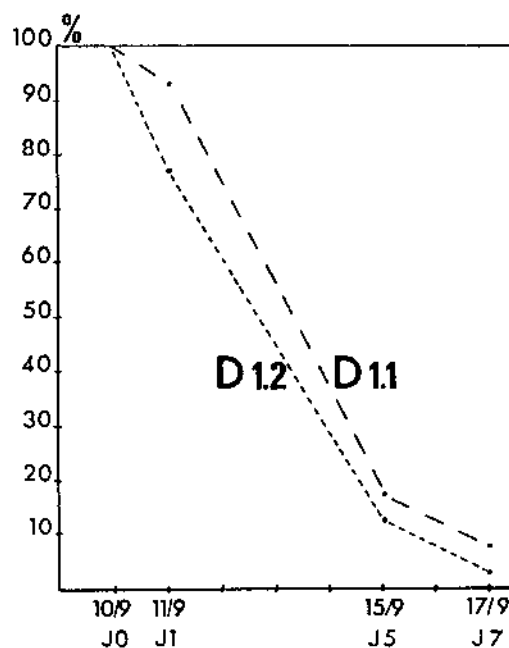


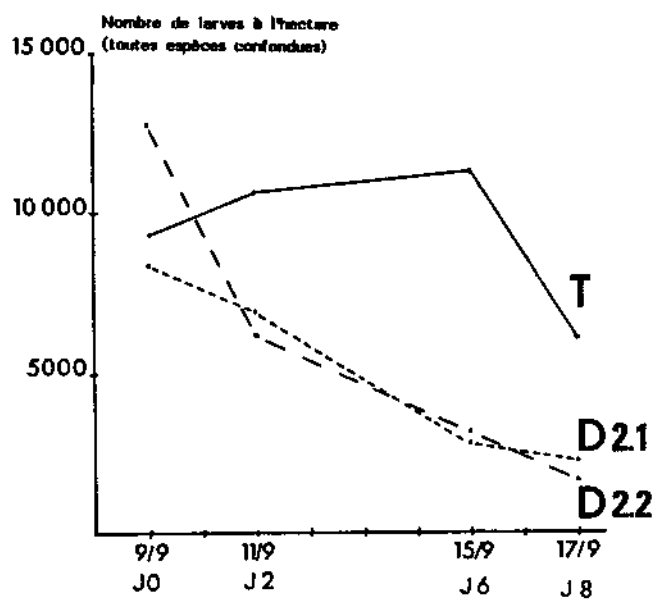
Fig. VIII.26 - Evolution du % de *Cataloipus cymbiferus* (Krauss, 1877) parmi les criquets observés ou capturés dans les parcelles traitées aux organophosphorés. Les flèches indiquent les dates des traitements. Dans les stations témoins, CCY n'est observé que le 12.09.89 (< 1 % du total).



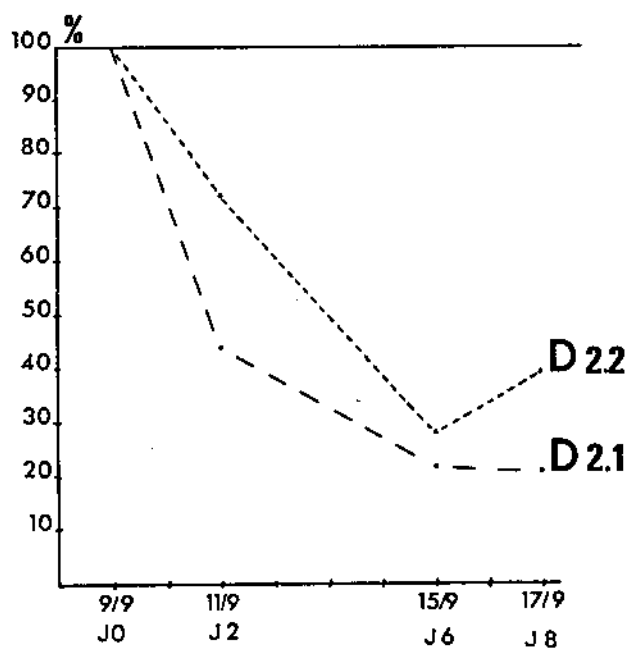
**Fig. VIII.27** - Evolution des densités larvaires brutes de sauteriaux dans les stations de la parcelle D1 soumise à un épandage de diflubenzuron à 40 g m.a./ha le 10.09.89 et dans la station témoin T.



**Fig. VIII.28** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations larvaires de sauteriaux soumises à un épandage de diflubenzuron à 40 g m.a./ha.



**Fig. VIII.29** - Evolution des densités larvaires brutes de sauteriaux dans les stations de la parcelle D2 traitée au diflubenzuron à 85 g m.a./ha le 9.09.89 et dans la station témoin T.



**Fig. VIII.30** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations larvaires de sauteriaux soumises à un épandage de diflubenzuron à 85 g m.a./ha.

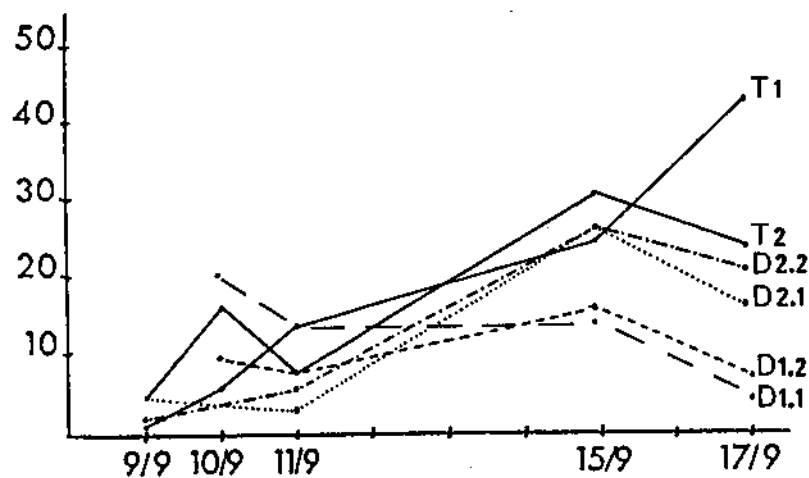


Fig. VIII.31 - Evolution du nombre de larves de criquets nouveau-nés observés sur 60 m<sup>2</sup> ou capturées par 100 coups de filets dans les 4 stations des 2 parcelles traitées au diflubenzuron (D) et dans les 2 stations témoins T.

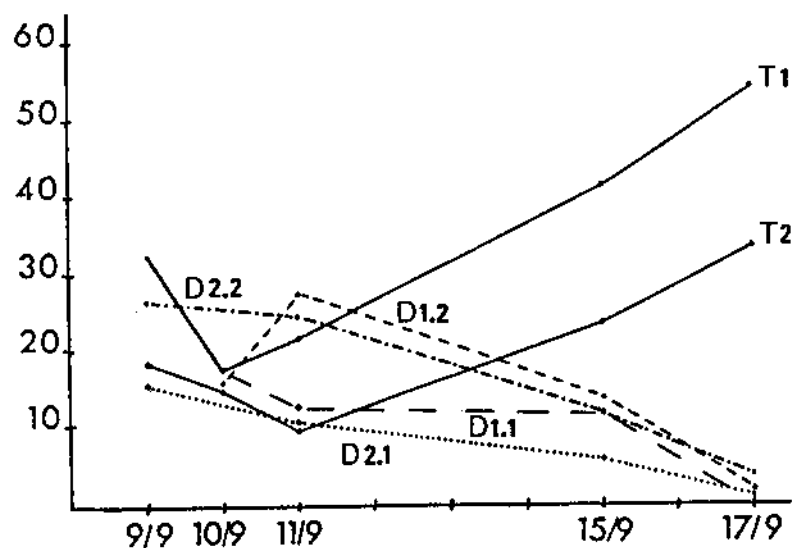
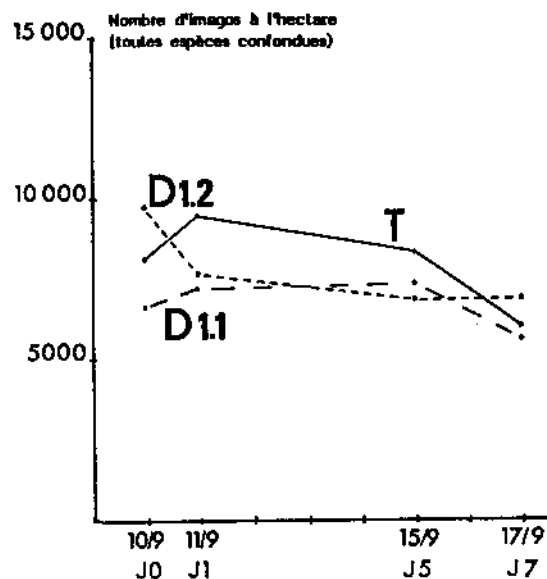
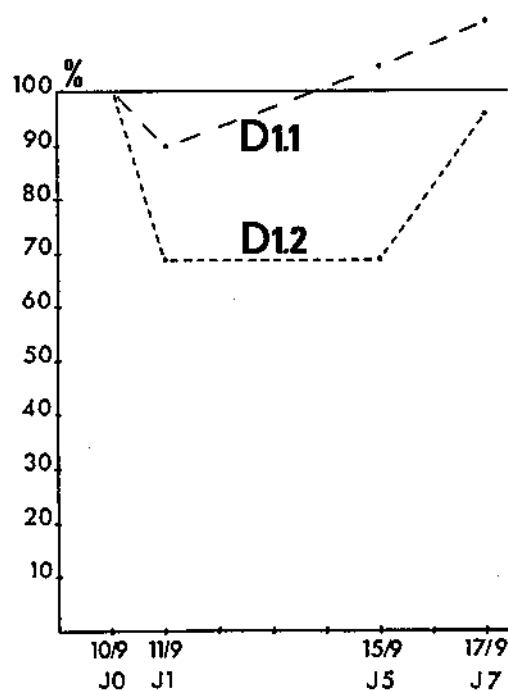


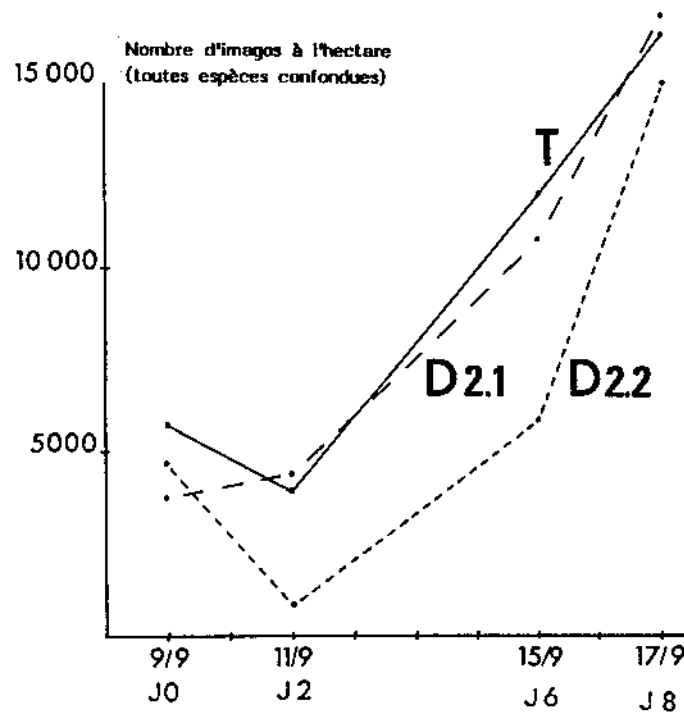
Fig. VIII.32 - Evolution du nombre de larves de criquets ayant mués au moins une fois, observées sur 60 m<sup>2</sup> ou capturées par 100 coups de filets dans les 4 stations des 2 parcelles traitées au diflubenzuron (D) et dans les 2 stations témoins T.



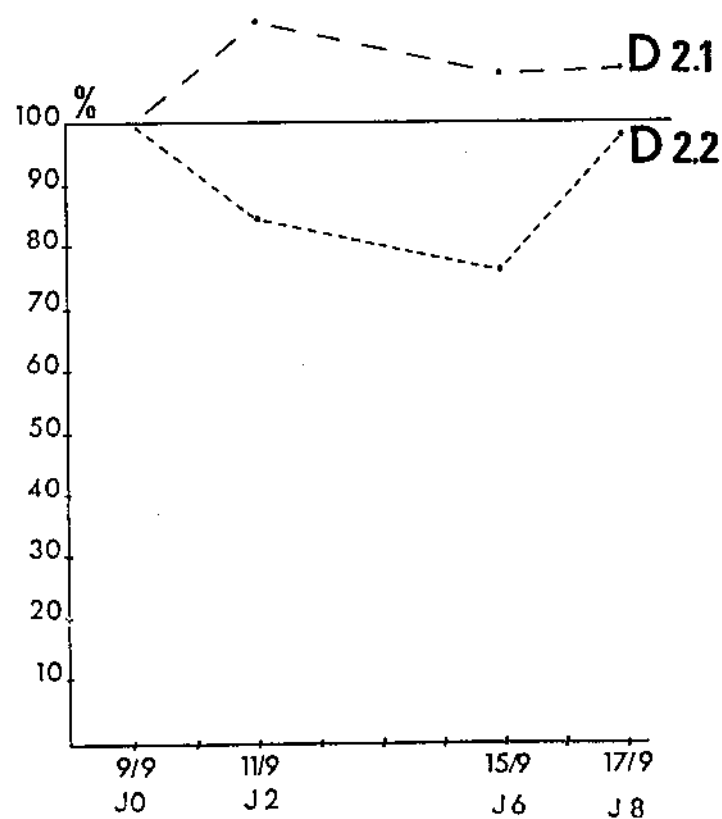
**Fig. VIII.33** - Evolution des densités imaginale brut de sauteriaux dans les stations de la parcelle D1 soumise à un épandage de diflubenzuron à 40 g m.a./ha le 10.09.89 et dans la station témoin T.



**Fig. VIII.34** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginale de sauteriaux soumises à un épandage de diflubenzuron à 40 g m.a./ha.



**Fig. VIII.35** - Evolution des densités imaginale brut de sauteriaux dans les stations de la parcelle D2 traitée au diflubenzuron à 85 g m.a./ha le 9.09.89 et dans la station témoin T.



**Fig. VIII.36** - Taux de survie, exprimé en % par rapport au témoin corrigé, des populations imaginale de sauteriaux soumises à un épandage de diflubenzuron à 85 g m.a./ha.

**TABLERAU VIII.1 Densités imaginales et larvaires dans les six parcelles expérimentales une heure avant le traitement**

Parcelle	Code station	Nombre d'imagos/ha	Nombre de larves/ha	Nombre total d'individus /ha	% d'OSE	% de larves
C1	C1.1	19.500	16.000	35.500	33	45
	C1.2	9.000	20.000	29.000	46	69
C2	C2.1	27.000	32.000	59.000	65	54
	C2.2	13.000	35.000	48.000	64	73
F1	F1.1	14.000	31.000	45.000	79	73
	F1.2	23.000	37.000	60.000	86	62
F2	F2.1	22.000	14.000	36.000	61	39
	F2.2	30.000	15.000	45.000	87	33
D1	D1.1	7.000	10.000	17.000	6	59
	D1.2	10.000	10.000	20.000	25	50
D2	D2.1	15.000	13.000	28.000	31	46
	D2.2	16.000	8.000	24.000	45	33

**TABIEAU VIII.2 : Valeur des paramètres d'efficacité des insecticides**

	dose de produits active par ha	Taux de criquets vivants 24 h après le traitement (en %)				Taux minimal de criquets vivants observés (en %)				Délai d'observation du taux minimal de criquets vivants (en jours)				Délai écoulé avant la recolonisation (en jours)				Vitesse de recolonisation + faible ++ moyenne +++ élevée			
		imago	larves	moyenne		imago	larves	moyenne		imago	larves	moyenne		imago	larves	moyenne		imago	larves	moyenne	
chlorpyrifos	270	6,0	3,9	8,1		6,0	0,0	6,2		1,0	3,0	3,0		2,0	9,0	5,5		+++	+++	+++	
		13,9	3,4			13,9	0,0			1,0	7,0			2,0	9,0			+++	+++		
	390	5,0	7,2	6,3		5,0	1,7	4,4		1,0	5,0	3,5		2,0	7,0	5,0		++	+	+	
		11,0	1,8			11,0	0,0			1,0	7,0			2,0	9,0			+	+		
féntrothion	485	2,2	0,0	1,1		2,2	0,0	1,1		1,0	1,0	1,0		7,0	> 9,0	> 8,0		+++	-	-	
		2,1	0,0			2,1	0,0			1,0	1,0			7,0	> 9,0			+++	-		
	825	4,4	0,0	1,8		3,3	0,0	1,5		2,0	1,0	1,3		4,0	> 5,0	> 4,5		++	-	-	
		2,6	0,0			2,6	0,0			1,3	1,0			4,0	> 5,0			++	-		
diflubenzuron	40	-	93,6	85,5		-	7,8	5,3		-	7,0	7,0		-	> 7,0	> 7,0		-	-	-	
		-	77,5			-	2,7			-	7,0			-	> 7,0			-	-	-	
	85	-	-	-		-	21,1	30,4		-	8,0	8,0		-	> 8,0	> 8,0		-	-	-	
		-	-			-	39,6			-	8,0			-	> 8,0			-	-	-	

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## Introduction

### General

Since none of the insecticides used in locust control at present are selective only to locusts, side-effects are likely to occur in other arthropods. However, many groups of arthropods perform important functions in both natural and agricultural ecosystems. They may improve soil fertility by accelerating litter breakdown or ameliorating soil structure; some are predators or parasitoids of crop pests or disease vectors and may regulate their numbers; others again ensure pollination of many field crops.

Many examples are known of the impact insecticides may have on these beneficial arthropods and indirectly on the functions they perform. Most examples come from situations where pesticides are used intensively, often in the temperate regions of the world. Increasingly, data is available from tropical or semi-arid regions, especially in vector control but also in crops such as cotton and rice (overviews in e.g.: Balk and Koeman 1984, Van der Valk and Koeman 1988). However, our knowledge of the potential impact pesticides may have in tropical and semi-arid ecosystems is still very limited. Hardly any studies have been carried out on the side-effects of pesticides under Sahelian conditions. Furthermore, extrapolation from knowledge gained under temperate conditions is difficult. Although the fate of a pesticide under Sahelian conditions may well be modelled with a certain confidence using data gathered elsewhere, knowledge of the ecology of many species of potential importance is lacking.

The latter poses two major problems. Firstly, it is very difficult to estimate to what extent specific ecological and physiological characteristics of sahelian organisms (e.g. adaptations to environmental disturbance, drought and a relative short growing season) influence the outcome of an effect. Secondly, even if a certain effect can be demonstrated in a taxon which is considered beneficial (e.g. a parasitic hymenopteran), we are often still not able to show its actual importance in the ecosystem (e.g. the chance of resurgence of a pest insect). In addition to these problems, the simple fact that very many arthropods in Africa have not even been properly described taxonomically makes the life of a "tropical ecotoxicologist" difficult.

Given the limited time and resources available for this pilot study it was decided from the beginning to concentrate only on specific groups of arthropods while still trying to cover a fairly wide spectrum of non-target organisms. The following arguments were taken into account in deciding which taxa to include:

- the taxon should have a known or strongly suspected role as 'beneficial arthropod' in natural or agricultural systems in the Sahel.
- the taxon should be easy to sample, sort and identify.
- the taxon should be relatively abundant during the study period to allow insecticide effects to be analysed.

In the rest of this introduction the choice of the study organisms will be discussed in the light of the above.

#### Beneficial arthropods in Sahelian ecosystems.

Some groups of beneficial arthropods of importance in the Sahel and possibly to be included in the study, are discussed below.

#### *Natural enemies<sup>1</sup> of grasshoppers and locusts*

An extensive review of the insect enemies of acridoidae was given by Greathead (1963). Only limited additional information has been gathered since, as far as locusts are concerned (Prior and Greathead 1989).

Many insect species are known to parasitize or predate upon desert locust eggs, nymphs and adults. But only a small number has been considered of importance as a regulating factor, and often only locally (Greathead 1966). These include egg predators such as *Stomorphina lunata* (only in East Africa), *Systoechus spp.* and *Trox procerus*, and enemies of the post embryonic stages such as *Symmictus spp.*, and *Blaesoxipha spp.*. A summary of the more important desert locust natural enemies is given in Table IX.1.

**Table IX.1:** Desert Locust Natural Insect Enemies

FAMILY	SPECIES	HOST STAGE	IMPACT (mortality)	REMARKS
<b>DIPTERA</b>				
Bombyliidae	<i>Systoechus spp.</i>	eggs	up to 30% locally	
Calliphoridae	<i>Stomorphina lunata</i>	eggs	0-90%	only in East Africa
Calliphoridae	<i>Blaesoxipha spp.</i>	nymphs,adults	0-40%	
Nemestrinidae	<i>Symmictus costatus</i>	nymphs,adults	0-34%	
Asilidae		eggs		little importance
<b>HYMENOPTERA</b>				
Proctotrupoidea	<i>Scelio spp.</i>	eggs		possibly on solitaria, transiens
Sphecidae	<i>Sphex aegypticus</i>	nymphs,adults		erratic, little importance
<b>COLEOPTERA</b>				
Trogidae	<i>Trox procerus</i>	eggs	0-75%	
Meloidae	<i>Mylabris spp.</i>	eggs		little importance
Caribidae		eggs		little importance

SOURCE: Greathead, 1963, 1966, Prior and Greathead 1989.

<sup>1</sup>In the rest of this chapter natural enemies refers only to arthropod natural enemies and does not include other organisms.

Natural mortality of senegalese grasshopper (*Oedaleus senegalensis*) was studied by Popov (1980, 1988). Considerable egg mortality was caused by larvae of the bombyliid flies *Xeramoeba oophaga* and *Systoechus spp.* and of the meloid *Mylabris spp.*. However, the most important mortality factor was egg pod damage caused by tenebrionid beetles, mainly thought to be *Pimelia senegalensis* (table IX.2). Natural enemies were a far more important cause of mortality than sterility or climatic factors. Van der Weel (pers. comm.) studied predation and parasitism of eggpods in Niger in 1989 and found it ranging from 7% to more than 80% depending on the region, although most often around 60%. Eggpod surveys in Mali during 1989-1990 showed similar rates of natural mortality, ranging from 40-80% in *O. senegalensis* and 0-80% in other species of grasshoppers (SNPV 1990).

Table IX.2: Senegalese Grasshopper Natural Enemies

SECTOR	total # eggpods	intact	EGG POD RECORDS (%)			
			S	X	M	T
Niamey-Ouallam	373	48	17		3	32
Ouallam-Mali border	39	36	15			39
Mali bord.-Menaka	5	40				60
Gao-border	42	57		15		28
Border-Tillabery	212	48	2	20	3	27
Tillabery-Niamey	39	23	15	7		55
Niamey-Tamou	253	45	3.5		3.5	48
Guesselbodi	377	30	15		3	47
Total	1340	42	11	4	3	40

S= *Systoechus spp.*, X= *Xeramoeba oophaga*, M= *Mylabris spp.*,  
T= Tenebrionidae and others. SOURCE: Popov, 1980

Table IX.3: Some important enemies of selected grain pests in the Sahel.

PEST	HOST CROP	NATURAL ENEMY	IMPACT*
<i>Heliocheilus albipunctella</i> (= <i>Raghuva albipunctella</i> ) (Noctuidae: Lepidoptera) [Millet headminer/millet spike worm/earhead caterpillar]	millet	<i>Bracon hebetor</i> (Braconidae: Hymenoptera) <i>Cardiochiles sahelensis</i> (Braconidae: Hymenoptera) <i>Lyiomastix sp.</i> (Encyrtidae: Hymenoptera) <i>Trichogrammatoidea</i> (Hymenoptera) <i>Palexorista sp.</i> (Tachinidae: Diptera)	-15%(-95%) -10%(-30%) -15%(-30%) -20%(-75%)
<i>Acigona ignefusalis</i> (Pyralidae: Lepidoptera) [millet stemborer]	millet	<i>Hyperchalcidia sp.</i> (Chalcididae: Hymenoptera) <i>Mesochorus sp.</i> (Ichneumonidae: Hymenoptera) <i>Syzeuctus sp.</i> (Ichneumonidae: Hymenoptera) <i>Sturmiopsis sp.</i> (Tachinidae: Diptera)	-30% -12% -30% -16%
<i>Geromyia penniseti</i> (= <i>Cecidomyia penniseti</i> ) (Cecidomyiidae: Diptera) [millet grain midge]	millet	<i>Tetrastichus sp.</i> (Eulophidae: Hymenoptera) <i>Eupelmus sp.</i> (Eupelmidae: Hymenoptera)	
<i>Helicoverpa armigera</i> (= <i>Heliothis armigera</i> ) (Noctuidae: Lepidoptera) [American bollworm]	maize, sorghum, (cotton, beans, others)	<i>Cardiochiles variegatus</i> (Braconidae: Hymenoptera) <i>Aleiodes sp.</i> (Braconidae: Hymenoptera) <i>Trichogrammatoidea</i> <i>Palexorista quadrizonula</i> (Tachinidae: Diptera) <i>Pseudogonia rufifrons</i> (Tachinidae: Diptera)	-40% -7% -30%(-90%) -10% -14%
<i>Sesamia calamistis</i> (Noctuidae: Lepidoptera) <i>Eldana saccharina</i> [sorghum stemborers]	maize, millet, sorghum, rice	Ichneumonidae + Braconidae (Hymenoptera) and Tachinidae (Diptera) make up 60% of known larval parasites in Africa	-50%?(-90%)

\*: 'typical mean' percentage of parasitism encountered in Sahel; -#% means 'up to' #%, percentage between brackets gives maximum reported

SOURCES: Guhakar *et al.* 1986; Bhatnagar 1987; Ndoye and Guhakar 1987; Huddleston and Walker 1988; Kranz *et al.* 1977; Nwanze 1989; Beibeder-Matibet 1989

Although records exist of arthropods predating on nymphs and adults of senegalese grasshopper, the extent of this mortality is not well known. It can be expected to be substantial, though, viewing examples from other species (e.g. in *Locusta migratoria migratoroides* ranging from 50-99% (Farrow 1975)).

Several other groups of natural enemies have been reported in relation to grasshoppers and locusts. *Scelio spp.* (Hymenoptera: Scelionidae) are known as specific egg parasites of acridoids (except of Desert Locust and Senegalese grasshopper (Greathead 1963, Popov 1988)). Carabid beetles have been found predating on grasshoppers and were a major cause of egg mortality in *L. migratoria* in Mali (Popov, 1959). Within the hymenopteran family of Sphecidae many orthopteran predators are found. *Sphex spp.* predate specifically on grasshopper larvae and adults as do several genera of Larrinae (e.g. *Tachytes spp.*) (Greathead 1963, Bohart and Mencke 1976). The Asilidae are the principal dipterous predators of acridoid larvae and adults. It is doubted, however, if these robber flies are host specific and they will probably only be important when grasshopper densities in a given area are high (Greathead 1963, Cheke et al. 1980). Indeed, Stortenbeker (1967), studying population dynamics of Red Locust *Nomadacris septemfasciata*, found that Asilidae were one of the main causes of mortality in early instar larvae when locust densities were high. Anisoptera (Odonata) were considered the potentially most important natural enemy of Red Locust larvae (Stortenbeker, 1967). However, this taxon, being linked to water for reproduction, can only be expected to be important for Red Locust which breed closely to or in floodplains. Several genera of ants have been found preying on eggs and young hoppers (e.g. Farrow 1975, Cheke et al. 1980).

#### *Natural enemies of grain pests*

Pearl or Bulrush Millet (*Pennisetum americanum*) is one of the main staple food crops in the Sahel, especially in the northern belt. Drought is generally considered a major production constraint but weeds, diseases insects and birds may cause considerable damage to the crop as well (Gahukar 1988,1989). Other important coarse grain crops in the Sahel include sorghum, maize and to a lesser extent rice. When locust or grasshopper control is carried out in cultivated areas in Africa, these crops are therefore often treated. The insecticides used to control locusts may, however, unintentionally cause outbreaks of secondary pests by killing the natural enemies of these potential pests. This may either happen in the year of treatment itself or in the next cropping season. For example, pesticide treatments increased the abundance of *Eldana saccharina* a sorghum stemborer, probably by reducing natural enemy abundance (Betbeder-Matibet 1989). Some more important insect pests of coarse grain crops in the Sahel and their major natural enemies as presently known are summarized in Table IX.3. The economic importance of these pests has only been studied to a limited extent. Even less is known of the impact natural enemies may have on the population dynamics of these pests. Data presented in Table IX.3 suggest, however, the potential importance of insect natural enemies.

#### *Pollinators*

Pollination by insects is very important for many tropical and subtropical crops. At least 105 tropical and subtropical crops are (partly) pollinated by bees, among them such major ones as cotton, soya, several oil crops and the majority of commercially grown fruits (Crane and Walker 1983, McGregor 1976). In addition, honey production can be a substantial source of income for farmers in developing countries. Bees are the principal pollinators. Except for

domesticated honeybees (*Apis mellifera*.), in the tropics and subtropics wild bees play an important role in pollination. They belong mostly to the families of Megachilidae, Apidae, Halictidae, Adrenidae and Melittidae (Crane and Walker, 1983).

#### Previous ecological impact studies of locust or grasshopper control in Africa

Several studies have been carried out over the last few years, looking at environmental impact of desert locust and grasshopper control. Most of these studied terrestrial invertebrates in some way or another.

Ottesen (1987) carried out a preliminary study in Mali of the acute impact of fenitrothion applied at 50 and 150 g ai/ha against *Oedaleus senegalensis*. He caught non-target invertebrates using sweep nets and pitfalls for two days before and two days after spraying. Fenitrothion, diluted with codacide oil, was applied by helicopter at 50 and 150 g ai/ha in 70  $\mu$ m droplets (nominal) on 300x400 m plots. Spraying was carried out under practically no-wind conditions, < 1 m/s, which may have caused uncontrolled drift of these small droplets either onto other plots (no interplot buffer zone) or outside the sample area. Most affected were ants (Formicidae) and thrips (Thysanoptera), showing >95% population reduction in the two days after spraying. In the herb layer especially plant feeding insects were affected (as a rule >50% acute population reduction), while spiders and mites were the least affected (ca. 40% population reduction). Except for mites and thrips, actual number caught were very low. Of ground dwelling arthropods Diptera (mainly Agromyzidae) and mites were most heavily affected, acute mortality being >70%. Carabid beetles were reduced ca. 50% but spiders showed no reduction. No difference in effect between the two doses was observed. Ottesen suggests that, since no total extinction was observed in any group, it seems likely that they will recover after some time.

A second preliminary study was carried out by Pinto et al. (1988) in Sudan. Fenitrothion was applied to two blocks of 80 and 72 ha at ca. 900 and 700 g ai/ha respectively. Spraying was carried out by aircraft, using micronair atomisers, spraying in winds of 2-8 m/s. Control blocks, located 150 m upwind of the treated blocks, were paired with the sprayed blocks. The first treatment resulted in a reduction of 85% in the number of arthropod species caught by sweepnet, and of 95% in arthropod abundance, 10 days after spraying. No more detailed analysis was reported. The second treatment reduced total number of species by 60% and total abundance by 83% after 8 days when compared with the control. Population assessment was by transect counts. Numbers were too low to analyse on a lower taxonomical level. Pitfall trapping revealed a 98% reduction of Formicidae in the treated plot seven days after spraying. No recovery could be observed because all plots were drying out rapidly and arthropod abundance dropped to almost zero in the control plots.

Dynamac (1988a) conducted trials in Mali to test the efficacy of several pesticides against grasshoppers. Although extensive monitoring of non-target arthropods was planned, only limited data could be gathered due to low invertebrate abundance and inappropriate sampling techniques. In the first set of trials 12 ha plots were treated by air (micronair atomisers), using a 150 m interplot distance. Of a total of eight chemicals tested, fenitrothion was applied at 150 g ai/ha and chlorpyrifos at 171 g ai/ha (nominal). Fenitrothion was applied in three replicates, chlorpyrifos in two. Droplet sizes were estimated at 100-150  $\mu$  and windspeed ranged from 0.8 to 1.8 m/s. Tenebrionid and carabid beetles did not show a significant reduction compared to the control over a 5-day sample period (pitfall trapping) for the above

treatments. The study team also carried out searches for dead insects after spraying, but its value is negligible if one can't relate this to (relative) population estimates. In a second set of trials on larger plots, sticky traps, visual transect counts and harvester ant mortality were used to attempt to assess side-effects. The first two methods did not yield any useful results, basically because low numbers of arthropods caught/observed. Ant mortality was only assessed using 'carcass counts', and can therefore not expected to be a quantitative measure of effect.

The trials basically showed that when side-effects are to be monitored in areas where arthropods are low in abundance, very specific population assessment methods are needed, and 'general insect sampling' does not supply enough data for any sort of analysis.

Müller (1988) studied the effect of 16 pesticides on selected non-target invertebrates in Sudan. However, given the methodologies used: incomplete topical application tests and 'semi-quantitative' searches for dead invertebrates in very small sprayed plots, results obtained do not seem very usefull as far as extrapolation to other circumstances is concerned. Furthermore, no application details were given.

A large side-effetcs testing programme was carried out in the Tokar Delta of Sudan in 1988 (Dynamac 1988b). Six pesticides were applied: fenitrothion (520 g ai/ha), malathion (1300 g ai/ha), chlorpyrifos (225 g ai/ha), bendiocarb (124 g ai/ha), carbaryl (576 g ai/ha) and lambdacyhalothrin (20 g ai/ha). Every pesticide was sprayed in triplicate on 1 km<sup>2</sup> plots with interplot distances of 250-600 m. Application was by aircraft, using micronair atomisers (estimated droplet size 100-150 µ) and spraying in crosswinds of mostly ca. 3 m/s (range 1.8-6.7). Non-target invertebrates were sampled using sweepnet, pitfall and sticky traps. Samples were taken over a one week pre- and a one week post-spray period (three samples per week), and subsequently sorted to taxonomic order level. Fenitrothion caused significant reductions for one week in Araneae (62%), Hemiptera(58%) and Coleoptera (90%), but not in Diptera and Hymenoptera. Chlorpyrifos reduced Coleoptera (56%) and Hymenoptera (53%) but did not significantly influence population levels of Araneae, Hemiptera and Diptera. In most cases, recovery to pre-spray levels had either started or completed by day-7. Since pitfalls were left without any killing/conservation fluid during sampling, it is very doubtful if the results obtained by this method (mostly for Coleoptera and spiders) are valid.

Ottesen *et al.* (1989) studied the impact of fenitrothion on non-target arthropods in Mali. The chemical was mixed with codicide oil and sprayed by helicopter on 12 ha plots in the rates of 50, 165 and 330 g ai/ha. Atomisers were electrically driven Micron X15 and applications were carried out in winds of 3-4 m/s. Invertebrates were sampled four consecutive days before spraying, five consecutive days post-spray and on day-8 and day-12 after spraying. Sweep netting was used to capture herb layer arthropods and pitfalls for ground dwelling ones. All herb layer arthropods sampled, showed high initial population reductions, often still more than 50% eight days after spraying. Data from the pitfalls were very variable. No clear effect of the pesticide could be demonstrated in such predatory groups as Araneae and Carabidae. Seed eating ants were reduced but predatory ants were not. Tenebrionid beetles increased markedly in the control plots, while being reduced lightly in the treated plots. No relation was found between dose rate and initial population reduction, but recovery seemed to be somewhat quicker in the lower dose plots.

### *Conclusion*

The studies carried out so far are limited in several aspects. All of them assess only acute impact of the pesticides, the maximum post-spray period being 12 days. Since the pre-spray period was short in all cases, it is difficult to evaluate such acute effects in the light of the, in the Sahel often very large, natural fluctuations. Furthermore, only the studies carried out by Ottesen consistently analyse impact on a lower taxonomical level than arthropod orders. The information obtained by mainly looking at order level is very limited (see discussion of this chapter).

Several trials consistently showed high initial mortality in Formicidae (ants) caused by organophosphates and carbamates, but the duration and extent of any population reduction is not known. This acute effect is consistent with observations of insecticide impact on ants in vector control (Everts and Koeman 1987). The effects observed on other groups are difficult to evaluate, either because trapping methods were different, or because analysis is only carried out at order level.

### *Choice of taxa for monitoring*

Based on the above considerations regarding functionally important arthropod groups and taking into account previous studies it was decided to concentrate on the following taxa:

- Hymenoptera: Braconidae (general parasitoids)  
Ichneumonidae (general parasitoids)  
Sphecidae: Larrinae (Orthoptera predators)  
Apoidae (pollinators)
- Diptera: Asilidae (general predators)  
Bombyliidae (acridoid egg parasites)
- Coleoptera: Carabidae (general predators)  
Tenebrionidae (acridoid egg predators)

Whenever feasible within the pilot study, impact on organisms was to be analysed at the lowest possible taxonomic level (i.e. subfamily, tribe, genus or species).

Since ants (Formicidae) were often found to be affected by several groups of insecticides, they will be looked at in more detail. However, because of the behaviour of ants, indirect trapping methods such as pitfalls, pose problems of high variability. Some preliminary tests using a direct population assessment were therefore planned.

Figure IX.1

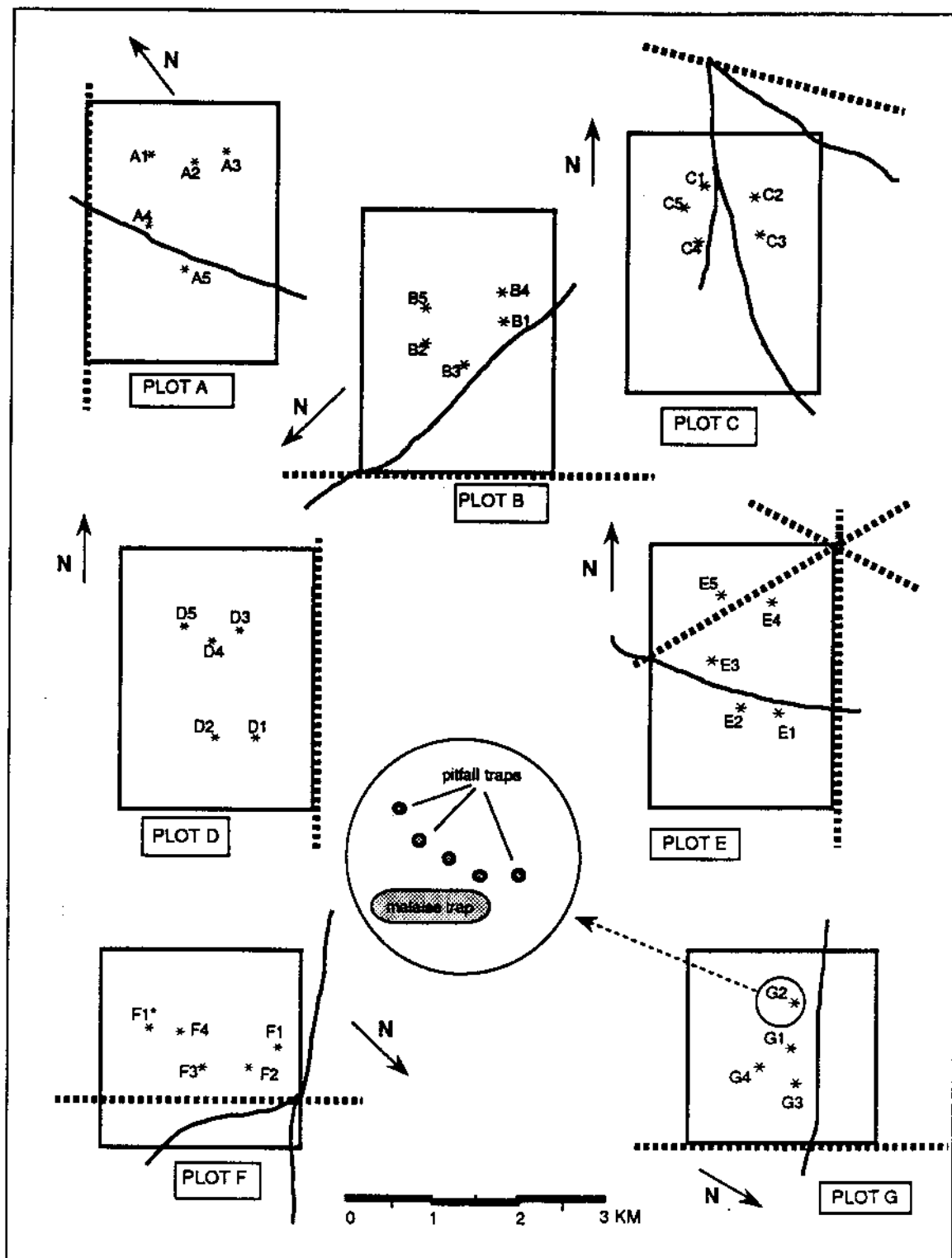


Fig. 4-1 : Positions of trapping units in all plots. Every trapping unit consists of 1 malaise trap and 5 pitfall traps; see general map for plot locations in study area.

--- : fire break

— : track

## Materials and Methods

For general trial design, plot size and lay-out, environmental and pesticide application data please refer to Chapter I and II.

### Trapping units

All plots, except the ones treated with diflubenzuron, contained five trapping units, each consisting of one malaise trap and five pitfall traps. The diflubenzuron plots, being a third smaller than the others, contained four trapping units each. The traps were not placed at random in the plots but stratified since the habitat was clearly patchy. As a rule the trapping units were placed at the edges of small depressions in the savanna. These depressions, lying approximately 0.2 to 1.0 m lower than the surrounding area, showed a concentration of vegetation and were expected to be richest in arthropod life. Therefore, effects of the pesticides were expected to be most marked near the depressions. In all but one case, the trapping units were located at least 500 m from the nearest edge of the plot (Fig IX.1). This was done to assure sampling to be carried out in an area with a fairly even spray deposit (see Chapter II).

### Malaise traps

Malaise traps were manufactured locally using fine mesh mosquito netting. The lower part of the trap was made from red/purple netting while the top part consisted of white netting. The trap has openings at two sides with interception areas of 1.5x1 m each. Total trap height was 1.8 m. One and a half litre mineral water plastic bottles were used as collection containers. The traps were installed with their wide, open sides perpendicular to the edges of the depressions. The collection bottle was filled with a 5% formol solution as preservative. The trap was surrounded by a ring of branches, ca. 0.5 m high and having a diameter of about 10 m, to prevent cattle from disturbing the traps. In the case of dessication of the collection fluid, or damage to the netting or collection bottle because of rain storms, catches were as a rule discarded.

### Pitfall traps

Five pitfall traps were dug into the ground on one of the higher edges of the depressions near every malaise trap. Plastic coffee cups, 6 cm in diameter and 10 cm deep, served as collection containers. On cup was permanently placed in the ground; a second was placed into it and filled with a formol 5% preservation solution. By changing only the inner cup at sampling days the soil did not need to be disturbed. The traps were spaced out in a straight line or semi-circle with an intertrap distance of 1.5 to 2 m. They were always placed in the shade of a tree or shrubs to slow down evaporation of the preservation solution. A 15x15 cm square sheet of metal was welded on to wire supports and served as a cover to prevent rain entering the traps. Samples of pitfalls which were dessicated or destroyed by cattle at the time of collection were as a rule discarded. The exact number of traps per location per week included in the analysis is given in Annex IX.1.

### Ant activity

Since pitfall trap catches do not give a reliable picture of changes in ant activity, a method based on the abundance of anthills was experimented with. Ants, possibly of the subfamily Myrmicinae, which were very abundant in the area, constantly remove sand from their nests. Since the soil in the plots was predominantly orange/red in appearance, nests in which ants

were active could easily be distinguished by the freshly deposited sand around the nest openings. In the control plot C and the double dose fenitrothion plot B, 5 transects were walked near the centre of the plot at every observation day. Transects measured 1.25 by 125 m. On every observation day new transects were laid out, the same transect was never visited twice, although the area within the plot where the observations were carried out was always the same. All "fresh" ant nests in the transects were counted. An ant nest was considered "fresh" when either ant activity was observed or sand had been newly deposited around the opening of the nest.

Sample programme terrestrial invertebrates

Table IX.4

	DAY	TU	WE	TH	FR	SA	SU	MO	TU	WEEK CODE
<b>AUGUST</b>		1	2	3	4	5	6	7	8	
	Installation	B1,2	B3-5 C1-5	E1-5 D1-3	D4,5 A1-3	A4,5	F1 G1	F2-4 G2-4	B C	1
				9	10	11	12	13	14	15
				D E	A			F G		1
				16	17	18	19	20	21	22
					B C D	A E		F G		2
				23	24	25	26	27	28	29
					B C D	A E		F G		3
<b>SEPTEMBER</b>										
				30	31	1	2	3	4	5
					B C D	A E		F G	D	4
				6	7	8	9	10	11	12
	treatment			E	A	F	G		B	
				13	14	15	16	17	18	19
				C D	A E	F G			B	5
				20	21	22	23	24	25	26
				C D	A E	F G			B	6
<b>OCTOBER</b>										
				27	28	29	30	1	2	3
				C D	A E	F G			B	7
				4	5	6	7	8	9	10
				C D	A E	F G			B	8
Letters refer to plots; numbers in the installation week refer to trapping units in the plots; hatched blocks in were considered as one sampling week in the analysis.										

### Sample frequency

All traps were emptied and preservation fluids replaced in a seven day rotation unless plots could not be reached due to flooded tracks. The complete sample scheme can be found in Table IX.4. It was physically impossible to collect the samples from all plots on the same day, although this would have been ideal from the point of view of reducing between-plot sampling error. The total sample period covered 4 weeks before and 4 weeks after spraying. Ant activity was registered twice before and 3 times after spraying. All traps were newly installed on every plot immediately after treatment, always within 6 hours after the last spray run.

### Sample treatment

All samples were washed over a fine mesh sieve and transferred to tap water. Sorting to order level was immediately carried out afterwards. Insects of the taxonomic orders of interest were separately stored in alcohol prior to further sorting and identification; all others were put together in alcohol, labelled and stored.

### Data analysis

Since it was not always possible to change traps exactly on every seventh day, capture data sometimes had to be corrected for the number of trapping days. This was done linearly, even though it can be expected that catches were not the same on every day, depending on e.g. the meteorological conditions. However, there was no way of quantifying such variation. All corrected data refer thus to a seven day trapping week. Similarly, in the case of missing pitfall traps, e.g. because of dessication or destruction, data were proportionally corrected to show a sample per five pitfalls (the standard number per trapping unit) per week.

It was found that a strong placement effect existed, i.e. that some traps consistently captured more or less arthropods than others. Since the number of traps was too limited to allow for this variation only complete trapping series can be compared and means for a specific plot only calculated using complete time series. Both because of 'missing catches' and the fact that there was not enough time to sort and identify catches of all traps installed in the field, data from three trapping units per plot were used, rather than the installed four or five. This ensured that only (almost) complete time series were compared in the analysis.

Methods for estimating missing values for this type of data sets, very short time series, are not well defined. Missing data generation as in ANOVA's is not possible since the data series are dependent (Sokal and Rohlf, 1981); the few missing value estimation techniques for time series, on the other, only work for datasets with many data (Kotz et al. 1983, Ansley and Kohn 1983). Here, missing values were estimated in a fairly crude manner, based on the principle that data in the series containing a missing value would follow the same trend as the other series in the plot: ratio's between 'missing-value' week catches and previous week's catches were calculated for all traps in the specific plot (except the missing value trap). The mean of these ratios is then used to estimate the missing value. If possible, the procedure is repeated for the ratio between the following week captures and 'missing value' captures. In such a case the mean of the two estimates is applied. However, no missing values were ever estimated for week 5 using data from week 4, and reverse, since this overlies the treatment, and it was not expected that the different locations in the plot would respond similarly to the treatment.

### Statistical analysis of the data

Statistical analysis was carried out according to the method described by Stewart-Oaten et al. (1986): consecutive catches on the different plots are used as "pseudo replicates".

All corrected catches were transformed using a  $\ln(N+1)$  transformation and subsequently for all treatments the sum of the three control traps was subtracted from the sum of the three treated traps for every trapping week. Before and after differences were compared using a non-paired, one sided t-test.

The method will be discussed more into detail further in this text (see Discussion).

## **Results**

### General

Most of the results are presented graphically below. Corrected numbers of arthropods per five pitfall, or per malaise trap, per week are depicted in bar graphs. The ratio treated number/control number (i.e. changes in the treated plots corrected for control variability) are shown next to these in line graphs. The significance level given in the "STATISTICS" box refers to the difference between the mean abundance in the stated pre-spray period compared with the mean abundance in the stated post-spray period.

The raw sampling data, the data corrected for unequal sampling weeks or missing traps, and the log transformed data used in the statistical analysis are given in Annex IX.2 for all groups discussed in this chapter.

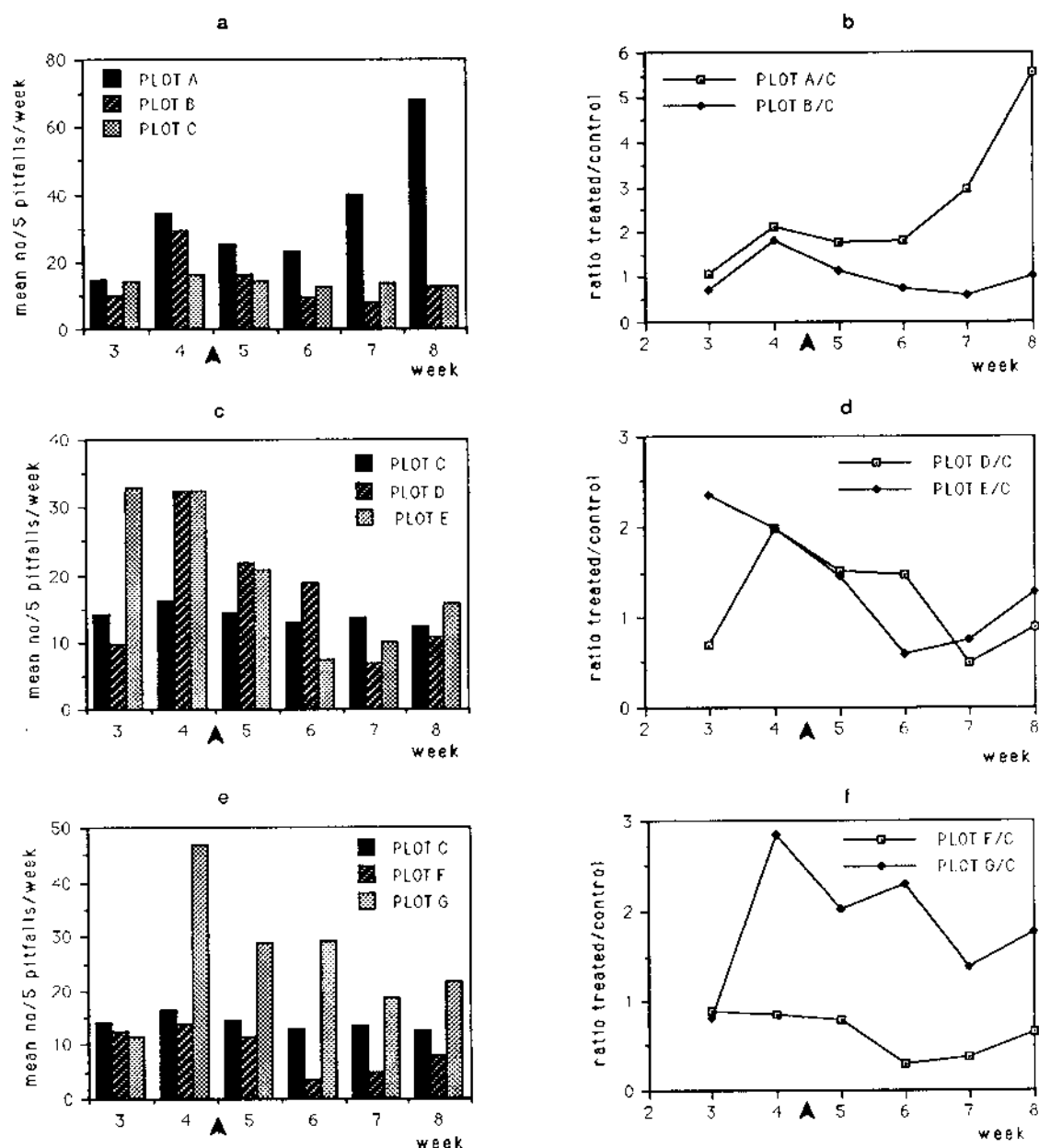
**When an increase or decrease in catches after treatment is mentioned in the text below this is always in comparison with the mean pre-spray levels, unless stated otherwise. Any mention of significance of changes is also in relation with mean pre-spray levels, unless otherwise stated. All changes in population levels on the treated plots discussed below are net changes, corrected for control plot fluctuations, i.e. as seen in the line graphs, unless stated otherwise.**

Sublethal dosages of insecticides often cause hyperactivity in arthropods. This is most strongly seen with certain pyrethroids but may occur as well with other groups of contact insecticides. Especially in pitfall trapping this may cause increased rather than decreased catches directly after spraying. Since in this study traps were installed closely following spraying, some of the increased catches in the pitfalls for week-5 may be explained by this phenomenon. In some cases, therefore, catches from week-5 have been excluded from analysis. It will be mentioned in the text when this has been done.

Because of an uneven pesticide deposit on the west side of plot D (chlorpyrifos 270 g ai/ha), trap unit D5 has been excluded from all further analysis. This to avoid any data being used from this underdosed band of the plot.

Figure IX.2

**Carabidae**



mean number of Carabidae per five pitfall traps per week (a,c,e) and the ratios of numbers in treated plots over the control (b,d,f), arrow signifies treatment.

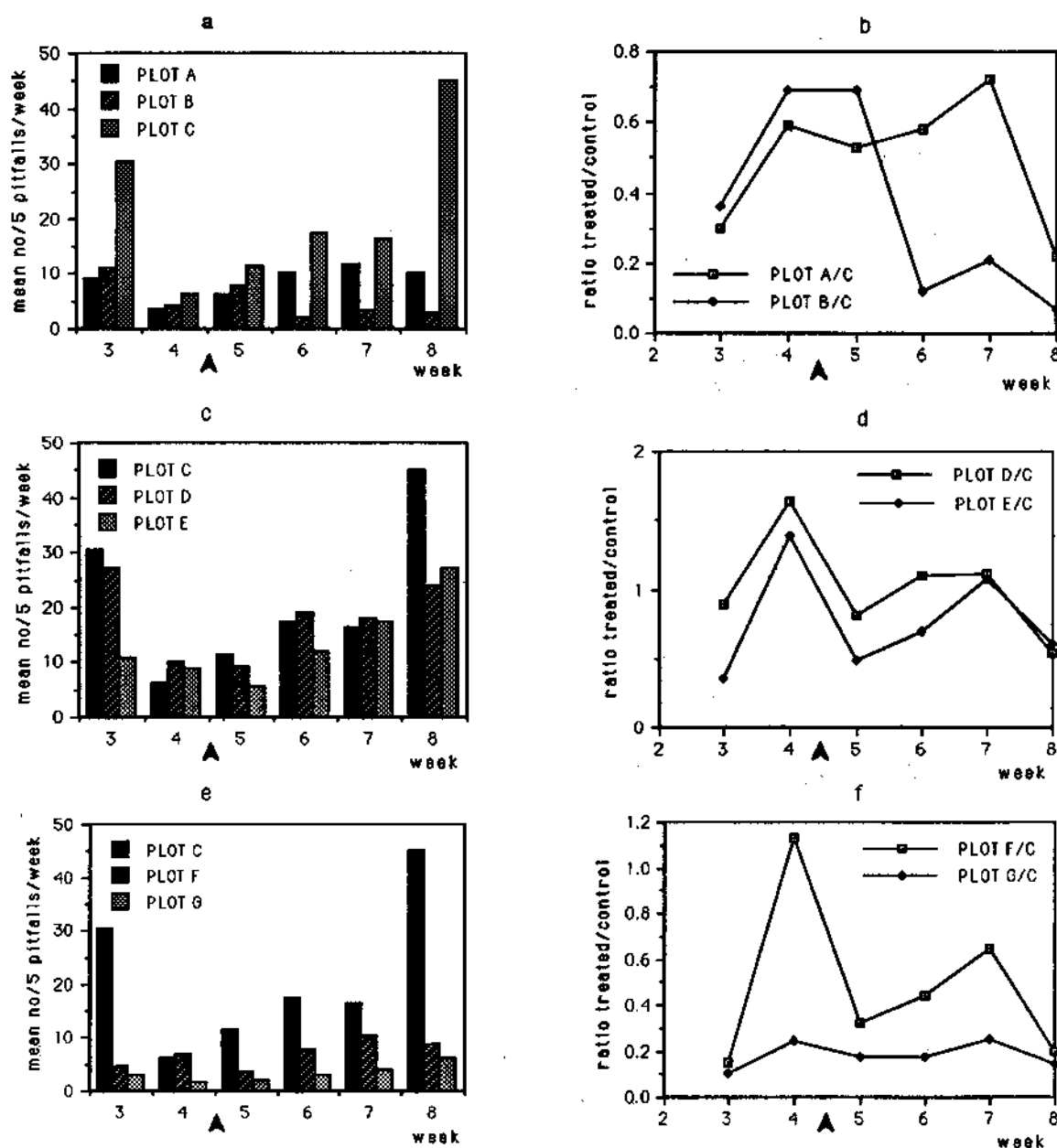
Plot A: fenitrothion 485 g a.i./ha; plot B: fenitrothion 825 g a.i./ha; plot C: untreated control; plot D: chlorpyrifos 270 g a.i./ha; plot E: chlorpyrifos 390 g a.i./ha; plot F: diflubenzuron 85 g a.i./ha; plot G: diflubenzuron 40 g a.i./ha.

**STATISTICS:**  
 Plot A,B,D: changes Not Significant (NS)  
 Plot E: week 3,4-5,6,7,8: ( $p=0.038$ )\*  
 Plot F: week 3,4-5,6,7,8: ( $p=0.053$ )  
 week 3,4-6,7,8: ( $p=0.02$ )  
 Plot G: week 4-5,6,7,8: ( $p=0.02$ )

\*: significance of reduction of mean of week 5,6,7,8 compared to mean of week 3,4.

Figure IX.3

*Pimella senegalensis*



mean number of *Pimella senegalensis* per five pitfall traps per week (a,c,e) and the ratios of numbers in treated plots over control (b,d,f); arrow signifies treatment.

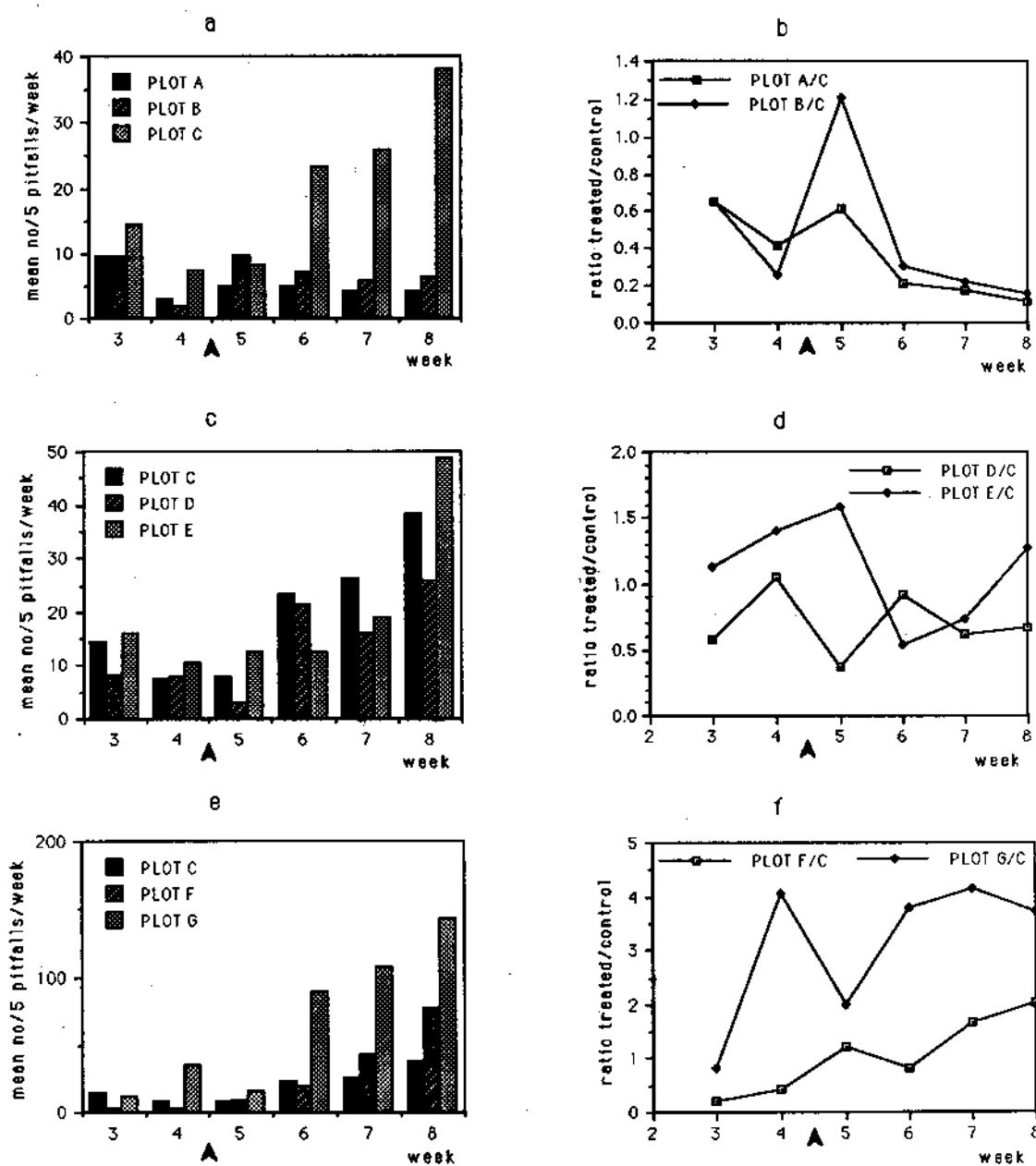
Dose rates for the different plots see fig. 2.

STATISTICS:

Plot A,D,E,F,G: changes not significant.  
Plot B: week 3,4 - 6,7,8: ( $p=0.065$ )  
week 4 - 6,7,8: ( $p=0.05$ )

Figure IX.4

*Vieta senegalensis*



mean number of *Vieta senegalensis* per five pitfall traps per week (a,c,e) and the ratios of numbers in treated plots over control (b,d,f), arrow signifies treatment.

Dose rates for the different plots see fig. 2.

STATISTICS:  
Plot D,E,F,G: changes not significant.  
Plot A: week 3,4 - 6,7,8: ( $p=0.01$ )  
Plot B: week 3,4 - 6,7,8: ( $p=0.03$ )

### Coleoptera (pitfall data)

A total number of 67394 Coleoptera were captured over a period of 8 weeks. No apparent effect of any of the treatments could be found on total Coleoptera numbers (Annex IX.2). Two groups of Coleoptera were sorted to family, genus or species level: Carabidae and Tenebrionidae.

### CARABIDAE

Carabidae made up approximately 6% of the total Coleoptera catches. They were sorted out for weeks 3 to 8.

No reduction was found in abundance in both of the fenitrothion treated plots (Fig. IX.2 ab). The plot treated with chlorpyrifos at 270 g ai/ha showed a clear reduction, but only from the second week after treatment onwards. It is not certain this has been caused by the pesticide. Double dose chlorpyrifos (390 g ai/ha), however, reduced carabidae by 70% during the second week after spraying (the slightly lesser reduction immediately after spraying is probably a trapping artefact as explained above). Four weeks after treatment populations had only recovered to 60% of the mean prespray level (Fig. IX.2 cd). In the plot treated diflubenzuron at 85 g ai/ha total carabid catches are significantly reduced ca. 50% from week 6-8. No effect was observed in the lower dose plot.

Carabids from the genus *Chlaenius*, sometimes mentioned as predators of both grasshoppers and lepidopterous millet pests, were regularly trapped. However, numbers were consistently too low for further analysis.

### TENEBRIONIDAE

Approximately 9% of the Coleoptera caught were Tenebrionidae. Two species made up more than 95% of the catches in this family: *Vieta senegalensis* and *Pimelia senegalensis*. [identification by comparison to reference collection of the Taxonomical Institute of the University of Amsterdam by the author] Larvae of the latter species have been reared out of *Oedaleus senegalensis* eggpods by Popov (1980) and are considered a major egg predator.

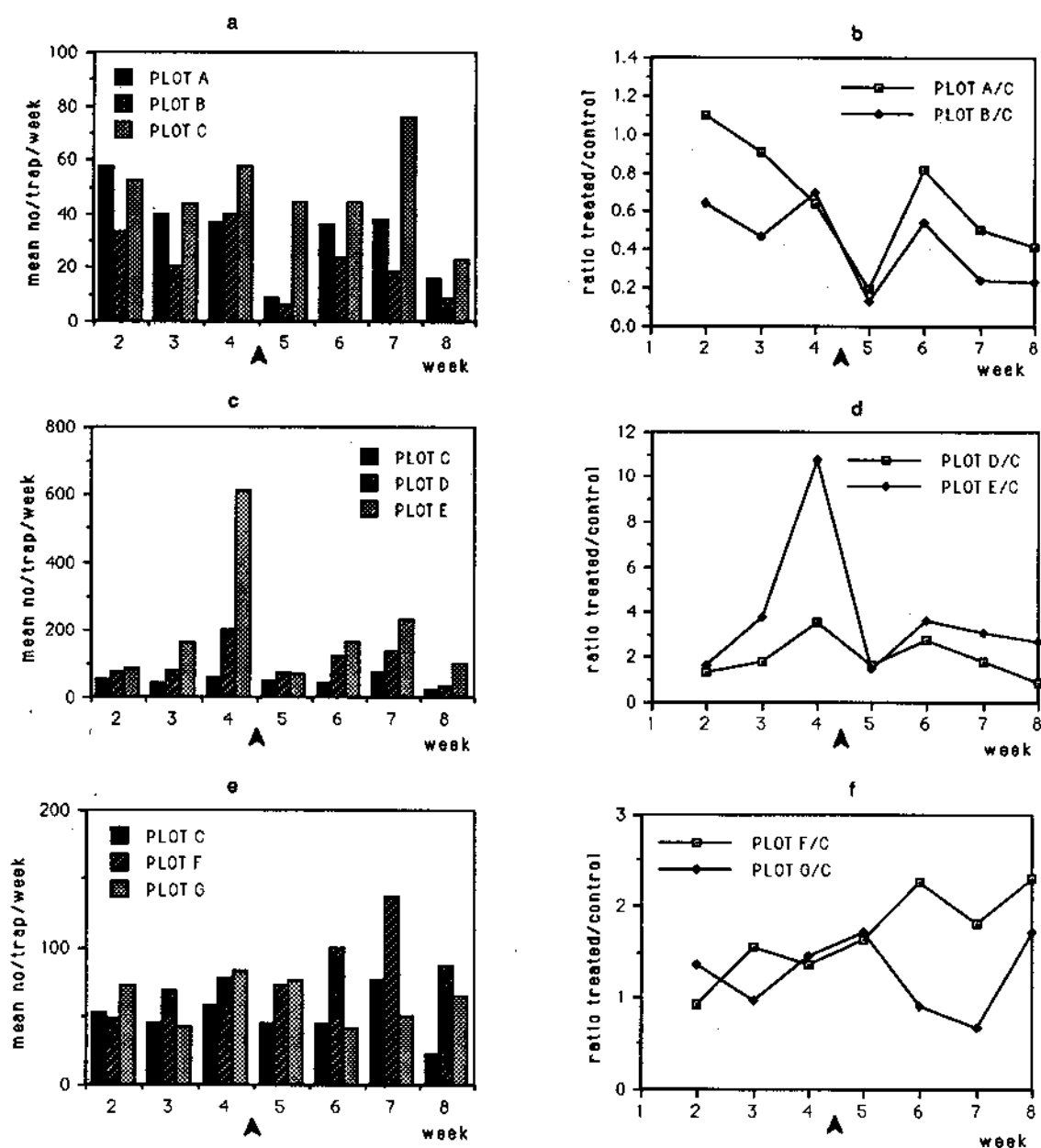
### *Pimelia senegalensis*

Fenitrothion at 485 g ai/ha does not cause a reduction in *P. senegalensis* abundance. However, at 825 g ai/ha the species is reduced 75% after one week and does not recover during the four-week post spray period (Fig. IX.3ab). Effects in both the chlorpyrifos plots are less clear and not significant (Fig. IX.3cd). No effect was seen in the plot sprayed with diflubenzuron at 40 g ai/ha and at 85 g ai/ha.

### *Vieta senegalensis*

*Vieta senegalensis* catches increase directly after spraying in both fenitrothion plots, which is probably caused by pesticide induced increased activity. Two to four weeks after spraying catches of *V. senegalensis* remain 50-60% lower than the mean of before treatment levels. No recovery is observed over this period (Fig. IX.4ab). Chlorpyrifos at 270 g ai/ha causes a possible one week reduction in *V. senegalensis* but recovery to prespray levels is rapid. Double dose chlorpyrifos, however results in a 60% reduction by week 6. Recovery to prespray levels seems to be completed by week 8 (Fig. IX.4cd). Changes in populations on both diflubenzuron plots are not significant.

Figure IX.5



mean number of total Hymenoptera (-formicidae) per malaise trap per week (a,c,e) and the ratios of numbers in treated plots over control (b,d,f); arrow signifies treatment.

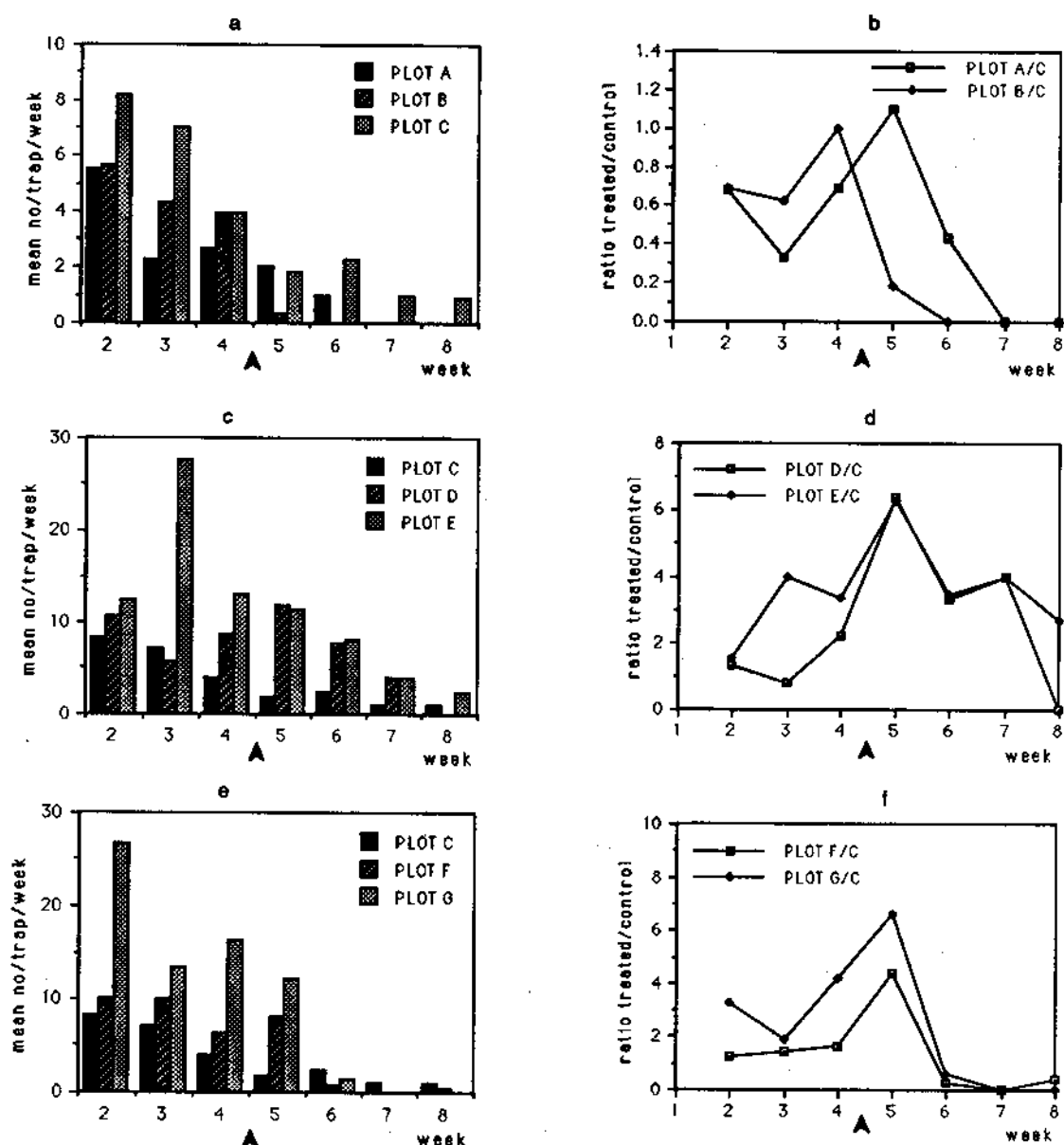
Dose rates for the different plots see fig. 2.

**STATISTICS:**

Plot D,G: changes not significant.  
 Plot A: week 2,3,4 - 5,6,7,8: ( $p=0.047$ )  
 Plot B: week 2,3,4 - 5,6,7,8: ( $p=0.052$ )  
 Plot E: week 2,3,4 - 5,6,7,8: ( $p=0.045$ )  
 Plot F: week 2,3,4 - 5,6,7,8: ( $p=0.048$ )

Figure IX.6

*Ichneumonidae*

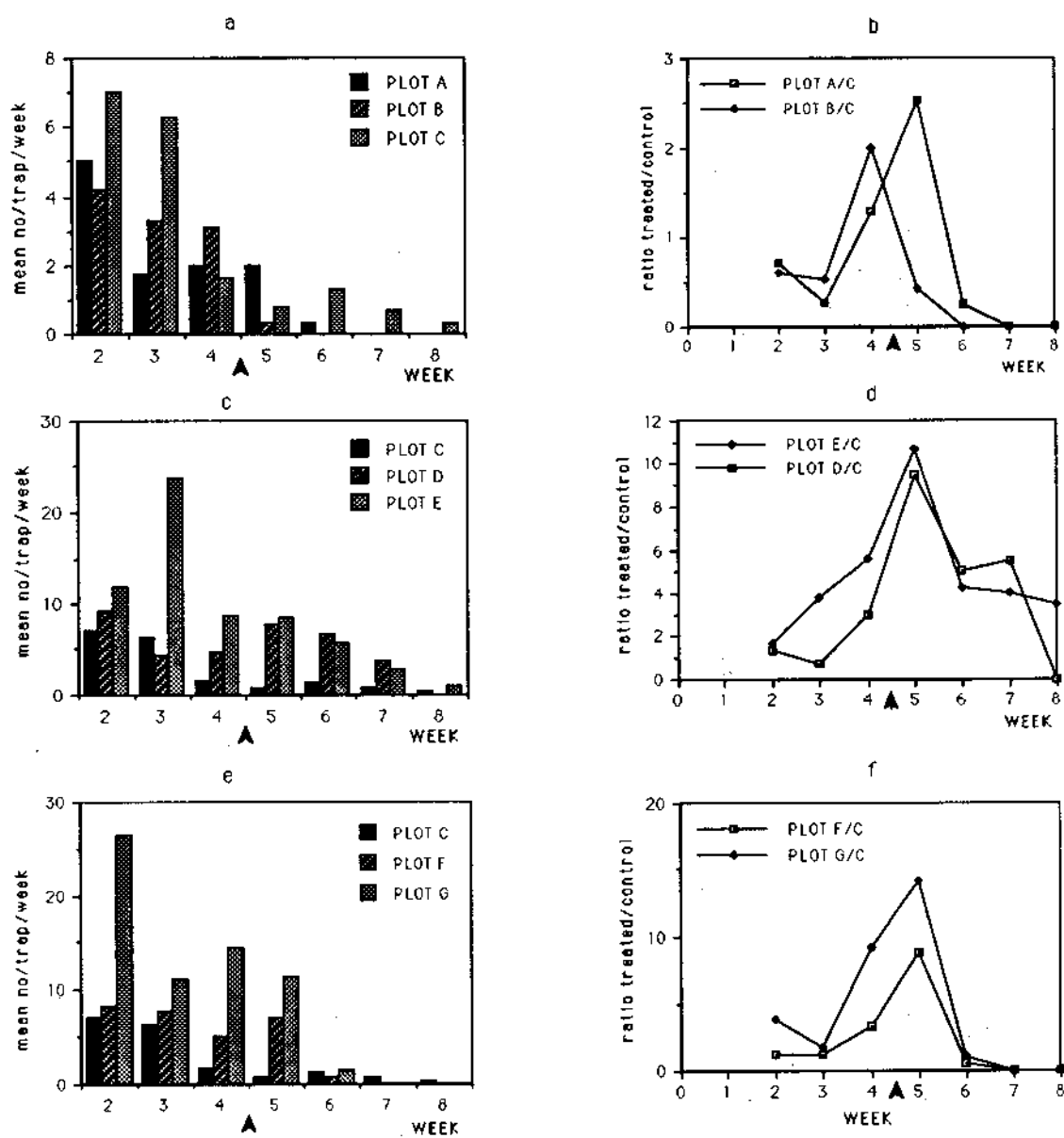


mean number of total Ichneumonidae per malaise trap per week (a,c,e) and the ratios of numbers in treated plots over control (b,d,f); arrow signifies treatment.

Dose rates for the different plots see fig. 2.

STATISTICS:  
 Plot A,D,E: changes not significant.  
 Plot B: week 2,3,4 - 5,6,7,8: ( $p=0.014$ )  
 Plot F: week 2,3,4 - 6,7,8: ( $p=0.001$ )  
 Plot G: week 2,3,4 - 6,7,8: ( $p=0.003$ )  
 week 2,3,4 - 5,6,7,8: ( $p=0.05$ )

Figure IX.7



mean number of *Temelucha* sp1 per malaise trap per week (a,c,e) and the ratios of numbers in treated plots over control (b,d,f); arrow signifies treatment.

Dose rates for the different plots see fig. 2.

STATISTICS:  
Plot A,B,D,E: changes not significant.  
Plot F: week 2,3,4 - 6,7,8: ( $p=0.02$ )  
Plot G: week 2,3,4 - 6,7,8: ( $p=0.01$ )

### Hymenoptera (malaise trap data)

Only flying Hymenoptera are assessed in this section. Although considerable numbers of Formicidae (ants) were sometimes captured in the malaise traps they are excluded from all further analysis. This is because ants appeared, understandably, very erratically in this kind of trap.

A total number of 13809 Hymenoptera (excluding Formicidae) was sorted to different taxonomic levels. The data cover week 2 to 8 of the sample series.

Both plots sprayed with fenitrothion show a clear reduction of total Hymenoptera catches immediately after spraying, apparently recovering in the second week, but subsequently decreasing again. Total Hymenoptera over the combined four postspray weeks are significantly lower than the three prespray weeks in both treatments, ca 30% on plot A and 50% on plot B (Fig. IX.5ab). Chlorpyrifos at 270 g ai/ha does not cause a significant reduction at any time. However, when sprayed at 390 g ai/ha the combined postspray catches are significantly reduced by ca 50% (Fig. IX.5cd). Plot F, diflubenzuron sprayed at 85 g ai/ha resulted in a significant increase compared to prespray levels, but it is difficult to see how this might have been caused by the application; an upward trend could already be seen before spraying. Diflubenzuron at 40 g ai/ha did not cause significant changes (Fig. IX.5ef).

### ICHNEUMONIDAE

The Ichneumonidae are wasps that parasitize larvae and pupae of holometabole insects (e.g. Lepidoptera) and some spiders. They are considered as an important group of beneficial insects. In general the Ichneumonidae prefer habitats with high humidity and in drier areas are limited to either a humid season or more humid microhabitats like those along streams (Britton et al. 1970). Several species of Ichneumonidae are mentioned as important parasites of coarse grain pests in the Sahel (see Table IX.2).

A total of 1034 Ichneumonidae were sorted out over the period of week 2 to 8. This comprised 7.5% of the total (flying) Hymenoptera catches. Eighty percent of the Ichneumonidae consisted of one genus, *Temelucha* sp. (subfam. Cremastinae). In the remaining 20% predominant taxa were *Pristomerus* sp. (subfam. Cremastinae), *Enicospilus* sp. (subfam. Ophioninae) and *Hyposoter*- or *Diadegma* sp. (subfam. Porizontinae) [identifications by R. Zwart, Wageningen Agricultural University].

Total Ichneumonid numbers show a 70% drop immediately after spraying in plot B, treated with 825 g ai/ha fenitrothion, and have disappeared completely by the second week after spraying. In plot A, fenitrothion at 485 g ai/ha, a similar trend is seen but with a delay of one week (Fig. IX.6ab). Because of the higher variation before spraying this is not significant. It should be noted that the ichneumonid population on the control plot steadily decreases during the sampling period. The population reduction in plot B is sharp enough and coincides well enough with the application to be considered caused by the pesticide. Both in plot D and E, the chlorpyrifos treatments, no acute effects of the chemical are observed in the week after treatment. The subsequent reduction in both plots could, in principle, have been caused by another unknown factor (Fig. IX.6cd). In both the diflubenzuron treated plots no immediate effect of the chemical was observed, as could be expected from a slow acting insect growth regulator. However, a sharp reduction of ca. 90% occurs in week 6 when compared to week 5 in both treatments. This reduction is contrary to the general upward trend before treatment,

and may well have been caused by the pesticide, possibly because of killing the lepidopteran hosts of the wasps. No recovery was observed anymore during the sampling period (Fig. IX.6ef).

#### *Temelucha spl.*

Although this taxon was coded "species 1", it is not clear if it was actually one species or a complex of closely related species. Considerable colour variation is known for other species in this genus. The majority of the species are believed to parasitize lepidopterous and coleopterous larvae, especially those that are found in stems and seed pods or live in leaf rolls. Species of *Temelucha* are frequently reared from economically important pests. Identification is often a problem since for many regions no keys are available (Gauld 1980, Mitchell et al. 1984, Kusigemati 1985). Of the genus *Temelucha* approximately 11 species are described for Africa south of the Sahara. In general they are species of relatively dry habitats. African hosts are known among Noctuidae and Pyralidae (:Lepidoptera) (R. Zwart, pers. communication). Although abundant in the area of our study, *Temelucha* species are not mentioned in the studies carried out by the CILSS integrated pest management project for West Africa. (Bhatnagar, 1987).

Catches of *Temelucha spl* follow a very similar pattern like the total Ichneumonid population, which was to be expected given it is the major proportion of the total Ichneumonidae captured. Chlorpyrifos does not decrease population levels; fenitrothion at 825 g ai/ha reduces them sharply. At 485 g ai/ha the reduction occurs with a delay of one week. However, both reductions are not significant. In both the diflubenzuron treated plots a sharp significant reduction is found from week 6 onwards (Fig. IX.7). Numbers in the control plot are low in the period after treatment.

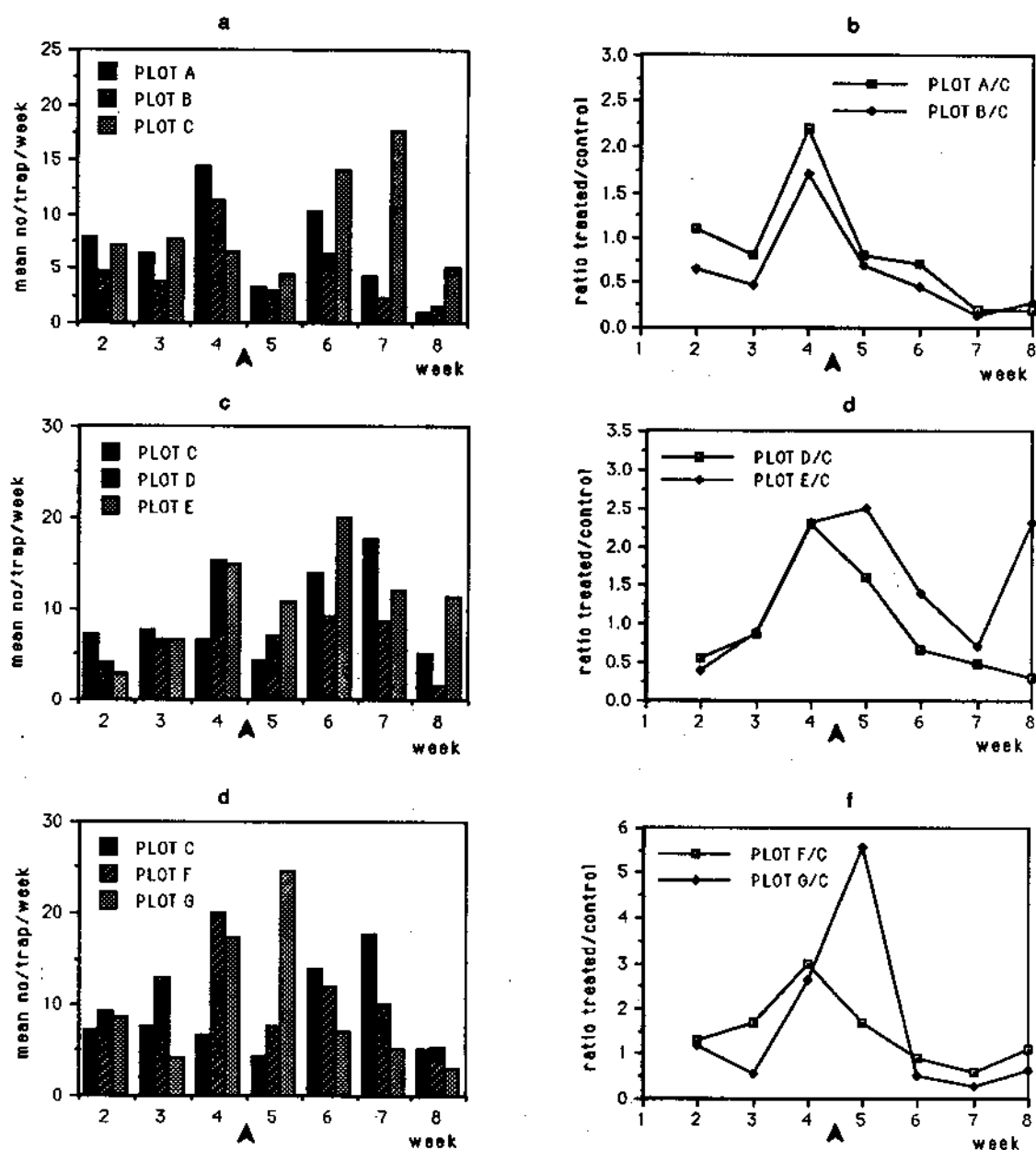
#### BRACONIDAE

Braconidae belong to the same superfamily of parasitic wasps as the Ichneumonidae. They parasitize a wide variety of hosts including Lepidoptera, Hymenoptera, Coleoptera, Homoptera and Diptera. Several are important parasitoids of coarse grain pests in the Sahel (Table IX.2), and some are used in biological control programmes in Africa. They tend to be found more often in drier habitats than the Ichneumonidae (Zwart, pers. comm.)

Braconidae made up approximately 10% of the total flying Hymenoptera catches. Over week 2 to 8, 1456 braconid parasitoids were captured and sorted out. The total number of different braconid species captured in the trial area was higher than that of the Ichneumonidae, although many species were encountered in low numbers. Sixty-eight percent of the total Braconidae catches consisted of three species. The most abundant was *Macrocentrus sulphureus* Szépligeti (subfam. Macrocentrinae)(37% of total Braconidae), followed by *Aleiodes spl* (dispar group)(subfam. Rogadinae)(17% of total Braconidae) and *Cardiochiles punctatus* Szépligeti (subfam. Cardiochilinae)(14% of total Braconidae) (identification by C. van Achterberg, Museum for Natural History, Leiden; see also van Achterberg 1976). Total Braconidae captured on the control plot remained fairly stable over the sampling period, increasing, however, over weeks 6 and 7. This increase seems to be caused partly by an increase in *Macrocentrus sulphureus*, the most important braconid, over the same period. In all treatment plots the braconid populations increased faster than in the control plot, before treatment.

Figure IX.8

**Braconidae**



mean number of total Braconidae per malaise trap per week (a,c,e) and the ratios of numbers in treated plots over control (b,d,f); arrow signifies treatment.

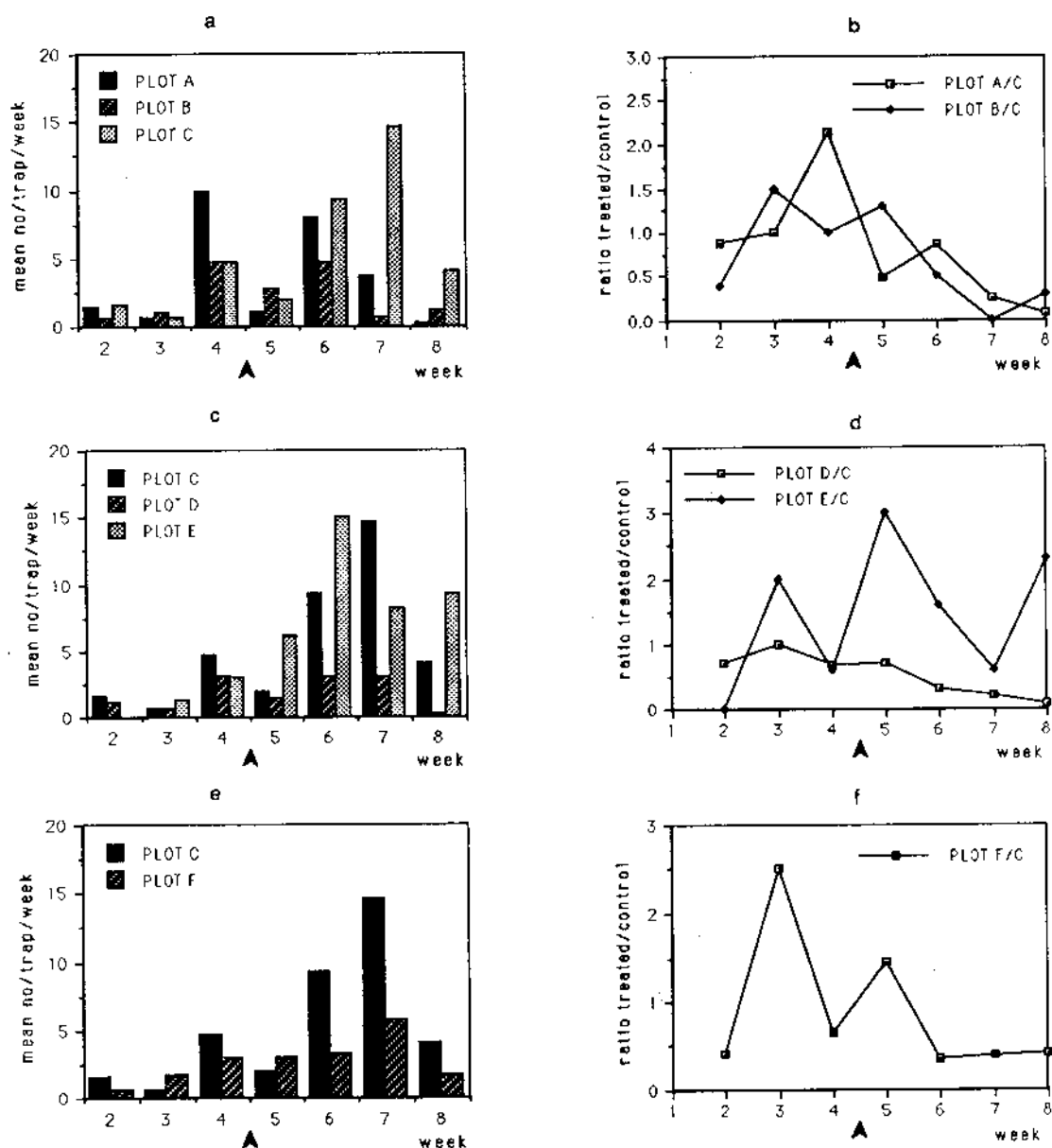
Dose rates for the different plots see fig 2.

**STATISTICS:**

Plot E,G: changes not significant.  
Plot A: week 2,3,4 - 5,6,7,8 ( $p=0.021$ )  
Plot B: week 2,3,4 - 5,6,7,8 ( $p=0.04$ )  
Plot D: week 2,3,4 - 6,7,8 ( $p=0.028$ )  
Plot F: week 2,3,4 - 5,6,7,8 ( $p=0.015$ )

Figure IX.9

**Macrocentrus sulphureus**



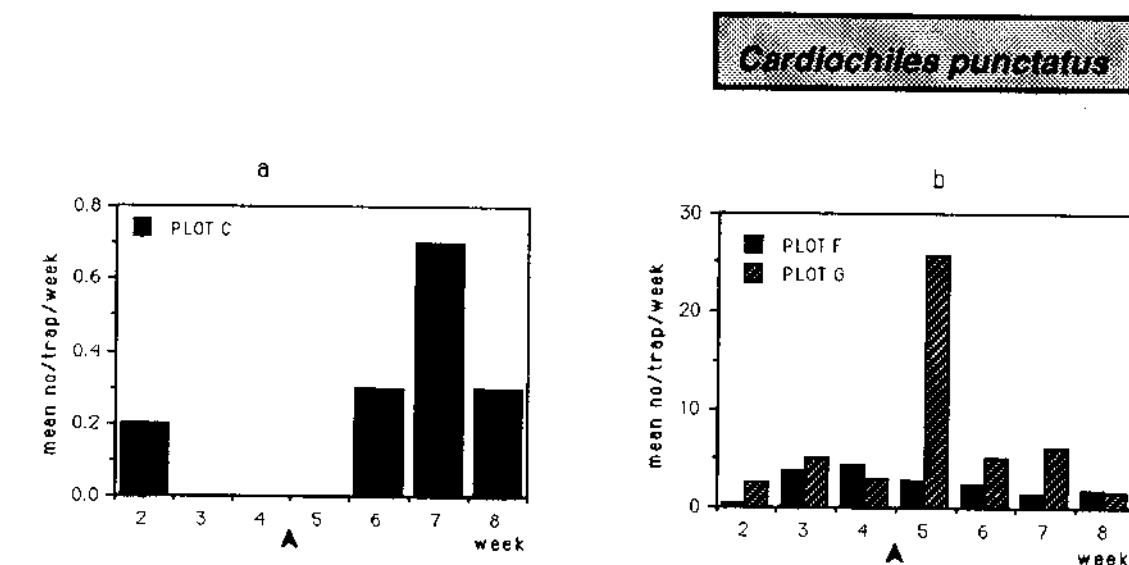
mean number of *Macrocentrus sulphureus* per malaise trap per week (a,c,e) and the ratios of numbers in treated plots over control (b,d,f); arrow signifies treatment.

Dose rates for the different plots see fig. 2.

**STATISTICS:**

Plot B, E: changes not significant  
 Plot A: week 2,3,4 - 5,6,7,8 ( $p=0.012$ )  
 Plot D: week 2,3,4 - 5,6,7,8 ( $p=0.023$ )  
 Plot F: week 2,3,4 - 6,7,8 ( $p=0.008$ )  
 Plot G not assessed due to low numbers.

Figure IX.10



mean number of *Cardiochiles punctatus* per malaise trap per week for the control plot (a) and the plots treated with diflubenzuron (b); arrow signifies treatment. Dose rates in fig. .2.

In both the fenitrothion plots A and B catches decrease about 60% the week after application when compared with one week before. They continue to decline afterwards and no recovery can be observed during the four week post spray period (reduction significant over whole period)(Fig. IX.8ab). No large initial reduction is seen after the chlorpyrifos treatments. However, weeks 6,7 and 8 combined are, and remain significantly reduced compared to the mean pre-spray level on plot D (reduction ca. 60%). No post-spray captures on plot E are significantly lower than the pre-spray levels (Fig. IX.8cd). This is remarkable since chlorpyrifos was applied at a higher dose-rate on this plot. A slight reduction in Braconidae is seen on plot F after spraying diflubenzuron at 85 g ai/ha. The mean post spray population is significantly reduced compared with the mean level before treatment (ca. 50%). In plot G, diflubenzuron at 40 g ai/ha., the mean abundance of weeks 6,7 and 8 is significantly lower (ca. 70%) than the mean pre-spray abundance (Fig. IX.8ef).

#### *Macrocentrus sulphureus*

This was the most common braconid species encountered in the malaise traps in the study area. It was captured consistently on all plots except plot G. No obvious explanation for its virtual absence on this plot could be found. The plot had slightly denser vegetation, however, than the other ones. Most Macrocentrinae parasitize Lepidoptera (Britton et al. 1970). In the past, several species of *Macrocentrus* have been introduced in biological control programmes; e.g. *Macrocentrus ancylivorus* (Rohwer) on Oriental Fruit Moth (*Grapholita molesta* Busck) in Canada (Pree 1979), and *Macrocentrus grandii* (Goidanich) on European Corn Borer (*Ostrinia nubilalis* Hubner) in the United States (Winnie and Chiang, 1982). No mention of *M. sulphureus*, or any other species in the genus was made by Bhatnagar (1987), however, when referring to parasitoids of major pests in Senegal. A taxonomical key for the species of the subfamily Macrocentrinae is in preparation (van Achterberg, pers. comm.).

Captures of *M. sulphureus* steadily increased on the control plot until week 7, after which the catches dropped sharply. On both fenitrothion plots there was a net decrease of the species following treatment. Mean reduction of post- compared to pre-spray periods were 70% for plot A (significant) and 50% for plot B (not significant) (Fig. IX.9ab). Single dose chlorpyrifos (270 g ai/ha) shows a steady decline after treatment but the higher dose (390 g ai/ha) fluctuations do not seem to be treatment related (Fig. IX.9cd). In plot F, treated with diflubenzuron at 85 g ai/ha, catches are significantly reduced (70%) from week 6 onwards. Given the high fluctuations found before treatment, this may not be conclusively attributed to the chemical (Fig. IX.9ef). Numbers of *M. sulphureus* in plot G were too low for analysis.

#### *Cardiochiles punctatus*

The genus *Cardiochiles* is widespread in all zoogeographical regions. Twelve species have been described for the Sahel and a recent key is available (Huddleston and Walker 1988). As far as known at present all species of *Cardiochiles* parasitize larvae of Lepidoptera, mainly Pyralidae and Noctuidae. Two species in the Sahel are thought to be important natural enemies of major crop pests: *Cardiochiles sahelensis* on *Heliocheilus albipunctella* (Millet Spike Worm) and *Cardiochiles variegatus* on *Helicoverpa armigera* (American Bollworm) (Table IX.2). The biology of the African species is not well known.

During the present study the above two species were not captured. The most commonly found species from this genus, however, was *Cardiochiles punctatus* Szépligeti [identification C. van Achterberg, Museum for Natural History, Leiden]. No host is known for this species, although it has been captured very regularly in both millet and maize fields in West Africa (Huddleston and Walker 1988). Numbers of *C. punctatus* were too low for analysis in all plots but F and G. This may be related to the slightly denser vegetation in the latter two plots compared to the rest. The build of the species indeed suggests it to be active in more vegetated areas rather than open savanna (van Achterberg, pers. comm.). There does not seem to be a dramatic effect in the species abundance in either of the plots treated with diflubenzuron (Fig. IX.10). However, results are not conclusive since numbers in the control were very low.

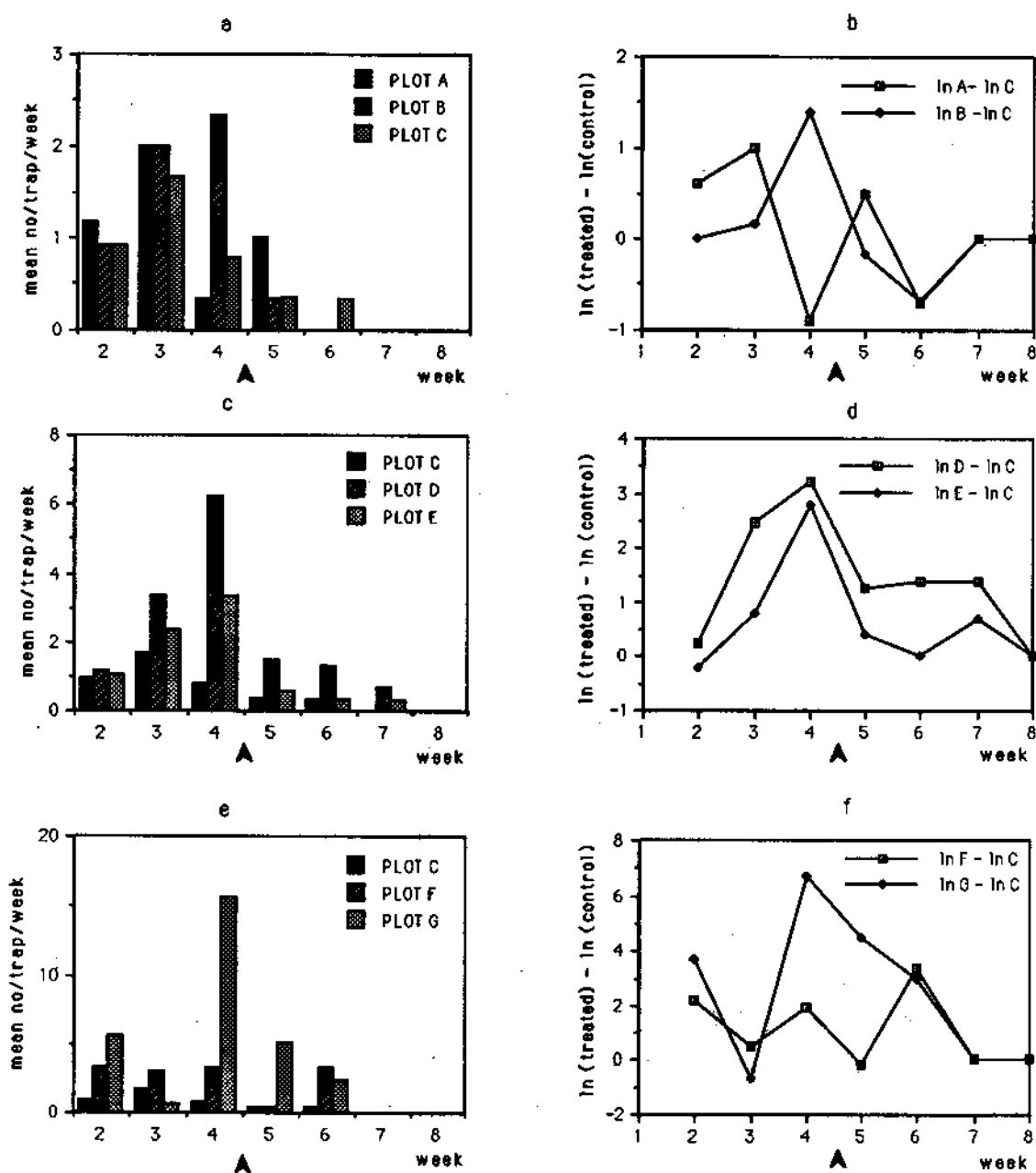
#### *Aleiodes spl*

The genus *Aleiodes* (formerly *Heterogamus*) belongs to the subfamily Rogadinae, endoparasitoids of Lepidoptera larvae. A species of *Aleiodes* or *Rogas* was mentioned by Bhatnagar (1987) to be reared out of *Helicoverpa armigera* in Senegal.

The species (or species complex) *Aleiodes spl* was captured regularly in all traps except on plots A and B where numbers were low. On all plots, including the control, it had completely disappeared by week 7. In both the chlorpyrifos plots catches were reduced by 50-70% immediately after spraying when compared to the week just before. However, numbers over the whole post spray period were not significantly reduced compared to pre-spray levels. No treatment related effect was observed in both diflubenzuron plots (Fig. IX.11).

Figure IX.11

*Aleiodes sp1*

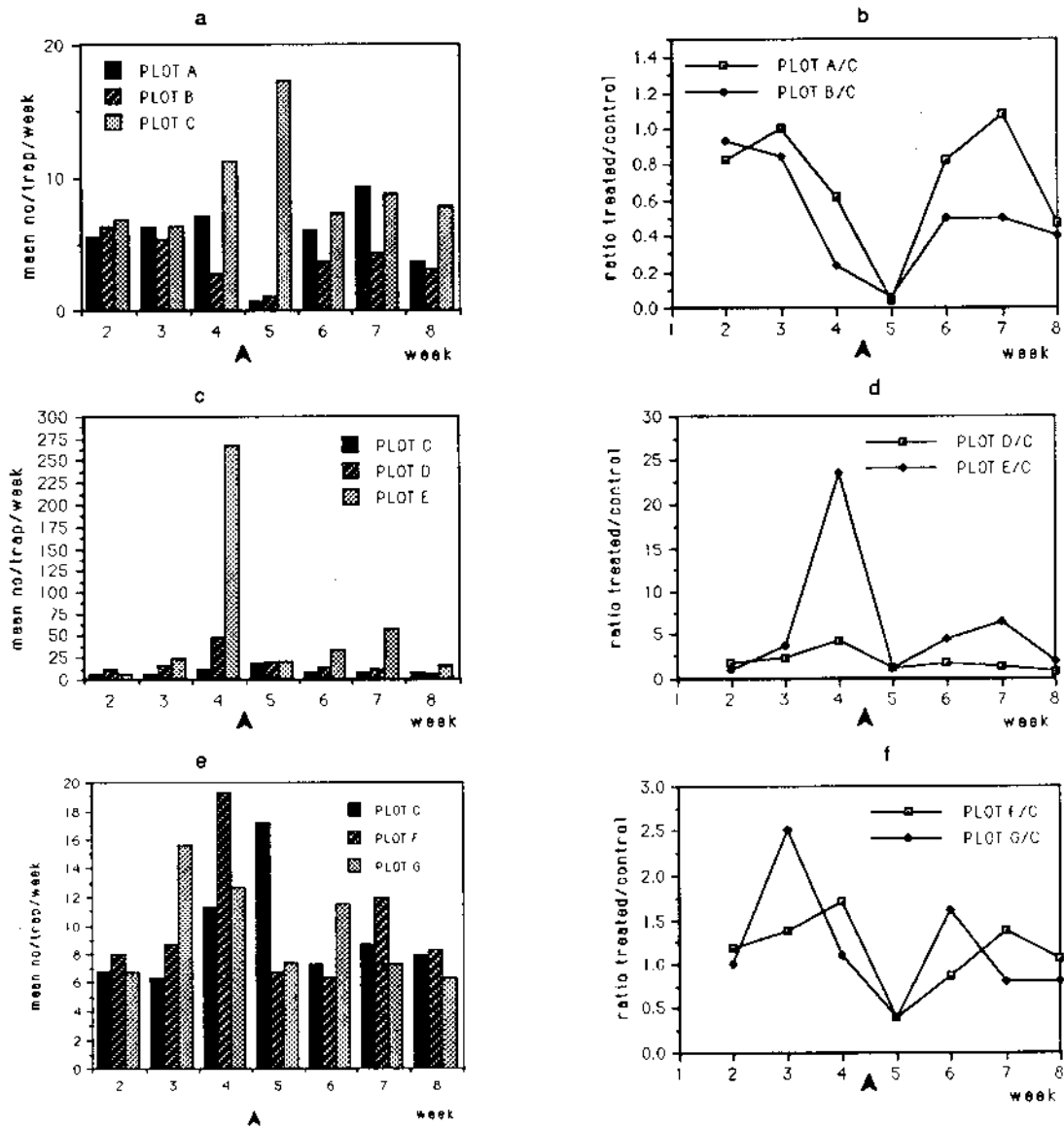


mean number of *Aleiodes sp1* per malaise trap per week (a,c,e) and the differences between log transformed treated and control plot numbers (rather than ratios of untransformed numbers because of zero's in control!); arrow signifies treatment

Dose rates for the different plots see fig. 2.

Figure IX.12

*Sphecidae: larrinae*



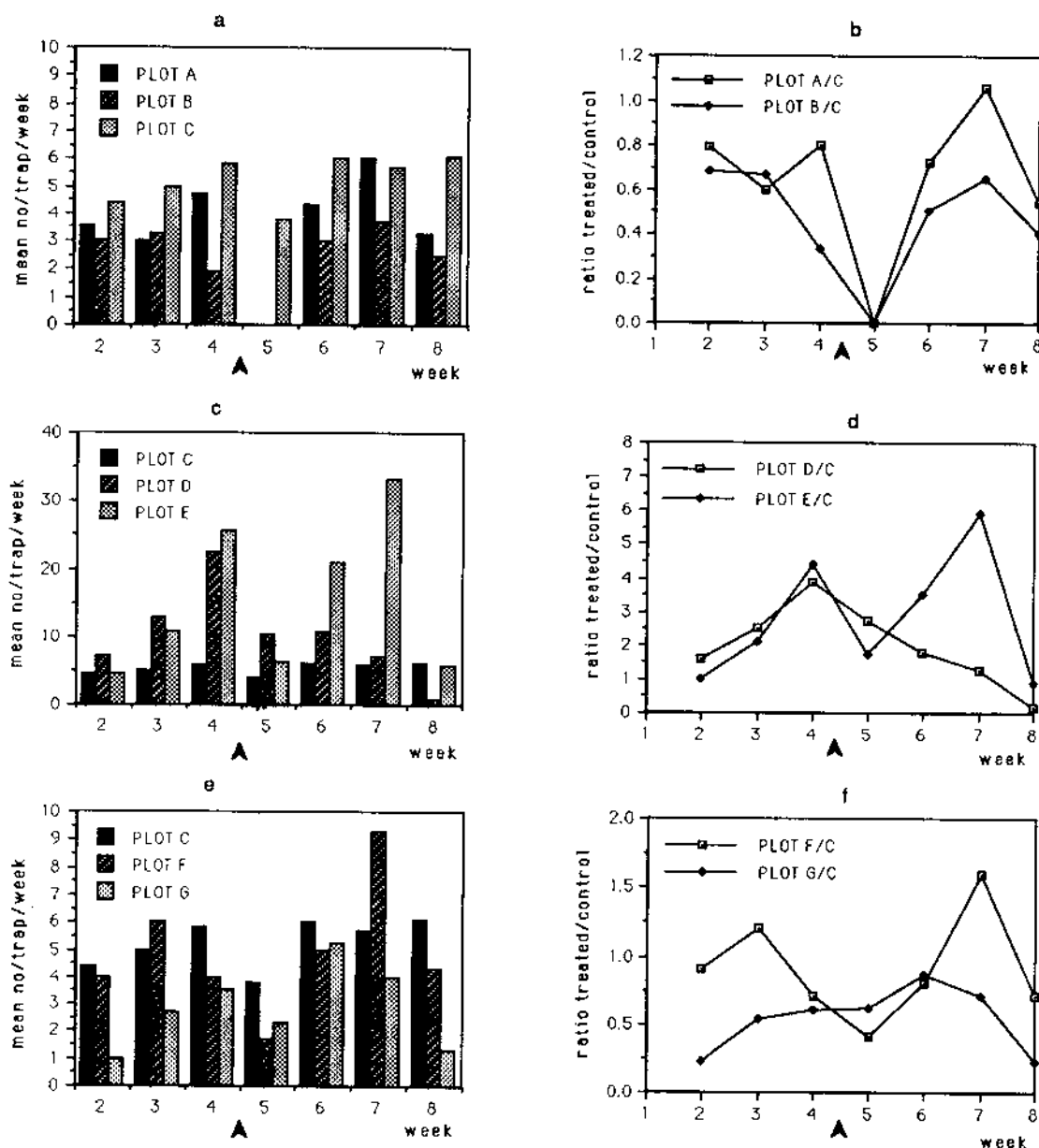
mean number of Larrinae per malaise trap per week (a,c,e) and the ratios of numbers in treated plots over control (b,d,f), arrow signifies treatment.

Dose rates for the different plots see fig. 2.

STATISTICS:  
Plot G: changes not significant.  
Plot A: week 2,3,4 - 5 ( $p=0.005$ )  
Plot B: week 2,3,4 - 5 ( $p=0.07$ )  
Plot D: week 2,3,4 - 5,6,7,8 ( $p=0.06$ )  
Plot E: week 4 - 5,6,7,8 ( $p=0.05$ )  
Plot F: week 2,3,4 - 5,6 ( $p=0.015$ )

Figure IX.13

*Tachytes* spp.



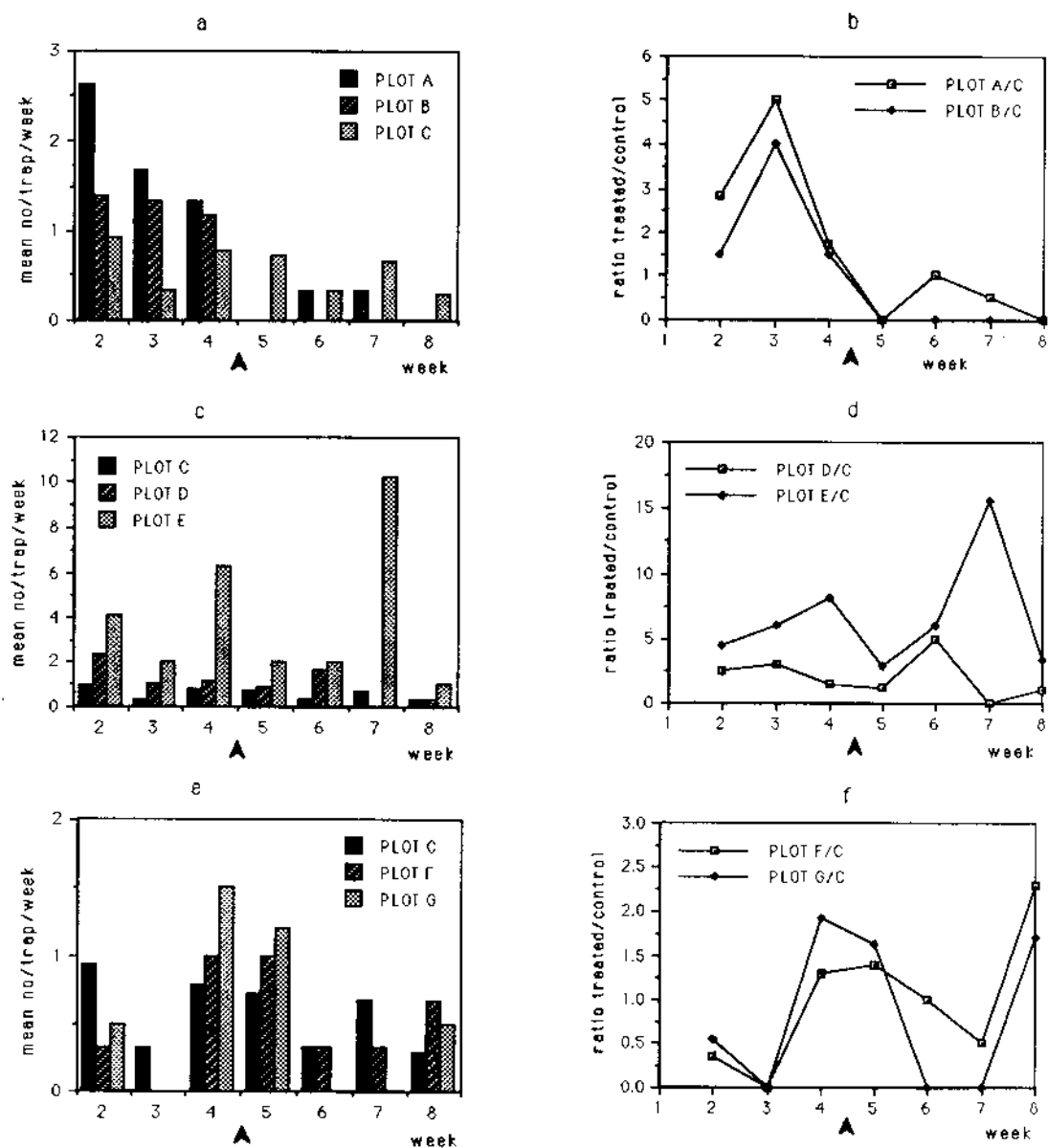
mean number of *Tachytes* spp. per malaise trap per week (a,c,e) and the ratios of numbers in treated plots over the control (b,d,f); arrow signifies treatment.

Dose rates for the different plots see fig. 2.

STATISTICS:  
Plot A,B,E,F,G: changes not significant.  
Plot D: week 2,3,4 - 7,8 ( $p=0.04$ )

Figure IX.14

*Tiphia sp.*

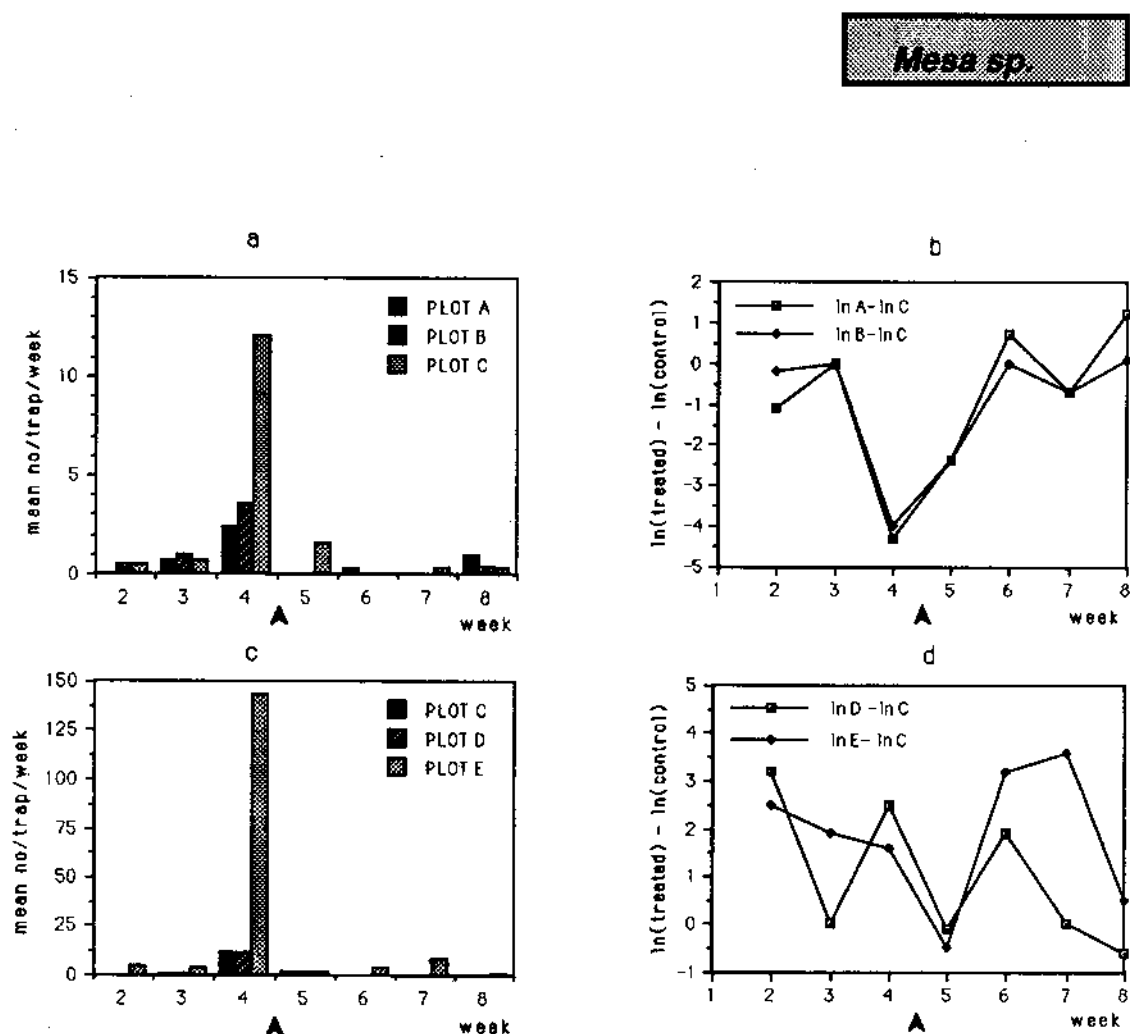


mean number of *Tiphia sp.* per malaise trap per week (a,c,e) and the ratios of numbers in treated plots over the control (b,d,f); arrow signifies treatment.

Dose rates for the different plots see fig. 2.

STATISTICS:  
Plot D,E,F,G: changes not significant  
Plot A: week 2,3,4 - 5,6,7,8 ( $p=0.022$ )  
Plot B: week 2,3,4 - 5,6,7,8 ( $p=0.0003$ )

Figure IX.15



mean number of Mesa sp. per malaise trap per week (a,c) and the differences between log transformed treated and control plot catches (b,d), arrow signifies treatment.

Dose rates for the different plots see fig. 2.

STATISTICS:  
Plot A,B,D,F,G: differences not significant  
Plot E: week 2,3,4 - 5 ( $p=0.02$ )

#### SPHECIDAE: LARRINAE

Several groups of Sphecidae are predators of Orthoptera. Several tribes in the subfamily Larrinae specialize to a large extent on the above prey. Wasps from this subfamily were readily caught in the malaise traps and made up approximately 20% of the total Hymenoptera catches.

Total Larrinae were significantly reduced by 95% on plot A (fenitrothion 485 g ai/ha) in the week following treatment. However, catches were back to pre-spray levels two weeks after spraying. Plot B, fenitrothion at 825 g ai/ha shows a fairly similar decline immediately after treatment, but this is just not significant ( $p=0.07$ ) because the catches had declined already largely in the week before treatment (Fig. IX.12ab). Larrinae declined about 50% in the plot treated with chlorpyrifos at 270 g ai/ha. Post-spray catches were significantly reduced when compared to the week before treatment, but not when compared with the total prespray period ( $p=0.06$ ). At 390 g ai/ha catches of this group were reduced significantly when compared with the one week before spraying but not with the whole pre-spray period. This is caused by the sharp increase in catches in week 4, which was mostly due to one specific species suddenly appearing (Fig. IX.12cd). Diflubenzuron sprayed at 40 g ai/ha did not induce significant changes. However, at 85 g ai/ha Larrinae were reduced by 55% for two weeks, after which catches were back to pre-spray levels (Fig. IX.12ef).

#### *Tachytes* spp.

Approximately 40% of the Larrinae captured belong to the genus *Tachytes*. Wasps from this genus prey specifically upon grasshoppers (Bohart and Mencke, 1976). They are generally fairly stoutbodied and can be distinguished as genus relatively easy. However, identification species level poses difficulties since no keys for Africa exist.

In both fenitrothion plots no *Tachytes* species were captured the week after spraying, however, this reduction was not significant when compared with pre-spray levels. No significant reductions were found in any of the other plots immediately after spraying. Only in plot D, chlorpyrifos at 270 g ai/ha, weeks 7 and 8 were significantly lower than pre-spray levels. It is not certain this was caused by the pesticide (Fig. IX.13).

#### TIPHIIDAE

Tiphiidae are wasps parasitizing larvae of Scarabaeidae (scarab beetles) in the soil. Some of them have been used in biological control programmes of scarab pests in North America (Borror *et al.* 1980). It is not known to what extent these wasps may regulate Sahelian pests such as *Rhyniptia* sp. on millet. Although *Rhyniptia* is generally considered a local pest of relatively little importance, increased pesticide use for grasshopper control could affect the natural regulation of the species, thus allowing it to build up higher infestation levels.

Two groups of Tiphiid wasps were caught regularly in the study area. One was named as *Tiphia* sp. (HYM023/TIP1) and the other as *Mesa* sp. (HYM044/TIP2). [identification by comparison to reference collections of the Taxonomical Institute of the University of Amsterdam and the DPV Nioro du Rip/CILLS Lutte Intégrée collection by author; needs confirmation]

### *Tiphia sp.*

Populations of *Tiphia sp.* remained fairly stable during the whole study period in the control plot. In both the fenitrothion plots *Tiphia sp.* was significantly reduced immediately after spraying; at 485 g ai/ha on average by 90% and at 825 g ai/ha the taxon completely disappeared without recovering during the post-spray period (Fig. IX.14ab). Chlorpyrifos did not cause a significant reduction. In both diflubenzuron plots fluctuations before treatment obscured any treatment effect (Fig. IX.14ef). In all plots but plot E numbers were low.

### *Mesa sp.*

Populations of *Mesa sp.* fluctuated substantially during the study period, clearly peaking in the week before treatment in all plots except the diflubenzuron ones where numbers were much lower. The fluctuations obscured treatment effects in plots A, B and D. At 390 g ai/ha of chlorpyrifos the reduction was 90% with recovery in the second week after spraying (Fig. IX.15); differences of log transformed data are shown in the figures rather than ratios because of the zero's in the control plot.

### FORMICIDAE (TRANSECT DATA)

Most of the ant colonies assessed for this study belonged to the same genus (coded FOR1; not yet identified). The entrances and surrounding "hills" normally covered an area of 10-40 cm in diameter (most of them at the lower side of the spectrum). Figure IX.16 shows the difference in active ant colonies as observed after the application of fenitrothion at 825 g ai/ha. Assessments were only carried out on this treated plot. Before spraying both treatment and control plots show similar numbers of active hills. After treatment, the number of active colonies drops 80%, when corrected for the changes in the control plot. Dead ants were observed around many hills. Ten days after spraying no recovery in ant activity was observed in the treated plot. The results of Gueye and Everts (Chapter XI) demonstrate that towards the end of this study this group had a tendency to recover.

Figure IX.16

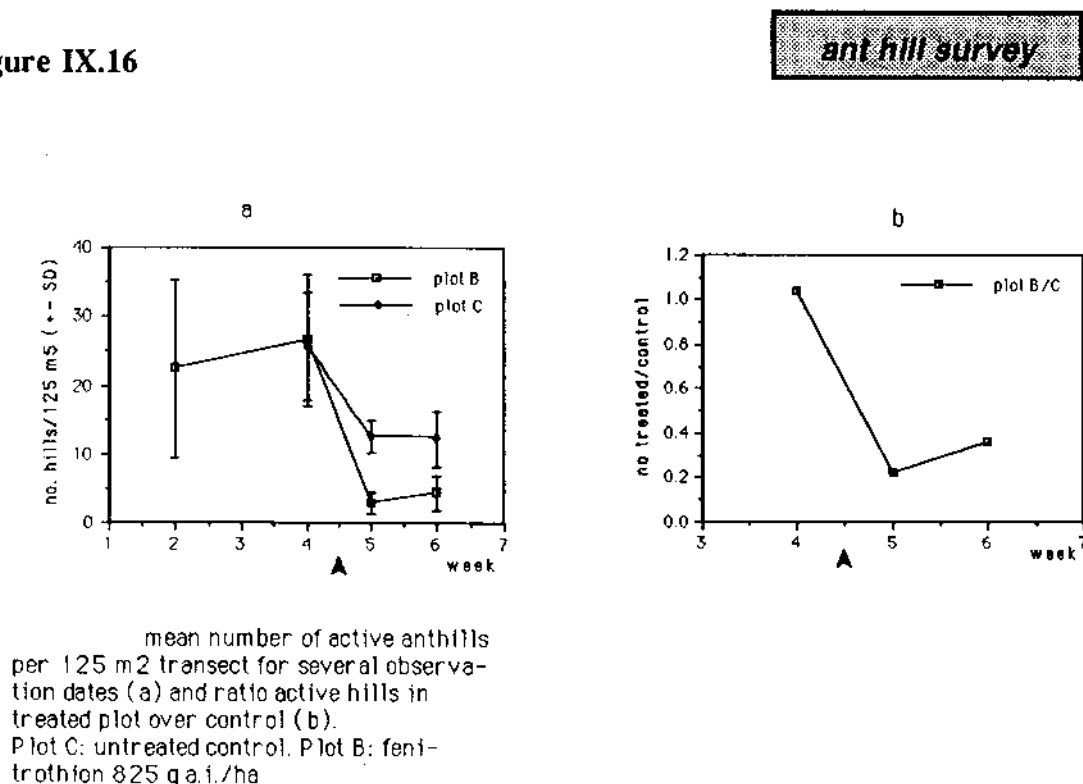


Figure IX.17

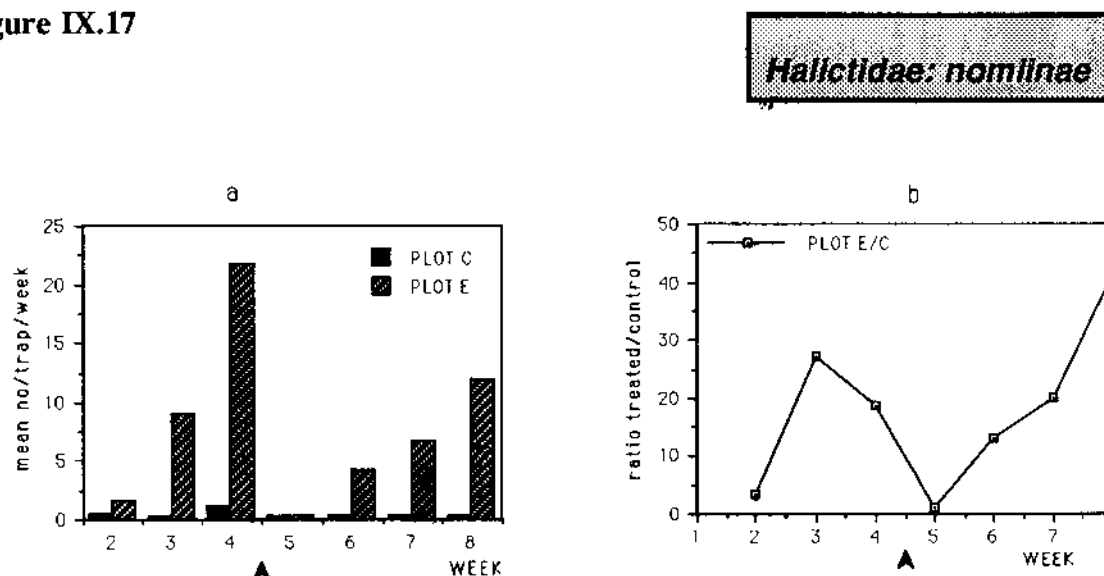


fig. 4.17 mean number of Halictidae: Nomiinae per trap per week (a) and ratio of treated plot over control (b); arrow signifies treatment. Plot C: untreated control, Plot E: chlorpyrifos 390 g a.i./ha

#### HALICTIDAE

They only bees which were regularly found in the traps were those belonging to the family Halictidae. Over 90% of these belonged to the subfamily Nomiinae, potentially important pollinators (Borror *et al.* 1980). Only in plot E, chlorpyrifos at 390 g ai/ha, were numbers high enough for any proper assessment. In this plot the week after spraying Nomiinae populations were reduced by 95%, but recovery had almost completed by week 6, the second week after treatment (Fig. IX.17).

#### OTHER HYMENOPTERA

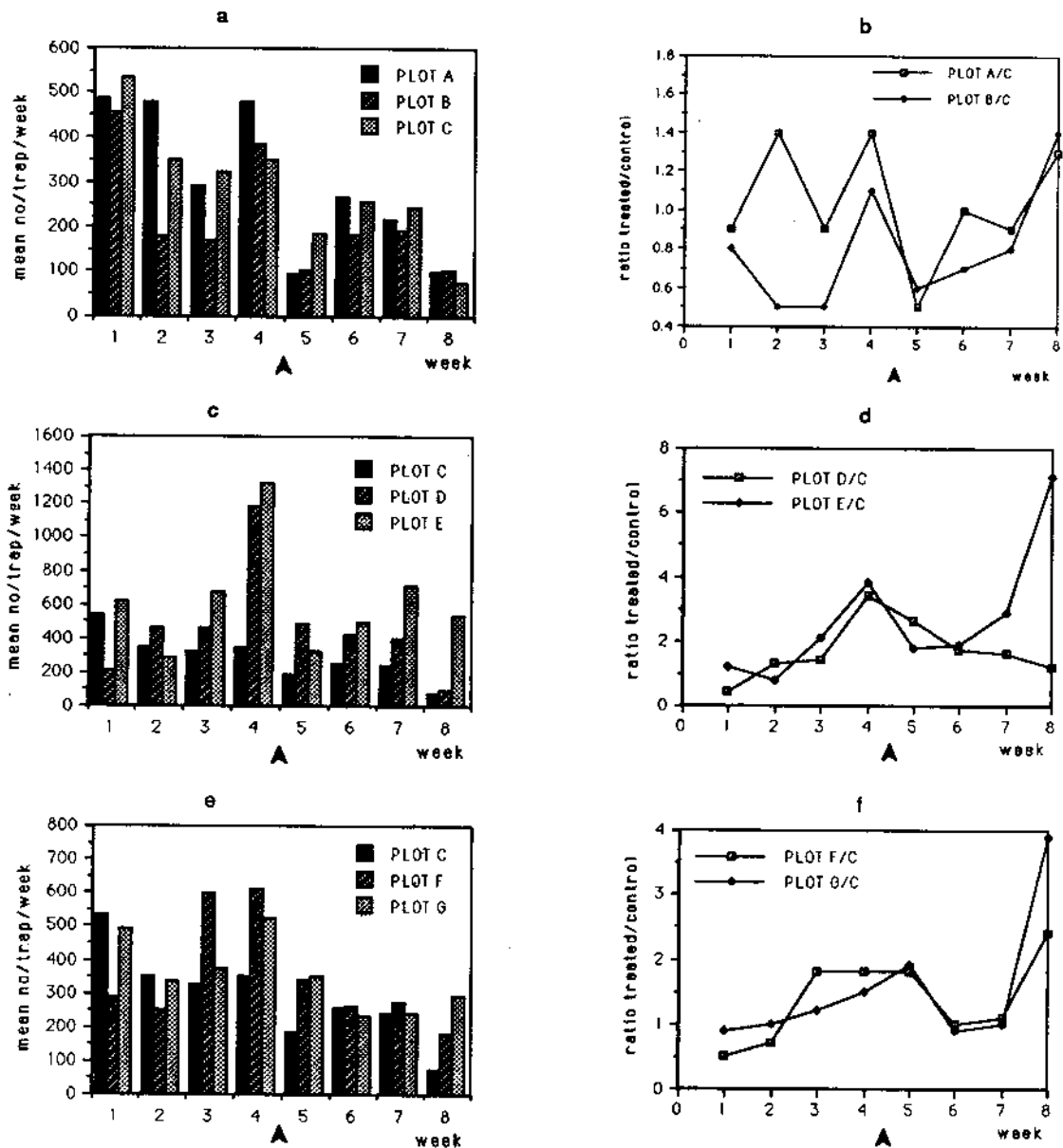
Potentially important groups of Hymenoptera such as parasitic wasps belonging to the superfamilies of Calcidoidea and Proctotrupeoidea were caught in the malaise traps. They were not further sorted because of lack of time and expertise. This does not mean that they should be ignored in future exercises. However, wasps from these superfamilies appeared only relatively late in the season in the traps, mostly after the treatments had taken place.

Aphid wasps (Sphecidae: Pemphridoninae: Psenini) were caught in considerable numbers in plots D and E and seemed to be heavily affected by the treatment (95% reduction in the week after treatment compared to the one before). However, since the taxon was virtually absent in the control plot, no further analysis was carried out.

Sphecid wasps from what was thought to be the genus *Oxybelus* sp. (H027/SPH12) (Crabroninae: Oxybelini), predators of flies including *Simulium* sp. (blackfly; vector of riverblindness), were abundant in the first few weeks of the study period. However, populations had almost disappeared by the time of spraying and no assessment of pesticide impact on this group could be made.

Figure IX.18

**Diptera**



mean number of total Diptera per malaise trap per week (a,c,e) and the ratios of treated plots over control (b,d,f); arrow signifies treatment.

Dose rates for the different plots see fig. 2.

**STATISTICS:**  
 Plot B,D,E,G: changes not significant  
 Plot A: week 1,2,3,4 - 5,6,7,8 ( $p=0.04$ )  
 Plot F: week 3,4,5 - 6,7 ( $p=0.002$ )  
 week 1,2,3,4 - 5,6,7,8: NS

Pompilidae, a wasp family parasitizing specifically spiders, were abundant in the malaise traps. Since they do not attack a crop pest, this group was not analysed. However, given the fact that Pompilidae were abundant during the whole study period it may be worth looking into their possible use as indicator organism in future studies.

Scoliidae of the subfamily Scoliinae, mostly belonging to an unidentified genus/species (HYM 012/SCO1), were abundant in most plots but catches fluctuated largely. No significant changes could be found in this family of parasitoids of clavicorne Coleoptera after any of the treatments.

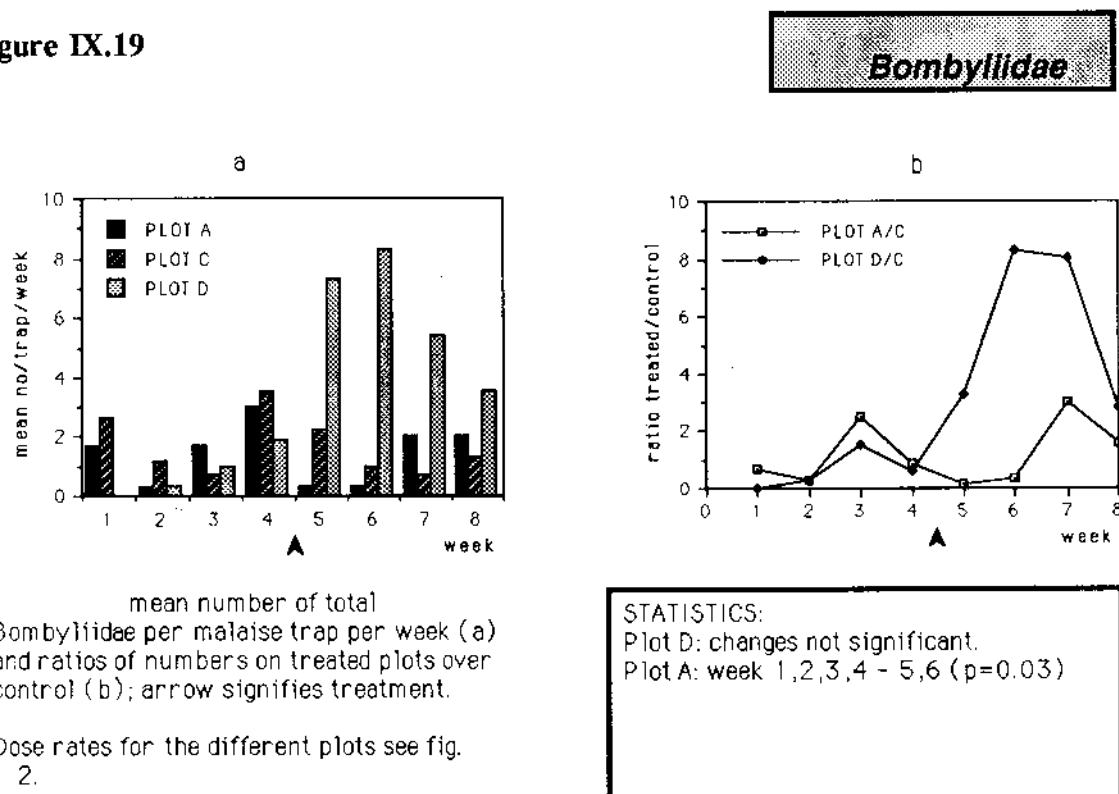
#### Diptera (malaise trap data)

Within the order of Diptera, several taxa of principally beneficial flies occur, e.g. the predatory Asilidae, and parasitic Tachinidae, Bombyliidae and some Sarcophagidae. In the pilot study only Asilidae and Bombyliidae were looked at on family level for the single dose organophosphate plots.

A total of approximately 83000 Diptera were caught in the malaise traps over the study period. The control plot showed a slow but steady decrease in total Diptera numbers during this period.

Only on plot A, fenitrothion applied at 485 g ai/ha, are total Diptera numbers significantly reduced after spraying. The initial reduction is by 55%; by week 6, numbers are not significantly different from the mean pre-spray levels. The mean post-spray catches over this whole period are significantly reduced, however, by 20% (Fig. IX.18).

Figure IX.19



## BOMBYLIIDAE

Bombyliidae made up 0.6% of the total Diptera for the analysed plots (A,C,D). Numbers captured were low during the whole study period and remained fairly stable in the control plot. Fenitrothion sprayed at 485 g ai/ha caused a significant reduction in total Bombyliidae for two weeks after spraying, after which numbers returned to normal. The mean reduction during these two weeks was 80%. Bombyliidae catches on plot D, sprayed with chlorpyrifos, increased significantly after treatment (Fig. IX.19)

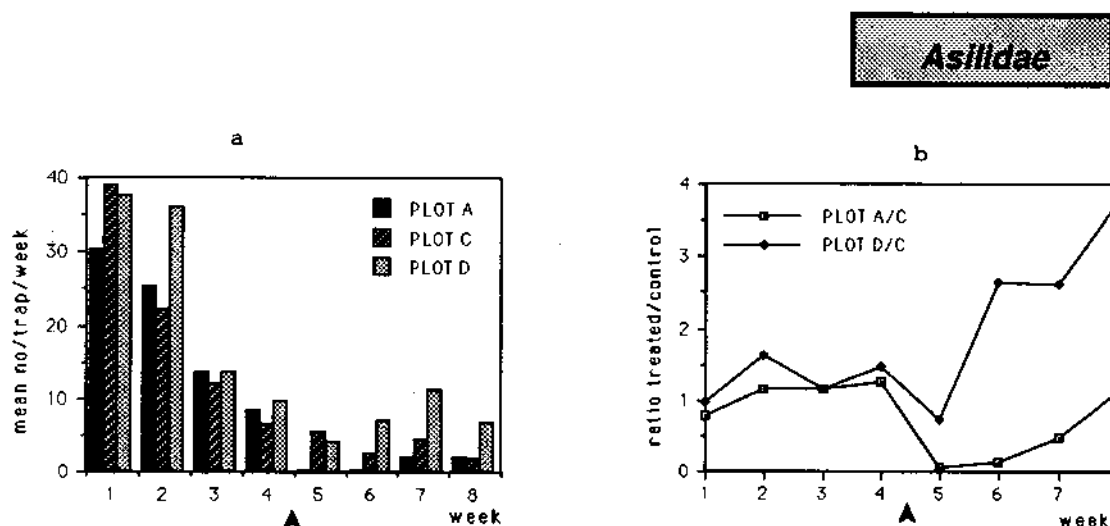
## ASILIDAE

Asilidae accounted for 4% of the total Diptera catches on the plots which were analysed. The control population decreased from 40 flies per trap per week to 2 per trap per week during the study period.

No negative impact of chlorpyrifos at 270 g ai/ha was observed. Fenitrothion applied at 485 g ai/ha, however, resulted in a significant reduction in Asilidae trapped in the malaise traps for three weeks after spraying. The mean reduction over these three weeks compared to the pre-spray period was 80%. By week 8, the fourth week after spraying, catches were back to "normal". However, this may not be a real recovery since the control plot contains very low numbers as well at that time of the season (Fig. IX.20).

Figures IX.21a-c summarize the impact of the tested pesticides on all taxa discussed in this chapter.

Figure IX.20

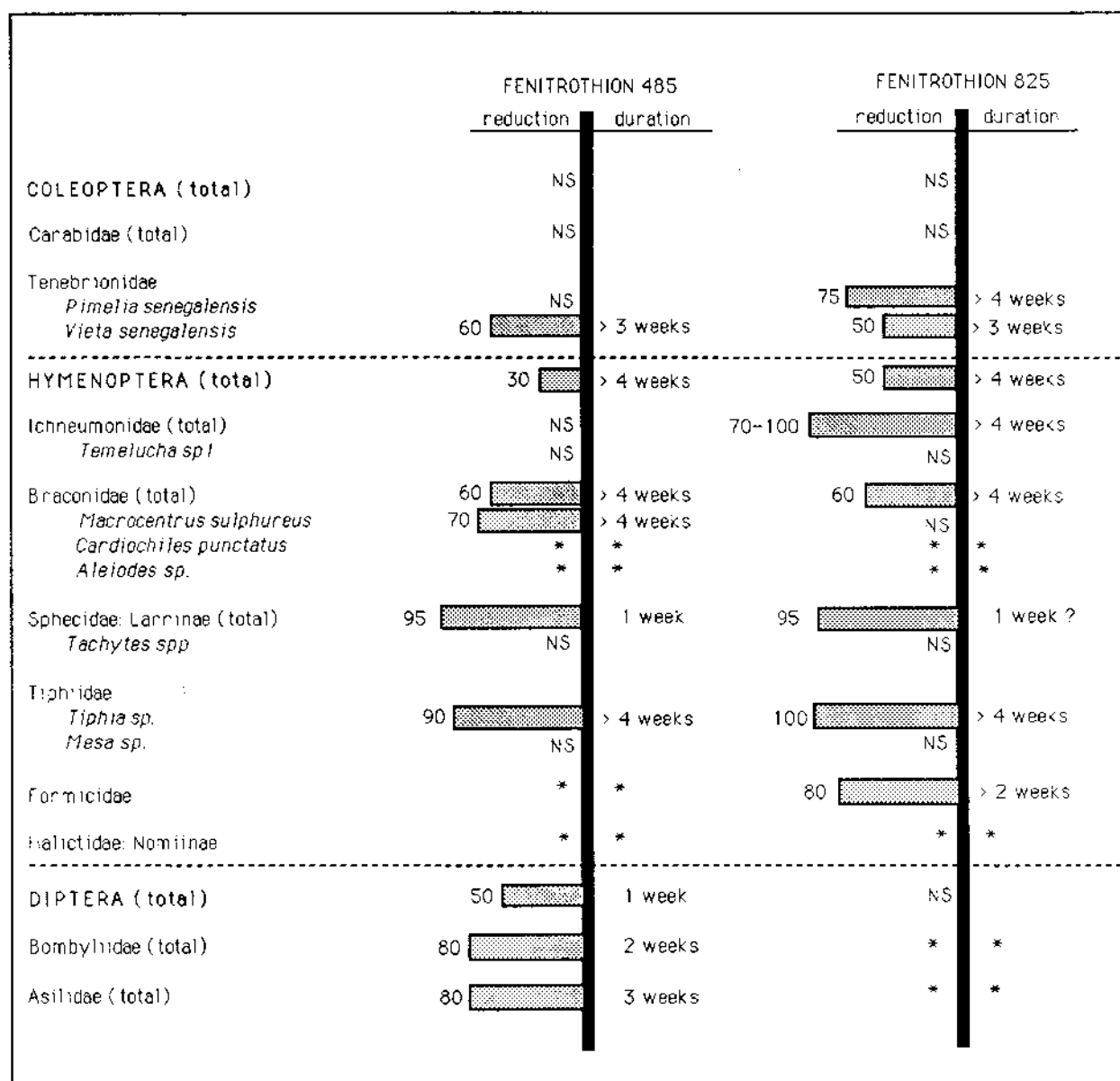


mean number of total Asilidae per malaise trap per week (a) and ratios of numbers on treated plots over the control (b); arrow signifies treatment.

Dose rates on different plots see fig.

STATISTICS:  
Plot D: changes not significant.  
Plot A: week 1,2,3,4 - 5,6,7 ( $p=0.018$ )

**Figure IX.21a**



#### fenitrothion

Summary of observed impact of fenitrothion, chlorpyrifos and diflubenzuron on selected terrestrial arthropods. Number behind the pesticide name refers to applied dose in gram active ingredient per hectare; "reduction" is the mean (significant) reduction (%) in catches after treatment compared to the mean before treatment; "duration" is the duration of this effect. If duration of effect is greater than a given number of weeks it surpassed the sampling period and the end of the rainy season; asterisk (\*) means that no assessment was/ could be made.

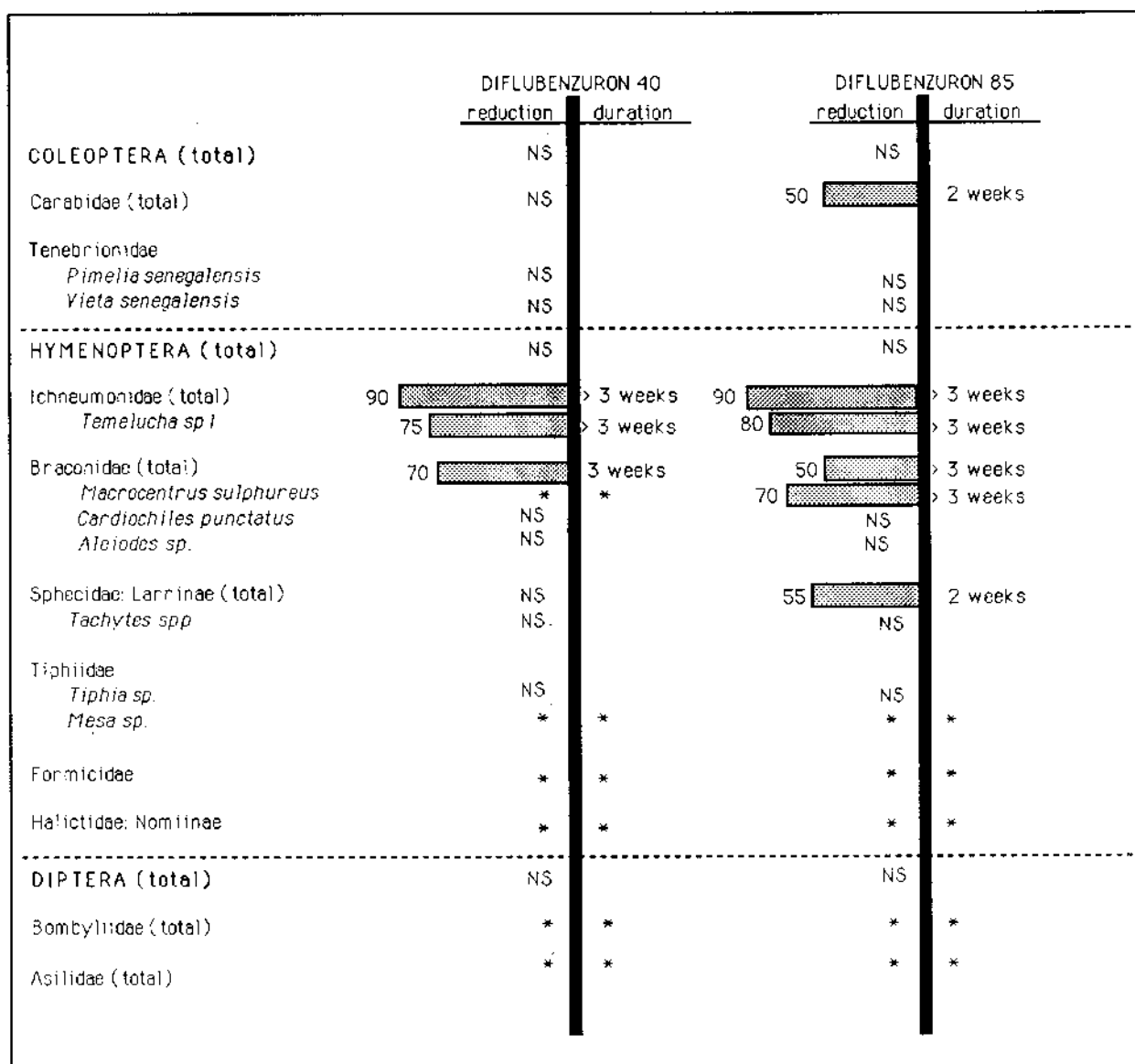
**Figure IX.21b**

	CHLORPYRIFOS 270		CHLORPYRIFOS 390	
	reduction	duration	reduction	duration
COLEOPTERA (total)	NS		NS	
Carabidae (total)	NS		70	3 weeks
Tenebrionidae				
<i>Pimelia senegalensis</i>	NS		NS	
<i>Vieta senegalensis</i>	NS		60	2 weeks
HYMENOPTERA (total)	NS		50	4 weeks
Ichneumonidae (total)	NS		NS	
<i>Temelucha sp1</i>	NS		NS	
Braconidae (total)	NS		NS	
<i>Macrocentrus sulphureus</i>	60	3 weeks	NS	
<i>Cardiochiles punctatus</i>	*	*	*	*
<i>Aleiodes sp.</i>	50	> 2 weeks ?	70	> 2 weeks ?
Sphecidae: Larrinae (total)	NS		NS	
<i>Tachytes spp</i>	NS		NS	
Tiphidae				
<i>Tiphia sp.</i>	NS		NS	
<i>Mesa sp.</i>	NS		90	1 week
Formicidae	*	*	*	*
Halictidae: Nominae	*	*	95	1 week
DIPTERA (total)	NS		NS	
Bombyliidae (total)	NS		*	*
Asilidae (total)	NS		*	*

### chlorpyrifos

Summary of observed impact of fenitrothion, chlorpyrifos and diflubenzuron on selected terrestrial arthropods. Number behind the pesticide name refers to applied dose in gram active ingredient per hectare; "reduction" is the mean (significant) reduction (%) in catches after treatment compared to the mean before treatment; "duration" is the duration of this effect. If duration of effect is greater than a given number of weeks it surpassed the sampling period and the end of the rainy season; asterisk (\*) means that no assessment was/ could be made.

**Figure IX.21c**



diflubenzuron

Summary of observed impact of fenitrothion, chlorpyrifos and diflubenzuron on selected terrestrial arthropods. Number behind the pesticide name refers to applied dose in gram active ingredient per hectare; "reduction" is the mean (significant) reduction (%) in catches after treatment compared to the mean before treatment; "duration" is the duration of this effect. If duration of effect is greater than a given number of weeks it surpassed the sampling period and the end of the rainy season; asterisk (\*) means that no assessment was/ could be made.

Table IX.5 (The rating strictly holds for the specific field situation of this study)

pesticide	FENITROTHION				CHLORPYRIFOS				DIFLUBENZURON								
	dose rate		485 g a.i./ha		825 g a.i./ha		270 g a.i./ha		390 g a.i./ha		40 g a.i./ha		85 g a.i./ha				
	impact	I	P	I	P	I	P	I	P	I	P	I	P				
TAXON																	
COLEOPTERA (total)	*	#		*	#		*	#		*	#		*	#			
Carabidae (total)	*	#		*	#		*	#	***	###		*	#	**	##		
(Tenebrionidae)																	
Pimelia senegalensis	*	#		***	###		*	#		*	#		*	#			
Viola senegalensis	***	###		**	##		*	#		***	###		*	#			
HYMENOPTERA (total)	**	##		**	##		*	#		**	##		*	#			
Ichneumonidae (total)	*	#		****	###		*	#		*	#		****	###	****	###	
Tamela sp1	*	#		*	#		*	#		*	#		***	###	****	###	
Braconidae (total)	***	###		***	###		*	#		*	#		***	###	**	##	
Macrocentrus sulphureus	[***	###]		[*	#]		[***	###]		[*	#]				***	###	
Cardiochiles punctatus													[*	#]	[*	#]	
Aleiodes sp1							**	##		***	###		*	#		*	#
Sphecidae: Larrinae (total)	****	#		****	#		*	#		*	#		*	#		***	##
Tachytes spp.	*	#		*	#		*	#		*	#		*	#		*	#
Tiphidae																	
Tiphia sp.	****	###		****	###		*	#		*	#		*	#		*	#
Mesa sp.	*	#		*	#		*	#		****	#						
Formicidae				****	##												
Halictidae: Nomiinae										****	#						
DIPTERA (total)	[**	#]		[**	#]		*	#		*	#		*	#		*	#
Bombyliidae (total)	****	##					*	#									
Asilidae (total)	****	##					*	#									
	Overview of the initial impact (I) and persistence of effect (P) of the pesticides used in the pilot study																
	Initial impact: *: harmless <25% reduction; **: slightly harmful 25-50% red.																
	***: moderately harmful 51-75% red.; ****: harmful >75% red.																
	Persistence of effect: #: shortlived ≤1 week; ##: moderately persistent 2-3 weeks;																
	###: persistent >3 weeks.																
	Data in brackets [ ..... ] are not fully consistent (see text); for empty boxes data were not assessed.																

## Discussion

### Study setup and validity of the results.

The fact that the study plots were unreplicated means that the results are only valid under the specific circumstances of this study. Replications in time and space are needed for any extrapolations of the conclusions. In the present study large blocks, of each 4-6 km<sup>2</sup> were treated. In future studies on non-target arthropods smaller plots can be used when assessing immediate population reductions by the pesticides, preferably replicated. However, when recovery needs to be studied, the plot size is of essential importance. This can be best assessed by using several blocks of increasing sizes. In all cases the minimum block size will be determined by the application method; aerial application requiring larger blocks than ground application to assure deposits in the sampling areas to be as even as possible.

Recognizing the above limitation in extrapolation, the validity of the results depends to a large extent on the variability among the plots. Viewing the data, this variability definitely exists, although in most cases differences in abundance between the plots do not surpass one order of magnitude, which for this type of data can be considered as fairly homogeneous. The remarkably different grasshopper fauna found on plots F and G when compared to the other plots (see Chapter VII and VIII) is not reflected in the non-target fauna when analysed at the present level of detail.

The validity of an observed effect is strengthened if a similar or larger effect occurs on the plot with the higher dose rate of the same chemical. In those cases where an effect is found in the lower dose rate but not in the higher, the outcome should thus be considered questionable. This is based on the assumption that the application, and thus the exposure of the organisms to the pesticide, was similar on all plots and cannot explain such differences (see Chapter II).

The statistical method used for analysing some of the observed differences can be questioned in several aspects, as is done below. It is difficult to say to what extent claims of significance or non-significance based on this method are appropriate. It is expected, however, that because of the limited number of data used in the present analysis, more often the tests will be conservative than claiming significance when it is not there. This is even more so since often an upward trend is observed on the treatment plots before treatment (when compared to the controls). Using the mean pre-spray levels rather than the number caught just before spraying, the actual effect is thus underestimated.

Table IX.5 summarizes the effects observed in the study, while also showing which results are questionable because of the above arguments. The ratings for initial effect are those applied by the International Organization for Biological Control (IOBC/WPRS) (Hassan et al. 1985); those used for persistence of the effect are specific for this study: Three weeks after the application the plots started to dry out rapidly and arthropod numbers in the control started to drop considerably. I defined this as the start of the dry season, after which population recovery of many species linked to the rainy season becomes unlikely.

## Comparison of the studied pesticides

### COLEOPTERA

Of all pesticides applied at recommended rates, only fenitrothion reduces catches of a coleopteran taxon, namely the tenebrionid beetle *Vieta senegalensis*. However, at double dose rates all three chemicals reduce at least one taxon by >50% for a minimum of three weeks. Tenebrionidae seem to be more susceptible to fenitrothion while Carabidae were more affected by chlorpyrifos. Diflubenzuron was the least harmful to the investigated Coleoptera. The immediate impact of fenitrothion was only slightly greater than the other two chemicals, but recovery seemed to be considerably slower.

Fenitrothion applied once at either recommended or double dose rates seems capable of reducing Tenebrionidae, potentially important predators of *O. senegalensis* egg pods, more than 50% over a prolonged period, and may interfere with the population regulation of this species. With chlorpyrifos reductions were slightly less and recovery took place within 3 weeks. Chlorpyrifos at 390 g ai/ha reduced carabid captures ca. 70% for 3 weeks, but although this group contains many general predators, no Sahelian pest is known to us of which populations are to a considerable extent regulated by Carabidae. Given the high persistence of diflubenzuron on vegetation even under Sahelian conditions, population levels of Tenebrionidae, whose adults feed partly on plant matter, need to be assessed over a longer period.

### HYMENOPTERA

Total Hymenoptera were reduced for prolonged periods in both organophosphate treated plots, but in chlorpyrifos only at double dose-rate. No effect was observed in the diflubenzuron plots.

However, both ichneumonoid families were clearly reduced for at least 3 weeks after treatment with diflubenzuron. Ichneumonidae seemed slightly more affected than Braconidae. After the diflubenzuron treatments, to our surprise, these two parasitoid families were consistently more reduced than after the organophosphate applications. Since diflubenzuron is not known to be very toxic to adult ichneumonids or braconids (Hassan et al. 1987), these reductions could have been caused by mortality in their lepidopterous hosts, which are very susceptible to these IGR's. Total adult Lepidoptera were not dramatically reduced in the malaise traps on both diflubenzuron plots, however (although this sampling method is not ideal for Lepidoptera). Ground dwelling holometabole larvae (Lepidoptera, Diptera, Carabidae) captured in the pitfall traps were reduced in plot F and G but also in all organophosphate plots (see Annex IX.2), so that does not explain the observed effect sufficiently either. It is very likely, however, that the parasitoid wasps in question were not parasitizing ground dwelling Lepidoptera, but species found on or in plants, which were not sampled in pitfall traps. Alternatively, the IGR may interfere directly with the development of the wasp in the host, or even with its fecundity after the adult has been exposed to the pesticide (either by direct impingement of the pesticide or through consumption of exposed food like honeydew). Broadbent and Pree (1984) observed reduced emergence of *Macrocentrus ancylivorus* from Oriental Fruit Moth treated with diflubenzuron which had, however, successfully moulted, suggesting development of the parasitoid could have been disturbed inside the normally pupating host. Another IGR, coded BAY SIR 8514, when fed to adults of *M. ancylivorus*, reduced the degree of successful parasitism by 25% and the

emergence of adult wasps by 75%.

Overall, The Braconidae and Ichneumonidae were most affected by the three investigated pesticides. Especially with fenitrothion and diflubenzuron applied at the recommended dose-rates, the initial reduction and the persistence of this effect, warrants concern with regard to the disturbance of their potential regulating function of agricultural pests.

Of the third parasitoid family studied, the Tiphidae, the treatment with fenitrothion at both dose rates reduced the catches of *Tiphia* sp. greatly and over a prolonged period. There seems to be a difference in susceptibility to such relatively closely related insecticides as fenitrothion and chlorpyrifos in this group of wasps. Contrary to the ichneumonoid parasitoids, diflubenzuron did not cause significant reductions in catches of Tiphidae. This may be a result of the life history of their hosts, larvae of Scarabaeidae, which often live concealed in the soil or in decaying organic matter and are thus less likely to be exposed to the insecticide.

Larrinae, sphecids wasps preying on Orthoptera, were clearly affected by both fenitrothion treatments, but recovered after one week. Larrinae lay their eggs in chambers in the soil (together with the captured prey), which means that eggs nor larvae are likely to be exposed to the pesticide. However, I do not know if the rapid recovery was caused by movement of adult wasps into the plots from untreated surroundings or emergence of young wasps already present in the plot. Chlorpyrifos did not cause significant changes in this taxon. The reduction observed in the double dose diflubenzuron plot is difficult to explain, however. Adult Larrinae are not expected to be susceptible to the IGR, eggs and larvae are not expected to be exposed. Since the effect occurred immediately after treatment means interference with the fecundity of the wasps was unlikely. This leaves either a behavioural response to the reduced availability of grasshopper larvae as prey (see Chapters VII, VIII) by "emigration" out of the plot, or a random variation. There is no data to support either of these hypotheses.

Halictid bees occurred only on one plot, chlorpyrifos at 390 g ai/ha, in sufficient numbers for analysis. The insecticide reduced catches dramatically, but recovery was equally rapid. Both chlorpyrifos and fenitrothion are known, however, to be highly toxic to honey bees (e.g. Stevenson 1980). Diflubenzuron, on the other hand, is less likely to affect adult bees or their brood. Applications up to 400 g ai/ha on blooming crops with foraging bees in England, did not reduce the number of adult or larval bees (Emmet and Archer 1980).

Impact on ants was only studied on one plot, double dose fenitrothion, where a large and persistent reduction was found. The method used needs further study, however. If it is confirmed that the number of ant nests is relatively stable in time, the effect on ants by counting active nests may be an easy method to assess impact of insecticides in this type of habitat. Formicidae are often found to be susceptible to many insecticides. If this "activity index" does not fluctuate very much during several weeks of the rainy season, the need for repeated pre-treatment observations is low, and the method could possibly be used in regular treatment monitoring.

#### DIPTERA

Total Diptera were only reduced significantly in the plot sprayed with the recommended rate of fenitrothion, which is an inconsistent result since no reduction was observed in the double dose plot.

Impact on Bombyliidae and Asilidae was only assessed in the single dose organophosphate plots. Fenitrothion was clearly more toxic than chlorpyrifos, resulting in 80% reductions over 2 or 3 weeks. Especially in Asilidae, which show a strong natural decrease in population levels from the middle of the rainy season onwards, the "recovery" observed after 3 weeks is probably false. It is caused by the natural decrease of the control plot to the level of the treated plot, rather than recovery in the treated one. This means that in the treated plot population levels of Asilidae in the following season may be low (since a large number has not been allowed to reproduce). This needs confirmation, however.

#### Sample size and taxonomic level of analysis

The effect of a pesticide could in this study be assessed only on a very limited number of taxa at the genus or species level, since numbers within specific genera were often very low. Viewing pesticide impact at higher taxonomic levels may be doubtful. When no impact can be observed at, say, order level, effects may be clear at genus or even family level, just because the latter taxon comprises a limited fraction of the former. A clear example in this study is found from the Coleoptera. No significant reduction in 'total Coleoptera' could be found after any of the treatments, while at family or species level significant effects were quite clear. The same happened with the Hymenoptera when compared with only the families of Ichneumonidae or Braconidae.

The reverse may be true as well; finding an effect at high taxonomical level, while this is not the case at genus level. In this study Braconidae catches were significantly lower after diflubenzuron treatments, but this was not the case for *Aleiodes spl.* one of the predominant braconid species.

Obviously, when a whole taxon at a fairly high organizational level is considered beneficial, e.g. the family Braconidae or even the order Hymenoptera, a negative effect of the pesticide on such a taxon can be considered undesirable, and further analysis at lower taxonomical levels not needed. However, specific questions such as: "what will this mean for parasitism of millet spike worm" cannot be answered since only a limited number of Hymenoptera species is responsible for this.

Conversely, if no pesticide induced effects are found in taxa at high taxonomical levels, no answers can be given to any questions at all. Observing "no impact" in 'total Hymenoptera' does not mean that no impact will have occurred in any lower taxon of Hymenoptera and the group does not need further attention.

This means that if this type of studies is to contribute something meaningful to either ecology/ecotoxicology or the daily practice of plant protection, analyses of pesticide impact should be carried out at the lowest taxonomic level possible ((sub)species or genus). Only if it can be expected that groups at higher taxonomical levels will react similarly to a specific pesticide, can generalisations be made. However, since 'pesticide impact' on an arthropod is not only determined by the susceptibility of the organism to the pesticide (which can be tested in the laboratory for a range of organisms), but also, and probably more so, by exposure (determined by e.g. ecology and behaviour) and recovery capability (determined by population dynamics and dispersal capabilities), one can safely state that the taxon required to study side-effects meaningfully in most cases will be very close to the species.

Table IX.6

TAXON	SUSCEPTIBILITY		ABUNDANCE	STABILITY	ECOLOGICAL RELEVANCE
	OP	IGR			
<b>COLEOPTERA</b>	-	-	+	+	-
Carabidae	" + - "	" + - "	+	+	+
<i>Vieta senegalensis</i>	" + - "	-	+	" + - "	+
<i>Pimella senegalensis</i>	" + - "	-	+	" + - "	+
<b>HYMENOPTERA</b>	+	-	+	+	" + - "
Ichneumonidae	+	+	" + - "	-	+
<i>Temelucha</i> sp1	+	" + - "	" + - "	-	+
Braconidae	+	" + - "	+	" + - "	+
<i>Macrocentrus sulphureus</i>	" + - "	" + - "	" + - "	-	+
<i>Cardiochiles punctatus</i>	na	-	" + - "	-	+
<i>Aleiodes</i> sp1	" + - "	-	" + - "	-	+
Sphecidae: Larrinae	" + - "	" + - "	+	" + - "	+
<i>Tachytes</i> spp.	" + - "	-	" + - "	+	+
Tiphidae					
<i>Tiphia</i> sp.	" + - "	-	-	" + - "	" + - "
<i>Mesa</i> sp.	" + - "	na	+	-	" + - "
Formicidae	+	na	+	+	" + - "
Haliictidae: Nominae	" + - "	na	" + - "	" + - "	+
Pompilidae	na	na	+	na	" + - "
Sphecidae: Crabroninae: Oxybelini	na	na	" + - "	-	" + - "
Sphecidae: Pemphridoninae: Psenini	na	na	" + - "	-	" + - "
Scoliidae: Scolinae	na	na	+	-	" + - "
<b>DIPTERA</b>	" + - "	-	+	" + - "	-
Bombyliidae	-	na	-	" + - "	+
Asilidae	" + - "	na	" + - "	-	+
table 4.8	Suitability of the different arthropod taxa studied in the pilot project for future impact assessment. Suitability classified according to the susceptibility of the taxon to organophosphates (OP) and insect growth regulators (IGR), abundance during the rainy season, stability of the population during the rainy season and the ecological relevance of the taxon, all based on results of this study only. "+": suitable, "+-": suitability doubtful/unclear, "-": unsuitable, "na": not assessed during this study				

The present study showed that only a very limited number of species were captured in sufficient numbers to allow such an analysis. This is not a promising conclusion since the habitats studied were very rich in arthropods. Studies to be carried out in more arid environments will certainly not encounter such abundance and variety of arthropods. Therefore sampling sufficient numbers for side-effect analysis will pose considerable problems in such areas.

#### Choice of taxa and methods for further study

The prerequisites for an ideal taxon for impact assessment on terrestrial invertebrates have been mentioned in the introduction of this chapter. A list of taxa encountered in the pilot study is shown in Table IX.6 giving a preliminary appraisal with regard to the above criteria. It should be noted that the outcome of some criteria, especially abundance and population regularity depend largely on the location of the study and will certainly be quite different either in more arid or in more humid environments.

Perusal of the table shows that the ideal taxon does not exist. Carabids and the mentioned tenebrionids are suitable with regard to their abundance, stability and ecological function, but most are relatively insensitive to pesticides. In more arid areas Tenebrionidae and in the more humid regions Carabidae will become more predominant. As far as pitfall trapping is concerned, these groups are the only ones likely to give good results. They are not likely to be good early indicators of effects however, since they are not very susceptible to pesticides. This has been concluded earlier for carabid beetles (e.g. Everts et al.1989).

Many of the Hymenoptera studied were affected by the organophosphates. The main problem with organisms in this group is that they are either not very numerous with the trapping methods used, or fluctuate considerably during the rainy season, or both. Braconidae were slightly more abundant than Ichneumonidae; the latter family may disappear almost completely in more arid environments. Larrinae populations were relatively regular and abundant but less susceptible than the two groups of parasitoids mentioned above. Both genera of Typhiidae were either not abundant or highly variable. Apidae (Halictidae) were only caught in low numbers and do not seem to be a good monitoring taxon when to be trapped from the wild. Ant activity showed, of all potential indicators perhaps the most promising possibilities since abundance, regularity and susceptibility seemed to be good. However, the method still needs further research before it can be introduced for wide application.

Within the Diptera, Bombyliidae were not caught in large numbers. Asilidae may be useful study organisms, but only for treatments taking place early in the season. The family of Tachinidae needs to be included in future investigations given its high potential importance as parasites of crop pests.

Not more than three methods were used to assess pesticide impact on non-target invertebrates: malaise trapping, pitfall trapping and transect counts for ant activity. For ground dwelling arthropods like beetles, pitfall trapping as practised in this study seems appropriate. In more arid environments where beetle abundance decreases, the number of traps may need to be increased. Malaise traps are generally considered appropriate for many groups of flying Diptera and Hymenoptera, and in this study large numbers were caught. It seems useful to investigate better trapping methods for Bombyliidae (sweep netting?) and parasitica. For the

latter, such devices as pyrethroid impregnated interception screens may prove efficient. Specialized, labour consuming techniques such as sticky traps, absolute density measurements and transect counts are, in general, unsuitable for the given situation.

#### Operations monitoring versus in-depth studies

In the terms of reference for the pilot project it was requested to study possible methods which could be used in operational monitoring of side-effects of locust and grasshopper control. A basic prerequisite of any operational monitoring technique for locust and grasshopper control is that the pre-treatment level of any monitoring statistic, be it an indicator organism or a biochemical indicator, can be set or predicted from one measurement just before the treatment takes place. This is essential because almost as a rule in locust control the area to be treated is not known until just before the treatment takes place. Locusts and some grasshoppers move and migrate rapidly so that control locations can not be predicted several weeks beforehand. However, the catches/populations of almost all the taxa studied so far fluctuate greatly, often a half or one order of magnitude from one week to the other. This makes all these taxa improper for general monitoring, since valid pre-treatment levels cannot be determined by one measurement. The only possible exception is ant activity.

Another technique which has not been used in this study but may prove easily applicable, is surveying for natural mortality in grasshopper eggpods. This technique is relatively easy to carry out and has the advantage that no pre-treatment comparisons are needed. Assessing natural mortality in treated areas and comparing them with closely situated non-treated areas should suffice. Since natural enemies are thought to act mostly in the months directly following oviposition (Popov 1980), these egg pod surveys should not be carried out directly after the end of the rainy season but, say, in the period from January to March (for the Sahel). Being able to identify both treated areas and areas where grasshoppers may likely have laid late in the rainy season, is of course necessary for this type of monitoring. However, this type of information should be available in any properly organised and executed grasshopper campaign and should thus not constitute an extra burden to Plant Protection Services. Furthermore, it gives considerably more meaning to egg pod surveys in general.

While recognizing that probably only a very limited number of real operational monitoring techniques may be developed, the more detailed studies, such as initiated under the pilot project, definitely have their place in the future. They are expected to answer specifically the following questions:

What are the differences in side-effects between different pesticides? The pilot study suggests that even closely related insecticides may have considerably different impact on non-target organisms. This means that the argument that advice might be given on the use of specific insecticides under specific circumstances based on knowledge of their side-effects is not only an empty statement to gain support for this type of study. In this respect it should be noted as well that for the comparison of pesticides standard laboratory assays do not appear to suffice. Fenitrothion and chlorpyrifos are considered "harmful" to parasitoids and diflubenzuron as "harmless" after laboratory and semi-field screening according to IOBC methods (Hassan et al. 1987, 1988, Peter and David 1988). From the present field study it appears that the IGR is not harmless while chlorpyrifos did not seem to influence the parasitoid ichneumonid family in any significant way.

The second question for which answers need to be found is the impact locust and grasshopper control has on the functioning of the (agricultural) system studied. Two subjects which immediately come to mind after viewing the results of the pilot study are the relation between egg pod predators (Tenebrionidae) and natural mortality in grasshopper eggs, and the relation between parasitoids (Braconidae and Ichneumonidae) and lepidopterous pests in coarse grain crops.

A third major subject which needs further study is the influence of the size of the sprayed blocks on the recovery capability of critical beneficial arthropods in these Sahelian ecosystems. This can only be investigated in well controlled experiments using differently sized spray blocks and relatively dense trapping grids to follow and possibly model the effect of diffusion and reproduction on recovery. This may result in recommendations on maximum block sizes to be sprayed with the intention to avoid long term disturbance of specific beneficial arthropod populations.

Both types of assessment, the superficial general monitoring after operational treatments and the in-depth analysis of pesticide impact under controlled circumstances can be developed simultaneously, and will sometimes overlap (e.g. egg pod natural mortality).

## Conclusion

Fenitrothion was the most harmful insecticide to non-target beneficial arthropods of the three studied. At recommended field rates for Desert Locust control chlorpyrifos had only limited impact on the selected non-target arthropods, while fenitrothion reduced a wide array both in terms of number and over prolonged periods. At double dose rates, fenitrothion treatment, while not affecting more taxa than chlorpyrifos, resulted in a slower recovery of the affected arthropods. Effects of diflubenzuron were mainly limited to braconid and ichneumonid wasps, at both the dose rates. All studied insecticides reduced at least one ecologically important taxon for a prolonged period, which might interfere with regulation of certain crop pests.

It should be added that, because of the design of the study, these conclusions only stand for this specific study. They need confirmation from other situations in order to gain extrapolative power.

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## References

- Ansley CF and Kohn R. 1983. Exact likelihood of vector autoregressive-moving average process with missing or aggregated data. *Biometrika* 70(1):275-278.
- Balk F and Koeman JH (1984) Future hazards of pesticide use. With special reference to West-Africa and South-East Asia. IUCN Commission on Ecology Papers No. 6. *The Environmentalist* 4, supplement No. 6:1-100.
- Betbeder-Matibet M. 1989. Biological control of sorghum stem borers. Proceedings of the International Workshop on Sorghum Stemborers. 17-20 Nov 1987, ICRISAT Center (International Crops Research Institute for the Semi-Arid Tropics), Patancheru, India. p 89-93.
- Bhatnagar VS. 1987. Rapport de synthèse (1981-1986) et recommandations, Sous-Programme Lutte Biologique. Projet CILSS de Lutte Intégrée au Sénégal. FAO Rapport Technique GCP/RAF/128/CLS. Rome. pp. 166.
- Bohart RM and Mencke AS. 1976. Sphecids wasps of the world. a generic revision. Univ. California Press Berkeley. pp ix+695.
- Borror DJ, DeLong DM & Triplehorn CA (1980) An introduction to the study of insects. IV Ed. New York 852pp..
- Britton EB, Brown WL, Calaby JH et al. 1970. The insects of Australia. A textbook for students and research workers. The Division of Entomology, Commonwealth Scientific and Industrial Research Organization. Melbourne University Press. Carlton. pp xiii+1029

Broadbent AB and Pree DJ. 1984. Effects of diflubenzuron and BAY SIR 8514 on beneficial insects associated with peach. *Environ. Entomol.* 13(1):133-136.

Cheke RA, Fishpool LDC and Forrest GA (1980) *Oedaleus senegalensis* (Krauss) (Orthoptera: Acrididae: Oediponinae): an account of the 1977 outbreak in West Africa and notes on eclosion under laboratory conditions. *Acrida* 9:107-132.

Crane E and Walker P. 1983. The impact of pest management on bees and pollination. Tropical Development Research Institute. London.

Dynamac Corporation. 1988a. Results of the Mali pesticide testing trials against Senegalese Grasshopper, final technical report. Study by Dynamac Corporation, Rockville MD and Consortium for International Crop Protection, College Park MD for US Agency for International Development.

Dynamac Corporation. 1988b. Results of the locust pesticide testing trials in Sudan, technical report. Study by Dynamac Corporation, Rockville MD and Consortium for International Crop Protection, College Park MD for US Agency for International Development.

Emmet BJ and Archer BM. 1980. The toxicity of diflubenzuron to honey bee (*Apis mellifera* L.) colonies in apple orchards. *Pl. Path.* 29:177-183.

Everts JW and Koeman JH. 1987. The ecological impact of insecticides in connection to the control of tsetse flies in Africa: a review. In Cavalloro R (ed). *Integrated tsetse fly control: methods and strategies*: 49-56. Rotterdam.

Everts JW, Aukema B, Hengeveld R, Koeman JH. 1989. Side effects on ground-dwelling arthropods in arable ecosystems. *Env. Poll.* 59:203-225

Farrow RA. 1975 The African Migratory Locust in its main outbreak area of the middle Niger: Quantitative studies of solitary populations in relation to environmental factors. *Locusta* 11:1-198.

Gahukar RT. 1988. Problems and perspectives of pest management in the Sahel: a case study of pearl millet. *Tropical Pest Management* 34(1):35-38.

Gahukar RT. 1989. Insect pests of millet and their management: a review. *Tropical Pest Management* 35(4):382-391.

Gahukar RT, Guevremont H, Bhatnagar VS, Doumbia YO, Ndoye M and Pierrard G. 1986. A review of the pest status of the millet spike worm, *Rhaguva albipunctella* De Joannis (Noctuidae:Lepidoptera) and its management in the Sahel. *Insect Sci. Applic.* 7(4):457-463.

Gauld ID. 1980. Notes on an economically important species of *Temelucha* Foerster (Hymenoptera:Ichneumonidae) and a preliminary key to australian species. *Bull. ent. Res.* 70:43-47.

- Greathead DJ. 1963. A review of the insect enemies of acridoidae (orthoptera). Trans. R. Ent. Soc. Lond. 114(14):437-517
- Greathead DJ. 1966. A brief survey of the effects of biotic factors on populations of the Desert Locust. J. appl. Ecol. 3:239-250.
- Green RH. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons. New York. pp xi+257.
- Hassan SA, Bigler F, Blaisinger P *et al.* 1985. Standard methods to test the side-effects of pesticides on natural enemies of insects and mites developed by the IOBC/WPRS Working Group "Pesticides and Beneficial Organisms". EPPO Bulletin 15:214-255.
- Hassan SA, Albert R, Bigler F *et al.* (1987) Results of the third joint pesticide testing programme by the IOBC/WPRS Working Group "Pesticides and Beneficial Organisms". J. Appl. Ent. 103:92-107.
- Hassan SA, Bigler F, Bogenschutz H *et al.* (1988) Results of the fourth joint pesticide testing programme carried out by the IOBC/WPRS Working Group "Pesticides and Beneficial Organisms" J. Appl. Ent. 105:321-329.
- Huddleston T and Walker AK. 1988. *Cardiochiles* (Hymenoptera: Braconidae), a parasitoid of lepidopterous larvae, in the Sahel of Africa, with a review of the biology and host relationships of the genus. Bull. ent. Res. 78:435-461.
- Kotz S. *et al.* 1983. Encyclopedia of statistical sciences. Vol. 4. John Wiley and Sons. New York.
- Krantz J, Schmutterer H, and Koch W. 1977. Diseases, pests and weeds in tropical crops. Paul Parey Verlag. Berlin. pp xiv+666.
- Kusigemati K. 1985. Descriptions of two new ichneumonid wasps (Hymenoptera) parasitic on *Etiella spp.* (Lepidoptera:Pyralidae) from Indonesia. KONTYU 53(1):75-80.
- McGregor SE. 1976. Insect pollination of cultivated crop plants. Agriculture Handbook N0. 496. USDA. Washington D.C.
- Mitchell ER, Waddill VH and Ashley TR. 1984. Population dynamics of the fall armyworm (Lepidoptera:Noctuidae) and its larval parasites on whorl stage corn in pheromone-permeated field environments. Environ. Entomol. 13(6):1618-1623.
- Müller P. 1988. Ökotoxikologische Wirkungen von Chlorierten Kohlwasserstoffen, Phosphorsäureestern, Carbamaten und Pyrethroiden im Nordöstlichen Sudan. Institut für Biogeographie der Universität des Saarlandes, Saarbrücken.
- Ndoye M and Gahukar R. 1987. Les insectes ravageurs du mil en Afrique de l'Ouest et les moyens de lutte. Proc. Intern. Pearl Millet Workshop, 7-11 April 1986, ICRISAT. p 183-194.

Nwanze KF. 1989. Insect pests of pearl millet in Sahelian West Africa. I. *Acigona ignefusalis* (Pyralidae:Lepidoptera): distribution, population dynamics and assessment of crop damage. *Tropical Pest Management* 35(2):137-142.

Ottesen P. 1987. The mortality of *Oedaleus senegalensis* (Orthoptera) and other invertebrates in Mali using reduced dosages of fenitrothion. Dept. of Zoology, University of Oslo. Draft October 1987.

Ottesen P, Fosslund S, Johannessen B and Simonsen JH. 1989. Reduced rates of fenitrothion: the effect on *Oedaleus senegalensis* (Orthoptera) and non-target arthropods in Mali, West Africa. Report to the Royal Norwegian Ministry for Development Cooperation. Oslo.

Peter C and David BV. 1988. Comparative toxicity of some insecticides to *Apanteles taragamae* (Hymenoptera: Braconidae). *Tropical Pest Management* 34(4):402-403.

Pinto LJ, Mann JB and Bottrell DG. 1988. Analysis of aerial application of fenitrothion ULV for locust control in Sudan. Environmental assessment. Sudan multi-donor locust/grasshopper control program. Study by Consortium for International Crop Protection, College Park MD for Food and Agriculture Organization of the United Nations.

Pree DJ. 1979. Toxicity of Phosmet, Azinphosmethyl and permethrin to the oriental fruit moth and its parasite, *Macrocentrus ancylivorus*. *Environ. Entomol.* 8(5):969-972.

Prior C and Greathead DJ. 1989. Biological control of locusts: the potential for the exploitation of pathogens. *FAO Plant Prot. Bull.* 37(1):37-48.

Popov GB. 1959. Ecological studies on oviposition by *Locusta migratoria migratoroides* (R.&F.) in its outbreak area in the French Sudan. *Locusta* 6:1-63.

Popov GB. 1980. Studies on oviposition, egg development and mortality in *Oedaleus senegalensis* (Krauss), (Orthoptera, Acridoidea) in the Sahel. Centre for Overseas Pest Research, London, United Kingdom. pp 48.

Popov GB. 1988. Sahelian grasshoppers. Overseas Development Natural Resources Institute Bulletin No 5. pp. vi+87.

SNPV Service National de la Protection des Végétaux. 1990. Rapport de Prospection des oothèques de Sautériaux. Ministère de l'Agriculture. Bamako. Mali.

Sokal RR. and Rohlf FJ. 1981. Biometry: the principles and practice of statistics in biological research. second edition. Freeman and Co. New York. pp xviii+859.

Stevenson JH. 1978. The acute toxicity of unformulated pesticides to worker honey bees (*Apis mellifera* L.). *Pl. Path.* 27:38-40.

Stewart-Oaten A, Murdoch WW and Parker KR. 1986. Environmental impact assesment: "pseudoreplication " in time?. *Ecology* 67(4):929-940.

Stortenbeker CW. 1967. Observations on the population dynamics of the Red Locust, *Nomadacris septemfasciata* (Serville), in its outbreak areas. Agricultural Research Reports 694. Institute for Biological Field Research, Arnhem, The Netherlands. pp 118.

van Achterberg C. 1976. A preliminary key to the subfamilies of the braconidae (hymenoptera). Tijdschrift voor Entomologie 119(3):33-78.

van der Valk HCHG and Koeman JH. 1988. Ecological impact of pesticide use in developing countries. Netherlands' IRPTC-IPCS Committee. Ministry of Housing, Physical Planning and Environment. The Hague. pp. 102

van der Voet H. 1987. Het bepalen van behandelingseffecten op grond van korte tijdreeksen. (assessing treatment effects on the basis of short time-series) TNO Institute for Applied Informatics. Wageningen. The Netherlands. Internal Document ITI B30. pp 40. (in Dutch).

Winnie WV and Chiang HC. 1982. Seasonal history of *Macrocentrus grandii* (Hym.:Braconidae) and *Eriborus terebrans* (Hym:Ichneumonidae), two parasitoids of the european corn borer, *Ostrinia nubilalis* (Lep.:Pyralidae). Entomophaga 27(2):183-188.

James W. Everts & Rudy C. Jocqué<sup>1</sup>

### **Introduction**

Groundspiders, though no major predators of large orthopterans, are important indicators of the epigeal predator arthropod fauna, with respect to side-effects of pesticides (Everts et al. 1989, Everts 1990). The group is an attractive tool for monitoring purposes for the following reasons:

1. They are sensitive to a wide range of insecticides (Sunderland 1987, Everts et al. 1983, 1989)
2. They are readily trapped, easy to handle, and generally abundant
3. Species are easily separated and reference material is available for many parts of West-Africa

### **Material and Methods**

For this study we identified all ground spiders from the pitfall trap catches of the terrestrial invertebrate programme (Chapter IX).

The material was identified in alcohol without further preparation. (After identification the material was stored and will remain available at the Museum of Tervuren. A reference collection will be available in Senegal.) We separated species, sex (for adults) and juveniles.

A few species were identified to name, the other were coded and will be processed in due time (i.e. identified by the specialists of the families concerned). The codes were used for the analysis of possible side-effects.

The catches have primarily been analysed at species level. For processing, however, species were lumped to families and weekly catches were, in a few cases, lumped to longer periods. By lumping weeks, the BACI method for statistical analyses is no longer applicable. Because there was no repetition in space, these cases merely provided indications of an effect.

Weekly catches were processed as follows. Numbers were transformed to  $^{10}\log$  and expressed as number per trap per trapping day. These numbers were compared with the same series from the control area (Block C) and a comparison was made between blocks treated at different dosages of the same compound. The third step was a comparison of the number of species per trap, lumped over two periods: before and after treatment. Of the spiders from the block treated by diflubenzuron a possible effect on population structure was investigated by comparing the ratio juveniles:adult to the control.

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## Results

The numbers of the spiders, per family, are given in Annex X.1. A total of 2.761 specimens was found, divided over 60 species and 8 families. Because very few of the species were identified by name, they are indicated by their code. (The records remain available for further processing at the Museum for Central Africa at Tervuren.)

The most abundant family is the Lycosidae (Wolf Spiders). Their numbers were rather irregular. In Figure X.1 the quotients are given of the numbers from the blocks treated at single and double dose. There is only a slight tendency towards a dose related response to fenitrothion and chlorpyrifos. In species richness, however (Fig. X.2), an effect of both compounds is strongly indicated. No indications were found for an effect of diflubenzuron.

The second largest family is the Salticidae (Jumping Spiders, Table X.2). In Fig. X.3 the numbers are given of the blocks sprayed with chlorpyrifos double dose, divided by the control values. There is a strong indication of an effect. The numbers from the double dose block divided by the single dose (Fig. X.4) confirm this (the difference is statistically significant at  $p < 0.05$ ). Neither fenitrothion nor diflubenzuron provide any evidence of an effect on Salticidae.

The third family, Gnaphosidae, are given in Table X.3. No indications were found of an effect of either fenitrothion or chlorpyrifos. From the numbers of the diflubenzuron treatment, however, a significant ( $p < 0.05$ ) indication of a slight, delayed effect manifesting itself four weeks after treatment was found (Figure X.5).

In none of the families an effect of diflubenzuron on the population structure was observed.

## Discussion

In this study a distinction is made between statistical and biological significance. Not all statistically significant effects are considered biologically relevant, given the apparent variability of the undisturbed situation. On the other hand, a clear but not statistically testable indication of an effect (e.g. the effect on species richness in Lycosidae) is seriously taken into consideration.

The toxic effects in the ground dwelling spiders observed in this test clarify the relative harmlessness to spiders of the three compounds used. Our observation on fenitrothion confirms the conclusion of Ottesen (1987), with respect to the effect on the spiders as one group. None of the taxa identified by us was eliminated completely by the treatments, even at the extremely high double dosages. Both Lycosidae and Salticidae showing clear indications of an effect, specifically at double dose, also have a tendency to recover during the last week of observation. Unfortunately, the indicated effect of diflubenzuron at double dose in Gnaphosidae could not be monitored until recovery, because the growing season came to an end.

Of the compounds used chlorpyrifos provided most indications of toxic effects, i.e. both in Lycosidae (on species richness) and in Salticidae. Diflubenzuron was the least harmful (or

"most harmless") insecticide.

### **Conclusions**

1. Ground spiders are not seriously affected by fenitrothion, chlorpyrifos and diflubenzuron.
2. Of the three pesticides chlorpyrifos showed most, and diflubenzuron the least effect.

### **References**

- Everts JW (1983) Animal indicators for side-effects of chemical vector control. *Environ Monitor Assess* 3:229-236
- Everts JW, B Aukema, R Hengeveld and JH Koeman (1989) Side-effects on ground-dwelling predatory arthropods in arable ecosystems. *Env Poll* 59:203
- Sunderland KD (1987) Spiders and cereal aphids in Europe. *Bull IOBC/WPRS* X:82-102
- Everts JW, van Frankenhuyzen K, Román B and Koeman JH (1983) Side-effects of experimental pyrethroid applications for the control of tsetseflies in a riverine forest habitat (Africa). *Arch Environ Contam Toxicol* 12:91-97

**Figure X.1:**

Numbers of Lycosidae from fields treated with double dosages divided by numbers from fields treated with single dosages.

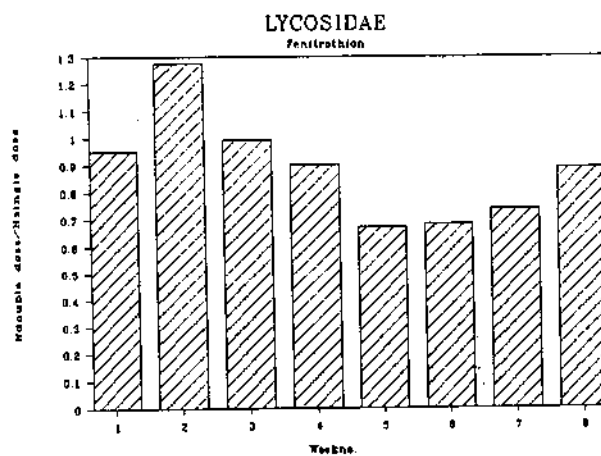
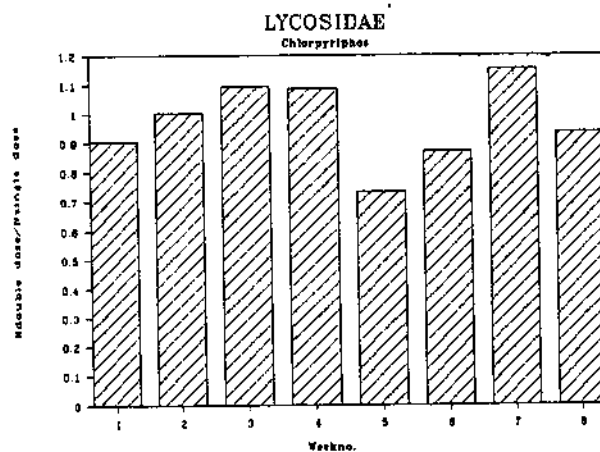
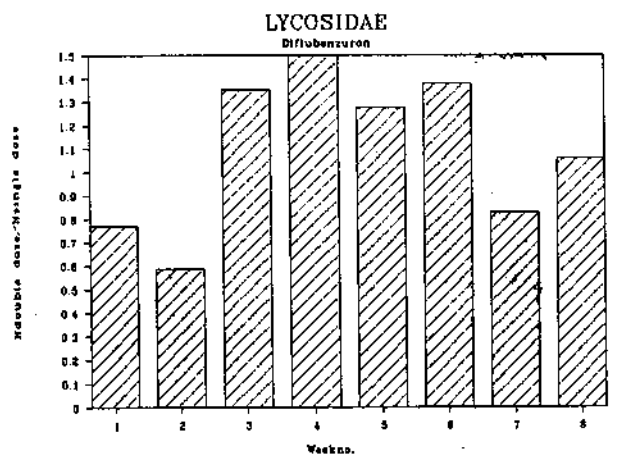
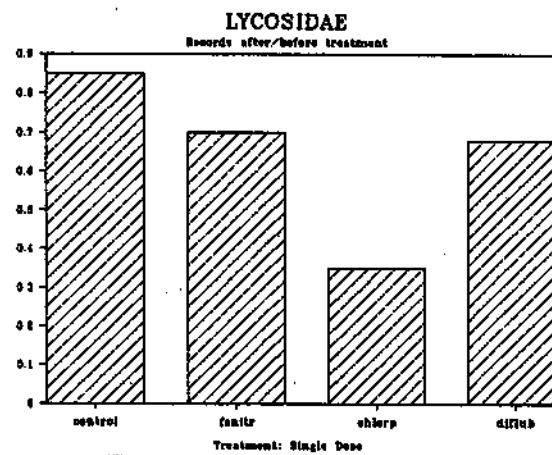
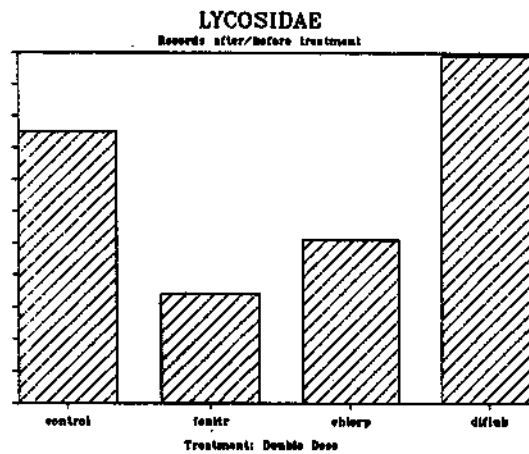


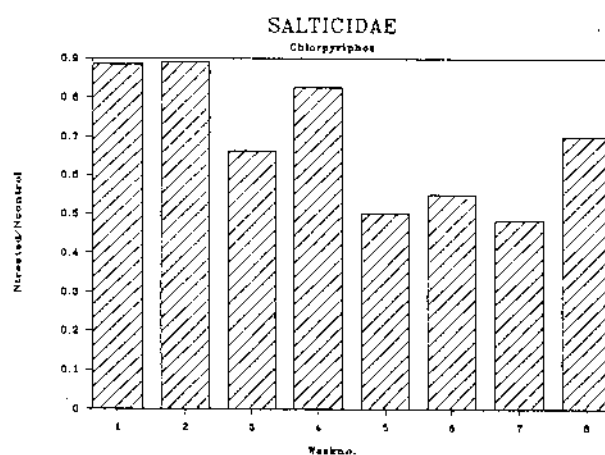
Figure X.2:

Number of Lycosidae species per trap after treatment divided by species number before treatment



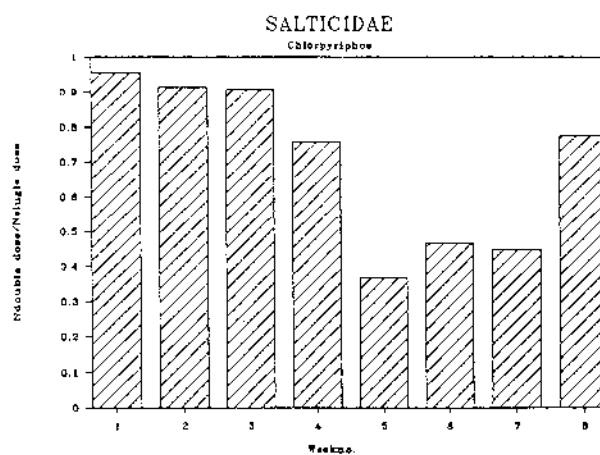
**Figure X.3:**

Numbers of Salticidae from the area treated with chlorpyrifos at double dose divided by the control numbers



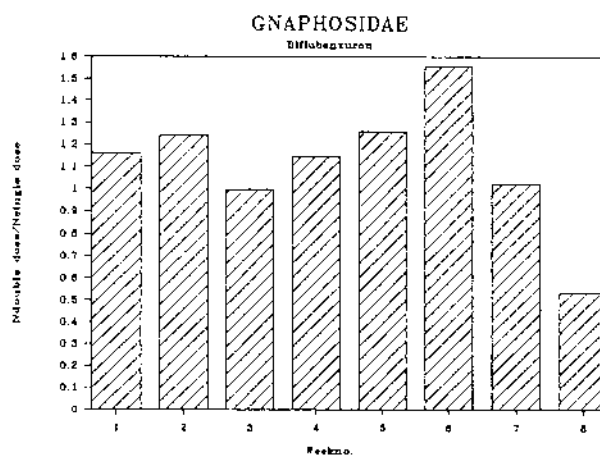
**Figure X.4:**

Numbers of Salticidae from the area treated with chlorpyrifos at double dose divided by the numbers from the single dose area



**Figure X.5:**

Numbers of Gnaphosidae from the area treated with diflubenzuron double dose divided by the numbers from the area treated at single dose



Ndiougou Gueye & James W. Everts

### **Introduction**

Les termites, bien que très connus pour leur rôle primordiale dans les écosystèmes terrestres tropicaux, n'ont été le sujet d'aucune étude écotoxicologique dont les résultats ont atteints la littérature scientifique internationale. Ceci est surprenant surtout compte tenu non seulement de leur importance écologique mais aussi de leur exposition élevée aux produits chimiques appliqués superficiellement, comme le sont presque tous les pesticides utilisées dans des grandes campagnes anti-vectorielles et anti-ravageurs aux pays tropicaux.

Dans la présente étude nous avons tentés d'obtenir des indications pour un effet néfaste possible des pesticides utilisés dans les programmes antiacridiens sur ce groupe, ceci pour identifier la nécessité d'une étude plus approfondie et à long terme.

Cette étude n'étant pas prévue dans la programmation générale, est d'une nature très limitée en ce qui concerne l'ampleur de la superficie étudiée aussi bien que la durée des observations. Malgré ces limitations nous croyons que les résultats (très incomplets) sont indicatifs pour des effets écotoxicologiques très importants et, généralement, trop négligés.

Nous avons profité de nos activités consacrées initialement aux termites, pour faire des observations sur les activités superficielles des fourmis, ceci comme suite aux études sur la faune entomologique terrestre (Chapitre IX).

### **Matériel et Méthodes**

L'objectif de cet étude était de se rendre compte de l'état des populations de termites et de fourmis de trois blocs de référence:

- bloc B : traité au fénitrothion à 825 g ma/ha
- bloc C : bloc témoin non traité
- bloc F : traité au diflubenzuron à 82.8 g ma/ha

Les termitières épigées des blocs d'étude sont mortes et suite aux rigueurs climatiques les populations des termites hypogées semblent avoir opéré de profondes migrations comme certaines études l'ont déjà montré (Lepage 1974)

Notre méthode a consisté à recenser l'activité de récolte, d'une part en strate herbacée (présence de placages humidifiées) et d'autre part sur les tiges sèches de canne à sucre imbibées d'eau et enfouillies à 50 cm dans le sol. Cette technique de piégeage permet une étude indirecte des populations de termites (Gueye 1987).

L'étude fut exécutée pendant la quatrième semaine après traitement.

### Strate Herbacée

Dans chaque bloc une corde de 100m est tendue sur trois zones choisies au hasard et à chaque mètre on note la présence ou l'absence de placages afin de déterminer la fréquence de récolte des termites. En détruisant certaines parties des placages on prélève certains individus qui continuent leur récolte à la faveur de la fraîcheur du matin. Pour les fourmis, leur présence est signalée par des petites monticules de terre fraîche construites sur le tapis herbacé.

### Pièges à Canne à Sucre

Au niveau de chaque bloc, trois trous piégés ont été pratiqués au hasard et enfouis pendant 48 heures. Les tiges de canne (env. 30 cm de long) ont été ensuite retirées et les termites piégés sont déterminés et comptés.

## Résultats

### La strate herbacée

Le tableau XI.1 récapitule la fréquence de récolte en strate herbacée.

**Tableau XI.1:** Fréquence de récolte en strate herbacée (pourcentage de présence)

Numéro d'échantillon	Bloc F		Bloc B		Bloc C	
	Termites	Fourmis	Termites	Fourmis	Termites	Fourmis
1	26	16	11	37	30	59
2	16	35	12	30	29	54
3	41	36	11	43	40	56
Moyen	27.6	29.0*	11.3**	36.6*	33.0	56.3

\* = différence de Bloc C est significative à  $p < 0.05$

\*\* = „ „ „ „ „ „  $p < 0.01$

La différence a été testé par analyse de variance.

Par rapport à la fréquence maximale (100) les fréquences de récolte observées pour les termites et les fourmis sont relativement faibles. Ce fait est probablement lié aux conditions écologiques très rigoureuses de la zone (sécheresse accentuée, sol sableux et sec, rapide disparition du tapis herbacé). Les populations de termites sont sensibles à cet état de déficit hydrique et en général, leurs activités de récolte s'en trouvent très compromises.

Les activités de récolte trouvés dans les blocs F et C ne sont pas significativement différentes, ce qui semble montrer que le traitement au diflubenzuron a peu ou pas d'effet sur la population récoltante.

Quant au Bloc B, les résultats sont deux fois plus faibles que dans les autres blocs expérimentaux. Ce fait serait probablement lié aux effets de l'insecticide. On constate visiblement une absence de la faune du sol sur la strate herbacée. Les quelques termites actifs découverts dans ce lieu récoltaient dans des troncs de bois morts et sous des bouses de vache qui servent en même temps d'abris à cette faune (Odontotermes et Amitermes).

L'observation faite sur les fourmis indique que les populations touchées par les traitements (Chapitre IX) sont en train de se récupérer au moment de notre observation, c'est à dire, à la fin de l'hivernage.

### Le piégeage

**Tableau XI.2: Résultats du piégeage**

Bloc	Nombre de Termites, par Piège	Espèces	Observations
B	18;46	Microtermes	Beaucoup d'ouvriers, quelques soldats
F	23;35	Microtermes	Beaucoup d'ouvriers, quelques soldats
C	35;48;65	Microtermes	Beaucoup d'ouvriers, quelques soldats
		Psammotermes	Beaucoup de soldats, très peu d'ouvriers

Les pièges installés dans les différents blocs ont attiré des termites, ce qui montre que les populations hypogées ont conservé une certaine activité. Les résultats montrent une différence entre les blocs traités et le bloc témoin. Ceci pourrait être interprété comme indication pour un effet des traitements.

### **Discussion et Conclusions**

Toutes les conclusions tirées des résultats présentés au-dessus ne donnent que des indications sur de possibles effets toxiques, à l'absence d'une surveillance avant-traitement dans les mêmes sites.

En strate herbacée les résultats obtenus sont assez conformes aux observations générales que nous avons faites sur le terrain. Le bloc B traité au fénitrothion renferme beaucoup de cadavres d'acridiens et les insectes vivants y sont très rares, comparativement aux blocs F et C.

Les espèces hypogées trouvées dans nos pièges ne semblent pas être touchées par les deux produits.

Il serait toutefois nécessaire d'affiner d'avantage les méthodes qu'on a utilisées de façon plutôt grossière compte-tenu les contraintes du temps. De même une meilleure étude des populations hypogées pourrait fournir des données importantes, surtout en ce qui concerne la composition des peuplements.

Une étude de laboratoire nous semble nécessaire pour tester la toxicité des insecticides chez les termites.

### **Bibliographie**

Gueye N (1987) Rôle des termites dans les plantations forestières du Cap-Vert (Mbao-Sénégal). Thèse de doctorat. Univ. Paris 6

Lepage M (1974) Les termites d'une savane sahélienne (Ferlo Septentrional, Sénégal): peuplement, populations, consommation, rôle dans l'écosystème. Thèse es-Sciences. Univ. Dijon, 344pp

James O. Keith and Wim C. Mullié

### Introduction

A plague of the Desert Locust (*Schistocerca gregaria*) occurred through the African Sahel between 1986 and 1988. Affected African countries responded by initiating surveillance and control programs with the assistance of international donors. A variety of insecticides were used in these programs, few of which had been evaluated for possible effects on Sahelian environments. Two commonly used compounds, fenitrothion and chlorpyrifos, have been shown to cause mortality in organisms on treated areas in North America.

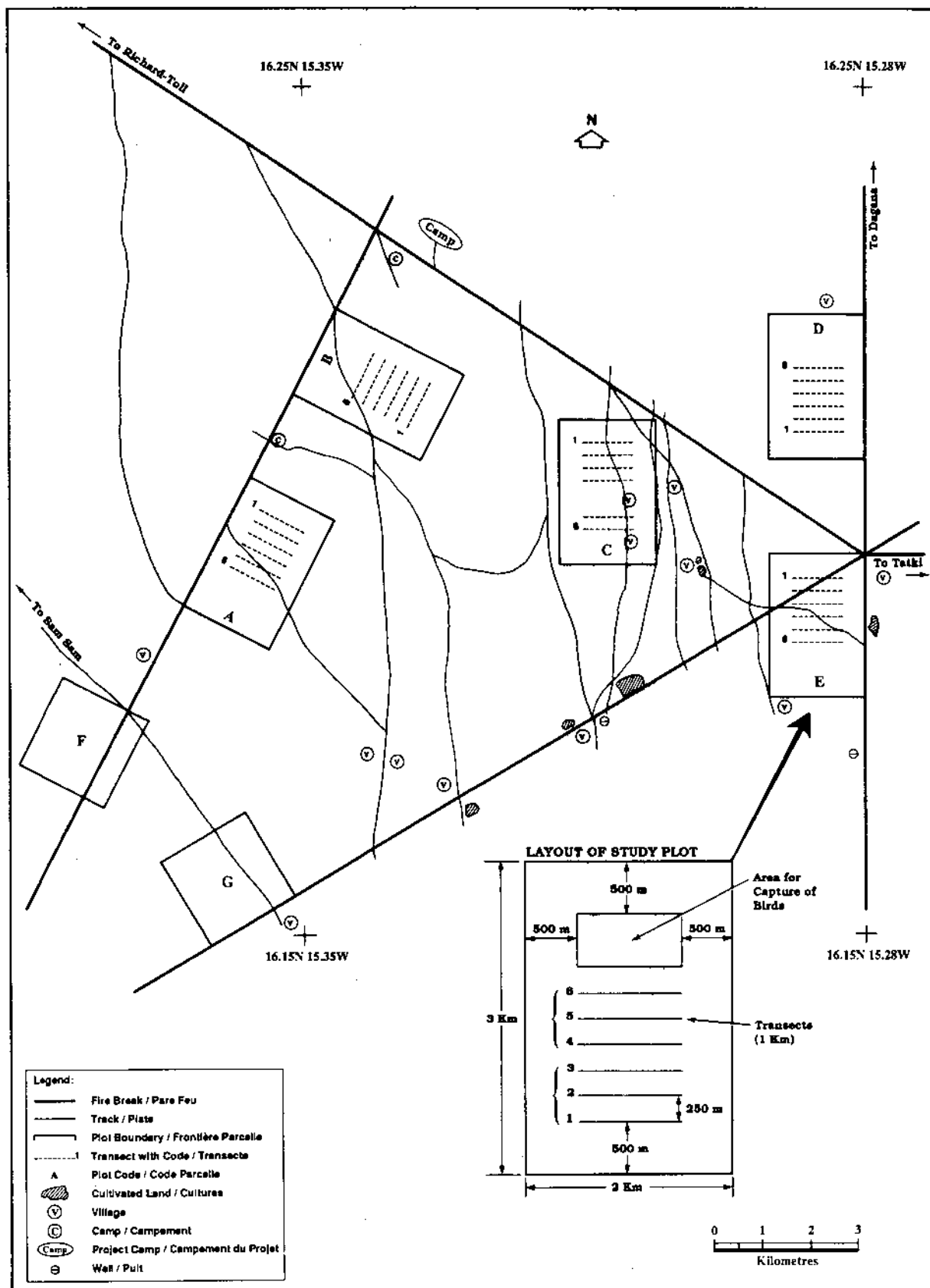
When applied to wetland habitats, chlorpyrifos has consistently caused mortality and other effects in aquatic invertebrates and fishes. In contrast, when used for insect control in terrestrial habitats, chlorpyrifos has not had severe effects on resident warm blooded animals (Odenkirchen and Eisler 1988).

Fenitrothion applications to forests in Canada at 300 g/ha and higher usually have had acute effects on passerines (Busby *et al.* 1983). Reductions in bird abundance were found at application rates of 140 to 280 g/ha, especially in canopy feeders (Pearce & Peakall 1977). Carcasses were recovered at the rate of 0.7 birds/h of searching after treatments of 560 g/ha. In addition, nest desertion by female White-throated Sparrows (*Zonotrichia albicollis*) increased from 12 to 58 percent after two applications totaling 630 g/ha (Peakall and Bart 1983). However, at an application rate of 300 g/ha in Scotland, Spray *et al.* (1987) did not find effects on the size of the breeding bird populations, on bird counts immediately before and after spraying, or on reproduction in Coal Tits (*Parus ater*). Of greater pertinence to locust control programs are the findings of mortality and decreases in bird abundance following applications of 210-420 g/ha of fenitrothion to rangelands in the western United States for grasshopper control (McEwen 1982).

Our studies of the effects on birds were part of a large, comprehensive study to evaluate the impact of experimental applications of fenitrothion and chlorpyrifos on aquatic and terrestrial habitats in northern Senegal. An experimental approach was chosen because it was impossible to predict when and where the insecticides would be applied for operational control of locusts. Thus, treatments were not made to areas containing locust swarms or bands; however, relatively high populations of grasshoppers (predominantly *Oedaleus senegalensis*) were present on treated areas.

Objectives of our bird studies were to assess treatment effects on bird abundance and mortality, on the foods eaten by birds, and on cholinesterase (ChE) levels in the brains of selected species. Bird populations could change due to either mortality or to movements from treated areas in reaction to reduced food availability. Food habit studies contributed to understanding effects of reducing insect biomass, and ChE measurements helped assess the intensity of insecticide exposure and the cause of death in birds found dead. In addition, attempts were made to evaluate the reproductive performance of several bird species on treated plots.

Figure XII.1: Layout of experimental plots.



## Study Area

### Plots and treatments

Five 2x3-km study plots, separated by at least 2 km (Fig.XII.1), were used to evaluate effects of four individual treatments on birds. Details on geology, vegetation, landscape and landuse and climate are given in Chapters I and II. The treatments that were assessed were fenitrothion (1F and 2F) and chlorpyrifos (1C and 2C) at the recommended and double rate for locust control respectively and an untreated control (Control). Details on the treatments are given in Chapter I. This pilot study was conducted primarily to observe the kinds of gross effects that took place and differences in the intensity of effects associated with the different chemicals and application rates. It was decided to use our research capabilities to differentiate among the variables of chemicals and rates. In the future, long-term work will be needed to examine experimentally the more important effects identified in this pilot study.

## Methods

### Bird counts on transects

To help assess treatment effects on bird numbers, six 1-km transects were established 250 m apart in each of the five study plots (Fig. XII.1). Along each transect, a tree or shrub was marked with white paint every 100 m. Bird counts were taken on most transects and plots each week between 24 July and 7 October (Table XII.1).

**Table XII.1:** Time Schedule of Counts

Week of											
July		August				September				October	
23	30	6	13	20	27	3	10	17	24	1	
Count 1	2	3	4	5	6*	7**	8	9	10	11	

↑  
Treatments

\* Three transects per plot.

\*\* Only 3 transects on plot C.

Plots were visited in about the same sequence each week. During counts on a plot, each of two observers recorded birds on three transects. Counts were begun at 0700h and completed at about 1000h each day. During 50 minutes on each transect, birds heard or seen within 50 m of the transect were tallied. A constant pace was maintained by covering each 100 m of the transect in 5 minutes. Our counts did not always measure bird densities, as they were designed to provide only indices of bird abundance. However, for many larger species (e.g.,

Abyssinian Rollers *Coracias abyssinica*), average numbers per transect tallied approximate densities per 10 ha.

Birds flying over transects were tallied as were others, especially large birds such as raptors, that flew from the transect well ahead of the observer. Secretive and nocturnal birds were seldom recorded, and counts did not evaluate treatment effects on these species.

While establishing plots, common species were seen or heard sufficiently often to enable future identification during counts. For others, positive recognition required more time and varied with observer experience and ability. Such problems did not greatly influence the counts of common birds that were ultimately used to evaluate treatment effects. Counts provided indices of species abundance, and differences in observers' abilities were not important as long as each observer's ability remained relatively constant over time.

#### Bird counts in depressions

Three to five of the depressions in each plot were selected for monitoring bird abundance in the unique habitat found in depressions. One to four 15-minute counts were obtained in each depression both before and after treatments. An observer sat or walked around and through depressions while noting the birds present. Such counts were taken between 1000 and 1300 hrs. after transect counts.

#### Evaluation of breeding performance

##### *Singing Bush Larks.*

Larks (*Mirafra javanica*) bred throughout the study area during the period of our investigations. Singing males were one of the most common birds seen on transects as they hovered above breeding territories and nests located within grasslands. Special searches were conducted to increase the number of known nests, while others were found during counts on transects. To prevent nest detection by predators, we did not approach closer than 1 m while marking nests with stakes and checking them to determine the number of eggs, young, and fledglings. These records were obtained before treatments of plots, but were not continued because nesting success was too low to enable assessment of treatment effects.

##### *Buffalo Weavers.*

Colonies of Buffalo Weavers (*Bubalornis albirostris*) were present throughout the study area primarily in large Baobabs and acacias. The status of a number of colonies was noted during bird counts on each plot. Colonies were characterized as being in a state of courtship, nest building, incubation, or feeding young. As colonies and bird behavior were easily observed, activities in colonies were recorded before and after insecticide applications to assess treatment effects on weaver reproduction.

##### *Nest boxes.*

To explore the value of nest boxes in measuring the impact of insecticide treatments on hole-nesting species, 33 boxes were attached to trees in two plots. Fifteen were placed in plot 2C on 18 August before chlorpyrifos was applied and, on 20 August, 18 boxes were set out in the control area. The boxes were about 20 x 20 x 30 cm, with an entrance hole of 5 to 6 cm in diameter, and with a detachable top. Boxes were placed at least 100 m apart at a density of about 1 box per 4.5 ha.

## Searches for dead or debilitated birds

### *Searches.*

To measure any direct mortality from treatments, special carcass searches were organized. Twelve young men were recruited from nearby camps and villages. It was anticipated that these Poular herdsmen, who spend their lives herding livestock and observing activities in the savannah, could provide the most complete searches for dead and debilitated birds. Two searches were conducted on each of the four treated plots: one at 24 h and another at 48 h after treatments. Two additional searches were carried out on plot 2F at 3 days and at 6 days following fenitrothion applications. Identical searches were made on plot C (control plot) during the same period on 2 consecutive days. In each search, the 12 men, supervised by an assistant, spread out 20 m apart over a distance of 250 m and walked abreast for 2.0 km during a period of 2 to 3 h, depending on the density of vegetation. Searchers covered 8.3 percent of the area within each plot and searched 1.3 - 1.9 ha/h/person.

### *Search efficiency.*

On two occasions a number of dead birds were placed in an area to be searched in order to establish search efficiency. The search team was not informed of this prior to counts. On 7 September, before the 48-h search in plot 1F, 4 Singing Bush Larks, 22 Buffalo Weavers, and 10 Golden Sparrows (*Passer luteus*) were put out in the area. (The carcasses used were the birds that were killed for ChE measurement.) Each species was placed in a habitat where it likely could have died. The birds were labeled to distinguish them from birds that may have died from spray applications. On 13 September, during the 24-h search in plot 2F, 1 Abyssinian Roller, 1 Singing Bush Lark, 58 Buffalo Weavers, and 1 Golden Sparrow were placed in the search area. After the searches, remaining marked carcasses were not removed but were left to help evaluate subsequent searches.

The search efficiency was needed to calculate the proportion of the population killed (Fite *et al.* 1988). Separate efficiency coefficients were calculated for small birds (weight < 30 g) and larger birds.

### *Carcass disappearance rate.*

Dead birds were also used to determine the disappearance rate of carcasses due to scavenger activity. Both search efficiency and a disappearance rate need to be known in order to make a reliable estimation of mortality following a treatment. On 5 September, 5 Buffalo Weavers and 9 Golden Sparrows were placed at five locations along a transect in plot 1C and were checked after 24 and 48 h. On 13 September, 33 Buffalo Weavers were placed in plot 2F at seven locations along a transect. They were checked after 24, 48, and 72 h. The disappearance rate was used to calculate the proportion of carcasses remaining ( $R = 1 - \text{disappearance rate}$ ). This was also used in calculating the proportion of the population killed (Fite *et al.* 1988).

## Collections for food habits and cholinesterase analyses

### *Collections.*

Singing Bush Larks, Buffalo Weavers, and Golden Sparrows were initially chosen for monitoring changes in cholinesterase (ChE) levels and food habits following treatments. These species were abundant, widely distributed, and ranged in food habits from insects to

seeds. It was found that Golden Sparrows decreased rapidly in numbers after rains started and they were deleted from collections. As Abyssinian Rollers, Hoopoes (*Upupa epops*), and Woodchat Shrikes (*Lanius senator*) proved susceptible to treatments, they were added for collection. Birds primarily were taken with mist nets, a 4.5-mm air rifle, and a 16-gauge shotgun. For each species an attempt was made to collect 10 individuals in the first and third week after treatments in treated plots. Birds from untreated areas were taken for controls. Birds found dead or debilitated during searches were also saved for analyses.

#### *Specimen handling.*

Live specimens were killed by thoracic pressure and were subsequently dissected. In a few cases, specimens were frozen from 1 day to 2 weeks before they were dissected. Each specimen received a field collection number, and information on the bird was noted in a field collection log. Body masses were taken using spring scales with a precision of 0.3 percent. Body masses below 30 g were rounded to the nearest 0.5 g, and body masses above 30 g, to the nearest gram. During dissection birds were sexed and aged. The size of gonads and other information on breeding condition, like presence of a brood patch, were noted when relevant. In a number of cases, the amount of subcutaneous fat was estimated using a score from 0 (no fat) to 4 (maximum fat deposits). The gizzard (and crop, if present) was removed, and the contents or the complete gizzard was stored in ethanol (96 percent) in a small vial. Information on the amount of food was noted; gizzards that were completely empty were discarded. Brains were removed and placed in 15-ml scintillation vials, labeled with cryolabels, and subsequently stored in liquid nitrogen until they could be processed in the laboratory.

Voucher specimens were labeled and stored as flat skins or preserved in 96 percent ethanol for deposition in the Field Museum of Natural History (FMNH) in Chicago, Illinois, U.S.A. In the Museum, tentative identifications were verified, specimens were assigned to species or subspecies, and recent fledglings were confirmed by the presence of a bursa fabricii (S. M. Goodman, FMNH, *in lit.*)

#### *Food habits analysis.*

Gizzard collections were transported to the Department of Toxicology, Wageningen Agricultural University, The Netherlands. The contents were identified using a low-power binocular microscope with 7-40x magnification. Identifications were usually performed to the level of Orders. Often specific remains were used for identification and counting (e.g., Orthoptera jaws and Coleoptera headparts). All remains were tallied, and the number of prey items present was calculated. The presence of grit was also noted.

In calculations, the number of prey items and their relative occurrence were compiled. Using numbers of food items as a basis for determining food habits tends to bias results in favor of the small, numerous items. However, the procedure was satisfactory for comparing the kinds of foods eaten before and after insecticide applications.

#### *Cholinesterase analysis.*

Brains were transferred to storage in a laboratory freezer after fieldwork was completed. They were held in the freezer for about 2 months and analyzed over the next 6 weeks. ChE activity was determined by the colorimetric method of Ellman *et al.* (1961) as modified by Hill and Fleming (1982). Analyses were conducted by Prof. Mounirou Ciss and Dr. Boubacar

Niane (Chapter III). Results are expressed as  $\mu$  moles of acetylthiocholine iodide hydrolyzed per minute per gram (wet weight) of brain tissue ( $\mu$  moles/min/g).

#### Statistical analyses

The experimental design for this study did not include replications of treatments and, therefore, it did not fulfill theoretical requirements to permit general inferences from the results. However, analyses were conducted with the understanding that any differences detected could be due either to the effects of the chemicals, to inherent differences among plots, or to both factors.

Analyses of bird count data were made for the sum of 71 selected species, the sum of 21 selected species, and for 22 individual species, using a two-factor, repeated measures ANOVA with unbalanced data. Analyses were conducted for birds grouped by taxonomic and life history traits using a three-factor, repeated measures ANOVA with unbalanced data. Data were unbalanced because several counts on some plots were conducted by only one of the two observers.

Differences between plots and -within plots- between weeks, in the proportion of grasshopper remains in gizzards of selected species, were tested separately in single classification ANOVAs. The same analysis was conducted to test differences in body masses of captured specimens between and within plots. Means were separated with Duncan's Multiple Range test.

## **Results**

### Bird counts on transects

More than 120 species of birds were identified on the study plots between June and October (Annex XII.1). Some identification was tentative as individuals were seen only a few times, at a distance, or when visibility was poor. Afrotropical species (both residents and intra-African migrants) dominated the avifauna in June and July, but palearctic migrants increased in August, September, and October. Some species populations presumably were composed of both resident and migrant individuals. It was sometimes unclear whether increases observed over time were the result of local movements or of an influx of palearctic migrants. Observations on the control plot and other untreated areas showed that normal increases and decreases in certain species occurred unrelated to insecticide treatments.

Counts on study plots were conducted during and after the rainy season (July, August, September). Some birds had reproduced during the dry season (Abyssinian Rollers), while others initiated breeding with the beginning of the rains (Singing Bush Larks, Buffalo Weavers, Blue-eared Glossy Starlings *Lamprocolius chalybaeus*, Cricket Warblers *Prinia clamans*, and Fantail Warblers *Cisticola juncidis*).

Some of the species seen on study plots were not used in the assessment of treatment effects. Many species were not known to be exposed to insecticides and could not be viewed as reliable indicators of treatment effects. These included wide-ranging species (raptors), migrating species (swifts), and those such as sandgrouse and aquatic species traveling over plots to distant water sources. A few species were considered incidentals, as they were rare

and seldom seen. All birds in these categories and all palearctic migrants, most of which arrived after treatments, were not considered in evaluating treatment effects. Golden Sparrows were so numerous that changes in their abundance were capable of masking effects on the less abundant species if included with the others in compilations of total birds present. Therefore, data for this species were considered separately. Golden Sparrows were seen both on transects and flying over transects, and decreased naturally during the course of the study (Fig. XII.2).

The removal of the above birds left 71 species (designated by a single asterisk in Annex XII.1) for consideration in assessing insecticide applications. Of the 71, 21 species (designated by a double asterisk in Annex XII.1) were common on plots. Totals of the 71 species, the 21 species, each of the 21 species, and of Golden Sparrows (both on transects and over transects) were compiled for each transect. Means and standard errors for transects on each plot and each count are presented in Appendices 6 through 30. To determine whether life history characteristics of the 71 species made them more or less sensitive to treatments, analyses were conducted based on taxonomy (2 groups), macrohabitat (2 groups), feeding stratum (2 groups), and foods (3 groups) (see Annex XII.1).

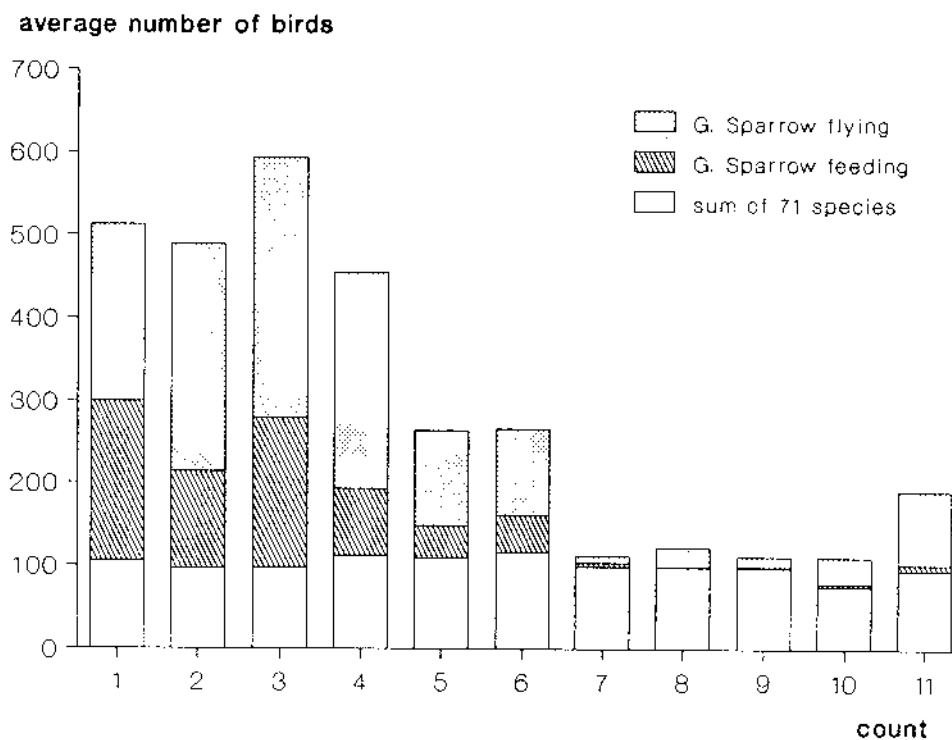
The total number of birds (sum of 71 species) and the total of the most common species (sum of 21 species) decreased after treatments ( $p < 0.01$ ). The percentage decrease in bird numbers was greatest on plot 2F and was greater on all treated plots than on the control plot (Table XII.2). In general, a greater decrease in bird numbers on plot 2F was indicated by all assessments ranging from the sum of 71 species (Fig. XII.3), the sum of 21 species (Fig. XII.4), and the life history traits of birds (Figs. XII.5a, 5b, 5c) to many of the individual species, such as the Singing Bush Lark (Fig. XII.6).

There were significant ( $p \leq 0.02$ ) interactions between counts and plots for 6 of the 22 species analyzed individually. Examination of data showed that interactions for Blue-eared Glossy Starlings, Golden Sparrows, and Grey Hornbills (*Tockus nasutus*) were not related to treatments. Mean separation tests indicated Abyssinian Rollers, Blue-naped Mousebirds (*Urocolius macrourus*), and Singing Bush Larks responded in the same way to treatments. In comparison to the control plot, their numbers temporarily decreased after treatment on plots 1F and 2F. By week 11 there were no real differences among plots in numbers of these three species.

Abyssinian Rollers increased during the study (Fig. XII.7), but by the third week after treatment (week 10), roller numbers on all treated plots were significantly ( $p = 0.01$ ) lower than on the control plot. Blue-naped Mousebirds also tended to increase during the first 8 weeks of the study (Fig. XII.8), especially on plots 1C and 2C, which by the eighth week had significantly higher numbers than the control plot ( $p = 0.01$ ). In contrast, on plots 1F and 2F, mousebirds numbers had dropped to zero 1 week after treatments. Singing Bush Larks were the second most abundant birds on plots (after Golden Sparrows). They likely were a good indicator species of treatment effects in the savannah; they were abundant, widely distributed, sedentary, and nesting in the grasslands. After treatments, lark numbers decreased on all plots as young fledged and birds presumably left the area. However, decreases were greatest and occurred more rapidly on plots 1F, 2F and 2C, all of which on the first or second week after treatment had significantly ( $p < 0.01$ ) fewer larks than the control plot (Fig. XII.6).

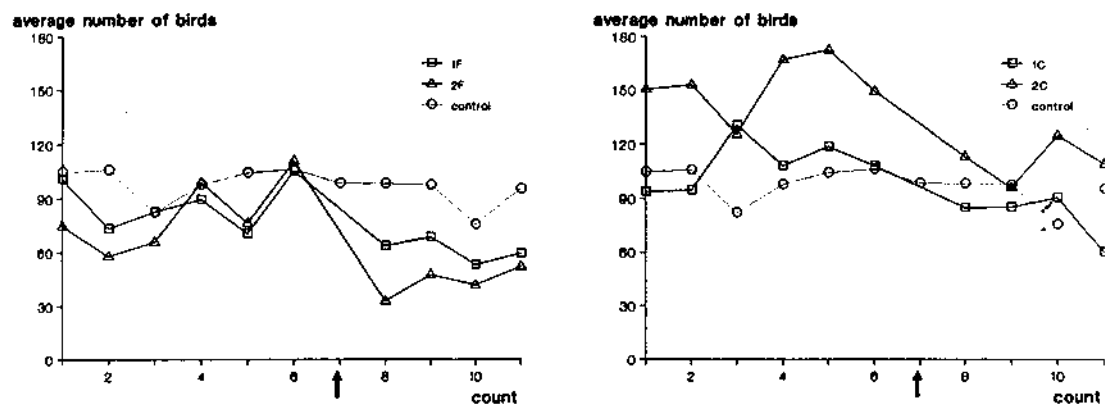
**Figure XII.2:**

Changes in average numbers per transect of Golden Sparrows in the control area seen flying over transects or feeding on transects. For comparison the average numbers of the 71 most common species are given as well.

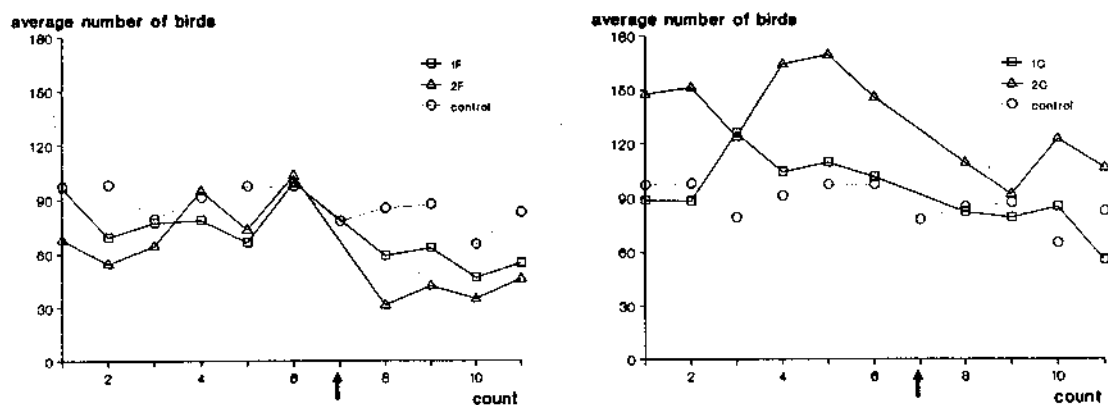
**Table XII.2:** Percent change in bird numbers between periods on study plots.

Data and means compared	Plot				
	1C	2C	1F	2F	Control
<u>Sum of 71 species</u>					
Pretreatment vs. posttreatment	-26	-28	-30	-46	-8
Count 6 vs. posttreatment	-26	-26	-42	-61	-14
<u>Sum of 21 species</u>					
Pretreatment vs. posttreatment	-26	-28	-32	-51	-13
Count 6 vs. posttreatment	-24	-26	-46	-63	-16

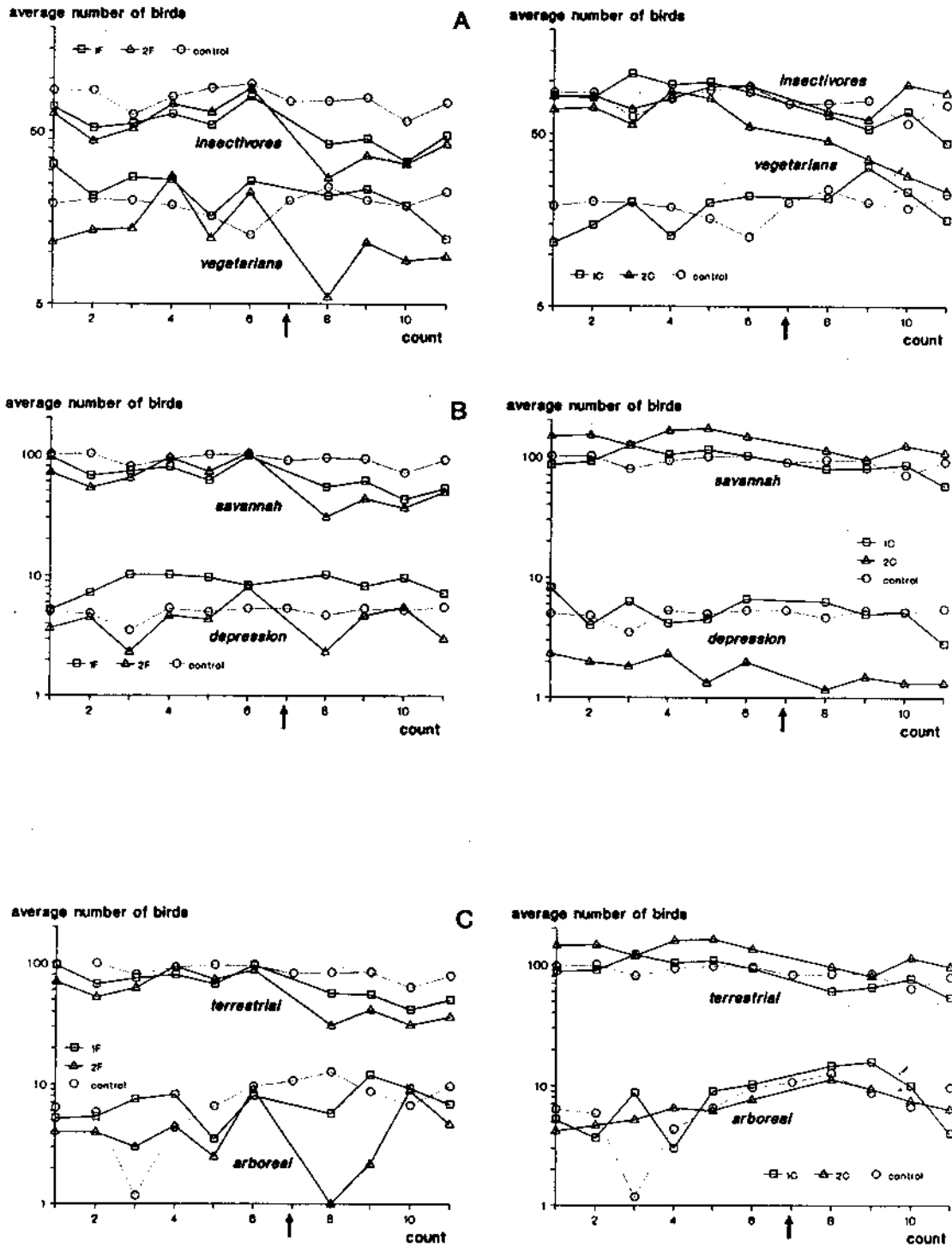
**Figure XII.3:** Average number per transect of 71 species seen during each count on experimental plots. An arrow indicates the moment of treatment.



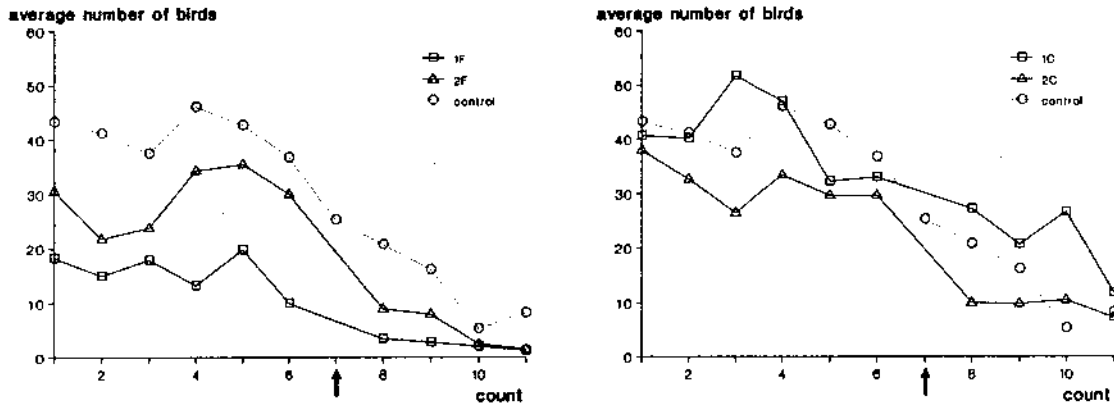
**Figure XII.4:** Average number per transect of 21 species seen during each count on experimental plots. An arrow indicates the moment of treatment.



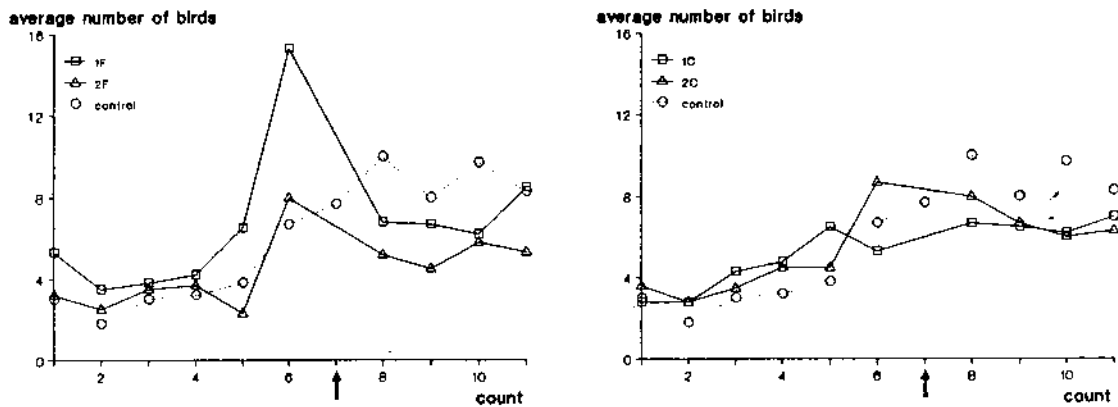
**Figures XII.5a-c:** Average number per transect of insectivores and vegetarians (A), savannah and depression birds (B), and terrestrial and arboreal feeding birds (C) seen during each count on experimental plots. An arrow indicates the moment of treatment.



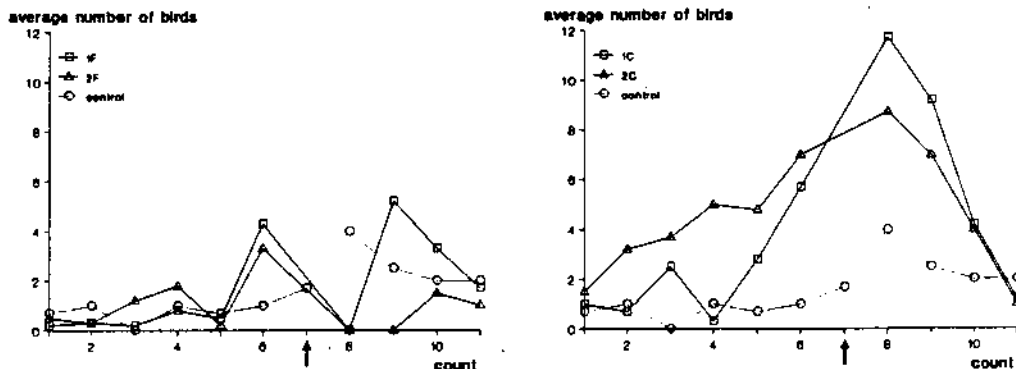
**Figure XII.6:** Average number per transect of Singing Bush Larks seen during each count on experimental plots. An arrow indicates the moment of treatment.



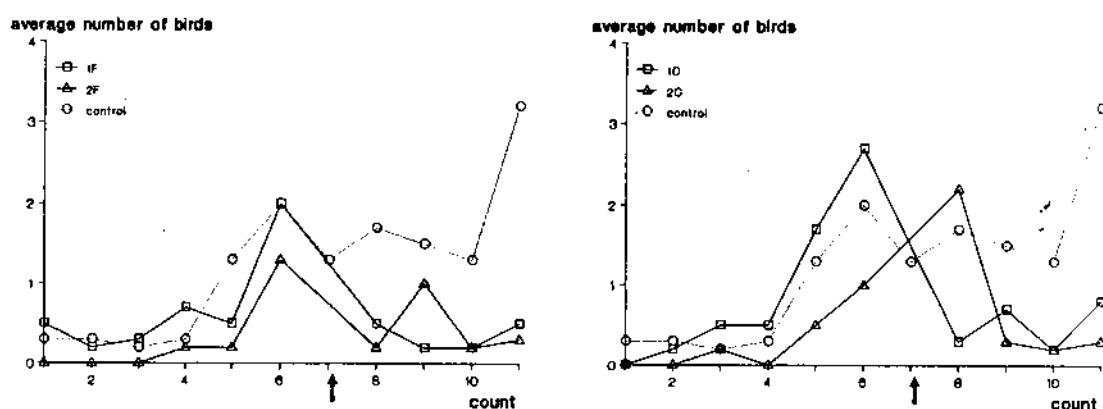
**Figure XII.7:** Average number per transect of Abyssinian Rollers seen during each count on experimental plots. An arrow indicates the moment of treatment.



**Figure XII.8:** Average number per transect of Blue-naped Mousebirds seen during each count on experimental plots. An arrow indicates the moment of treatment.



**Figure XII.9:** Average number per transect of Hoopoes seen during each count on experimental plots. An arrow indicates the moment of treatment.

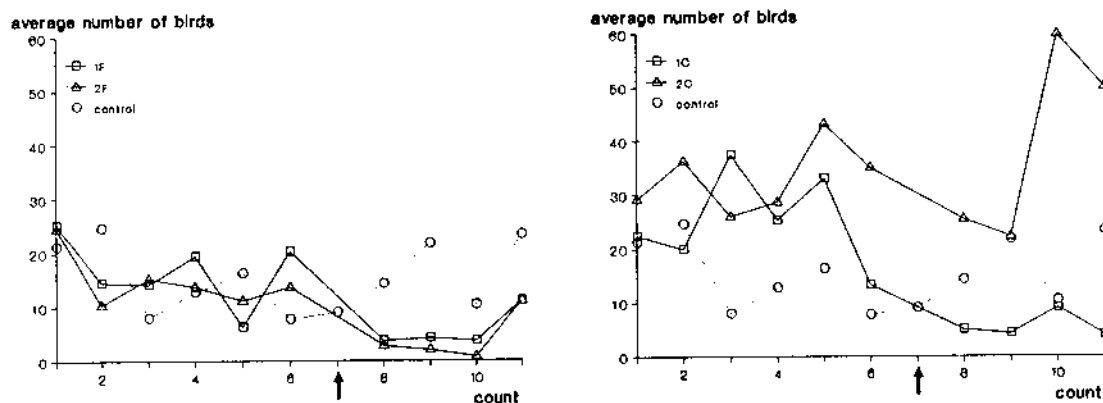


Interesting, but nonsignificant, changes were documented after treatments in numbers of Hoopoes and Buffalo Weavers on treated plots. Hoopoes increased in the general study area up until insecticide applications. During the next 4 weeks, numbers on treated plots decreased and were usually lower than on the control plot (Fig. XII.9). Hoopoe numbers were highly variable among transects and plots, and differences were not significant ( $p = 0.12$ ).

Buffalo Weavers were highly gregarious and were most often seen flying between colonies and feeding areas, the location of which varied over time. Counts of weavers frequently changed erratically on transects, probably depending on whether they fed near transects or whether feeding flight lines crossed transects. Buffalo Weavers were often seen in flocks, locally following terrestrial movements of grasshoppers. Weavers decreased on treated plots immediately after insecticide applications (Fig. XII.10). Although these changes were not significant ( $p = 0.11$ ), they provided a strong indication of a treatment effect. Weavers had gathered into colonies before treatments. On treated plots, all colonies monitored (3 or 4 per plot), except one on plot 2C, were deserted after treatments. Colonies on the control plot persisted, one until 27 September.

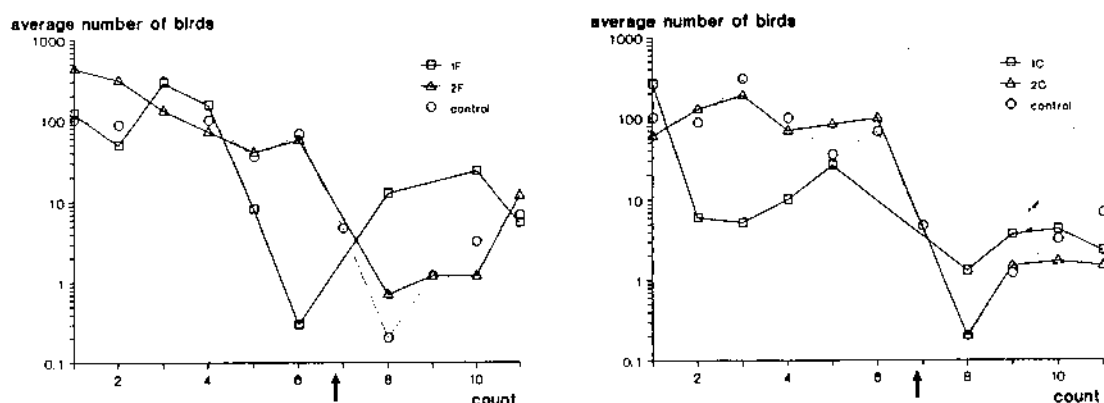
Dove abundance did not change appreciably on most plots after spraying, but numbers of Pink-headed Doves (*Streptopelia roseogrisea*) on plot 2C dropped considerably during weeks 8 through 11 (Annex XII.10). These decreases were not significant, but may have been real as observers independently recognized and commented on the general decrease in Pink-headed Doves on plot 2C. Before treatments, all doves tended to be more abundant on plot 2C than elsewhere. A nearby water well used daily by local inhabitants provided a dependable water source to support doves. After rains, a source of water may have been less critical, and grass seed production elsewhere in areas receiving earlier rains may have provided better food resources.

**Figure XII.10:** Average number per transect of Buffalo Weavers seen during each count on experimental plots. An arrow indicates the moment of treatment.

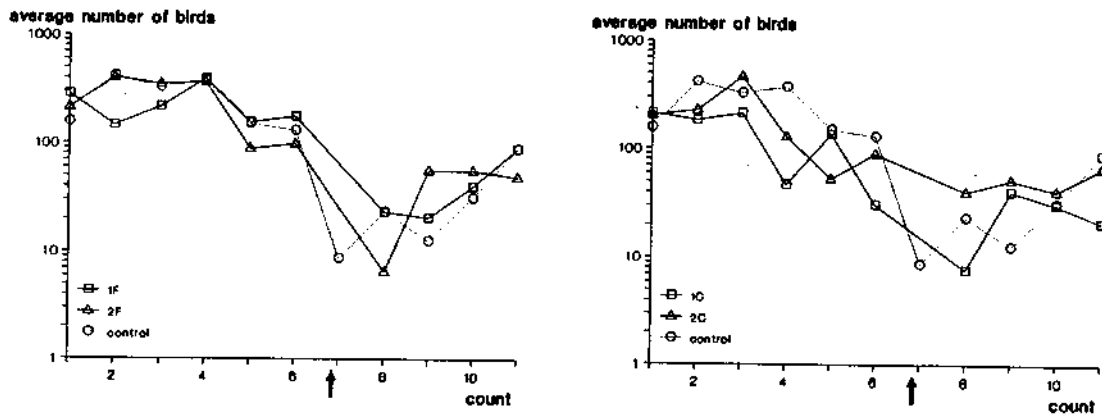


Golden Sparrows were apparently not affected by treatments; however, their numbers decreased significantly ( $p = 0.01$ ) on all plots over time (Figs. XII.11 and 12). They constituted 80 percent of total birds seen on the control plot during the first five counts and only about 30 percent during the last four counts (Fig. XII.2). Their decrease was correlated with breeding elsewhere in the region and with the growth of new annual grasses in the study area, which may have restricted their ability to forage for seeds on the ground. Sparrows were increasing during our last counts as grasses dried and a new crop of seeds ripened. At that time flocks consisted largely of recently fledged birds.

**Figure XII.11:** Average number per transect of Golden Sparrows seen during each count on experimental plots. An arrow indicates the moment of treatment.

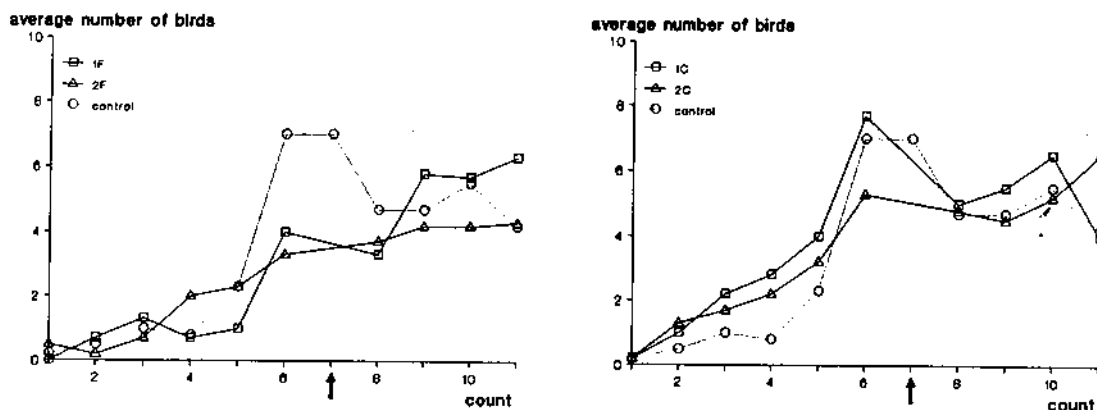


**Figure XII.12:** Average number per transect of Golden Sparrows seen during each count flying over experimental plots. An arrow indicates the moment of treatment.



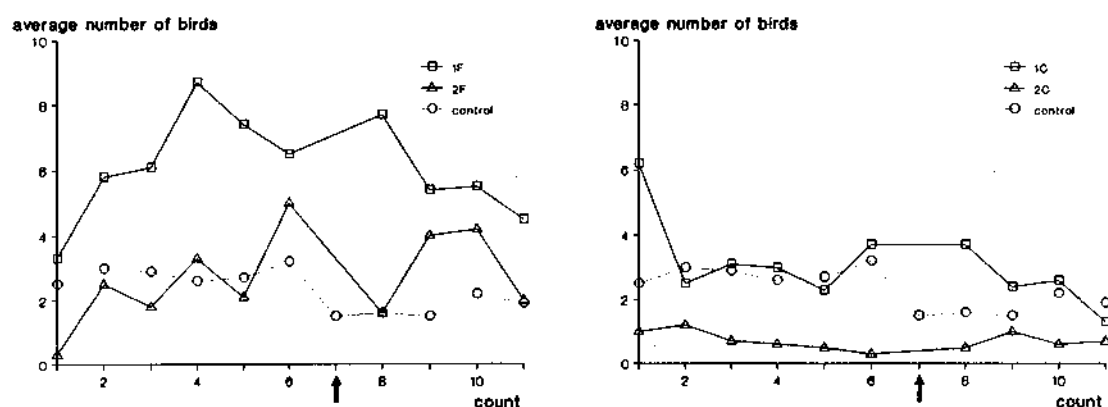
In contrast to Golden Sparrows, Woodchat Shrikes greatly increased on plots during the study period but, like sparrows, the shrikes were not apparently affected by treatments. The Woodchat Shrike precedes all other palearctic migrants in autumn (Morel and Roux 1966). Shrike numbers gradually increased through week 6 (Fig. XII.13). After treatments, shrike numbers on all plots remained somewhat stable, suggesting that they already had reached their winter density. Cricket Warblers also increased during the study and did not appear to be affected by insecticide treatments (Annex XII.25). Increases partly were due to the appearance of young with adults; the Cricket Warblers bred during the period of the study.

**Figure XII.13:** Average number per transect of Woodchat Shrikes seen during each count on experimental plots. An arrow indicates the moment of treatment.



Other afrotropical species that were widely distributed and bred during the study period did not appear affected by insecticide treatments. Numbers of Black Bush Robins (*Cercotrichas podobe*) ( $p = 0.03$ ), Grey-backed Camaropteras (*Camaroptera brachyura*) ( $p < 0.01$ ), and Fantail Warblers ( $p = 0.07$ ) varied among plots and over time, but not in relation to treatments (Fig. XII.14). These species were considered obligate depression species, and the lack of an effect on them suggests the depression habitat was not affected by spraying to the same degree as the savannah habitat (see also Fig. XII.5b).

**Figure XII.14:** Average number per transect of Black Bush Robins, Grey-backed Camaropteras, and Fantail Warblers seen during each count on experimental plots. An arrow indicates the moment of treatment.



Effects of fenitrothion were indicated, especially on plot 2F, for most groups of birds whether separated on the basis of taxonomy, food habits, or feeding stratum (Table XII.3). This suggests that these traits did not predispose birds to fenitrothion effects. In contrast to birds on the control plot, those on fenitrothion plots tended to decrease after treatments regardless of their taxonomic position or their life history traits (except that depression species increased). This situation probably reflects the fact that birds are somewhat opportunistic in their choice of foods. The abundance of grasshoppers on plots (see Chapters VII and VIII) may have supported high bird populations. Reduction of that food source, therefore, could have caused some birds to leave plots.

**Table XII.3:** Percent change in numbers of birds grouped by taxonomic and life history traits on control and fenitrothion plots.<sup>a</sup>

Traits	Plot		
	1F	2F	Control
<u>Taxonomy</u>			
Passerine	-39	-67	-12
Nonpasserine	-40	-65	+91
<u>Habitat</u>			
Depression	+32	-67	+12
Savannah	-72	-81	+24
<u>Feeding stratum</u>			
Terrestrial	-42	-60	+10
Arboreal	-34	-78	+76
<u>Food habits</u>			
Insectivores	-20	-54	+77
Omnivores	-54	-74	-20
Granivores/frugivores	-38	-66	+89

<sup>a</sup> Percent difference between birds seen during Count 6 (last pretreatment count) and Count 8 (first posttreatment count).

A normal variation was observed among plots in the abundance of certain species (Table XII.4). These differences were not related to treatments, but undoubtedly reflected the preference of birds for habitat resources on specific plots. Such habitat preferences were not identified, but such variations in the abundance of a species among plots illustrate why replication of plots is necessary in experimentation. Resources affected by insecticide treatments were not uniform among plots, so the possibility of each treatment's effect on birds was not equal. Replication of plots increases the probability that variations in resources and thereby in the kinds and numbers of birds will be equally tested against each treatment.

**Table XII.4:** Variations among plots in the numbers of birds of selected species.\*

Species	Plot				Control
	1C	2C	1F	2F	
Namaqua Dove	13	61	26	19	19
Vinaceous Dove	3	<u>15</u>	10	5	7
Pink-headed Dove	26	<u>231</u>	37	19	44
Laughing Dove	8	<u>23</u>	13	4	9
Blue-naped Mousebird	7	<u>18</u>	2	4	3
White-throated Bee-eater	8	<u>14</u>	2	4	7
Red-beaked Hornbill	2	0.5	<u>6</u>	3	2
Singing Bush Lark	207	160	84	137	<u>209</u>
Chestnut-backed Finch Lark	15	11	<u>24</u>	16	4
Chestnut-bellied Starling	9	19	<u>22</u>	10	12
Black Bush Robin	2	2	<u>6</u>	2	5
Fantail Warbler	13	1	<u>23</u>	9	8
Buffalo Weaver	138	<u>164</u>	80	75	83

\* Values are the totals of Counts 1-5 on each plot for each species. Highest value for each species is underlined.

Table XIL5:

Total numbers of birds seen during depression counts.\*

Plots	1C		2C		1F		2F		Control	
Species	Pre (10)	Post (5)	Pre (10)	Post (3)	Pre (8)	Post (3)	Pre (9)	Post (7)	Pre (14)	Post (5)
Namaqua Dove	1	1	2	4	-	-	12	-	8	-
Vinaceous Dove	7	1	1	3	1	1	-	5	4	-
Pink-headed Dove	2	1	8	1	4	-	3	4	6	8
Laughing Dove	6	4	-	3	3	-	-	2	6	2
Blue-naped Mousebird	8	1	10	8	-	-	7	3	2	-
White-throated Bee-eater	-	11	1	2	1	-	1	1	14	22
Abyssinian Roller	11	7	5	5	9	3	3	4	11	12
Red-beaked Hornbill	1	-	-	-	7	2	2	-	3	-
Woodchat Shrike	10	3	8	1	3	5	5	1	1	10
Blue-eared Glossy Starling	6	1	2	5	3	1	1	-	9	1
Chestnut-bellied Starling	1	17	3	2	2	-	1	3	22	-
Black Bush Robin (d)	10	3	10	6	6	1	6	1	11	3
Fantail Warbler (d)	4	1	-	-	7	2	3	5	4	1
Cameroptera (d)	1	2	5	6	4	1	8	1	10	6
Long-tailed Beautiful Sunbird	10	1	4	-	9	-	7	2	4	4
Vitteline Masked Weaver (d)	10	1	11	5	1	1	9	-	13	16
Buffalo Weaver	1	-	8	-	8	-	4	-	22	14
Total	88	54	78	46	68	17	72	32	150	99
Average	9	11	8	15	8	6	8	5	11	20
Change (%)	+20		+88		-25		-38		+82	

\* Number of counts in parentheses. "Pre" indicates pretreatment, and "post," posttreatment.  
 (d) indicates birds are depression species; other species also used savannah habitats (ds or s species).

### Bird counts in depressions

A total of 55 species of birds was seen during depression counts, including incidentals and palearctic migrants. Of these, only 17 species were relatively abundant (Table XII.5). There were large variations in counts, both within individual depressions and among different depressions. Numbers of observations were too few to test for significant changes due to treatments. Still, it was of interest that the data, when compiled, suggested the same detrimental effects of fenitrothion as indicated by transect counts and other observations. Whereas depression counts in the control and chlorpyrifos plots indicated an increase in total birds present after treatments, numbers in fenitrothion plots apparently decreased. These findings do not conflict with the increase in depression species shown in Table XII.3. Counts in depressions reported here included all birds that were seen in depressions and were not limited to only the obligate depression species.

These results again suggested that fenitrothion treatments decimated food resources to a much greater extent than chlorpyrifos treatments. In contrast to transect counts, depression counts on the chlorpyrifos plots and the control plot suggested bird numbers increased. Birds on those plots may have used the verdant depressions more frequently as the savannah habitat dried following the rainy season.

### Evaluation of breeding performance

#### *Singing Bush Larks.*

Twenty-eight lark nests were located during searches. Virtually all nests had the entrance facing a northerly direction. Once this feature was identified, nests were found more easily. Information on the nests, as well as on the calculation of the breeding success, is given in Annex XII.2.

Records for the complete nesting cycle were obtained for only a few nests. Therefore, Mayfield's (1961) method was used to calculate breeding success. With this approach the probabilities for nest, egg, and nestling survival were calculated based on the number of days each nest was under observation. Combining these figures gives the probability for a single egg to produce a fledgling.

The probability of nest survival during the incubation period was 16-24 percent (4 nests were destroyed by predators; 2 nests were deserted; while in 5 new nests, no eggs were detected despite the observation of birds on the nests). The probability of nest survival during the nestling period was calculated to be 53-59 percent, with 3-5 nests destroyed by predators. Egg survival was 94-100 percent, and nestling survival appeared to be 92-93 percent. Combining these probabilities, the total production for the entire duration of the nest is between 7 and 13 percent. In other words, for each 100 eggs laid, only 7-13 produced a fledgling. It is unknown whether our activities, despite precautions, may have contributed to this low breeding success.

#### *Buffalo Weavers.*

Frequently colonies of Buffalo Weavers were established, became involved in early reproductive behavior, and then were deserted. Others lacked synchrony, with nest building occurring in colonies where young were being fed. In some, successive cohorts of young were produced; these often were large colonies and, of course, were very productive. It was

impossible through casual observation to monitor the establishment, progress, and success or desertion of colonies. However, records were maintained for a number of active colonies observed during the first 5 and last 4 weekly transect counts on each plot. These records documented the locations of colonies, their desertion, and in many cases their reestablishment. The number of colonies active before and after treatment compared to the total initiated are shown in Table XII.6.

**Table XII.6:** Occupancy rate of Buffalo Weaver nesting colonies before and after treatment of plots.<sup>a</sup>

	Plot				
	1C	2C	1F	2F	Control
<u>Period</u>					
Prespray (end of August)	3/6	5/7	3/6	2/4	3/6
Postspray (mid-September)	0/6	2/7	0/6	0/4	3/6

<sup>a</sup> Data represent number of active colonies/total number of colonies initiated on plot.

Most colonies on treated plots were deserted at about the time of spraying. Observations were insufficient to determine if desertion was due to treatments, but results indicated insecticides may have caused these changes. Some evidence suggested that, during applications, areas containing colonies that persisted on plot 2C were not sprayed.

#### *Nest boxes.*

A complete nest was built in 9 of the 33 nest boxes set out. In an additional 7 boxes, nests were started, but not completed. Of the 9 completed nests, 1 was built by Blue-eared Glossy Starlings, 5 by Red-beaked Hornbills (*Tockus erythrorhynchus*), and 3 by Grey-headed Sparrows (*Passer griseus*). Nesting success was poor. Four of the 5 hornbill nests were destroyed by Peulh children from a nearby village. The fifth hornbill nest was in plot 2C and contained four young when last checked on 12 October. Of the Grey-headed Sparrow nests, one produced a single fledgling; another was deserted before egg laying. The third, in plot 2C, was successful, but the number of young fledged was not determined. The Glossy Starling nest in the control plot produced one fledgling.

## Searches for dead and debilitated birds

### *Searches.*

A few dead or debilitated birds were found in all treated plots (Table XII.7), while none were located in the control plot. The greatest number and variety of birds were found in plot 2F, which had been treated with 825 g ai/ha of fenitrothion. Button Quail (*Turnix sylvatica*), Abyssinian Rollers, Hoopoes, and Singing Bush Larks were most frequently affected on plots. Searchers captured a number of fledglings from the ground, and these also were predominantly Singing Bush Larks. These were likely affected by treatments, based on the ChE analyses.

**Table XII.7:** Dead (D) and debilitated (d) birds found on plots after treatment.\*

Species	Plot			
	1F	2F	1C	2C
Button Quail	-	2(d)	1(d)	-
White-throated Bee-eater	-	-	-	1(d)
Abyssinian Roller	1(d)	1(d)	-	3(D)
Hoopoe	-	1(D)	2(d)	--
Singing Bush Lark	1(D)	1(D)	-	1(D)
Tree Pipit	-	-	1(d)	--
Woodchat Shrike	-	2(d)	-	-
Cricket Warbler	-	1(d)	-	-

\* Fledglings of the Long-tailed Beautiful Sunbird (2), Buffalo Weaver (1), Singing Bush Lark (28), Pink-headed Dove (1), and Black-headed Shrike (1) were picked up during searches. Results of ChE analyses suggest that at least a number of these birds were debilitated, rather than simply flightless (see text).

Two fledgling larks and one fledgling Pink-headed Dove and no dead or debilitated birds were found on the control plot.

### *Search efficiency.*

Of the 22 Buffalo Weavers placed in the search area of plot 1C, 9 (42 percent) were found, while only 2 (14 percent) of 14 Singing Bush Larks and Golden Sparrows were located. These results and the fact that vegetation was more dense on most other plots prompted us to intensify the searches by increasing search time from 1 h to 1.5 h per km. In plot 2F, 33 (57 percent) of 58 Buffalo Weavers were recovered, but none of the other three carcasses (roller, lark and sparrow) were located. After 24 h, another search was made, and 7 more weavers and a roller were found, giving a total recovery of 69 percent for larger birds. A third search after 48 h did not produce additional carcasses. Calculated efficiencies are given in Annex XII.3.

#### *Carcass disappearance rate.*

Of 9 sparrows and 5 weavers put out on plot 1C, 1 sparrow and 2 weavers (total of 22 percent) disappeared within 24 h. After 48 h, most carcasses contained fly larvae. In plot 2F, none of 33 weavers were missing after 24-, 48-, and 72-hour checks, and there was little evidence of sarcophagic fly and beetle activity. For calculations it was assumed that the proportion of carcasses remaining on plot 2C was the same as on 1C, and on plot 1F the same as on 2F. Therefore, the proportion of carcasses remaining was taken to be 1.0 on plots 1F and 2F, and 0.8 on plot 2C (Annex XII.3).

#### *Population mortality.*

Values for calculation of mortality in large (> 30 g) and small (< 30 g) species populations of savannah birds are given in Annex XII.4. Mortalities calculated on plots 1F, 2F, and 2C are given in Table XII.8. In plot 1C, only one debilitated bird was found, and population mortality was not calculated. Calculated population mortality was low on all plots. Mortality was not sufficiently high to account for decreases observed in bird numbers on transect counts.

**Table XII.8:** Calculated minimum mortality (percent) of the bird populations occurring in savannah habitat due to treatment with insecticides (see Appendix 4).

Size of birds	Plot <sup>a</sup>		
	1F	2F	2C
> 30 g	2	7	2
< 30 g	7-9	6-13	3-10

<sup>a</sup> Insufficient numbers of birds were found on Plot 1C to calculate mortality.

#### Collection of birds

The sex, age, and breeding condition of birds collected are listed in Annex XII.4. Buffalo Weavers, Abyssinian Rollers, Singing Bush Larks, and Golden Sparrows made up of most of the individuals collected. Brains and gizzards were saved from most birds to enable ChE and food habits analysis, respectively. Gonad condition indicated clearly that Buffalo Weavers were breeding in August and September. Most Abyssinian Rollers were immature birds and were not in breeding condition. Larks were in full breeding condition throughout the study period as were most Golden Sparrows. Many juvenile sparrows, apparently produced after rains had started, were mixed with adults in the population.

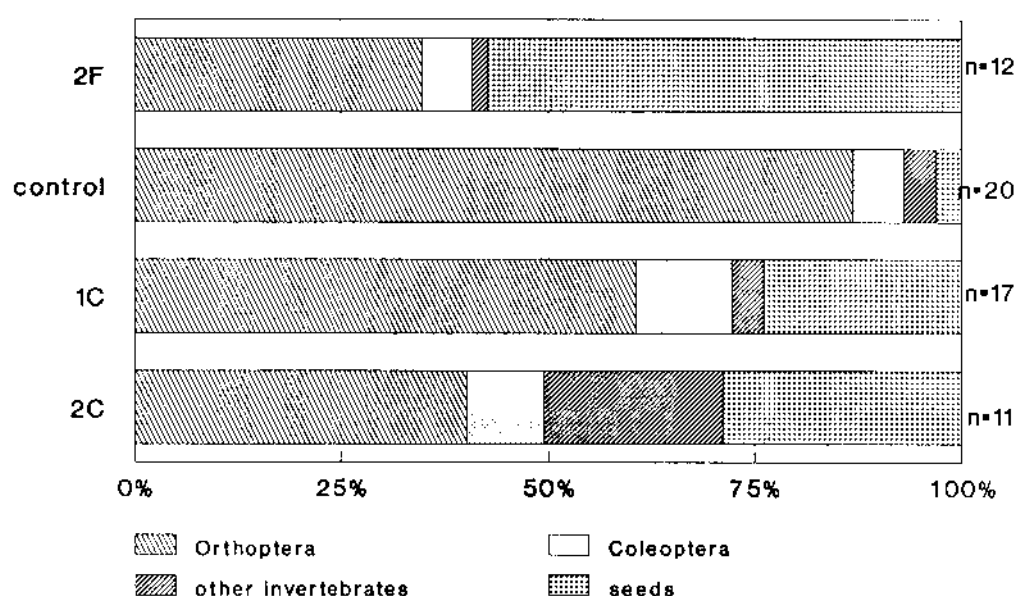
### Food habits analyses

Numbers of items found in gizzards of birds collected posttreatment on study plots are shown in Annex XII.5. From these data certain inferences can be drawn on differences in foods eaten by several birds after insecticide applications.

#### *Singing Bush Larks.*

The percent composition of Singing Bush Lark gizzard contents, based on numbers of food items, is shown in Figure XII.15. The Singing Bush Lark showed a clear response to treatment in its feeding behavior. In the control areas, food items consisted predominantly of grasshopper larvae, with seeds present in only two of the 18 gizzards containing food (11-percent). In the sprayed plots, however, 17 of 38 gizzards (45 percent) had seeds in them. The proportion of Orthoptera in the gizzard remains from the control areas was statistically greater ( $p < 0.05$ ) than in the chlorpyrifos and fenitrothion plots (plots 2C and 2F).

**Figure XII.15:** Percent composition of various foods in gizzards of Singing Bush Larks on experimental plots after treatments (based on numbers of food items in gizzards).



There were no apparent differences in prey selection between adults and fledglings. There was, however, a marked difference in the presence of grit in gizzards between adults and juveniles. In juvenile birds, 16 of 25 gizzards (64 percent) contained 1 to 25 small stones (maximum weight 0.25 g/gizzard), while in adult birds only 4 out of 33 birds (12 percent) contained grit in the gizzard.

Flightless fledgling Singing Bush Larks were significantly heavier ( $p < 0.05$ ) in the control than in the treated plots, while among treated plots there were no significant differences in body masses. There were no significant differences in adult lark body masses between control and treated plots.

#### *Abyssinian Rollers.*

Treatment effects were not obvious in Abyssinian Roller gizzard contents (Fig. XII.16). Grasshoppers made up 60-95 percent of all prey remains that were identified. The main species was probably *Oedaleus senegalensis*, but *Acrida bicolor* and *Cataloipus cymbiferus* were incidentally identified in the prey remains. Based on the size of the jaws, predominantly adults or subadults were eaten. Four rollers that were found dead or debilitated 24 h after spraying (1 in plot 1F and 3 in plot 2C) had 35, 32, 29, and 51 grasshoppers, respectively, in their gizzards. In contrast, up to 14 grasshoppers were found in each of the nine rollers from the control plot and up to 19 grasshoppers were found in each of the 39 gizzards collected in treated plots. An immediate shift to feeding on dead or dying grasshoppers and rapid intoxication is likely, therefore, to have been responsible for the observed direct effects on Abyssinian Rollers in the study plots. A comparison of the relative proportion of the different prey items in roller gizzards between week 1 and week 3 posttreatment (Fig. XII.17) shows a decreasing proportion of grasshoppers present in treated plots and a stable proportion in the control. However, because of large individual variation, decreases were not statistically significant.

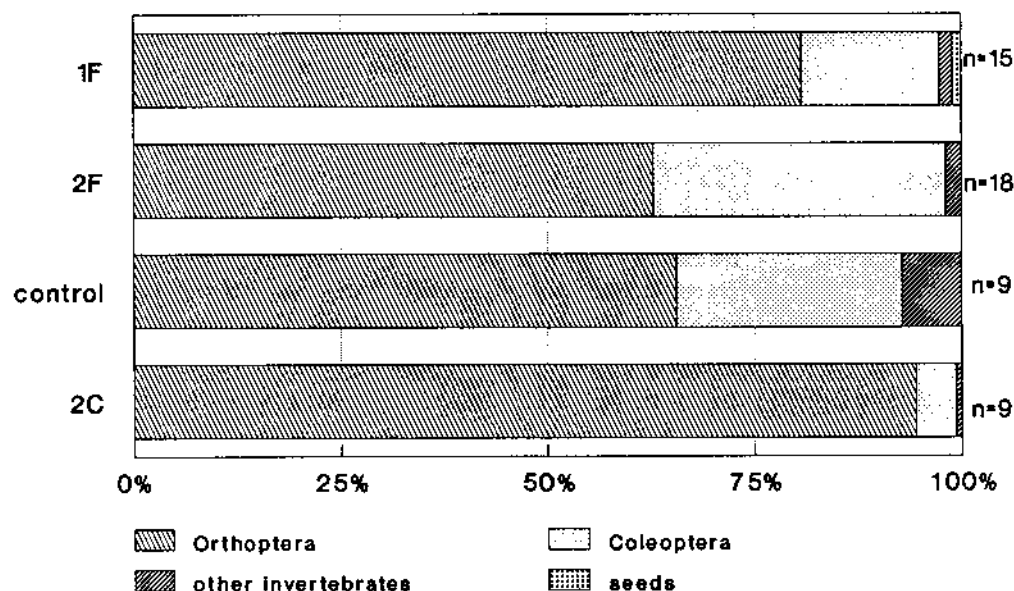
Abyssinian Roller body masses were not significantly different in control and treated plots. There were also no significant differences in body masses of rollers between week 1 and week 3 posttreatment.

#### *Buffalo Weavers.*

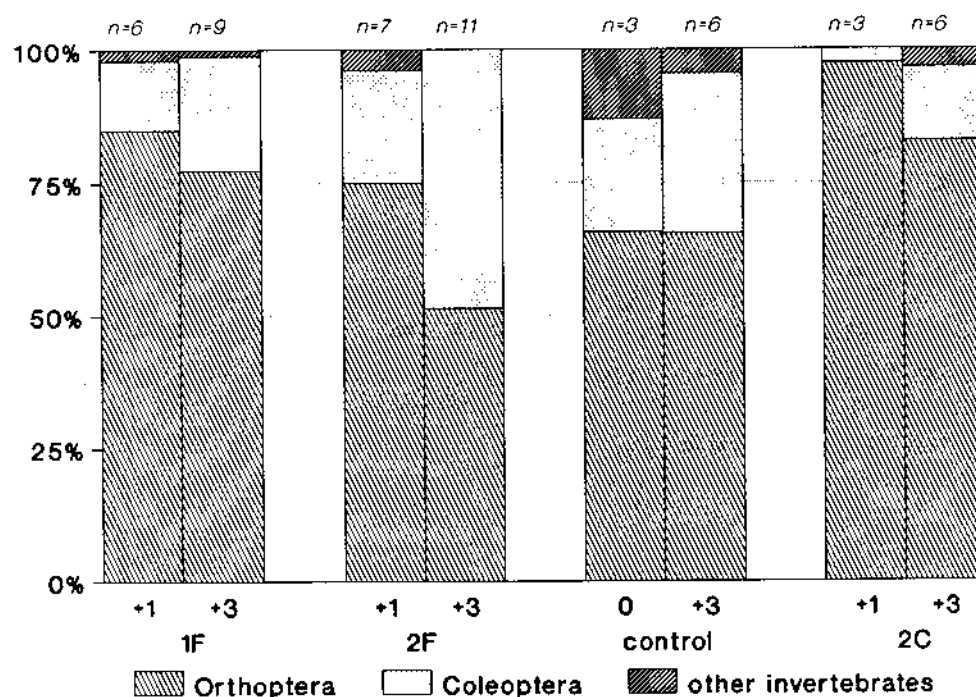
Treatments had little effect on gizzard contents of Buffalo Weavers (Fig. XII.18). Orthoptera were an important prey of Buffalo Weavers, making up 25-90 percent of the total remains present in individual gizzards and averaging 35-70 percent. Apparently, Buffalo Weavers were opportunistic feeders, adapting rapidly to the prey that was locally available. Birds from a colony at the project camp, used as controls, showed a dramatic shift in their diet within 1 week (Fig. XII.19). Therefore, it was more difficult to determine if changes in diet were an effect of treatments. Like Abyssinian Rollers, the Buffalo Weavers had a lower proportion of Orthoptera in their diet in week 3 than in week 1 posttreatment (Fig. XII.19), but changes were significant ( $p < 0.05$ ) only in plot 2C.

Adult female Buffalo Weaver body masses decreased significantly ( $p < 0.05$ ) from week 1 to week 3 posttreatment in both plots 2C and 1F. No changes were observed in the control plot; insufficient data were available from other plots to examine possible effects. Information on food habits of other species found dead or debilitated or otherwise obtained is summarized in Annex XII.6.

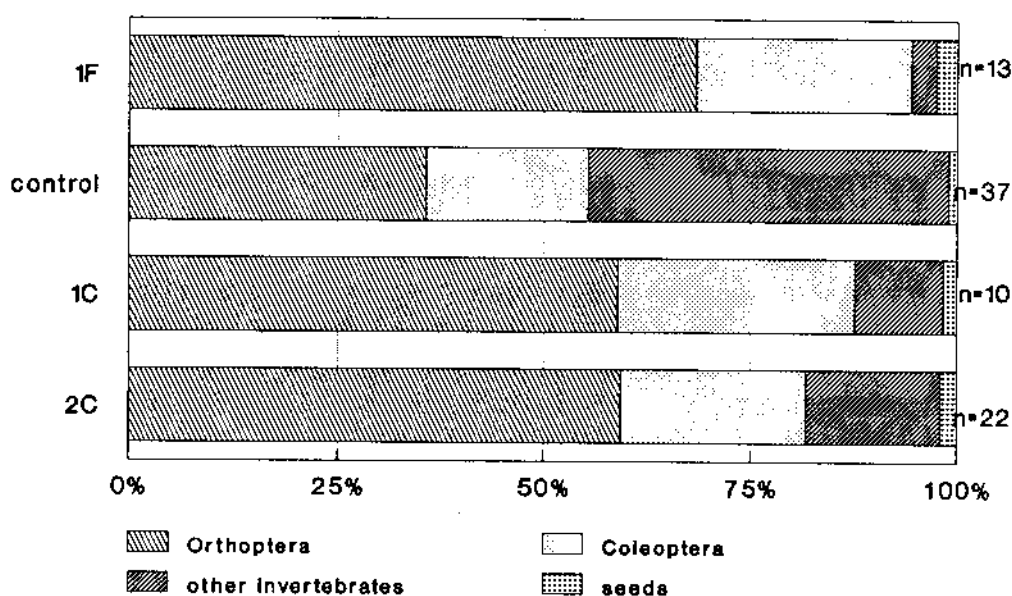
**Figure XII.16:** Percent composition of various foods in gizzards of Abyssinian Rollers on experimental plots after treatments (based on numbers of food items in gizzards).



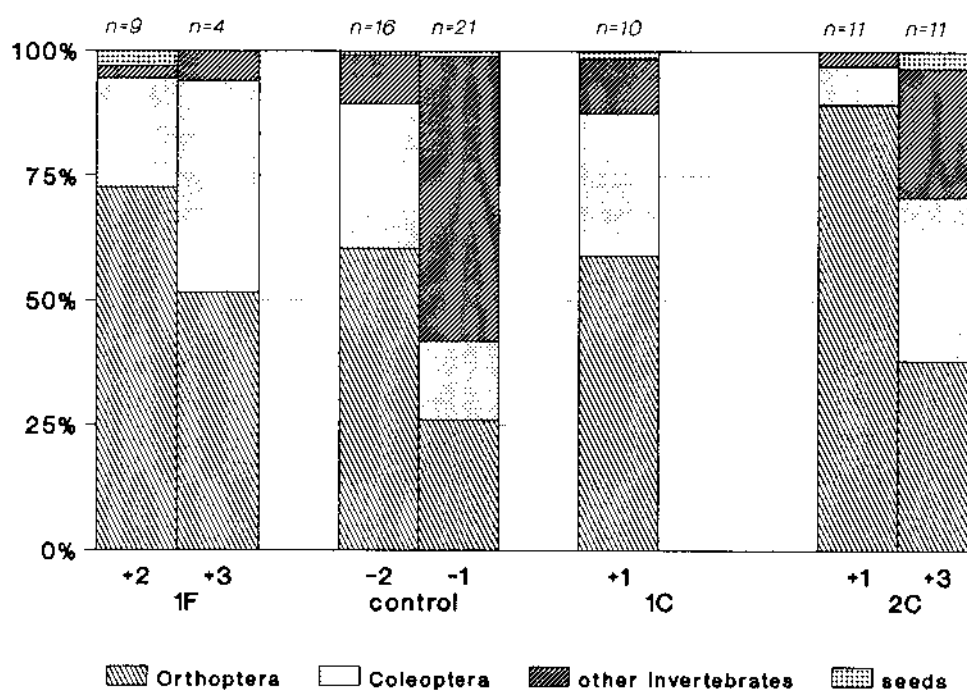
**Figure XII.17:** Percent composition of various prey in gizzards of Abyssinian Rollers on experimental plots at 0-1 weeks and at 3 weeks posttreatment (based on numbers of prey in gizzards).



**Figure XII.18:** Percent composition of various foods in gizzards of Buffalo Weavers on experimental plots after treatments (based on numbers of food items in gizzards).



**Figure XII.19:** Percent composition of various foods in gizzards of Buffalo Weavers on experimental plots before and at 1 to 3 weeks after treatments (based on numbers of food items in gizzards).



### Cholinesterase analyses

Brain samples were stored in liquid nitrogen from the time they were collected until mid-September. The method of analysis and the results are given in Chapter III. Because of sample losses, adequate numbers of unexposed birds were available for only two species--Abyssinian Rollers and Singing Bush larks. After treatments, Singing Bush Larks, Abyssinian Rollers, and Buffalo Weavers were the principal species collected. Buffalo Weavers decreased on all plots, except plot 2C, and were very difficult to collect, especially on plot 2F. Likewise, Singing Bush Larks decreased on all plots, and adequate collections were not always obtained. The problem of maintaining systematic collections on plots as bird abundance decreased due to treatments was not anticipated and was one of the lessons learned during this pilot study.

Dead and debilitated birds found on plots immediately after treatments (Table XII.7) had low ChE levels in their brains (Table XII.9). Compared to unexposed birds (Table XII.10), ChE levels were sufficiently inhibited to have caused death and debility of the birds. ChE levels also were low in fledglings found by searchers. In the young larks from plot 2F, ChE ranged from 6.32 to 16.27  $\mu\text{mol}/\text{min}/\text{g}$ ; lowest levels were in birds found 72 h after treatment. ChE levels in brains of fledgling larks from all plots were well below those in adult larks ( $x = 40.0$ ) and in one fledgling (29.9) from untreated areas (Table XII.10). This suggested that lark fledglings were impaired by exposure to insecticides, but (except in one bird) their normal ChE levels were not determined.

ChE inhibition of 50 percent or more is accepted as severe and is considered diagnostic as the cause of death in dead birds (Hill and Fleming 1982). Debilitated adult birds and fledgling larks in plots 1F and 2F showed an inhibition greater than 50 percent compared to controls. ChE inhibition was not as severe in dead birds found in plots 1C and 2C.

Live birds collected from plots 1 week after treatments often had lower ChE levels than controls, but after 3 weeks ChE levels in birds from treated plots were about the same as those in controls (Table XII.10). ChE inhibition usually was not severe in live birds collected from plots after treatments, but Singing Bush Larks collected 1 week after treatment of plot 2F showed a 50 percent inhibition. After 1 week, Abyssinian Rollers on plots 1F and 2F had ChE levels in the same range as those in rollers found dead on plot 2C. One Red-beaked Hornbill, shot three days post-treatment on plot 2F, had a low ChE activity (16.6  $\mu\text{moles}/\text{min}/\text{g}$ ) compared to a control level of 27.8 in this species in Kenya (Bruggers *et al.* 1989).

### Bird identification verification

Ninety bird specimens were shipped to the Field Museum of Natural History in Chicago where they were examined by S. M. Goodman. For ten specimens additional information on specific or subspecific identity was provided; a number of other identifications were verified. In addition, birds not sexed in the field were sexed, when possible, at the Museum.

A series of slides and color prints of Beaudouin's Snake Eagle (*Circaetus gallicus beaudouini*) was examined by Dr. J. M. Thiollay, Paris, and identifications were verified.

**Table XII.9:** Brain cholinesterase levels ( $\mu$  moles/min/g) in brains of individual dead (D) and debilitated (d) birds and in groups of fledglings found on plots after treatments.<sup>a</sup>

Birds	Plot			
	1C	C	1F	2F
Button Quail	-	-	-	5.2 (d) 6.2 (d)
Abyssinian Roller	-	20.5 (D)	5.1 (d)	- 16.5 (D)
Hoopoe	-	-	-	8.6 (d) 7.9 (d)
Singing Bush Lark	-	23.5 (D)	-	-
Woodchat Shrike	-	-	-	11.2 (d) 7.7 (d)
<b>Fledglings</b>				
<b>Bush Larks</b>				
24 h	(4) 20.1 5.8	(2) 16.2 0.9	-	(4) 11.6 2.4
48 h	(2) 15.9 5.9	(2) 20.5 0.4	(2) 16.8 0.5	(3) 12.6 3.2
72 h	-	-	-	(3) 7.9 0.8
<b>Buffalo Weaver</b>				
24 h	-	(1) 15.5 0.0	-	-
<b>Pink-headed Dove</b>				
24 h	-	(1) 18.5 0.0	-	-

<sup>a</sup> See Table 35 for ChE levels in control birds. For fledglings, *n* is given in parentheses before means, and standard errors follow means when pertinent.

**Table XII.10:** Brain cholinesterase levels ( $\mu$  moles/min/g) in live unexposed (control) birds and in birds collected on study plots after treatments.

Species and period posttreatment	Plot											
	1C			2C			1F			2F		
	(n)	$\bar{x}$	SE	(n)	$\bar{x}$	SE	(n)	$\bar{x}$	SE	(n)	$\bar{x}$	SE
Abyssinian Roller 1 week 3 weeks	(1)	30.7	0.0	(1)	46.4	0.0	(4) (6)	21.3 37.4	1.2 5.2	(5) (10)	27.1 34.8	2.5 3.5
Bush Lark (adult) 1 week 3 weeks	(7)	33.1	3.8	(2) (4)	32.0 41.1	7.5 4.5	- -	- -	-	(4)	20.8	1.7
Bush Lark (juv.) 1 week	(2)	18.5	7.5	-	-	-	-	-	-	(1)	15.2	0.0
Buffalo Weaver 1 week 3 weeks	(8)	30.6	2.7	(10) (9)	32.4 29.5	2.1 2.2	(7) (1)	22.0 54.2	2.2 0.0	(1) (2)	14.4 26.2	0.0 3.7
Golden Sparrow 3 weeks	-	-	-	-	-	-	(1)	38.8	0.0	(2)	31.1	1.1
Woodchat Strike 3 weeks	-	-	-	(2)	28.6	2.3	-	-	-	-	-	-
Red-beaked Hornbill 3 days	-	-	-	-	-	-	-	-	-	(1)	15.2	0.0
Hoopoe	-	-	-	-	-	-	-	-	-	(2)	37.3	0.4
Pink-headed Dove	-	-	-	-	-	-	-	-	-	(1)	20.8	0.0

## Discussion

The varied and abundant avifauna on study plots provided an excellent situation for study of insecticide effects on the habits and population abundance of diverse species. Total bird numbers (sum of 71 species) decreased on all plots after treatments. Some of this decrease was due to bird mortality, but most apparently represented movement of birds from plots. Mortality, debility, and decreases in bird numbers were greatest on plots treated with fenitrothion. Decreases in Abyssinian Rollers, Blue-naped Mousebirds, and Singing Bush Larks were statistically significant, but decreases were also indicated in numbers of Hoopoes and Buffalo Weavers. Fenitrothion treatments caused decreases in these species and, in addition, reduced numbers of birds grouped on the basis of either their taxonomic position or life history traits.

Insecticides kill insects and other arthropods, reducing the food supply of birds. Decreases in bird numbers observed on study plots probably were largely due to such decreases in food. Results suggested fenitrothion more effectively reduced food availability than chlorpyrifos. For instance, Singing Bush Larks ate few seeds on the control plot after treatments, and relied primarily on insects. On the chlorpyrifos plots, larks ate about 75 percent insects and 25 percent seeds, but on the high dose fenitrothion plot (2F), larks ate more seeds than insects. These findings suggest larks were forced to eat seeds as insect biomass decreased.

The two insecticides appeared to differ in their impact on birds. Fenitrothion applications resulted in greater decreases in bird numbers. If decreases were caused by reductions in food availability, it follows that fenitrothion must have reduced arthropod biomass to a greater extent than chlorpyrifos. This appears to have been the case. Singing Bush Larks and Abyssinian Rollers consumed primarily grasshoppers in the study area before treatments. After insecticide applications, the acridologists found four to five times as many grasshoppers remained on chlorpyrifos plots as on fenitrothion plots (Chapter VIII). Also, in contrast to the chlorpyrifos plots, grasshopper larvae were absent on fenitrothion plots, and grasshopper recolonization began later and progressed at a slower rate. These findings support the idea that a greater decrease in food resources was responsible for a greater movement of birds from fenitrothion plots and thereby a greater decrease in their numbers.

Insect biomass should increase as insects invade or otherwise re-establish populations on plots. Bird abundance would respond to increased food resources and return to normal. Under such conditions, the effects of treatments should be temporary. Birds are opportunistic in their feeding habits and tend to respond negatively to food decreases and to congregate where food resources are the richest. However, food restrictions can have more serious and long-lasting effects if they occur during the reproductive period and adversely influence nesting success. Observations suggested nesting success of Singing Bush Larks and Buffalo Weavers were affected by fenitrothion treatments. Both species were reproducing during spraying, and their numbers decreased rapidly afterwards. This implied that the insecticide terminated the process of reproduction in some Buffalo Weavers and may have caused some Singing Bush Larks to move before young were fully fledged. Young larks usually leave the nest well before they can fly (Green 1985; Cramp 1988). However, fledgling larks analyzed were

debilitated by ChE inhibition, and many probably died on all treated plots. Stromborg *et al.* (1988) dosed nestling European Starlings (*Sturnus vulgaris*) with dicrotophos to examine its influence on postfledging survival and development. They found effects were rapid (death and reduced ChE levels), but survivors recovered rapidly and adverse effects did not extend into the postfledging period.

Birds are not equally exposed to insecticides applied to the environment. Their activities and habits at the time of treatments largely determine the intensity of their exposure. ChE measurements suggested that a few adults of species eating grasshoppers ingested sufficient insecticides to cause intoxication and death. Fledglings, and especially those of the Singing Bush Lark, received high exposure to the insecticides, which resulted in an even greater inhibition of ChE than in adults. However, normal ChE levels of young larks are subject to further study. It has been demonstrated that nestling Starling brain ChE activity was age dependent and increased linearly toward adult levels (Grue *et al.* 1981). As young larks were in grasslands, they were probably subjected to greater dermal contamination than birds active in trees and depressions. Young birds being fed by adults probably were given contaminated insects, as insect protein is a prerequisite for growth in young of most bird species. ChE levels in fledglings decreased substantially during the first 3 days following insecticide treatments.

In Passerines, anorexia is usually observed following sublethal exposure to organophosphorus compounds under laboratory conditions (Grue *et al.* 1982). The significantly lower body masses of flightless fledgling Singing Bush Larks collected 24 and 48 h posttreatment compared to those collected in the control area may have been an effect of exposure to the insecticides. Delayed growth or loss of body mass in nestling songbirds, in the range of 5-25 percent, in the first 24 h after experimental oral exposure to organophosphates has been reported in various studies (Grue and Shipley 1984; Stromborg *et al.* 1988). If the parent birds are also affected by exposure to organophosphates, an even stronger effect on the development of the nestlings may be expected. Female Starlings given an oral dose of dicrotophos made significantly fewer sorties to feed their young and they remained away from their nests longer than controls (Grue *et al.* 1982). ChE levels in some adult Singing Bush Larks in breeding condition indicated that they likely were affected.

ChE measurements in mature birds after insecticide treatments did not indicate serious inhibition at 1 week, and ChE levels in general were near normal after 3 weeks. These findings are consistent with the observation of minimal mortality and debility in adult birds resulting from insecticide applications. Applications of fenitrothion at 300 g/ha in forests of northern Scotland resulted in ChE inhibition in four species of songbirds. Inhibition averaged 47 percent on the day after treatments in one species, and it was still 34 percent after 1 week and 13 percent after 3 weeks in another species (Hamilton *et al.* 1981).

Chlorpyrifos degrades rapidly in birds and residues largely disappear after about 9 h (Odenkirchen and Eisler 1988). In wheat fields treated with 560 and 1,000 g/ha of chlorpyrifos, Horned Larks (*Eremophila alpestris*) showed a 22 percent reduction in ChE after 3 days and only 8 percent after 16 days. No dead larks were found in treated fields (McEwen *et al.* 1986). Our results also indicated ChE inhibition was brief, and mortality in adult birds was low in areas treated with chlorpyrifos.

Residues of 1.0 ppm and higher have been reported from grasshoppers following applications of organophosphate insecticides (Stromborg *et al.* 1984). In consuming their own body mass of grasshoppers carrying 1.0 ppm of fenitrothion residues, birds would ingest 1.0 mg/kg of fenitrothion. Zebra Finches dosed with about 1.0 mg/kg fenitrothion showed 50 percent ChE inhibition (Holmes and Boag 1990). ChE inhibition increased at higher doses, and some mortality occurred. It follows that Singing Bush Larks that consumed their body mass or more in contaminated grasshoppers could possibly suffer ChE inhibition of 50 percent or more and die. Fledgling larks collected on treated plots and showing ChE inhibition of 50 percent or more were apparently debilitated, rather than just flightless, and probably would have died if left in the field.

## Conclusions

Fenitrothion and chlorpyrifos treatments to study plots did not cause severe, widespread mortality, but a number of birds were killed. It is doubtful mortality was sufficient to cause measurable decreases in the adult populations of affected species. Decreases found probably resulted from the movement of birds from treated areas in response to a decrease in their supply of insect foods. Decreases in insect biomass and in the proportion of insects eaten by birds were documented and likely were correlated.

The greatest potential for detrimental effects on birds in this study was in limiting reproductive success. Reproducing birds cannot move young and must obtain their foods within a reasonable distance from nests. If inadequate food resources are available, young will fail to mature or adults may desert young to search for better food resources. ChE levels were severely reduced in fledglings, and it is possible that most fledglings on treated plots did not survive. A number of other species, whose reproductive success was not assessed, nested during the study period. Further study of avian reproductive effects in plots treated with fenitrothion would be of high priority in future programs of study in Senegal and throughout Africa where insecticides are applied to control locusts and grasshoppers.

In summary, chlorpyrifos and fenitrothion treatments resulted in temporary decreases in the abundance and changes in the food habits and ChE levels in several bird species. Fenitrothion effects appeared somewhat greater than those of chlorpyrifos. It is possible that both insecticides decreased reproductive success on plots either by reducing numbers of birds fledged or by killing fledglings soon after they left the nest.

The objective of this study was to determine the kinds of effects on birds most likely to result from applications of fenitrothion and chlorpyrifos. Both were felt to be capable of causing considerable direct mortality in birds. This did not prove to be the case. Food resources in treated habitats were reduced, and this caused some species of birds to move in search of food. Those effects appeared to be temporary as insect populations began to increase within several weeks (Chapter IX).

Reproductive effects were apparent and could potentially cause the greatest long-term effects on bird populations. Methods were explored for monitoring performance of breeding birds; such studies should be of priority in future work in Senegal or elsewhere in Africa.

Other insecticides now used for locust control are not expected to cause widespread adult mortality. Their effects, if present, probably would be related to decreases in food supplies, starvation of nestlings, and poisoning of fledglings. These features should be investigated by monitoring movements of adult birds, reproductive performance in nesting species, and survival of immature birds.

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## **References**

- Bruggers RMM Jaeger JO Keith PL Hegdal, JB Bourassa, AA Latigo & JN Gillis (1989) Impact of fenthion on nontarget birds during *Quelea* control in Kenya. *Wildl Soc Bull* 17:149-160
- Busby DG, PA Pearce, NG Garrity, & LM Reynolds (1983) Effect of an organophosphorus insecticide on brain cholinesterase activity in white-throated sparrows exposed to aerial forest spraying. *J Appl Ecol* 20:255-263
- Cramp S (ed) (1988) *The birds of the western Palearctic*, Vol. V. Oxford: Oxford University Press
- Ellman GL, KD Courtney, V Andres, Jr, & RM Featherstone (1961) A new and rapid colorimetric determination of acetylcholinesterase activity. *Biochem Pharmacol* 7:88-95
- Fite EC, LW Turner, NJ Cook & C Stunkard (1988) Guidance document for conducting terrestrial field studies. USEPA, Washington, DC
- Green RE (1985) Article "lark". In: B Campbell & E Lack (eds) *Dict Birds Calton & Vermillion* 319-320

- Grue CE, GVN Powell & NL Gladson (1981) Brain cholinesterase (ChE) activity in nestling Starlings: implications for monitoring exposure of nestling songbirds to ChE inhibitors. *Bull Environ Contam Toxicol* 26:544-547
- Grue CE, GVN Powell & MJ McChesney (1982) Care of nestlings by wild female Starlings exposed to an organophosphate pesticide. *J Appl Ecol* 19:327-335
- Grue CE & BK Shipley (1984) Sensitivity of nestling and adult Starlings to dicotophos, an organophosphate pesticide. *Environ Res* 35:454-465
- Hamilton GA, K Hunter & AD Ruthven (1981) Inhibition of brain cholinesterase activity in songbirds exposed to fenitrothion during aerial spraying of forests. *Bull Environ Contam Toxicol* 27:856-863
- Hill, EF & WJ Fleming (1982) Anticholinesterase poisoning of birds: field monitoring and diagnosis of poisoning *Environ Toxicol Chem* 1:27-38
- Holmes SB & PT Boag (1990) Inhibition of brain and plasma cholinesterase activity in Zebra Finches orally dosed with fenitrothion. *Environ Toxicol Chem* 9:323-334
- Mayfield H (1961) Nesting success calculated from exposure. *Wilson Bull* 73:255-261
- McEwen LC (1982) Review of grasshopper pesticides vs rangeland wildlife and habitat. Pages 362-382 in JM Peek & P D Dalke (eds) *Wildlife-Livestock Relationships Symposium* 10. University of Idaho, Moscow
- McEwen LC, LR DeWeese & P Schladweiler (1986) Bird predation on cutworms (Lepidoptera: Noctuidae) in wheat fields and chlorpyrifos effects on brain cholinesterase activity. *Environ Entomol* 15:147-151
- Morel G & F Roux (1966) Les migrateurs paléarctiques au Sénégal. II Passereaux et synthèse générale. *Terre et Vie* 113:143-176
- Odenkirchen EW & R Eisler (1988) Chlorpyrifos hazards to fish, wildlife, and invertebrates: a synoptic review. *Contaminant Hazard Reviews Report No 13* US Fish and Wildlife Service, Laurel, Maryland 34 pp
- Peakall DB & JR Bart (1983) Impacts of aerial application of insecticides on forest birds. *CRC Crit Rev Environ Control* 13:117-165
- Pearce PA & DB Peakall (1977) The impact of fenitrothion on bird populations in New Brunswick. Pages 299-306 in JR Roberts, R Greenhalgh & WK Marshall (eds) *Fenitrothion: the long-term effects of its use in forest ecosystems--current status*. Publ No 15389. National Research Council of Canada, Ottawa
- Spray, CJ, HQP Crick & ADM Hart (1987) Effects of aerial applications of fenitrothion on bird populations of a Scottish pine plantation. *J Appl Ecol* 24:29-47

Stromborg KL, CE Grue, JD Nichols, GR Hepp, JE Hines & H C Bourne (1988) Postfledging survival of European Starlings exposed as nestlings to an organophosphorus insecticide. *Ecol* 69:590-601

Stromborg KL, LC McEwen & T Lamont (1984) Organophosphate residues in grasshoppers from sprayed rangelands *Chem Ecol* 2:39-45



## **PART 6**

## **GENERAL DISCUSSION AND CONCLUSIONS**

## DISCUSSION

### Recovery

Although the treated surfaces of the present study were the largest among the ecotoxicological tests for locust control carried out thus far, the size of the sprayed area was still relatively small when compared to the action radius of many species, specifically the flying ones. A comparison with the large surfaces treated for grasshopper control (thousands of sq. kms), at lower pesticide dosages, is therefore difficult to make.

The speed of the recovery of affected populations in a treated area depends on the disappearance of the toxic substance, the recovery of individuals from sublethal effects, the character of the effect (direct or indirect) and the capacity of populations to invade empty areas. We have observed that residues of diflubenzuron persisted until the end of the rainy season while very low residues were probably still present of the organophosphates. It is unknown, however, to what extent possible residues on the vegetation represent a risk to other parts of the ecosystem. The biological availability of these residues, therefore, has to be tested in future studies, using herbivorous organisms.

The insecticides did not affect the vegetation. Therefore, herbivorous species were expected to be among the first to recover, food not being a limiting factor. Recovery of predators of herbivores, however, will require more time because the density of the former depends on the latter. In general, predator species being not prey species specific (such as insectivorous birds, carabids, asilid flies ) will recover sooner than most parasitic species, of which many show a strict host specificity. Because important parasitic taxa which appeared to be affected (ichneumonid wasps, typhiids) showed a slow recovery, the long term effect of treatments and the possibility of a constant reduction at repeated annual spraying in these taxa should be the subject of utmost concern.

Even though the role of the species is virtually unknown, it was unfortunate that it was not possible to study sufficiently the isolated populations of ephemeral crustaceans in savannah pools. In these species, which are adapted to harsh conditions such as high temperatures and many years of drought an insecticide may cause serious damage. At our present stage of knowledge these populations are considered the most vulnerable group in the ecosystem. In future studies they may be useful indicators for the recovery of the system as a whole.

A local effect on a part of a bird population may be of limited importance, given the numerous non-anthropogenic factors that may affect a population locally, combined with their good capacity for migration. In this test, however, the sprayed areas were relatively small, compared to the surfaces treated in campaigns against the Senegalese Grasshopper (OSE). Although the dosages in OSE campaigns are lower than the ones used in our test, the recovery of any species affected by these treatments will take considerably more time. It is in these situations that important bird populations, specifically those affected by lack of food, are seriously at risk.

### Ecosystem effects

Although no effects were found on the functioning of microbial communities on the soil surface, the results of other parts of the study strongly suggest that an annually repeated large scale treatment (such as treatments against OSE) may affect other functions of the ecosystem, mainly by reducing the biomass and the activity of a number of vertebrates. Among the species that are most important for the functioning of the ecosystem ants were affected and in the epigeal termites an indication was found of a possible effect. Because of the role of both groups in fragmentation of plant material, remineralisation and bioturbation of the soil, this effect should be considered as an important result of the pilot study. Further research on the subject should include vegetal composition and biomass production.

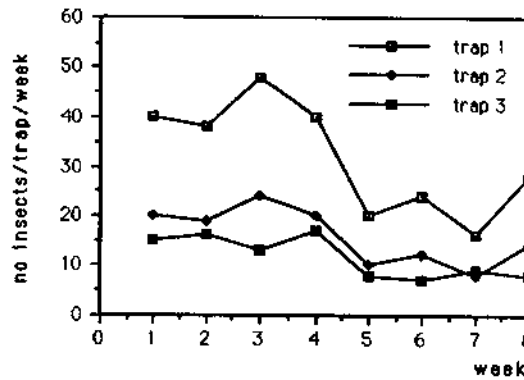
### Statistical analysis

Statistical analysis of the data generated by this type of study is not straightforward and some remarks need to be made on this subject. A typical set of data for one plot may look like fig. XIII.1a. On a specific plot insect numbers in three trapping units are collected four weeks before and after a treatment. No replicate plots exist, only replicated traps within a treated plot. We need to test if the numbers after treatment are significantly lower than before when compared to trends in the control block. However, since trap catches show a strong placement effect, this test needs to be done per individual trap. In the classical approach, we need to test if the changes per trap, replicated over the plot, are significant compared to the control. This means that any analysis which lumps the different trap catches on a specific date(s) before treatment and then compares them with lumped data after treatment, should be avoided. This will cause a larger intertrap variance to be taken into account than needed and make the test less discriminative. This is clarified in Figure XIII.1b,c. Figure XIII.1b shows the decline of three traps in a certain plot from one date before to one date after spraying; all captures decline in a parallel way and the standard deviation around this rate of decline is small. If the data are expressed as mean and standard deviation over the three traps combined, the graph would look like Fig. XIII.1c. The decline looks much less convincing given its high standard deviation. Any analysis which is based on such lumped variances (e.g. standard ANOVA's) should be avoided with these datasets. Some sort of paired analysis, with pairing of before and after treatment data of the same trap is needed.

Stewart-Oaten et al. (1986) and van der Voet (1987) describe a methodology for analysing similar data, based on "pseudo-replication". They use as test statistic the difference of the mean log(abundance) in (to be) treated and control plots, and comparing these before and after treatment. By using such a test statistic they claim the sampling dates function as "pseudo-replicates". They argue that replicates within the plots are of no value for the estimation of, what they call, the "process mean" of the process one investigates. Their arguments for this statement seem quite convincing. However, if one is only interested in mean values without any measure of variability around this mean, strictly speaking one sample per date would suffice. The way in which their argument for using only means holds, however, is that they base their variance estimates on variability in time, which, as it seems from their argumentation, is a better way of dealing with our type of trial data. Thus, the applicability of their method then depends on the number of pseudo-replicates or samples on consecutive dates. In our pilot study there are a maximum 4 such replicates and often less. This would seem a fairly thin basis for statistical comparisons and will in many cases lead to conservative tests. Furthermore, Stewart-Oaten et al. (1986) state that their analysis only holds for treated and control plots which fluctuate in the same way; i.e. for which the graph

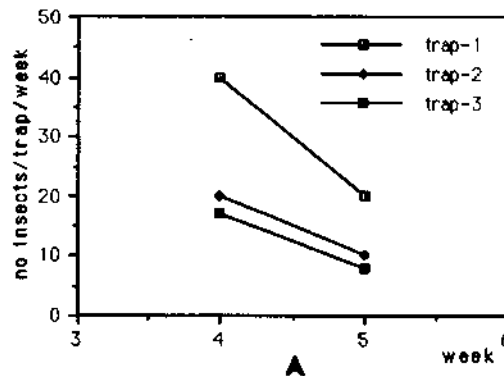
of the differences between treated and control blocks do not show a trend before treatment. Unfortunately, this was often not the case with the arthropod data of our pilot study.

**Figure XIII.1a**



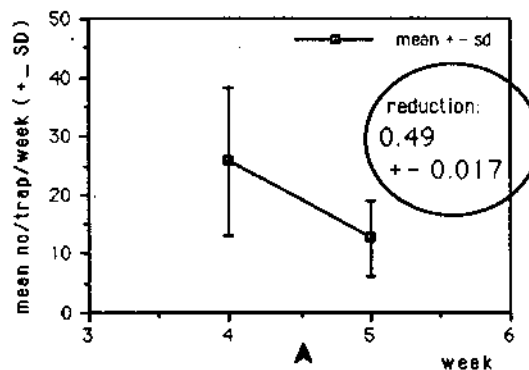
Typical set of catches from 3 traps on the same plot. Treatment takes place between week 4 and 5.

**Figure XIII.1b**



Change in abundance in the 3 traps from week 4 to week 5.

**Figure XIII.1c**



Mean trap catches of week 4 and week 5 plus their standard deviations (SD). Note that SD's are more than 50% of the mean catches. However the SD around the mean reduction after treatment is only 3% (encircled).

Since future impact analysis of locust and grasshopper control will almost always consist of short time series, because of the short sahelian wet season, the method proposed by Stewart-Oaten et al. does not seem ideal. In situations, however, where means are limited and the areas to be compared large, their method is, at present, the best one. Their argument for using different dates in the sampling sequence as "pseudo-replicates" after proper transformation, is valuable. Their approach also offers a possibility for the use of a model for recovery, by applying for instance a logarithmic transformation on the post-treatment differences between means. Furthermore, the variation between traps originates from two sources: the intertrap variation and the stochastic variation around the mean value for each trap. Therefore, rather than just using mean values, we propose including the variance around these means as well. This variance may not be useful to estimate the variance of the process mean, i.e. the validity of the observed effect under other circumstances, but it does give information on the validity of the pesticide effect found in the particular case under study. Such an analysis would probably look like an ANOVA in which before and after treatment data are paired per trap. The test statistics would be those described by Stewart-Oaten et al., i.e. the difference between  $\log(\text{control})$  and  $\log(\text{treated})$ .

It is imperative that in the near future a proper statistical method for these short time series be further developed.

## Conclusions

The results of this pilot study strongly suggest that the use of the organophosphorous compounds chlorpyrifos and fenitrothion against locusts in the sahelian savannah may bring about long-term effects in the aquatic and terrestrial non-target fauna.

The data also provide evidence for the relative harmlessness of the insect growth regulator diflubenzuron when used under the same conditions.

Further ecotoxicological surveys for chemical locust and grasshopper control should include the following indicator parameters:

- avian reproductive performance; movements and survival of immatures
- small fish species (such as *Porogobius schlegelii*)
- macrocrustaceans, such as *Caridina africana*, *Triops sp.* and *Palaemonetes africanus*.
- various coleopteran and hymenopteran species, mentioned in Chapter IX
- above ground foraging termites

Future field tests should include replication whenever possible, either in the same test or by repeated observations elsewhere and statistical methods have to be refined.

The following taxa may be good indicators for use in predictive laboratory based toxicity tests:

- macrocrustaceans
- carabids or tenebrionids
- several hymenopterans

This present survey should be considered as a case study with restricted predictive value for other areas and compounds. Therefore more tests should be carried out with other acridicides, in comparable and other habitat types, in Senegal and elsewhere (e.g. Mali, Mauritania)

The results suggest that large scale spraying operations such as treatments against Senegalese Grasshopper may bring about serious long-term effects. These operations should therefore be monitored in Senegal and elsewhere

The approach of integration of several disciplines (environmental chemistry, toxicology and ecology) realized in the pilot study worked very well and should be continued; the cooperation of several local and foreign institutes and the training started in the pilot study should be continued.

## References

Stewart-Oaten A, Murdoch WW and Parker KR. 1986. Environmental impact assesment: "pseudoreplication " in time?. *Ecology* 67(4):929-940.

van der Voet H. 1987. Het bepalen van behandelingseffecten op grond van korte tijdreeksen. (assessing treatment effects on the basis of short time-series) TNO Institute for Applied Informatics. Wageningen. The Netherlands. Internal Document ITI B30. pp 40. (in Dutch).



