DYNAMAC
CORPORATION

Technical Report

Results of the Locust Pesticide Testing Trials in Sudan

USAID Contract No. AFR-0517-C-00-7035-00
December 1988

Prepared by:
Dynamac Corporation
The Dynamac Building
11140 Rockville Pike
Rockville, MD 20852

In association with:
Consortium for International Crop Protection
4321 Hartwick Road, Suite 404
College Park, MD 20740

Prepared for:
U.S. Agency for International Development
African Grasshopper/Locust Pesticide Testing Project (698-0517)

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EXECUTIVE SUMMARY

During the winter and spring of 1988, Dynamac Corporation, under contract to USAID, set out to conduct field trials along the Red Sea coast of Sudan to test for the efficacy against the desert locust Schistocerca gregaria and the environmental impacts of six pesticides: bendiocarb, carbaryl, chlorpyrifos, fenitrothion, lambda-cyhalothrin, and malathion.

A. FIELD TESTING PROGRAM

The field trials were conducted as follows:

1. Locust Survey: Although repeated locust infestation reports had been favorable, deployment of the efficacy team to potential test sites revealed that locust populations adequate for efficacy testing were not present. Therefore, no efficacy tests were conducted.

2. Site Selection: A study site along the Red Sea coast, consisting of 40 km^2 of Sahelian grassland within the agricultural Tokar Delta, was selected for the environmental impact trials. The grass Paspalidium germinatum, ranging from a few centimeters to a full meter (m) in height, and scattered acacia trees characterized the landscape. In the trials, a randomized design of twenty-four 100-hectare (ha) plots (including six controls) was used to determine the effects of the six pesticides on nontarget species and environmental substrates.

3. Pesticide Application: All materials were applied at ultra-low-volume (ULV) rates with Micronair atomizers mounted on an Agtruck or Antonov sprayplane. Preliminary tests were conducted to assure that proper droplet size (100 to 150 microns), uniform coverage (narrow 35- to 40-m swaths), accurate metering (onboard computer and repeated prespray calibration), and plot integrity (250- to 600-m buffer zones) were obtained. During each application, two flagging cars and minimum flying heights (3 to 5 m) were used to obtain precise application of the pesticides to the test plots. The sprays were conducted during the

favorable environmental conditions of the early morning. Oil-sensitive cards and slides were used to monitor spray deposition for coverage and drift.

4. Environmental Impact Methodology: The environmental impact of the pesticides was determined by (a) conducting bird transect counts for mortality and bird captures for cholinesterase inhibition; (b) sampling for three guilds of nontarget arthropods, i.e., ground-dwelling (pitfall traps), plant-dwelling (sweep-netting), and flying (sticky traps); and (c) collecting soil, grass, and animal samples for pesticide residue analysis. Equivalent prespray and postspray sampling periods were used for an array of samples at -8 days, -5 days, -2 days, +1 day, +4 days, and +7 days relative to treatment. Three replicate treatment plots and a companion control plot were designated for each pesticide application. Each treatment result was adjusted for simultaneous control abundances and then tested for postspray versus prespray differences. All collected samples were kept frozen until analysis and then compared with appropriate controls from the field and laboratory.

B. ENVIRONMENTAL IMPACT TRIALS

The findings of the environmental impact trials were as follows:

1. Effects on Arthropods

Nontarget arthropod samples were described to taxonomic order and cataloged for future reference. Five arthropod orders were sufficiently abundant for adequate analysis: Araneae (spiders), Hemiptera (true bugs), Coleoptera (beetles), Diptera (flies), and Hymenoptera (bees and wasps). Each pesticide produced significant numerical reductions in at least two of these orders. The only pesticide that did not show an adverse effect on the Coleoptera and Diptera (orders containing 77% of known locust predator and parasite species) was carbaryl. There were no differences in selectivity among the three chemical classes of pesticides: organophosphorus, carbamate, and pyrethroid. The most important result of

the nontarget arthropod sampling was the rapid rebound in arthropod numbers, which occurred after pesticide-induced reductions. This suggests that arthropod survival was substantial, either outside the 100-ha plots or in microhabitats within the plots. It appears unlikely that these six pesticides will dramatically alter the arthropod fauna in single small-scale applications.

2. Effects on wildlife

Carcass searches, conducted over a combined area of 24 km^2, revealed no dead or injured vertebrate wildlife. At the same time, normal behavior was observed among more than 5,000 live birds counted during 160 transect runs. Although the variability of the bird numbers was reduced with replication and simultaneous controls, no instances of reduced bird activity were discernible from the analysis of transect counts. Only the moderate brain cholinesterase depression observed in carbaryl-exposed birds indicates possible adverse effects.

3. Effects and Residues on Vegetation

No phytotoxicity was observed among the collected material or in visual surveys of the test plots. Same-day and 1-day posttreatment forage grass samples contained residues near possibly hazardous levels for all the pesticides except malathion and carbaryl. Bendiocarb residues in forage grass remained substantially above concern levels through the +7-day sample. However, in each case the analysis of soil and forage grass samples demonstrated that the pesticide residues declined rapidly and, therefore, should not pose a long-term hazard. A detailed survey of the vegetation and ecosystem components of the test site did not identify any especially vulnerable natural habitats that might be exposed during locust control operations.

C. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations are as follows:

1. Following the application of all six pesticides, no dramatic environmental impacts were seen.

2. The degree of differences among the pesticides in the impact on nontarget arthropods was small, but pesticides can be identified that appear to be less harmful to specific arthropod groups.

3. All the pesticides degraded rapidly in the environment, but residue results indicate that the use of chlorpyrifos and fenitrothion may require restrictions on postspray harvesting and that bendiocarb applications should be limited to areas not used for agriculture or grazing.

4. Therefore, we conclude that single applications of fenitrothion, malathion, chlorpyrifos, carbaryl, lambda-cyhalothrin, and possibly bendiocarb can be performed safely in grassland areas subject to desert locust infestation.

5. However, because our trials used careful application methods and because we did not treat aquatic or other sensitive habitats, we cannot assess the potential impacts of careless locust control programs.

6. For this reason, we recommend that future pesticide control strategies give priority to ensuring that the selected pesticides are properly applied and that sensitive habitats, such as wetlands, are carefully avoided.

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AUTHORS, CONTRIBUTORS, AND REVIEWERS

The following Dynamac Corporation and Consortium for International Crop Protection (CICP) personnel were involved in the preparation of this document: Mark Southerland, Ph.D. (Scientific Manager and Principal Author); Allan Hirsch, Ph.D. (Project Manager); Andrew Stancioff (Department Manager); Jeffrey Evans, Chris Hemming, Rodney Kepner, Ph.D., Thomas Schwartz, and Wesley Yates, Ph.D. (Contributing Authors); Karen Swetlow (Technical Editor); Paula Deschamp and James Fraser (Reviewers); David Bettendorf (Information Specialist); and Tom England (Computer Specialist).

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PREFACE

This report presents the findings of the Sudan field trials conducted as part of the USAID Africa Grasshopper/Locust Pesticide Testing Project. A final project report will evaluate the literature on these pesticides as well as the results from the Mali and Sudan trials. The final report will provide recommendations concerning the use of these pesticides for grasshopper and locust control in Africa.

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1. INTRODUCTION

1.1 BACKGROUND

In 1985 and 1986, the return of normal rains to previously drought-stricken areas of Africa resulted in an emergence of major infestations of grasshoppers and locusts. In 1986, the infestation was unusually severe because it involved the rare appearance of numerous grasshopper species and the four major species of locusts most harmful to African agricultural production. In February 1987, the Africa Bureau of the U.S. Agency for International Development (USAID) issued a Strategy Paper that proposed several activities aimed at containing the initial emergency and establishing a program for long-term control and management of the pests.

In April 1987, USAID issued a Request for Proposals (RFP) for a contractor to develop and execute a scientific program to study the efficacy and environmental impacts of certain pesticides under consideration for the control of locusts and grasshoppers in Africa. This testing program was to be part of the USAID effort to provide for "timely, efficient, and cost effective pest survey and control activities, that fully take U.S. environmental concerns and legislations into account." The RFP called for the testing of eight pesticides on four species of locusts and the Senegalese grasshopper to determine the efficacy of the pesticides on the target organisms, to monitor their effects on grasshopper/locust parasites and predators and other beneficial fauna and flora, and to determine pesticide residues on selected crops and other environmental substrates.

In response to the RFP, Dynamac Corporation, as the primary contractor, and the Consortium for International Crop Protection (CICP), as a subcontractor, submitted the technical proposal "Testing of Pesticides Against African Locusts and Grasshoppers." The proposal indicated that CICP would provide entomological and aerial application technical assistance, and Dynamac, as the primary contractor, would provide all other personnel and logistical support for completion of the

project. The contract was awarded in May 1987. Plans were immediately begun, and a test program against the Senegalese grasshopper Oedaleus senegalensis was conducted in Mali between July and October 1987 (Dynamac Corporation, 1988). In January 1988, a Technical Plan was developed for the testing of pesticides against the desert locust Schistocera gregaria in the Republic of the Sudan (see Appendix T).

The scientific team operated at a field site in Tokar, Sudan, between February 23 and April 12, 1988. This report presents the results of the field test in Sudan. Additional information relating to the known literature on these pesticides will be included in the final report on this project. The final report will compare the different field tests and will provide final recommendations to USAID.

1.2 OBJECTIVE

The testing program was directed at the abundant and wide-ranging desert locust Schistocera gregaria. The objective of this program was to perform a scientifically rigorous test, under African field conditions, on eight pesticides for their efficacy in controlling the locust and for their impact on nontarget organisms and the environment. To achieve these two goals, four types of information had to be acquired:

1. Accurate measures of the reduction in locust numbers attributable to the specific formulation and rate of each pesticide;

2. Data on the adverse effects of these pesticides on animals beneficial to the agricultural ecosystem, e.g., locust predators/parasites and other arthropods affecting crop production;

3. Evidence of direct mortality or other acute effects on the full range of fauna and flora constituting the Sudanese grassland ecosystem; and

4. Determination of residue levels in important environmental substrates (e.g., soil, water, grasses, prey animals) and field crops.

This information will enable better assessment of the value of specific pesticide uses for control of the desert locust.

1.3 PESTICIDE SELECTION

USAID identified the following pesticides as candidates for the testing program following discussion with the U.S. Environmental Protection Agency, the Food and Agriculture Organization, and others:

Pesticide	Class
Carbaryl (Sevin)	Carbamate
Carbosulfan (Marshal, Advantage)	Carbamate
Chlorpyrifos (Dursban, Lorsban)	Organophosphorus
Lambda-cyhalothrin (Karate)	Pyrethroid
*Acephate (Orthene)	Organophosphorus
*Bendiocarb (Ficam)	Carbamate
*Diazinon (Diazinon)	Organophosphorus
*Propoxur (Baygon)	Carbamate
Fenitrothion (Sumithion)	Organophosphorus
Malathion (Malathion)	Organophosphorus

*Candidates for two open slots.

The following additional pyrethroid pesticides were proposed for consideration by their manufacturers:

Pesticide	Manufacturer	Date
Cyfluthrin (Baythroid)	Mobay	April 7, 1987
Alpha-cypermethrin (FASTAC)	Shell	May 21, 1987
Tralomethrin (Scout/Tralate)	DuPont	June 4, 1987

Based on a preliminary review of available information, the general characteristics of each pesticide class are presented below.

- Carbamates - The carbamates are residual insecticides of moderate to low mammalian toxicity (toxicity category II). The antidote is atropine (but not 2-PAM). The LD_{50} value (male rat, acute oral) for bendiocarb is 40 to 156 mg/kg; for carbaryl, 283 mg/kg; and for propoxur, 95 mg/kg. The dermal LD_{50} for these compounds is from 500 to 2000 mg/kg (toxicity category III). Carbamates are generally not oncogenic, but some are suspect teratogens and weak mutagens. They are rapidly excreted by animals, and they disappear from the surface of plants by mechanical attribution, volatilization, and uptake into the plant. These compounds do not seem to be appreciably photodegraded, but they are degraded by soil organisms through hydroxylation of both the side-chain and ring structures. The carbamates are of low toxicity to birds; moderate toxicity to fish; and high toxicity to honeybees, aquatic invertebrates, and estuarine organisms.

- Organophosphorus Compounds - These pesticides are broad-spectrum contact insecticides of high to moderate acute toxicity to mammals. The following LD_{50} values (male rat, acute oral) have been determined for those listed above: acephate, 866 to 945 mg/kg; chlorpyrifos, 97 to 270 mg/kg; diazinon, 300 to 400 mg/kg; fenitrothion, 800 mg/kg; and malathion, 1000 to 1375 mg/kg. Although some of the most highly toxic pesticides known are organic phosphates, compounds such as malathion are relatively safe to use. The organophosphorus compounds are photodegradable, but they can be leached into the soil where they tend to have rather long half-lives. The organophosphorus compounds are cholinesterase inhibitors; atropine and 2-PAM (pralidoxime chloride, iodide, or methanesulfonate) are the common antidotes. The effects of this group of pesticides are so varied that few generalizations are valid for all member compounds; however, the organophosphorus compounds tend to show little or no oncogenicity, teratogenicity, or mutagenicity. Environmental toxicity effects vary, depending upon the compound. Diazinon, for example, is highly toxic to wildlife (birds, fish, aquatic invertebrates); applications to golf

courses have caused serious bird kills. In contrast, aircraft have applied malathion over broad areas of the United States to control imported fruitfly outbreaks with little or no evident environmental problems (except for damage to automobile paint). Chlorpyrifos, on the other hand, is highly toxic to wildlife and honeybees.

- Pyrethroids - These compounds are based on "pyrethrum," a naturally occurring insecticidal complex derived from certain species of chrysanthemum. Pyrethrum consists of pyrethrins (esters of pyrethrolone and chrysanthemic acid and pyrethroid acid), cinerins (esters of cinerolone and chrysanthemic acid and pyrethroid acid), and jasmolines (jasmoline and chrysanthemic acid and pyrethroid acid). They are characterized as being resistant to photodegradation, and they are applied at extremely low active ingredient dose rates (in the range of 0.05 to 0.3 pounds active ingredient per acre). Like the organophosphorus compounds, the U.S. EPA classifies many pyrethroid products as Restricted Use Pesticides for some or all uses.

Of the chemicals listed above, six were identified for testing in the USAID Scope of Work: carbaryl, carbosulfan, chlorpyrifos, lambda-cyhalothrin, fenitrothion, and malathion. Fenitrothion and malathion were identified as potential test standards because of their widespread use for grasshopper and locust control in Africa. It was deemed essential that chemicals of known efficacy under the test conditions be included as a reference. Four chemicals were identified as candidates for the remaining two test positions: diazinon, bendiocarb, propoxur, and acephate. Three additional chemicals nominated by manufacturers did not appear in the USAID Scope of Work: cyfluthrin, alpha-cypermethrin, and tralomethrin.

A preliminary literature review and evaluation conducted for all candidate chemicals provided a basis for designing the field program and for selecting the eight pesticides to be used in the West Africa testing program. It is the Africa Bureau Policy "that any AID-financed pesticide for locust/grasshopper control be registered with the EPA and have a tolerance established for at least one food use, or meet the established

acceptable daily intake and maximum residue levels recommended by the Joint Meeting on Pesticide Residues to the FAO/WHO Codex Committee on Pesticide Residues." The EPA registration and Codex status of the candidate pesticides are presented below:

Candidate Pesticide	EPA Registration	Food Crop Tolerance (40 C.F.R. 180) yes	Food Crop Tolerance (40 C.F.R. 180) no	FAO/WHO Codex ADI/MRL
*Carbaryl	✓	✓		✓
Carbosulfan	**pending		✓	✓
*Chlorpyrifos	✓	✓		✓
*Lambda-cyhalothrin	**pending		✓	✓
Acephate	✓	✓		✓
*Bendiocarb	✓		✓	✓
*Diazinon	✓	✓		✓
Propoxur	✓		✓	✓
*Fenitrothion	✓		✓	✓
*Malathion	✓	✓		✓
Alpha-cypermethrin			✓	
Cyfluthrin	**pending		✓	
*Tralomethrin	✓	✓		

*Proposed for West Africa testing program.
**Section 3 application submitted; data under review.

Manufacturers of these products were contacted to determine their continued interest in the testing program and to identify any logistical problems that would prohibit availability of their products within the appropriate timeframe for testing in West Africa. On the basis of product availability, satisfaction of the Africa Bureau technical criteria, general balance among the three classes of pesticides to be evaluated, and consideration of potential environmental impacts and efficacy as determined by the initial literature review, the following compounds were selected for field testing in West Africa:

Pyrethroid	Carbamate	Organophosphorus
Lambda-cyhalothrin (Karate)	Carbaryl (Sevin)	Chlorpyrifos (Dursban)
Tralomethrin (Scout/Tralate)	Bendiocarb (Ficam)	Diazinon (Diazinon)

Test Standard

Fenitrothion (Sumithion) - organophosphorus
Malathion (Malathion) - organophosphorus

The five candidate pesticides not selected for field testing in West Africa (carbosulfan, acephate, propoxur, alpha-cypermethrin, and cyfluthrin) were placed on a backup list. Additional information on these chemicals was requested from EPA and the manufacturers of the compounds. The rationales for eliminating these pesticides from the West Africa field testing program follow:

- Carbosulfan - This compound does not appear to completely satisfy the technical criteria. Although Codex Acceptable Daily Intake (ADI) and proposed temporary Maximum Residue Limit (MRL) are established, EPA registration is still pending. The other members of the carbamate class selected for West Africa, carbaryl and bendiocarb, more fully satisfy the technical criteria because both have established Codex ADIs/MRLs and both have EPA registrations; carbaryl also satisfies the domestic food crop tolerance criterion. In addition, concern exists regarding the potential health and environmental toxicity of the major degradate of carbosulfan, carbofuran.

- Acephate - This compound was not recommended for field testing in West Africa for the following reasons: (1) there is no documented record of the manufacturer's expression of interest in participating in the field testing program; and (2) concerns exist for the potential health effects of acephate (i.e., the compound is a suspected human oncogen), and its metabolite methamidophos is highly toxic to birds.

- Propoxur - Propoxur was not recommended for inclusion in the West Africa field testing program because no documented record exists of the manufacturer's expression of interest in program participation. This chemical has been widely used in Africa for locust control; it is a good candidate for the East and Southern Africa field testing programs pending expression of interest by the manufacturer. EPA has expressed some concern regarding the potential oncogenic activity of the compound that needs to be addressed pending receipt of additional information.

- Alpha-cypermethrin - This compound was not selected because it does not appear to satisfy the technical criteria (i.e., no EPA registration or Codex tolerances). Concern has also been expressed regarding the mammalian toxicity of the compound. More data were requested from the manufacturer.

- Cyfluthrin - Cyfluthrin does not satisfy the technical criteria as completely as the pyrethroids selected for testing. For example, tralomethrin has an EPA registration and an established domestic food crop tolerance. Lambda-cyhalothrin, like cyfluthrin, has an EPA registration pending, but unlike cyfluthrin, also satisfies the Codex tolerance criterion. Lambda-cyhalothrin has also been field tested in Africa for locust control. Cyfluthrin appears to be a good candidate for the East and Southern Africa field testing programs. By the time these programs are under way, the compound may more fully satisfy the AID technical criteria, e.g., the manufacturer has stated that pending receipt of domestic registration, an application will be made for domestic food crop tolerances. The manufacturer has also stated that approval of EPA registration is expected in the next several months. The manufacturer of cyfluthrin will provide information to update the status of this candidate for future use.

After completion of the trials in Mali, the information on those compounds not chosen for the West Africa trials was updated. This review indicated that the status of these compounds had not changed, i.e., either they still did not meet the technical criteria (EPA registration or Codex tolerances) or the manufacturers continued to express no interest in their inclusion in the testing project. Because of this, and because the desire to make the East Africa trials as comparable as possible with the West Africa trials, the same list of eight compounds was designated for testing in East Africa. Shortly before the initiation of the East Africa trials in Sudan, the manufacturer of tralomethrin indicated its desire to remove the compound from inclusion in the trials. Dynamac thus proceeded with plans to test the remaining seven compounds: malathion, fenitrothion, chlorpyrifos, diazinon, bendiocarb, carbaryl, and lambda-cyhalothrin. (Diazinon was subsequently eliminated during the test phase when test stock failed to arrive at the field site.)

1.4 PROJECT CHRONOLOGY

1987	
November 21-December 1	Initial Dynamac meeting with AID/Sudan.
1988	
January 7	Obtain approval for Sudan Project from USAID/Washington.
January 10	Dynamac team arrives to negotiate agreement with Government of Sudan (GOS).
January 24	Logistical and administrative team arrives in Khartoum.
February 8	Dynamac project manager arrives in Khartoum.
February 15-20	Micronair application expert prepares Plant Protection Directorate (PPD) aircraft.
February 15-24	Scientific personnel arrive in Khartoum.
February 20-24	Begin camp setup in Suakin and then move to Tokar.
February 22-28	Perform survey for field site.
February 27	Meet with the director of the Tokar Delta Agricultural Corporation. Obtain approval to spray and reach agreement on plot locations.
February 28-March 1	Stake out experimental plots and develop preliminary sampling protocol.
March 2	Calibrate sprayplane (Agtruck) application equipment with industry representatives.
March 2-11	Conduct initial preliminary sampling of insects and birds.
March 6	Dynamac, CICP, and PPD scientists in Tokar to discuss efficacy campaign.
March 7	Conduct initial vegetation survey and identification.
March 9	Practice spray and flagging procedure. Review Delta Corporation efforts to remove locals from plots.
March 10-13	Spray chlorpyrifos, fenitrothion, lambda-cyhalothrin, and bendiocarb.
March 10-20	Conduct posttreatment environmental and residue sampling for four pesticides.

1988 (continued)

March 9-13	Efficacy team surveys Salala site and determines that testable locust populations do not exist.
March 16	Communicate to Dynamac/Washington and AID/Sudan intention to abort efficacy trials.
March 14-27	BanAir sprayplane remains grounded due to expired certification.
March 20-24	Photograph and describe the habitat of each plot.
March 21	Begin identification and counting of insect samples.
March 27-31	Conduct additional preliminary environmental sampling.
March 31-April 4	Pezetel sprayplane (Antonov) arrives and undergoes repairs and spray calibration.
April 4-5	Spray malathion and carbaryl.
April 4-12	Conduct additional posttreatment environmental and residue sampling.
April 6	Fly first shipment of residue samples to Khartoum.
April 12	Remaining scientific personnel leave Tokar.
April 14	Fly last shipment of residue samples to Khartoum.
April 18	Close camp.
April 28	Ship duplicate residue samples to Miami and deliver to PPD - Wad Medani.
May 2	Residue samples arrive Miami Laboratory still frozen.
May 4	Ship insect samples to Dynamac/Washington.
May 4	Summary Dynamac meeting with USAID/Sudan.

2. ECOLOGICAL DESCRIPTION OF THE SITE

2.1 CLIMATIC AND PHYSIOGRAPHIC REGION

The study area near Tokar, Sudan, lies at 18° north latitude within the tropical region known as the Sahel (described as Semi-Desert in Sahni, 1968). From a geographic perspective, the Sahel is the area bordering the Sahara Desert where open herbaceous formations and scattered woody plants occur. Climatic conditions include irregular rainfall, an 8-month-long dry season, annual rainfall between 75 and 300 mm, and 20 to 40 days of precipitation per year. Throughout most of the Sahel, atmospheric currents known as the harmattan and the monsoon control the climate. From September until May, the high-pressure centers of colder air to the north produce the harmattan, a dry season dominated by winds from the northeast. In June, as the intertropical front moves northward, the wet season begins with the monsoon bringing in humid air and isolated, intense thunderstorms.

In contrast, the Red Sea region of Sudan experiences a different weather pattern, one that is influenced by northeasterly winds that approach from over the Red Sea waters. These winds intensify during the winter months and are joined by southeasterly winds that are connected with the Arabian high-pressure belt. These onshore winds are capable of transporting water vapor that eventually falls as rain. This precipitation is restricted to the near-shore area, because when the moisture-laden winds meet the extensive Red Sea Hills only kilometers from the coast, water vapor in the uplifted air condenses, causing rain to fall on the eastern side of the hills and across the coastal plain. Thus, the rainy season in Tokar, in dramatic contrast to the rest of Sudan, occurs during the winter months of November, December, and January (see climatogram for nearby Suakin in Figure 2-1). The annual coefficient of variation of precipitation in the Red Sea region is between 50 and 75%, indicating that very little rain falls during the remainder of the year (El-Tom, 1975).

Physiographically, the Sahel is an arid grassland dotted with shrubs and small trees. In the Red Sea region in particular, the landscape is very flat

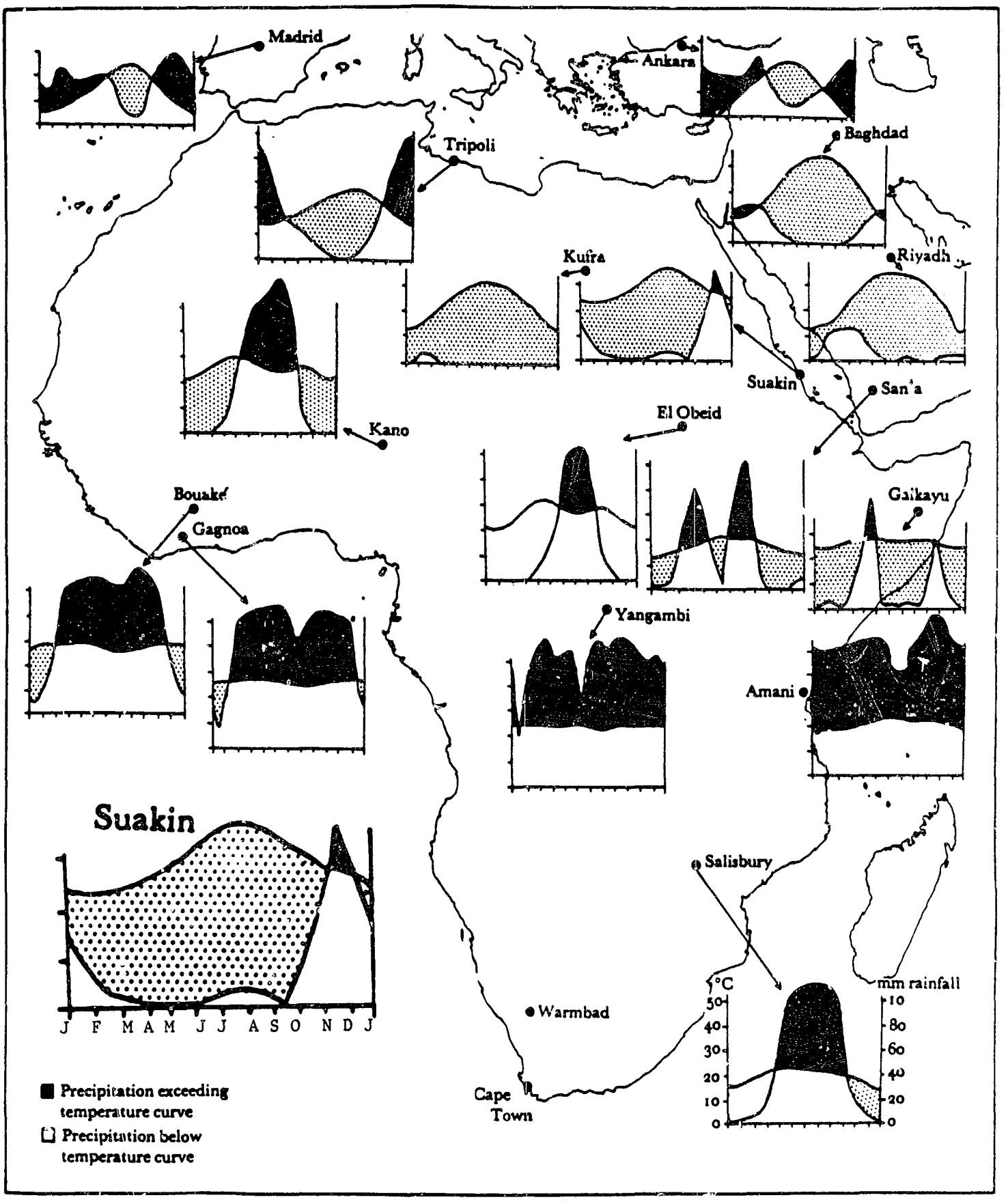


Figure 2-1. Climatogram of Suakin representing winter rainy season in the Red Sea Coast Region (after Wickens, 1976).

with the only relief caused by seasonal water runoff and dune formation. The few woody species are dominated by thorny acacias less than 5 m in height. Grass species from genera such as Aristida and Schoenfeldia form a continuous cover over many areas during the rainy season. Although relic species of a more humid regime can be found throughout the region, the current trend is toward even less vegetation as human and animal pressures coincide with the climate shift toward more arid conditions.

2.2 SOIL AND VEGETATION ZONE

The Semi-Desert zone of Sudan (Sahni, 1968) contains several vegetation zones, of which the Acacia tortilis subsp. raddiana - Maerua crassifolia Desert Scrub association (Harrison and Jackson, 1958) predominates in the Red Sea region. The soils are immature lithosols, including both sands and clays and frequent hard gravel "pavements" (Sahni, 1968). The diversity of tree species is restricted by the erratic rainfall patterns, although additional species consistently join the Acacia and Maerua along drainage lines. For example, Leptadenia pyrotechnica and Salvadora persica occur on sandy soils and Capparis decidua, Ziziphus spina-christi, and Balanites aegyptiaca occur on clay soils. The seasonal pattern of vegetative cover begins each fall with the first heavy showers. At that time, the annuals germinate and the perennial herbs and shrubs produce new green leaves. For the next 2 months, the landscape develops a green mantle. After the rains stop, the annual grasses begin to dry, quickly become standing hay, and soon disappear completely. The dominant annual grass species is Aristida mutabilis, with other Aristida species and Schoenefeldia gracilis also common. The principal perennial grass is Panicum turgidum.

2.3 FAUNA

The region of scrub grassland surrounding Tokar possesses a depauperate fauna compared to most regions of Africa. Due to harsh physical conditions and to hunting pressure and habitat destruction, virtually no large mammals remain. The ibex, duikers, gazelles, and hyenas previously found have disappeared. A number of smaller mammals such as warthogs, foxes, jackals, mongooses, and caracals may persist in remnants of native vegetation, but they are rare throughout the region. Hedgehogs, shrews, mice, gerbils, rats, hares, and bats are the only abundant mammals in most of the grassland areas.

Birds are much more numerous, with over 60 species occurring near Tokar (see Appendix B). At least six species of weavers breed in the local grasslands and frequently attack crops. Many insectivorous species are also common, including the larks, wagtails, bee-eaters, and egrets. The populations of insects, lizards, and small birds support a large and diverse group of raptors, with the black kite being the most common. The egrets and raptors are noted for following locust infestations, and they likely increase in numbers during plague years.

The lizards are a distant second to birds as the most abundant vertebrate group. The lacertids are common in the dune areas and possibly play an important role in the ecosystem. Snakes are less common; they are represented largely by small colubrids and vipers. Their principal prey may be toads, which, although numerous during the flood season, will aestivate for most of the year.

2.4 AGRICULTURE AND GRAZING USAGE

Throughout most of the year, the Red Sea region of Sudan is totally unsuitable for agriculture. However, in the months following the short rainy season, certain areas can produce substantial quantities of the subsistence grain crops sorghum and millet. These areas include the valley basins in the Red Sea Hills and the drainage zones for floodwaters that flow seaward from the hills. The Tokar Delta is the most fertile of these areas because it receives substantial flooding (up to 20 days under water) and clay soil deposition from the Baraka River. Because of this productivity, the delta is managed by a government corporation for the production of high-quality cotton. The cultivated areas of the delta comprise 175,000 hectares (ha) of cotton, 30,000 ha of sorghum, 17,000 ha of millet, and 1,700 ha of vegetables. An equally large area of the delta remains fallow each year and serves as grazing pasture for goats, sheep, cattle, and camels. Throughout arid Sudan, far more animals exist than the poor grazing lands can safely carry; consequently, overgrazing is the common practice (Halwagy, 1962). While the very center of the delta can have a surplus of forage grasses, the majority of the fallow areas become severely overgrazed by April. In general, the plant species found in the delta are adapted to overgrazing pressures, and the overall environment, while rich in many wildlife species, is greatly modified by human activities.

3. APPLICATION TESTING

3.1 AIRCRAFT SPECIFICATIONS

A Cessna Agtruck ST-ATZ aircraft was used for the first four applications (chlorpyrifos, fenitrothion, lambda-cyhalothrin, and bendiocarb). The aircraft was constructed with the following specifications: wingspan, 12.7 meters (m); gross weight, 1890 kg; hopper capacity, 1064 liters (L); fuel capacity, 205 L.

The aircraft was fitted with an internally mounted centrifugal pump having a variable speed hydraulic drive system and a standard trailing edge boom. Four Micronair AU5000 mini-atomizers were installed on the trailing edge boom, two at a distance 4.6 m from the centerline and two 1.4 m from the centerline. In addition, the Micronair application computer system was installed on the aircraft. This system provided a direct readout of the flow rate and of the revolutions per minute (rpm) of each atomizer.

An Antonov AN-2 aircraft was used for the last two applications (malathion and carbaryl). Although the Antonov is much larger than the Agtruck, the Antonov is able to fly with the same amount of precision. Six Micronair AU3000 mini-atomizers were installed on the boom. Although the Antonov was generally the more versatile plane, it was not equipped to spray at very low rates. However, the rates for the remaining applications (malathion and carbaryl) were relatively high (1.4 L/ha) and well within the output range of the Antonov.

Both aircraft proved to be satisfactory for the application of the test chemicals in the field trials. However, two additional features would have improved the efficiency of the application phase: (1) provision of a quality radio, antenna, and headset to simplify the logistical complexities of precise application (it was often impossible for the pilot to communicate with the flagging team on the ground using the hand-held transceivers); and (2) provision of a portable computer printer output to enable the pilot to collect exact application data during the spray runs (the pilot was not able to

observe and record data from the Micronair computer during the actual low-level flights over the plots; therefore, he flew to a remote area before each treatment to record the information on flow rate and rpm of each atomizer).

3.2 MICRONAIR SPECIFICATIONS AND CALIBRATION

On February 16 at the BanAir base in Kosti, Tim Sander of Micronair installed a complete Micronair AU5000 application system on the Agtruck sprayplane. The specifications of the atomizers, variable restrictor units (VRUs), diaphragms, check valves, and application monitor are described below.

1. ATOMIZERS. The aircraft was fitted with four Micronair AU5000 atomizers mounted on a streamlined boom fitted in place of the standard round spray boom used for nozzles. The inboard atomizer on each side was approximately 1 m from the fuselage, and each outboard atomizer was approximately 1.7 m from the wingtip. This configuration was adapted from the original six-atomizer installation, which had been used for agricultural spraying. Four atomizers were chosen instead of six to simplify the task of calibrating the aircraft at very low flow rates and to use the same configuration as used in the Mali trials. All atomizers were fitted with standard fan blades and 20-mesh gauze screens.

2. VARIABLE RESTRICTOR UNITS. Each atomizer was fitted with a variable restrictor unit to regulate the chemical flow from the boom to the atomizer. All VRUs were fitted with standard odd-numbered restrictor plates (these have holes numbered 1, 3, 5, 7, 11, and 13, with the higher numbered holes providing correspondingly higher flow rates at a given pressure).

3. DIAPHRAGM CHECK VALVES. Each atomizer was fitted with a diaphragm check valve to shut off the chemical supply when the plane was not spraying and to prevent dripping from the atomizer. The check valves were initially fitted with Viton diaphragms. These are resistant to the majority of agricultural chemicals, but Teflon diaphragms were provided for use with the bendiocarb ultra-low-volume (ULV) formulation.

4. APPLICATION MONITOR. The aircraft was fitted with a Micronair application monitor to measure the output of chemical from the spray system and to check the rotational speed of each atomizer. The flowmeter turbine that feeds flow information to the application monitor was tested both at a typical flow rate (7 L/min) and at a rate at the bottom of its operating range (4.5 L/min). The turbine calibration figures were entered into the application monitor as follows:

Normal flow range (5.5 to 40 L/min) Turbine 1 1394 pulses/L
Lower flow range (4.0 to 5.5 L/min) Turbine 2 1464 pulses/L

The application monitor should give accurate readings, provided that Turbine 1 is selected for flows above about 5.5 L/min and Turbine 2 is selected for lower flows.

After the aircraft and pilot arrived in Tokar, the Dynamac-CICP team conducted onsite calibration and rpm adjustments. Based upon the consensus of our application experts and the chemical company representatives, it was agreed to initially calibrate the system based upon the following:

Flight height	= (4.6 m) 15 feet
Swath spacing	= (35 m) 115 feet
Airspeed	= (160 km/h) 100 mi/h
Desired rpm of Micronair	= 6000 rpm

Spray tests with the VRU set at 3 and the pressure set at 34 psi produced the desired flow rate of 4.8 L/min. Two tests were made on the ground by collecting material from each atomizer for 30 seconds. The flow rate measured by the collection method was 4.84 and 4.68 L/min. This verified that the Micronair flowmeter provided a satisfactory flow-rate measurement for further calibrations. The angles of the Micronair blades were adjusted to the recommended angles and test flown to check the rpm. The rpm ranged from 5224 to 5770 for the four units. All angles were adjusted to increase the fan speed. This adjustment produced a range of fan speeds from 6260 to 6560 rpm. Thus, the blades were readjusted to an intermediate angle.

On March 7, Wes Yates, chief application scientist, conducted further calibration trials. Flow rates appeared to drop, and a partial reduction in flow at one nozzle was discovered. The VRU unit was cleaned, and the system was flushed with diesel oil. Adjustments were again established to obtain a flow rate of 4.7 L/min. The final adjustments on the blade angle for the four atomizers gave a range of 5660 to 6470 rpm, which was considered satisfactory for the applications.

3.3 WEATHER MONITORING

A base weather station was set up near the main camp, 0.4 km from the pesticide loading area at the airport. Weather records were collected for several days prior to the aerial applications, both at the base camp and on the plots during preliminary sampling. The weather station contained the following equipment:

1. One 6.5-m mast for the support of TEMPERATURE SENSORS used to measure the temperature gradient between 6.5 and 2 m. Each sensor was a thermocouple mounted in a fan-aspirated radiation shield. The motor-driven fan was powered by a 12-volt battery that was recharged with a small solar-cell panel. The temperature was measured with a hand-held digital instrument that recorded temperatures with an accuracy of $\pm 0.2°F$. The operator could select the measurement of T_1, T_2, or (T_1-T_2). Thus, the system could accurately measure the atmospheric temperature gradient within 6 m of the ground. Experience has shown that the presence of an inversion $(T_2>T_1)$ greatly improves deposition of fine particles, and a strong lapse $(T_1>T_2)$ results in a greater loss of fine particles through vertical diffusion and dispersion.

2. One 2-m mast with a lightweight WIND VANE for the determination of wind direction. A visual observation was made of the vane's position on a clear plastic disk with 30° graduations indicating compass direction.

3. One 2-m mast with a TOTALIZING CUP ANEOMETER used to measure the number of wind-driven revolutions of the cup. The observer routinely determined the average speed for a 1-minute time interval. A calibration chart was used to convert revolutions per minute to miles per hour (mi/h).

4. One 2-m mast with a PROTOTYPE CUP ANEOMETER, sensitive to 1 mi/h. This instrument utilized a small generator to produce direct analog recordings between 0 and 10 mi/h.

5. A battery-operated PSYCHROMETER to measure the wet-bulb and dry-bulb temperatures. The instrument consisted of two mercury thermometers, one fitted with a wick that was saturated with distilled water, and a battery-operated fan to aspirate air past the two thermometers. The relative humidity was determined from psychrometric charts based on the paired wet-bulb and dry-bulb readings.

6. A RAIN GAUGE in case of significant rainfall.

3.4 APPLICATION TESTING

Following the calibration of the application equipment, a mock spray trial was conducted to verify that the predicted pesticide deposition was actually occurring. Because an accurate application of a ULV pesticide requires precise swath spacing and consistent groundspeed as well as proper Micronair performance, all of these factors were evaluated before the actual test applications were conducted.

The guidance for each spray swath was provided by the location of vehicles with flags on each side of the spray block. Rubber-rope counters were attached to the front wheel of each vehicle and calibrated to measure the 35-m swath spacing. Two teams of two vehicles were used to enable the pilot to proceed from one test plot to the next one, while the second team of flaggers moved to set up for the third test plot.

Where possible, the spray flights were made first in one direction and then reversed, so that the airspeed of the aircraft would approximate the average groundspeed. To check the accuracy of the indicated airspeed on the

aircraft, several flight tests were conducted along a marked length of 500 m. Observers stationed at each marker observed the lapsed time for four passes, yielding a calculated speed of 96 mi/h, compared to the pilot's indicated speed of 100 mi/h. It was assumed that within the accuracy of the measurement, the indicated airspeed was correct. Thus, we used the airspeed of 100 mi/h (161 km/h) for the calibration calculations.

A mock spray test was conducted near the airstrip on a 250- by 250-m block. Diesel oil was used and applied at the calibrated rate of 0.5 L/ha. Two of the guidance vehicles were used to mark the 35-m swath spacing. Forty oil-sensitive spraycards were used to measure the spray deposition in the spray block as well as the downwind drift. The cards were placed at an 11-m spacing along a north-south line extending through the center of the block to a point 185 m downwind. The prevailing wind was 4 to 8 mi/h from the north, and the aircraft passes were from the east and west. Observers on the ground noticed a delay in the spray output and instructed the pilot to start the spray system before the edge of the plot and to stop slightly before reaching the opposite edge of the field. The spray cards showed good deposition in the plot area with a decreasing amount of deposition reaching to 185 m downwind.

A preliminary reading of droplet sizes indicated a volume median diameter (VMD) range of 100 to 150 microns. This confirmed the manufacturer application experts' assertion that an rpm of 6000 would produce the desired droplet size.

After the default of the BanAir contract, we replaced the Agtruck with an Antonov AN-2. As described in sections 3.1 and 3.2, the larger plane performed very much like the Agtruck. Nonetheless, the application testing was repeated and a second mock spray trial was conducted. The spray swath was increased to 40 m, but the flagging procedure was otherwise identical to that used with the Agtruck. Deposition on the spray cards was comparable to that found in the first mock trial and in the earlier plot treatments with the Agtruck.

4. LOCUST SURVEY FOR EFFICACY TESTING

4.1 LOCUST INFESTATION TRACKING

The head of the Sudanese Plant Protection Directorate (PPD) Locust Section, Dr. Karrar, indicated during the November 1987 visit of Dynamac vice president Allan Hirsch that locust breeding could continue into May and, therefore, that February would be an appropriate time to begin project activities in the Tokar Delta. Dr. Karrar described the PPD scouting network and stated that the network would be advising on the location of locust outbreaks by January or February. Although FAO consultant Mark Gorta deemed the December-January breeding period to be more reliable, the roads in the Tokar Delta are impassable during winter.

In January, scientific coordinator Jeffrey Evans and PPD project liaison Dr. Munir visited the Red Sea coast both north and south of Port Sudan. The only known locust populations were in Gebeit Mine, an area of rugged valleys north of Port Sudan where control operations were under way. Because it was not possible to conduct large-plot environmental trials in this type of terrain, it was decided to locate the environmental trials near Suakin and to await further reports on the extent and distribution of locust infestations in the north.

In February, before the field team left to set up the base camp for the environmental trials, Dynamac scientific manager Mark Southerland met with Dr. Karrar to review the latest locust reports. Dr. Karrar stated that efficacy trials were still possible in the north, where eggpod fields and locust hatchings were being reported and where small bands were forming in wadis with green vegetation. Later in the month, the locust reports continued to indicate that large areas around Wadi Diib and Wadi Oko were becoming infested. On March 7, the Dynamac-CICP-PPD efficacy team met to review the latest PPD locust report, which stated that 2600 ha in Wadi Diib were infested with small hopper bands spaced 5 m apart at a density of 10 bands/ha. This medium-density infestation primarily consisted of 1st and 3rd instar hoppers, with some later instars and copulating and egg-laying adults also present.

Both vegetation (green bushes, grasses, and sorghum) and the temperature and humidity were reported to be favorable. In Wadi Oko, a medium-density infestation of 400 bands covering 1500 ha was reported. The distance between bands was 5 to 15 m, and all instars were present. The vegetation was reported to be good.

4.2 MOBILIZATION OF THE EFFICACY TEAM

In the judgment of the efficacy team, including locust expert Chris Hemming, the reported conditions were conducive to an efficacy testing program. Hemming presented important facts concerning the behavior of locust bands, and the team discussed the logistics of conducting the aerial application and the sampling program for these pesticide trials in the narrow wadis of the north. A new test design, substantially modified from the original technical plan, was developed by efficacy leader Tom Schwartz and Mark Southerland. This design depended on following individual bands as replicated test units within a single sprayed area. Sequential treatments would be applied along the wadi, and a simultaneous control would be sampled in an area parallel to the central test area. Twenty-four-hour mortality measures would be used for the primary efficacy trial. Because barrier-strip tests were not feasible, movable cages were proposed to follow mortality over 1 to 2 weeks for the persistence trials.

Dynamac requested that the PPD Locust Control Section leave one major area untreated so that the efficacy team could move immediately to that site and begin the tests. A section in the Wadi Diib wide enough for aircraft maneuvers was selected. The team moved to Port Sudan on March 8, and the team moved from Port Sudan to a camp approximately 24 km north of Salala by March 10. On March 11, the team was shown the area in the Wadi Diib that had been reserved for the efficacy trials. The site was examined carefully and was visited again on March 13, when further observations were made and photographs were taken. The following notes describe the site and give the background on the decision to not proceed with the efficacy trials.

4.3 ONSITE LOCUST SURVEY AND EVALUATION

4.3.1 The Site

The infestation of desert locust hoppers was situated in a belt of sorghum cultivations lying along the foot of a long, low, rocky ridge. The cultivations were approximately 3 km in length and varied in width from less than 50 m to 400 m. The sorghum crop was fully mature, and a small amount of harvesting had already been undertaken. The crop was best developed close to the rocky ridge, where more runoff water had accumulated before the seeds were sown. The whole area was drying out rapidly, particularly in the sections farthest from the ridge. In the area where the crop was at its best, there was also the best development of weeds between the sorghum plants; locally the weeds provided an almost 100% ground cover to a depth of 20 to 30 cm. In the section of the cultivated area, where the width was less than 50 m, the vegetation on the side away from the rocky ridge consisted of dense salt bush (*Suaeda* sp.) reaching more than 2 m in height.

4.3.2 The Locust Population

The locust population in the sorghum cultivations comprised all five hopper instars, a few fledgings, and the occasional adult of the parent generation. The commonest instar appeared to be 4th. The distribution of the instars was such that one did not find all the instars in any one area, but a patch of 3rd instars might be followed by a patch of 4th instars and then a dense group of 2nd instars. The greatest numbers were found in the 50 m closest to the rocky ridge, which also was the area containing the greatest quantity of weeds (the only green vegetation). The hoppers were not generally grouped into well-defined bands but were somewhat dispersed. The dense weed cover made hopper band cohesion difficult, and an examination of the hopper color patterns showed a decreasing amount of black in the later instars indicating disassociation, as would be expected in the dense ground vegetation.

4.3.3 The Problems of Spraying

The following problems associated with spraying were identified:

1. It is not acceptable to spray a fully mature standing crop in which harvesting has already begun.

2. Owing to the height of the sorghum crop (up to 2.5 m) and to the locally dense ground cover of weeds, very little spray would reach the hoppers on the ground (a requirement for a contact insecticide to be effective). The pickup of spray droplets by the vegetation would be high even in the lightest breeze, but windspeeds exceeding 8 mi/h (3.3 m/sec) were recorded even at dawn (0530 hours).

3. To divide the site into the required number of blocks for the different treatments and controls, it would have been necessary to spray the long, narrow, cultivated area at right angles to the rocky ridge. A sprayplane flying either toward or away from the ridge would have been unable to spray close to the ridge where most of the hoppers were situated.

4. Owing to the small number of fledglings observed on the first day (March 11) and to the expectation that the majority of the population (4th instar) would fledge within 7 to 10 days, fledging would, after a few days, be followed by dispersal of the entire population. The time available for the various pesticide treatments would be very short.

4.3.4 The Problems of Population Assessment

The following problems associated with population assessment were identified:

1. Most of the hoppers occurred in the area with the densest weed cover. When hoppers on open ground were approached, they immediately started hopping into the dense weeds and soon were well hidden. The number of hoppers that could be counted by an observer under these conditions would be only a small proportion of the total. This would be particularly true in the case of the early instars, which are smaller and inconspicuously colored. The dense ground cover and hopper behavior together would make accurate density estimates impossible.

2. The hopper population was not evenly distributed throughout the sorghum belt; the age distribution of the hoppers was even more irregular. As natural mortality in desert locust hopper populations is always high, one would have to assess this mortality separately and allow for it when estimating the numbers killed by the various treatments. With the uneven age distribution observed, one could not infer that the natural mortality observed in control blocks was the same as that in treated blocks, even if they were adjacent.

3. The uneven distribution of the different-aged hoppers would have resulted in some blocks containing an above-average population of more vulnerable younger instars. The differential mortality based on age would make it very difficult to compare treatments in different blocks.

4.4 RECOMMENDATIONS FOR FUTURE TRIALS

4.4.1 Timing

1. The likelihood of suitable breeding populations occurring in the Red Sea winter breeding area can be assessed only toward the end of the summer campaign, when the number of control swarms produced can be determined. Toward the end of 1986, for example, large numbers of swarms were reported and a large-scale Red Sea campaign ensued. This campaign reduced the number of swarms, so that the 87/88 winter campaign was much smaller than the 86/87 campaign.

2. It is essential that the trials be conducted in the open plains where vegetation is sparse and low, so that a reasonable level of accuracy can be achieved in the population assessment. These conditions are only likely to occur early in the rainy season. The efficacy team must therefore be in the field ready to start work not later than mid-January.

3. As first and second instar hoppers are very easily killed, it is recommended that the trials be conducted on 3rd to 5th instar populations. The later instars are not only larger but also more conspicuously colored and, therefore, easier to count, producing more accurate population estimates.

4. To more easily compare different treatments, it is desirable that the age of the hoppers in all blocks be approximately the same. Synchrony of hatching is a characteristic of highly gregarious populations and is therefore more likely to occur in the winter breeding area following the escape of swarms from the control after summer breeding.

4.4.2 Population Assessment Techniques

The conventional randomized block design used in grasshopper trials may be appropriate for locust work when the hopper bands are very large, i.e., the same size or larger than the experimental blocks. However, this situation is by no means the norm and the efficacy team must be prepared to assess a population comprising a large number of highly mobile small bands often separated by 50 to 100 m. Under these circumstances, it might be necessary to follow the fate of individual bands. Such decisions, however, cannot be made in advance and the team must be prepared to develop sampling techniques appropriate to the conditions they find in the field.

5. ENVIRONMENTAL IMPACT TRIALS

5.1 SITE SELECTION

Historical outbreaks of the desert locust, including the outbreak of 1986-87, began with winter breeding in well-known regions of Africa and Asia. The area along the Red Sea coast of Sudan is one of the breeding areas where the concentrations of emerging hoppers can be expected to be the greatest. Consequently, this site was chosen for our fields. It was not only the site where the best testable populations of locusts (abundant hopper bands) had occurred but also a likely area for future desert locust control efforts.

During January 1988, the Dynamac scientific coordinator worked with the Sudan Plant Protection Directorate to analyze the status of the locust infestation and to determine the best sites for the efficacy trials and the environmental impact trials. After it was determined that the only likely testable populations of locusts for efficacy trials this season would occur in narrow wadis to the north, a separate site with enough area for the 100-ha plots needed to conduct the environmental impact trials was sought south of Port Sudan. The initial determination was that the area near Suakin would provide an adequate environmental impact test and would supply the best logistical support to the efficacy trials in the north. When the field team arrived in February, the scientific manager concluded that the increasingly arid areas around Suakin did not contain adequate populations of nontarget organisms to conduct a rigorous environmental field test. Consultation with PPD scientists led the team to survey the Tokar Delta region. Observation confirmed that the delta region contained the most lush vegetation and was the most biotically diverse area along the Red Sea coast. After negotiation with the administration of the Tokar Delta Agricultural Corporation, it was agreed that grassland areas totaling approximately 50 km^2 would be used for test plots during the field trials.

The Tokar Delta is a relatively water-rich area in the Red Sea Province that, by virtue of the rains channeled into the delta by the Baraka River, supports the city of Tokar on the economy of a government-managed agricultural corporation. Owing to floodwaters received during the fall months, regions of the delta are under water for up to 3 weeks. This water allows cotton, subsistence grain crops (sorghum and millet), and occasional vegetables to be grown through the winter and into the spring. Uncultivated areas grow thick grasses that are grazed by goats, sheep, cattle, and camels. To provide comparability among plots, to avoid exposure to field workers, and to expose the widest variety of possible nontarget organisms, we selected fallow grassland areas along a northeast line from Tokar to the Red Sea. With the camp set up next to the airstrip southwest of Tokar, daily sampling of the plots was possible, as was constant maintenance of the spray equipment.

5.2 TEST DESIGN

5.2.1 Plot Delineation

Surveys of the region with Delta Corporation and PPD personnel showed that the areas directly east and south of Tokar were too heavily cultivated for consideration as test plots. With the guidance of the local inspector, a southwest-northeast line that began 5 km southeast of camp was identified. This line (length 15 km) encompassed enough grassland areas to designate 24 paired plots, with one 100-ha plot on each side of the line. Even though this area was 80% fallow grassland, considerable care had to be taken to avoid including large cultivated areas or villages in the plots. By varying the buffer zones from 250 to 600 m and by eliminating certain areas, the majority of fields and habitations were excluded from the test plots. The final plot layout covered 15 by 2.5 km, stretching from lush 1-m-tall grasses to very dry shrubland and to more maritime vegetation (Figure 5-1).

5.2.2 Plot Size and Arrangement

Every plot measured 1 km (1000 m) on each side and encompassed 100 ha of grassland, with scattered shrubs and occasional cultivated fields. A minimum of 0.25 km (250 m) was maintained as a buffer zone between plots

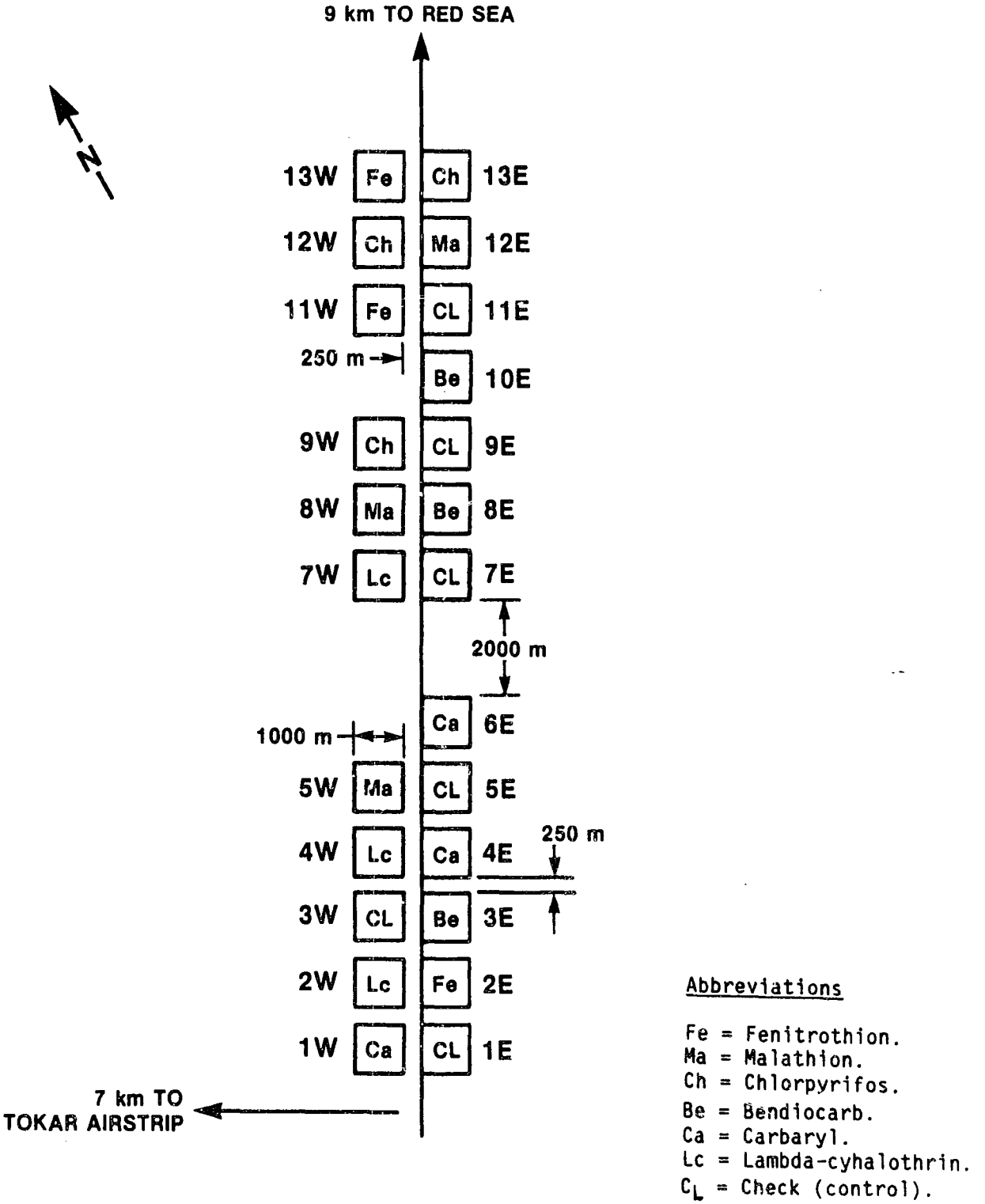


Figure 5-1. Location of environmental impact test plots (100 ha) along a northeast line in the Tokar Delta.

in both the east-west and north-south directions. Distances up to 3.5 km occurred between plots separated by inhabited areas. Although the vegetation profile varied among plots (see section 5.2.3), the site was not partitioned into distinct habitats requiring a blocked or stratified design. Insofar as each plot was essentially a unique combination of habitats, a completely randomized design was used (see Figure 5-1). Three replicate plots for each treatment (spraying with fenitrothion, malathion, chlorpyrifos, bendiocarb, carbaryl, and lambda-cyhalothrin) and six control plots, to be sampled with each treatment, were designated. The plots on the west side of the line were numbered in a north-south sequence 1W to 13W; those on the east side were numbered 1E to 13E. Plots originally designated as 6W and 10W were deleted because they encompassed cotton fields and unvegetated dunes, respectively. The treatments were assigned using a simple random number generator. No like treatments were assigned to adjacent plots.

5.2.3 Habitat Description

All of the plots were located on the Tokar Delta, an area of entisol aquent soils created by the annual flooding of the Baraka River. The Tokar Delta Corporation captures the floodwaters with earthen dikes as they move from the Red Sea Hills toward the Red Sea. Within the test plot area, the effects of flood control, livestock grazing, and cultivation (principally with cotton) were present. Generally, the pattern of vegetative cover on our plots became drier and less dense as the plots extended northeast from the center of the delta (plots 1 through 4) toward the Red Sea (up to plot 13). The soils gradually changed from a fine silty clay loam, dense and deeply cracked, to a looser sandy clay. The plots closest to the sea exhibited increased shrub cover on more saline soils.

The controls were plots 1E, 3W, 5E, 7E, 9E, and 11E. These plots encompassed the full range of vegetative structure and composition seen in the test area. Plots 1E, 3W, and 5E all contained silty clay loam soils covered with the dominant grass species *Paspalidium germinatum*, and a scattering of the tree *Acacia nilotica* v. *adansonii* at one to three trees per hectare. On plot 1E, the *P. germinatum* was overgrazed to clumps 15 cm

high with occasional bare spots and invasion by Argemone mexicana. P. germinatum was considerably lusher on plots 3W (up to 25 cm high) and 5E (up to 40 cm high), and both plots contained five or more Caltropis procera per hectare. Plots 7E, 9E, and 11E were on sandy clay soils with much drier P. germinatum. This grass was often grazed to the soil level, with the only patches higher than 10 cm occurring on plot 7E. Plot 7E also showed invasion by A. nilotica, C. procera, and Hyphanea spp. at a density of 10 per hectare. Only C. procera at a density of three to five per hectare occurred on plot 9E.

The fenitrothion-treated plots were 2E, 11W, and 13W. On the deeply cracked silty clay loam soils of 2E, P. germinatum formed a dense cover of 50- to 75-cm-tall grass. C. procera was also present at a density of one to two per hectare. On the sandy clay soil of 11E, the P. germinatum was drying out and often closely grazed, reaching no higher than 10 cm. On 13W, the more saline sandy soils supported numerous Suaeda pruinosa in the northern portion of the plot. More characteristic than the grassy cover of P. germinatum was the very dense stand of C. procera (up to 2 m in height) and the scattering of A. nilotica (up to 2.5 m in height, five to seven per hectare).

The malathion-treated plots were 5E, 8W, and 12E. Plot 5W contained tall P. germinatum grass (30 to 60 cm high) that was beginning to dry down on the silty clay loam. Occasional A. nilotica, C. procera, and Hyphanea spp. up to 75 cm high were present. Also on sandy clay, but with some saline conditions, the P. germinatum on plot 12E formed a mosaic of bare ground and green patches up to 30 cm in height. Numerous small (30 cm high) S. pruinosa bushes were scattered throughout the plot.

The chlorpyrifos-treated plots were 9W, 12W, and 13E. All three plots had sandy clay soils with a cover of P. germinatum. The grass on 9W was dried out, and dry areas on 12W alternated with green patches up to 10 cm high. Density of C. procera (up to 1.5 m tall) on both plots was two per hectare, with an equal density of A. nilotica also occurring on 12W. Plot 13E contained some saline conditions and occasional areas of silty clay loam but was characterized by dense groves of S. pruinosa covering approximately half of the plot.

The bendiocarb-treated plots were 3E, 8E, and 10E. On plot 3E, a very dense cover of P. germinatum (60 to 100 cm high) grew from the deeply cracked silty clay loam soil. Tall (2 to 3 m high) A. nilotica and C. procera occurred at densities of 10 to 15 per hectare. On the sandy clay soils of 8E and 10E, the P. germinatum was drying out, although occasional green patches were interspersed with bare ground. C. procera and Hyphanea spp. were present.

The carbaryl-treated plots were 1W, 4E, and 6E. A lush growth of P. germinatum (50 to 75 cm high) covered the deeply cracked silty clay loam soils of plots 1W and 4E. C. procera occurred in moderate density (one to two per hectare) on plot 1W and in dense stands with A. nilotica on plot 4E. Plot 6E, which included a large area of bare shady clay behind a long dike, was generally dry. Vegetation was limited to depressions and consisted of dry P. germinatum (up to 30 cm high) and scattered clusters of 10 to 20 A. nilotica and C. procera (up to 1.5 m in height).

The lambda-cyhalothrin plots were 2W, 4W, and 7W. On the deeply cracked, silty, clay loam soils of 2W, P. germinatum formed a uniform carpet of tall (60 to 100 cm high) grass. On the similar soils of 4W, the lush grass was beginning to dry and was overgrazed in spots. On the sandy clay of 7W, P. germinatum was dried out and closely grazed with only occasional green patches up to 25 cm high. This plot also included A. nilotica, C. procera, and Hyphanea spp., ranging up to 1.5 m in height at a density of 10 per hectare.

5.2.4 Order of Treatments

To reduce the confounding factors of temporal variation, application of the test pesticides was completed as quickly as possible. The sampling regime required same-day and 1-day posttreatment samples and thus prevented the application of more than one pesticide each day. The BanAir aircraft was unable to complete the last two sprays; therefore, two spray sequences, one of four pesticides (chlorpyrifos, fenitrothion, lambda-cyhalothrin, and bendiocarb) and one of two pesticides (malathion and carbaryl), were completed 3 weeks apart.

The sampling sequence duplicated the spray sequence in that counts or samples were taken at set intervals after pesticide application. In

addition, sampling was performed at the same time of day whenever possible. In some cases, evening samples were substituted for morning samples, but in no case were observations made when abundances or behaviors were expected to vary greatly from the usual pattern. While environmental and biotic changes undoubtedly occurred over the course of the trials (e.g., the general drying of vegetation), the restriction of sampling to 7-day intervals likely produced little temporal bias in the estimates of the treatment effects. Same-day controls were sampled for every set of treatment replicates so that temporal biases could be removed statistically.

Appendix E contains wide-angle photographs showing the landscape and vegetation profile of each plot.

5.3 PESTICIDE APPLICATION

5.3.1 Treatments and Rates

Six of the seven pesticides selected for testing were applied in the Sudan environmental trials: fenitrothion and malathion (organophosphorus compounds chosen as test standards), chlorpyrifos (organophosphorus), bendiocarb and carbaryl (carbamates), and lambda-cyhalothrin (synthetic pyrethroid). The rates used were those recommended by the manufacturers: malathion at 1300 grams active ingredient per hectare (g a.i./ha), fenitrothion at 500 g a.i./ha, chlorpyrifos at 250 g a.i./ha, bendiocarb at 125 g a.i./ha, carbaryl at 576 g a.i./ha, and lambda-cyhalothrin at 20 g a.i./ha. The specific formulations used, the rates in liters per hectare, and the product trade names are given in Table 5-1. Diazinon was not tested because the test stock did not reach the field site.

5.3.2 Pesticide Handling

All materials supplied by the manufacturers were transferred by truck to the Tokar field camp and stored in an enclosure next to the airstrip. A thatched roof was built to reduce daytime temperatures. A watchman stayed in a tent at the storage site. Materials in 20-L containers were hand poured into the aircraft hopper. A rotary hand pump was used to transfer the formulations stored in 55-gallon drums. The system required

Table 5-1. Pesticides Used in the Tokar, Sudan, Environmental Impact Trials

Compound	Chemical class	Trade name	Formulation	L/ha[a]	g a.i./ha[b]
Fenitrothion	Organophosphorus	Sumithion	L100	0.52	520
Malathion	Organophosphorus	Malathion	96% ULV	1.41	1300
Chlorpyrifos	Organophosphorus	Dursban	450 ULV	0.50	225
Bendiocarb	Carbamate	Ficam	20% ULV	0.62	124
Carbaryl	Carbamate	Sevin	4 - oil	1.46	576
Lambda-cyhalothrin	Pyrethroid	Karate	4% ULV	0.51	20

[a]Liters/hectare.

[b]Grams active ingredient/hectare.

a minimum of 40 liters (L) of material to prime the spray system. When possible, the pesticide remaining in the hopper after the application was transferred with the same pump back into the original container. The spray system was flushed with diesel oil after the first three treatments. Bendiocarb was the last material applied with the Agtruck and in this case, Solvesso was used to flush the system both before and after the application. There appeared to be some incompatibility between the Solvesso and the previous formulation (lambda-cyhalothrin). The main in-line filter became clogged with large, gel-like granules during the flushing process. The filter was cleaned, and no further problems appeared. Diesel oil was also used to flush the Antonov spray system before and after the applications of malathion and carbaryl. All personnel involved with the loading were supplied with coveralls, waterproof boots, gloves, aprons, face shields, and respirators.

The hand-operated rotary pump was satisfactory for transferring the material. Since all loading personnel used protective clothing, no direct exposure to workers occurred. For future programs, however, the handling hazards could be reduced by the use of a closed loading system. Simple devices include special enclosed probes that can be extended into the containers (1 to 10 gallons or 55 gallons). These probes can be used with a hand- or battery-powered system.

5.3.3 Calibration of Equipment

The spray application was calibrated for each material and was based on the following relationship:

$$L/ha = \frac{L/min}{ha/min} \qquad \text{Eq. 1}$$

The constant factors for all applications were obtained from the precalibration trials and were as follows:

Swath spacing = 35 m (40 m for Antonov)

Airspeed = 161 km/h

$$\text{Thus, } ha/min = (35\ m)\left(\frac{161\ km}{h}\right)\left(\frac{1000\ m}{km}\right)\left(\frac{ha}{10{,}000\ m^2}\right)\left(\frac{h}{60\ min}\right) = 9.4\ \frac{ha}{min}$$

From Eq. 1:

$$L/min = \left(\frac{ha}{min}\right)\left(\frac{L}{ha}\right)$$

$$L/min = (9.4)\left(\frac{L}{ha}\right)$$

The desired application rates (L/ha) were taken from the recommendations of the chemical companies. For example, the recommended application rate for chlorpyrifos was 0.5 L/ha.

Thus, the desired flow rate was:

$$L/min = (9.4)(0.5) = 4.7\ L/min$$

The general application procedure was to load sufficient material in the hopper to cover the proposed three replicate plots. The pilot was instructed to fly to a remote area (away from the plots) and to adjust the hydraulic pump drive system to obtain the desired flow rate, record the value, and then record the rpm of each atomizer. During the mock trial, hand signals between the ground crew and pilot were discussed and included basic signals to stop spraying, continue spraying, and return to airport. In addition, the pilot was given a transceiver to enable him to hear verbal instructions from the flaggers even if excessive noise in the cockpit prevented the pilot from talking to the ground crew. However, radio communication with both aircraft proved to be inadequate, and visual signals were used almost exclusively. The application data for the first four materials (obtained from the Micronair monitor) are shown in Table 5-2.

5.3.4 Weather Conditions

Weather data gathered prior to the aerial applications indicated that the temperature and wind conditions were essentially the same at the camp and on the plots. The temperature gradient data from the base station tower revealed that no local inversions were present, even during early morning hours. Thus, the transport and diffusion of the fine spray particles were primarily dependent on the wind velocity. During the

Table 5-2. Aerial Application Parameters for the First Four Pesticides[a]

Date	Material	Micronair[b] rpm_1	rpm_2	rpm_3	rpm_4	VRU setting	Spray pressure (psi)	Flow rate (L/min)	Application rate (L/ha)
3/10	Chlorpyrifos	5860	5450	6050	5810	3	40	4.7	0.50
3/11	Fenitrothion	5910	5530	6020	5810	3	59	4.9	0.52
3/12	Lambda-cyhalothrin	6100	5500	6320	6490	3	30	4.8	0.51
3/13	Bendiocarb	5920	5940	6520	5840	5	26	5.8	0.62

[a]Swath spacing = 35 m; height = 2 to 5 m; airspeed = 100 mi/h; manifold pressure = 21 inches; engine speed = 2300 rpm.
[b]Subscripts on the rpm refer to the location of the Micronair; the units were numbered from left to right as observed by the pilot.

entire spray period, the prevailing wind was from the north with the lowest velocity at daylight and the highest velocity and most turbulent conditions in the midafternoon (1400-1500 hours). Table 5-3 lists the date and time for the application of each material to its three replicate plots. Weather conditions before, during, and after the spray applications are also included.

5.3.5 Field Application and Deposition Results

Flagging teams arrived on the site at first light to begin spraying between 0630 and 0730 hours. Two teams of two vehicles were used so that the sprayplane could move immediately to the second plot while the first team repositioned for the third spray. Each vehicle was equipped with a wheel counter that indicated 2.5 m for every wheel rotation. Radio communication among most of the vehicles was unreliable. Careful planning and occasional visual signals were used in the flagging procedure.

One vehicle was positioned on the east end of the plot; a second vehicle was positioned on the west end. Both vehicles began on the southern corners and moved north for each additional swath. Prevailing winds were from the north (Table 5-3); therefore, the plane flew successive east-to-west swaths while moving north. The flagging vehicles drove along the boundary of the test plot. Spray turnon was initiated an instant before the plane passed over the vehicles, on the eastern edge of the plot; turnoff was begun before the plane reached the west flagging vehicle. A total of 28 swaths (for 35-m spacings) or 25 swaths (for 40-m spacings) were flown over each plot.

A 200- by 200-m grid of nine spray deposition cards (5- by 5-cm oil-sensitive sheets on Kromecote cards) was constructed on each plot before spraying. Each card was secured in a plastic holder and placed flat on the ground. Visual determination of the spraycards in the grid verified that adequate deposition was achieved for all chemicals. Although the wind velocities exceeded the optimal range for some applications, the uniform deposition on the spraycards indicated that the spray was not displaced more than a couple of swaths downwind. This was likely due to the low flying height of the aircraft and the lack of a thermal inversion. The greater than 250-m buffer zones were more than adequate to

Table 5-3. Weather Data During Pesticide Application, Tokar, Sudan, 1988

Date	Pesticide	Time	Plot sprayed	Temp (°C)	RH	Wind direction	Wind-speed (mi/h)	Sky
March 10	Chlorpyrifos	0700	9W	23.3	72	NE	9.0	Cloudy
		0745	--	24.4	67	NE	7.5	Cloudy
		0830	13E	25.6	62	NE	12.3	Cloudy
		1045	12W	28.9	48	NE	8.4	Cloudy
		1315	--	28.9	48	NE	11.0	Cloudy
		1800	--	25.0	60	NE	6.0	Cloudy
March 11	Fenitrothion	0645	--	21.1	68	N	N.D.	P. cloudy
		0745	13W	25.0	58	N	7.0	Clear
		0900	--	27.8	54	N	8.0	Clear
		1000	11W	29.4	45	N	9.2	Clear
		1100	--	28.9	45	N	N.D.	Clear
		1630	2E	26.1	58	N	11.0	Clear
March 12	Lambda-cyhalothrin	0645	2W (part)	21.7	65	N	4.5	P. cloudy
		0800	7W	25.0	50	N	8.5	P. cloudy
		0900	2W (part)	26.1	54	N	10.0	P. cloudy
		1000	4W	28.3	50	N	11.0	P. cloudy
		1400	--	21.7	N.D.	N	12.0	P. cloudy
		1630	--	16.6	N.D.	N	14.5	P. cloudy
March 13	Bendiocarb	0600	10E	23.3	80	N	4.5	Tr. rain
		0700	3E	25.0	70	N	11.0	Cloudy
		0800	--	25.0	52	N	11.3	Cloudy
		1000	8E	27.2	65	N	15.0	Cloudy
		1600	--	27.2	62	N	N.D.	Cloudy
April 4	Malathion	1130	5W	30.0	48	N	4.0	Clear
		1215	8W	30.5	48	N	5.0	Clear
		1300	12E	30.5	45	N	7.0	Clear
		1400	--	31.5	N.D.	N	8.0	Clear
		1545	--	32.5	N.D.	N	9.0	Clear
April 5	Carbaryl	0730	4E					
		0815	1W	28.3	61	N	6.0	P. cloudy
		0900	6E	31.1	61	N	5.0	P. cloudy
		1015	--	31.2	N.D.	N	6.0	P. cloudy
		1230	--	32.4	58	N	7.0	P. cloudy
		1330	--	32.6	N.D.	N	8.0	P. cloudy

RH = Relative humidity.
N.D. = No data available.
P. cloudy = Partly cloudy.
-- = No plot sprayed.
Tr. rain = Trace of rain.

avoid interplot contamination through drift. Although the spraycards were used during each pesticide application, the deposition of two chemicals (carbaryl and lambda-cyhalothrin) was faint or ephemeral, and accurate readings of droplet density and droplet size were not possible. Magnesium oxide-coated slides were used for the lambda-cyhalothrin application and were returned to the manufacturer for evaluation.

As in the Mali trials, the chemicals producing the most readable deposits on the oil-sensitive spraycards were fenitrothion, malathion, chlorpyrifos, and bendiocarb (see Figure 5-2). As expected, the depositions of fenitrothion and malathion were best represented on the cards. Analyses of the droplet densities on each of the nine cards placed on each plot (taking three replicate counts per card) produced 27 density measures per chemical. For fenitrothion, the mean droplet density was 7.8 drops/cm^2. For malathion, the droplet density was 22.6/cm^2, only 2.5% greater than that expected for malathion given its 2.8-fold higher application rate. This remarkable agreement between the deposition observed for fenitrothion and that observed for malathion indicates that the application results achieved by the Agtruck (fenitrothion) and by the Antonov (malathion) were indeed equivalent. The relatively low coefficient of variation of 34% obtained from the droplet counts for these pesticides also indicates that the application was uniform across the plots.

The spraycards exposed during the bendiocarb application were somewhat more difficult to read, but they recorded a mean droplet density of 8.0/cm^2, only 15% less than that expected from the results of the fenitrothion cards. Chlorpyrifos, however, produced very faint marks on the spraycards, and although the cards were readable, the droplet counts are undoubtedly an underestimate. The mean droplet density obtained from the chlorpyrifos deposition was 4.6/cm^2, or 43% below the expected number.

However, although the droplet size produced by the Micronair atomizer is also a function of airspeed, flow rate, and the physical properties of the formulation, the adjustment of the cage revolutions per minute is the major means of regulating the droplet size produced for a given application. It was decided that a constant monitoring of rpm during application was preferable to attempts to assess droplet-size spectrum on

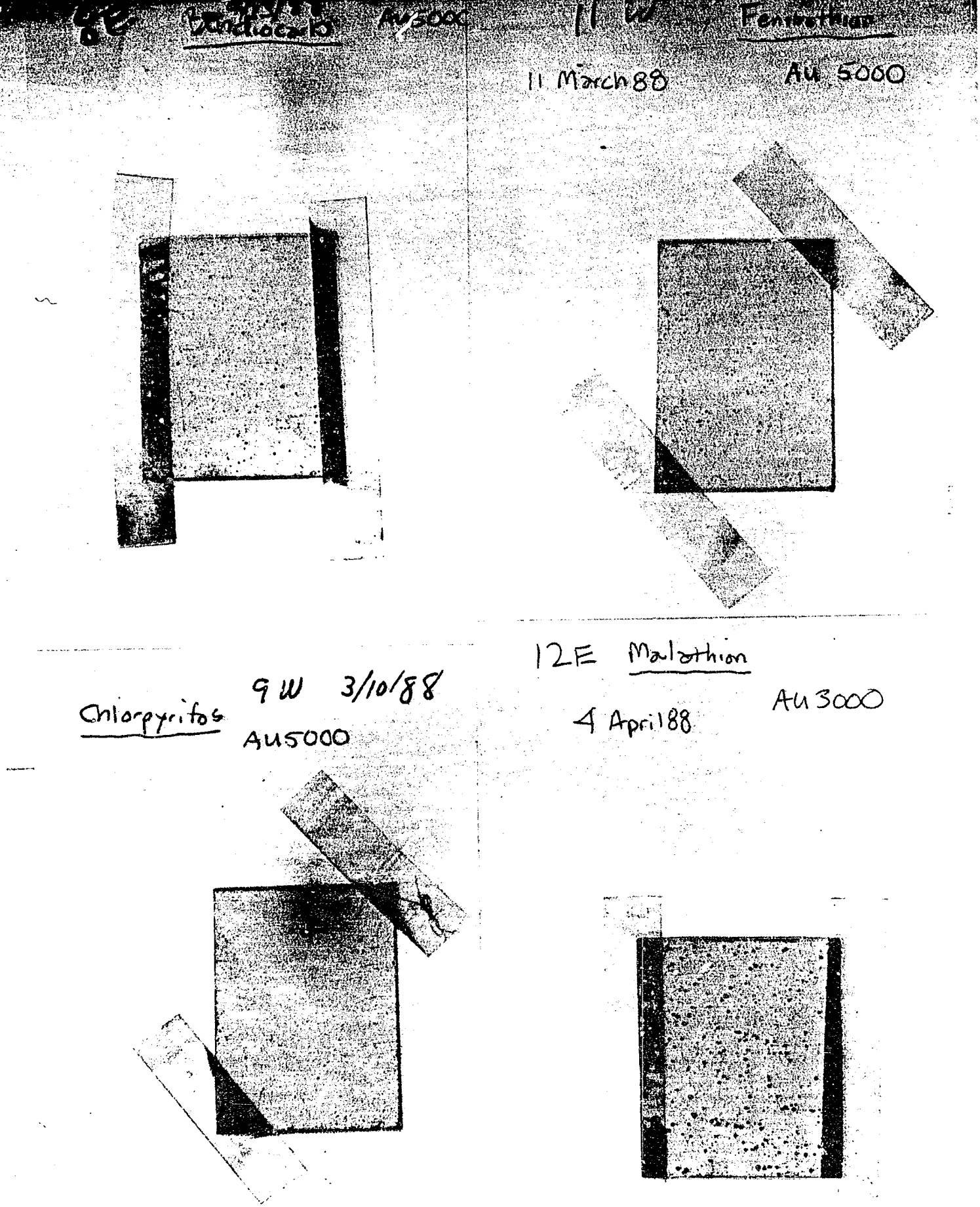


Figure 5-2. Examples of readable deposition on spraycards following the application of four ULV pesticides.

the deposition cards. The desired rotational speed of 6000 rpm was selected based on previous experience and the consensus of Micronair and chemical company representatives. As stated in section 5.3.3, the recorded rpm count for Agtruck application remained near 6000. Measurement of the droplet-size spectrum in the field is extremely difficult because of various factors, including the following: (1) the loss of the fine particle fraction due to drift; and (2) the variability in the stain size spread factor among the different formulations. Based on estimates from tests with the Laser Particle Measurement system at the University of California-Davis, droplet sizes of approximately 150 microns volume median diameter (VMD) are to be expected under the conditions existing during these trials.

5.4 PRESPRAY AND POSTSPRAY SAMPLING

5.4.1 Replication and Controls

As described in the Sudan Technical Plan (Appendix T), the sampling design for environmental impact assessment was modified from the Mali trials to provide both greater replication and more systematic comparison with the controls. For each pesticide treatment, three replicate treatment plots and one control plot were designated. In addition to describing the natural population fluctuations of nontarget organisms throughout the course of the tests, these control plots served as simultaneous checks for their respective set of treatment replicates. In this way, the pesticide effects on treatment plots could be adjusted for control of abundance levels without temporal confoundment. The variation in habitat among plots was controlled across treatments through the usual random assignment of treatments to replicate plots within the study area (section 5.2.2). While the vegetation differed substantially among plots, no bias could be discerned from an evaluation of the habitat parameters within individual plots (section 5.2.3).

While the test design included the usual pattern of repeated posttreatment sampling (at different times postspray), an equally extensive preliminary (or prespray) sampling was added. Samples were taken at 1 day, 4 days, and 7 days posttreatment so that the immediate effects of the pesticides, as well as the persistence of these effects, could be

measured. This time frame was chosen because the Mali results indicated that the acute effects would be decreasing through the first week posttreatment, and that many insect groups would likely be rebounding by day 7. However, it was anticipated that these posttreatment samples might have to be combined and compared to a pooled measure of abundance for pretreatment samples, both because insect populations are notoriously variable and because any effects on birds were expected to be quite subtle. Therefore, the equivalent prespray periods were sampled (-8 days, -5 days, and -2 days). In this way, each treatment and control plot was sampled six times (additional pretreatment samples were conducted on the malathion and carbaryl plots because of delays in application). For the pitfall and sticky board sampling methods, 3-day capture measures (requiring two visits per sample) were used, thus producing only four samples per plot.

5.4.2 Bird Transects and Carcass Searches

On each pre- and posttreatment sampling day, two 300-m transects were walked and all birds observed within 50 m were recorded. The identification to species and the location along the transect were noted for each individual bird. If a bird could not be identified to species, but its general characteristics were visible, then a designation as to whether the bird was an insectivore, a granivore, or a predator was made; other birds were classified as unknown. These unidentified birds made up less than 5% of all observations.

The two transects were arranged in a "V" with its vertex at the plot's center and with the directions selected at random so that no transect pair formed an angle of less than 90° (Figure 5-3). Each transect was marked with numbered flags at 25-m intervals so that the same transect could be walked on each sampling day. The observer stopped at each of the 12 flags and visually searched the 50 m on each side. All birds seen by the observer either after he had stopped or while he was walking were recorded. The majority of the bird counts were performed before 1300 h, when bird activity was the greatest. For each treatment, the replicate plots were sampled in random order, often with two sampling teams operating together so that no same-treatment samples had to be carried over to the next day.

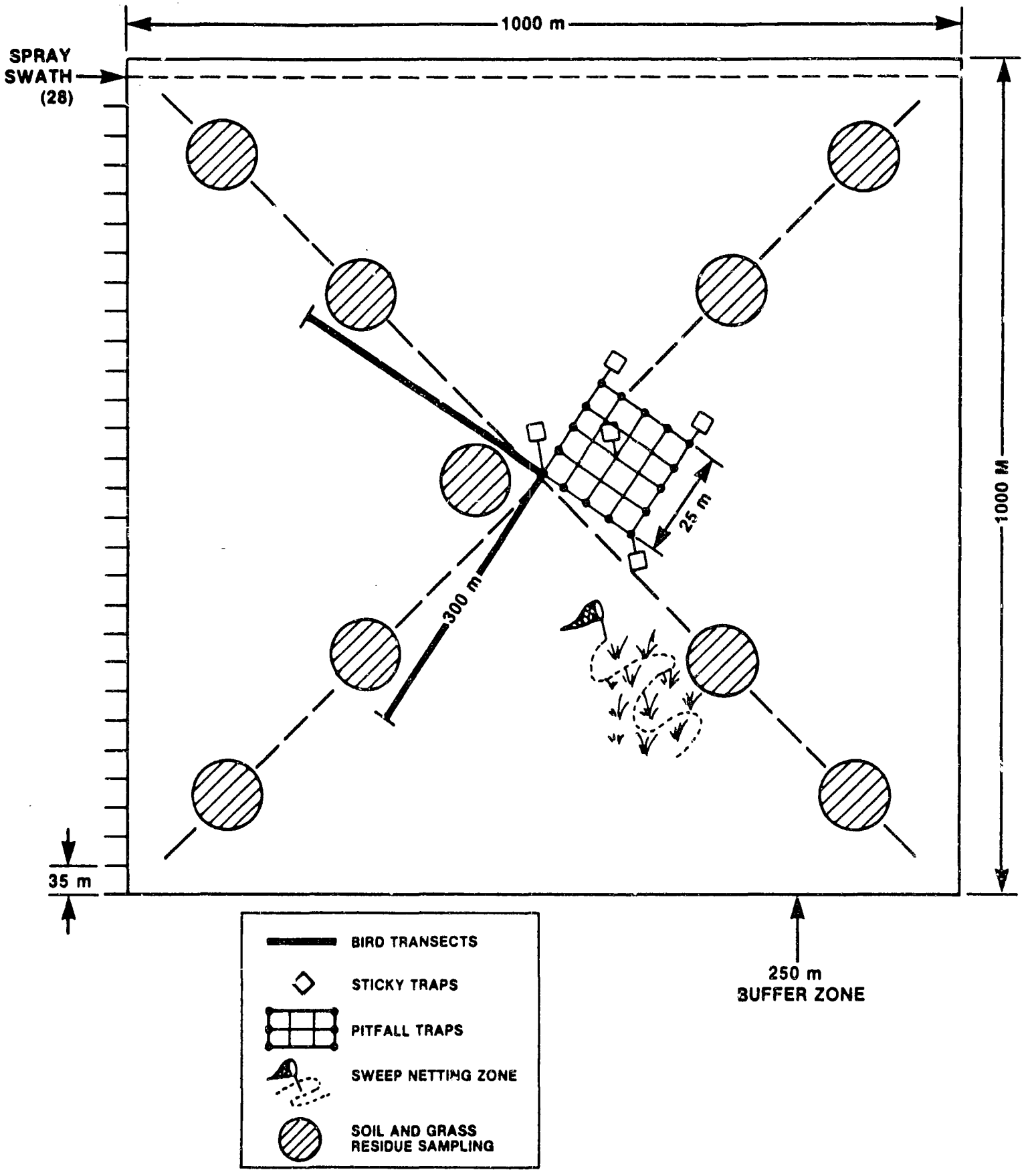


Figure 5-3. Dimensions of typical test plot (100 ha) for environmental impact.

The bird transect counts were conducted at 8 days, 5 days, and 2 days pretreatment and at 1 day, 4 days, and 7 days posttreatment. During each transect walk, a 20-m width of ground adjacent to the transect was simultaneously searched for vertebrate carcasses. In addition, same-day (0-day) carcass searches were done 6 hours after pesticide application in conjunction with the 0-day soil and grass residue sampling. The total search effort on posttreatment plots amounted to 85 ha of ground examined during 144 carcass searches.

5.4.3 Flying Insect Traps

To sample the assemblage of flying insects that inhabited the test plots, five 10- by 20-cm sticky boards were placed at the center of each plot for 3-day capture intervals. Four yellow sticky traps and one white sticky trap were arranged vertically on poles at the height of the surrounding vegetation and folded so that both sticky sides were perpendicular to the wind (one windward and the other leeward). Each sticky trap was collected after being on the plot for 3 days. For preliminary sampling, two flying insect samples were collected: (1) insects trapped on the sticky boards 8 to 5 days before treatment; and (2) insects trapped 5 to 2 days before treatment. Similarly for posttreatment sampling, insects were trapped from 1 to 3 days and from 4 to 7 days after spraying. Again, for the malathion and carbaryl treatments additional preliminary samples were taken because of the delay in the pesticide application.

Vandalism by the local inhabitants and damage from goats browsing on the sticky boards reduced the number of replicate traps on some plots. Few traps were missing, but several were found on the ground. Because these traps were not available for trapping flying insects for the full 3 days, they were excluded from the primary analysis. Upon collection, every trap was frozen to kill the captured insects and to preserve them for later counting and identification. Approximately two-thirds of the sticky traps were counted at the test site, and the remainder were counted after shipment back to Dynamac headquarters in Maryland. Each individual arthropod (spiders as well as insects were captured) was identified to taxonomic order, and the total for each order was recorded for each sticky trap. Although further identification, especially to species, is very difficult for animals enmeshed in this glue, all the sticky traps remain stored at Dynamac for later reference, if necessary.

5.4.4 Plant-Dwelling Insect Sweep-Netting

To capture plant-dwelling insects and spiders, sweep samples of 100 sweeps with a 40-cm diameter insect net were conducted within a grassy area near the center of each plot. Even sweeps across the top 0.5 m of the grasses were made, and all the captured arthropods were transferred to labeled jars. Sweep samples were collected during each plot visit for a minimum of six samples per plot. Each plot was sampled at 8 days, 5 days, and 2 days pretreatment and at 1 day, 4 days, and 7 days posttreatment.

Each sample jar was frozen upon return to the camp to kill the predatory species and to preserve the contents until analysis. While in camp, every sweep sample was counted with each individual arthropod identified to order. The contents of each sample were then preserved in alcohol for shipment to the United States. These sweep samples are currently being cataloged in the invertebrate collections of the National Museum of Natural History (NMNH) of the Smithsonian Institution in Washington, DC. As family, genus, and species identifications are determined by the museum staff, they will be sent to Dynamac for incorporation in later reports as appropriate.

5.4.5 Ground-Dwelling Insect Pitfall Traps

To capture ground-dwelling insects, spiders, and other animals, 25 pitfall traps were placed in a 5- by 5-m grid at the center of each plot. Each pitfall trap consisted of a 200-mL plastic cup inserted into the soil so that the lip of the cup was flush with the ground. A small flag was placed next to each pitfall trap to enable easy recovery of the cups, even in tall grass. Each pitfall was p[illegible] place for a 3-day period to capture animals walking across the surface during both the day and the night. No killing fluid was used because it might have evaporated, caused avoidance, or presented a hazard to the human or livestock populations. Therefore, these pitfalls sampled only animals that could not crawl out of the cups.

The 3-day captures of insects were collected from each pitfall and placed in labeled jars at 5 days and 2 days pretreatment and at 4 days and 7 days posttreatment. As with the sticky traps, the full 2-week period (1 week before and 1 week after) was sampled, but with two collections rather than the three used for the sweeps and the bird transects. Three-day capture samples were used to reduce the number of zeros in the data and to decrease its overall variability.

As the samples were collected from the cups, the number of intact (i.e., functional) pitfalls was recorded. Therefore, although many cups were stolen by the local inhabitants or destroyed by grazing livestock, a per cup capture statistic could be determined to maintain comparability among plots. As with the other insect samples, the jars containing the pitfall samples were frozen upon return to camp and analyzed when time permitted. Because the majority of individuals captured in the pitfalls were hard-bodied beetles, a pinned collection with temporary species designations was possible. Each beetle collected was thus identified as taxon A, etc., so that their subsequent species identifications could be added. Arthropods other than the beetles, principally spiders, were preserved in alcohol for shipment to the United States. This collection was also donated to the NMNH-Smithsonian Institution as a reference collection.

5.4.6 Bird and Mammal Captures for Chemical Analysis

In addition to the use of transects for bird counts and carcass searches, individual birds and rodents were collected for chemical analyses to determine the degree of their exposure to the aerial pesticides. On the day following treatment, two or three 12-m mist nets were set up near the center of each replicate plot. During the course of approximately 2 hours, one to four birds were captured and sacrificed on each plot. Only birds from common species were taken so that adequate control birds from the same species could be obtained. Each bird was wrapped in aluminium foil and placed in a labeled plastic bag. In areas several kilometers from the test site, unexposed birds from the same species as those captured on the treatment plots were captured in mist nets and preserved as species-specific controls for cholinesterase analysis.

Also on the day following treatment, eight snap traps were placed near the pitfall grid on each plot. The traps were baited with bread and peanut butter. Three days later, the snap traps were collected and all rodent captures were wrapped in foil and placed in labeled plastic bags.

Every vertebrate sample was frozen on return to camp and maintained with the soil and grass residue samples for transport to the analytical laboratory in Miami, Florida. The brains of the birds were removed for measurement of cholinesterase activity; whole-body homogenates were used to determine pesticide residue levels for both the birds and the rodents.

5.4.7 Soil and Grass Sampling for Residue Analysis

Duplicate samples of soils and forage grasses were taken at regular intervals after pesticide application. Each plot was sampled at points along an "X" drawn through the 1.4-km plot diagonals. Each diagonal was sampled at the center and at two equidistant points along each arm to produce five samples that were combined in a single bottle. The other diagonal was sampled similarly for two replicate samples per plot. In addition, every sampling operation was duplicated so that separate analyses could be conducted in Sudan as well as by a U.S. laboratory.

To collect soil, hand trowels were used to remove a 2-cm-deep section of topsoil. The soil was placed directly into glass bottles and capped with Teflon lids. To collect grasses, 20 cuttings of 10-cm-wide bunches were made at 5 cm above the ground using grass shears. The cuttings were recut as necessary to fit in glass bottles. All samples were kept in an insulated chest until frozen 1 to 3 hours later. Plastic gloves were worn during all phases of the operation and discarded after use. Hand trowels and grass shears were washed after each replication. Pretreatment samples were taken from each treatment plot to establish a baseline residue concentration. Samples from treated plots were taken on the day of application (6 hours posttreatment), 1 day posttreatment, and 7 days posttreatment. Untreated soil samples (200 g) were spiked with 1 mL of each pesticide formulation diluted in 50 mL of acetone.

Two separate shipments were flown directly from the Tokar camp to Khartoum. In Khartoum, the samples were stored in freezers at the AID/Sudan warehouse. On April 28, all Dynamac samples of soil, grass, and animals were packed in 400 kg of dry ice and airshipped through London to Miami. Every sample was kept frozen in a freezer or insulated chest during storage and transport.

All samples except the birds were retrieved at the airport and deposited still frozen into freezers at the Miami laboratory. Due to the lack of a USDA quarantine permit, the bird samples remained in customs for 1 week, but they were kept frozen through the replenishment of dry ice. These samples were then moved to the laboratory on March 9. A chain of custody was maintained throughout the transfer from field site to analytical laboratory.

The University of Miami Department of Epidemiology and Public Health Laboratory (HRS No. E76071) is a Florida-certified environmental analytical laboratory that participates in the EPA/Cincinnati Quality Control (QC) Program administered through Florida Health and Rehabilitative Services (HRS). This program requires that QC samples be sent for analysis four times each year to maintain certification. Miami also has a Quality Assurance Plan registered with the Florida Department of Environmental Resources. The laboratory follows the U.S. Environmental Protection Agency "Manual of Quality Control for Pesticides in Human and Environmental Media" and follows EPA-approved storage, preparation, and analysis methods. See Appendix M for a description of the extraction and gas-liquid chromotography techniques used.

Approximately 10% of all samples analyzed were QC samples prepared by adding a known amount of pesticide (spike) to a portion of the "PRE" sample after a different portion of the "PRE" sample had been analyzed and determined to be pesticide free. The spiked "PRE" samples were then extracted and analyzed in the same manner as the other samples. Since two samples were taken from the same field on the same day, only a few duplicate (from the same container) samples were analyzed. The "PRE" samples were used as sample blanks, negating the need for reagent blanks. All data are reported as determined. No corrections were made for recoveries.

5.5 IMPACTS ON BIRDS

5.5.1 Direct Mortality

No dead or injured birds were seen on the 72 transect counts conducted on plots during the first week posttreatment, and none were observed during the 6-hour postspray residue sampling done on each treatment plot. The only possible evidence of a bird fatality was the record of two dozen quail feathers collected on plot 2E one day after treatment. These feathers were very likely the result of a predatory event where the quail may or may not have been affected by the pesticide treatment. It should be noted that the fenitrothion residue found on the feathers was 24.9 ppm, roughly 100 times that found on the live birds collected for cholinesterase and residue analysis.

While no conclusion can be drawn from the isolated quail example, the absence of any carcasses over the entire 85 ha of carefully examined ground is strong evidence that direct mortality did not result from any of the six pesticide applications. Because many of the birds observed on the test plots can travel beyond the 100-ha boundaries of a single plot, attribution of individual fatalities to a specific pesticide treatment would have to be confirmed by residue and cholinesterase analysis. However, since no dead or debilitated birds were observed over the entire plot area of 24 km^2, the conclusion that no direct mortality resulted from any of the pesticide applications is robust. Because no carcasses were found, a test of carcass searching efficiency was not performed. It should be noted, however, that the flat savannah environment of the test site is one of the more easily searched habitats. It is unlikely that every carcass would be missed in a comprehensive search of a savannah environment.

5.5.2 Cholinesterase Inhibition and Residue Analyses

Brain cholinesterase activity and whole-body pesticide residue analyses were conducted on 15 control birds and 35 exposed birds collected from the study area (Table 5-4). The control birds were collected from unexposed areas near the test site and were designated as species-specific controls for the weavers, wagtails, and larks captured on the test plots. Seven enzyme activity measurements were obtained from the weaver controls for a baseline cholinesterase level of 24.5 μmoles/minute/gram (standard deviation (SD) = 2.9). Only two and three cholinesterase measurements were obtained from the wagtail and lark controls, respectively. The baseline cholinesterase levels were 19.1 (SD = 0.0) for wagtails and 15.5 (SD = 1.9) for larks.

None of the specimens collected exhibited a 50% or greater depression in cholinesterase activity compared to controls. This level of cholinesterase inhibition was observed in two carbaryl-exposed birds during the Mali trials and is the level commonly used as an indicator of pesticide-related death when obtained from a bird carcass. Because the degrees of inhibition obtained from these trials were relatively small and the sample sizes for most comparisons were also small, it was difficult to demonstrate statistically significant differences between exposed and control birds. In fact, only with carbaryl, malathion, and chlorpyrifos were the mean cholinesterase levels of pesticide-exposed birds lower than

Table 5-4. Pesticide Residue Levels (ppm) and Brain Cholinesterase (ChE) Activity of Birds on Plots Receiving Single Aerial Applications of ULV Pesticides

Pesticide	Sample	Plot	Species	ChE[a]	% Depression[b]	Residue
Chlorpyrifos	0201	13E	wagtail	22.36	0.0	0.839
Chlorpyrifos	0202	13E	wagtail	14.17	26.0	0.264
Chlorpyrifos	0203	13E	wagtail	21.06	0.0	0.379
Chlorpyrifos	0205	12W	wagtail	16.19	15.3	0.126
Fenitrothion	1202	11W	wagtail	22.88	0.0	0.067
Fenitrothion	1203	11W	lark	17.42	0.0	0.167
Fenitrothion	1204	11W	lark	13.52	12.8	N.D. (<0.02)
Fenitrothion	1205	13W	finch	23.79	2.9	0.017
Fenitrothion	1205	13W	finch	24.70	0.0	0.019
Malathion	4201	5W	weaver	27.69	0.0	1.740
Malathion	4202	5W	weaver	26.26	0.0	0.009
Malathion	4203	5W	weaver	18.85	23.1	0.010
Malathion	4204	8W	lark	14.04	9.4	0.114
Malathion	4205	12E	weaver	26.13	0.0	0.013
Malathion	4206	12E	weaver	18.46	24.7	0.011
Malathion	4207	12E	weaver	23.92	2.4	N.D. (<0.01)
Carbaryl	5201	1W	wagtail	18.59	2.7	0.18
Carbaryl	5202	1W	wagtail	23.79	0.0	4.85
Carbaryl	5203	1W	wagtail	14.95	21.8	0.09
Carbaryl	5204	1W	weaver	21.31	13.0	1.40
Carbaryl	5205	1W	weaver	18.07	26.2	N.D. (<0.045)
Carbaryl	5206	4E	weaver	16.38	33.1	0.63
Carbaryl	5207	4E	weaver	21.19	13.5	0.12
Carbaryl	5208	4E	weaver	21.97	10.3	N.D. (<0.045)
Carbaryl	5209	4E	weaver	19.89	18.8	N.D. (<0.045)
Carbaryl	5210	4E	weaver	21.32	13.0	N.D. (<0.045)
Carbaryl	5211	6E	weaver	21.19	13.5	0.13
Carbaryl	5212	6E	weaver	28.73	0.0	N.D. (<0.045)
Carbaryl	5213	6E	weaver	20.15	17.8	2.33
Bendiocarb	3201	3E	weaver	26.26	0.0	N.D. (<0.1)
Bendiocarb	3204	10E	wagtail	24.57	0.0	N.D. (<0.1)
Control	9201	--	weaver	21.06	--	N.D.
Control	9202	--	weaver	29.38	--	N.D.
Control	9203	--	weaver	21.58	--	N.D.
Control	9204*	--	weaver	13.91	--	N.D.
Control	9205	--	weaver	25.61	--	N.D.
Control	9206*	--	weaver	20.28	--	N.D.
Control	9207	--	weaver	23.01	--	N.D.
Control	9208	--	weaver	26.52	--	N.D.
Control	9210	--	weaver	24.31	--	N.D.
Control	9211*	--	weaver	18.58	--	N.D.
Control	9212	--	wagtail	19.11	--	N.D.
Control	9214*	--	lark	15.21	--	0.012[c]
Control	9215	--	lark	17.55	--	N.D.
Control	9216	--	lark	13.78	--	N.D.
Control	9217	--	wagtail	19.11	--	N.D.

[a]Cholinesterase activity in μmoles/gram/minute.
[b]Depression of brain cholinesterase activity as a percent of the average value for untreated birds of the same species.
[c]Control birds were analyzed for contamination with organophosphorus compounds. A small chlorpyrifos residue was found on sample 9214.
N.D. = No residue detected at the level of detection indicated.
*Samples having an unidentified phosphorus response were not included in the calculations.

their respective controls. In 11 of the 13 carbaryl-exposed birds, the cholinesterase levels were depressed, and in the malathion- and chlorpyrifos-exposed birds only 4 of 7 and 2 of 4 were depressed, respectively. The degree of cholinesterase depression in carbaryl-exposed birds ranged from 10 to 30%, with a mean of 17%. For carbaryl, a one-way analysis of variance confirmed that the cholinesterase levels in exposed birds were significantly depressed as compared with controls ($F_{1,15}$ = 5.16, $p < 0.05$).

The correlation between cholinesterase activity and pesticide residue level was not significant either for all exposed birds ($p = 0.34$) or for all birds exhibiting depressed cholinesterase levels ($p = 0.19$). This supports the conclusion that cholinesterase inhibition was rare or absent among the birds exposed to aerial applications of these pesticides. However, carbaryl appears to have caused a moderate sublethal depression in cholinesterase activity among weaver birds. The relative persistence of carbaryl may result in continued inhibition for several days, but the reversible nature of carbamate-induced cholinesterase inhibition argues against a severe cumulative effect.

5.5.3 Abundance and Activity Changes

Bird abundance data from the 320 transect counts were analyzed for significant differences between pretreatment and posttreatment numbers. Simultaneously, differences between the different pesticide treatments and the controls were analyzed for statistical significance. In cases where substantial mean differences in bird abundance were noted, a direct test of the pre- and postspray change in treatment plot versus control plot difference was performed using the Before-After-Control-Impact method (Stewart-Oaten and Murdoch, 1986). In no case was the relationship between treatment bird abundance and control abundance shown to change after the aerial application of a pesticide. Tests were conducted on total bird numbers, numbers of insectivorous birds, numbers of predatory birds, and number of granivorous birds (Table 5-5). In many cases, the variation in the data exceeded the power of the test to determine differences. However, no distinct trends were discernible in a visual evaluation of the graphic results (Figures 5-4 and 5-5).

Although the difficulties in assessing bird abundances and bird activity are considerable, the system used in this study provided a good opportunity to uncover indirect mortality, changes in feeding patterns,

Table 5-5. Number of Live Birds Observed on Replicated Transects (TR) During Environmental Impact Field Trials in Tokar, Sudan

Treatment	Plot	TR	Day relating to treatment -8	-5	-2	+1	+4	+7	Bird guild*	Posttreatment numerical change per transect
Bendiocarb	10E	NE	0	23	2	10	8	5	INS	-0.7
Bendiocarb	10E	NE	0	0	0	0	0	3	PRED	+1.0
Bendiocarb	10E	NE	0	12	1	7	4	0	GRAN	-0.7
Bendiocarb	10E	NE	0	10	4	7	8	2	UNK	+1.0
			0	45	7	24	20	10	TOTAL	+0.7
Bendiocarb	10E	W	10	1	14	0	1	9	INS	-5.0
Bendiocarb	10E	W	1	0	2	4	4	3	PRED	+2.7
Bendiocarb	10E	W	4	0	0	2	5	11	GRAN	+4.7
Bendiocarb	10E	W	45	5	6	2	15	2	UNK	-12.3
			60	6	22	8	25	25	TOTAL	-10.0
Bendiocarb	3E	NE	2	3	5	5	8	0	INS	+1.0
Bendiocarb	3E	NE	3	0	1	2	1	2	PRED	+0.3
Bendiocarb	3E	NE	4	12	10	4	3	2	GRAN	-5.7
Bendiocarb	3E	NE	0	4	7	11	2	11	UNK	+4.3
			9	19	23	22	14	15	TOTAL	0.0
Bendiocarb	3E	SE	5	0	5	20	5	0	INS	+5.0
Bendiocarb	3E	SE	0	1	3	3	0	0	PRED	-0.3
Bendiocarb	3E	SE	11	18	1	3	5	20	GRAN	-0.7
Bendiocarb	3E	SE	0	2	9	19	5	1	UNK	+4.7
			16	21	18	45	15	21	TOTAL	+8.7
Bendiocarb	8E	E	2	2	1	1	45	0	INS	+13.7
Bendiocarb	8E	E	0	0	1	3	0	0	PRED	+0.7
Bendiocarb	8E	E	0	2	1	1	0	0	GRAN	-0.7
Bendiocarb	8E	E	17	1	2	13	3	0	UNK	-1.3
			19	5	5	18	48	0	TOTAL	+12.3
Bendiocarb	8E	N	3	133	2	0	14	0	INS	-41.3
Bendiocarb	8E	N	1	0	1	2	0	0	PRED	0.0
Bendiocarb	8E	N	5	1	0	4	1	0	GRAN	-0.3
Bendiocarb	8E	N	5	0	25	6	40	0	UNK	+5.3
			14	134	28	12	55	0	TOTAL	+36.0
Carbaryl	1W	W	41	34		69	67	26	INS	+16.5
Carbaryl	1W	W	1	1		0	1	2	PRED	0.0
Carbaryl	1W	W	0	0		5	6	0	GRAN	-3.7
Carbaryl	1W	W	16	0		0	0	0	UNK	+8.0
			58	35		74	74	28	TOTAL	+20.8
Carbaryl	1W	S	115	34		31	1	21	INS	-53.8
Carbaryl	1W	S	1	1		1	0	0	PRED	-0.7
Carbaryl	1W	S	4	0		2	1	1	GRAN	-0.7
Carbaryl	1W	S	1	0		0	11	0	UNK	+3.2
			121	35		34	13	22	TOTAL	-55.0

Table 5-5. (Continued)

Treatment	Plot	TR	Day relating to treatment -8	-5	-2	+1	+4	+7	Bird guild*	Posttreatment numerical change per transect
Carbaryl	4E	W	14	1		2	4	8	INS	-2.8
Carbaryl	4E	W	7	2		2	0	2	PRED	-3.2
Carbaryl	4E	W	15	18		11	13	4	GRAN	-7.2
Carbaryl	4E	W	2	2		1	0	0	UNK	-1.7
			38	23		16	17	14	TOTAL	-14.8
Carbaryl	4E	S	3	1		4	4	8	INS	+3.3
Carbaryl	4E	S	4	2		1	1	0	PRED	-2.3
Carbaryl	4E	S	8	6		12	4	12	GRAN	+2.3
Carbaryl	4E	S	2	4		0	3	3	UNK	-1.0
			17	13		17	12	23	TOTAL	+2.3
Carbaryl	6E	SW	6	5		8	3	12	INS	+2.2
Carbaryl	6E	SW	0	1		0	0	0	PRED	-0.5
Carbaryl	6E	SW	11	15		9	2	5	GRAN	-7.7
Carbaryl	6E	SW	1	6		1	0	0	UNK	-3.2
			18	27		18	5	17	TOTAL	-9.2
Carbaryl	6E	NE	2	6		3	11	1	INS	+1.0
Carbaryl	6E	NE	0	1		0	0	1	PRED	-0.2
Carbaryl	6E	NE	2	0		0	3	1	GRAN	+0.3
Carbaryl	6E	NE	0	0		0	0	0	UNK	0.0
			4	7		3	14	3	TOTAL	+1.2
Chlorpyrifos	12W	SW	38	16	18	3	9	2	INS	-19.3
Chlorpyrifos	12W	SW	1	1	0	0	0	1	PRED	-0.3
Chlorpyrifos	12W	SW	4	0	0	1	3	2	GRAN	+0.7
Chlorpyrifos	12W	SW	0	0	0	5	13	1	UNK	+6.3
			43	17	18	9	25	6	TOTAL	-12.7
Chlorpyrifos	12W	NE	6	16	25	0	8	3	INS	-12.0
Chlorpyrifos	12W	NE	0	0	0	0	2	1	PRED	+1.0
Chlorpyrifos	12W	NE	3	0	0	0	4	1	GRAN	+0.7
Chlorpyrifos	12W	NE	0	6	0	0	0	3	UNK	-1.0
			9	22	25	0	14	8	TOTAL	-11.3
Chlorpyrifos	13E	E	13	10	7	13	0	5	INS	-4.0
Chlorpyrifos	13E	E	0	3	0	1	2	0	PRED	0.0
Chlorpyrifos	13E	E	0	0	0	2	0	2	GRAN	+1.3
Chlorpyrifos	13E	E	0	9	0	0	5	3	UNK	-0.3
			13	22	7	16	7	10	TOTAL	-3.0
Chlorpyrifos	13E	S	16	5	18	61	19	6	INS	+15.7
Chlorpyrifos	13E	S	0	0	0	3	0	1	PRED	+1.3
Chlorpyrifos	13E	S	0	0	0	0	0	5	GRAN	+1.7
Chlorpyrifos	13E	S	0	5	0	0	7	1	UNK	+1.0
			16	10	18	64	26	13	TOTAL	+19.7

Table 5-5. (Continued)

Treatment	Plot	TR	Day relating to treatment -8	-5	-2	+1	+4	+7	Bird guild*	Posttreatment numerical change per treatment
Chlorpyrifos	9W	S	15	3	16	16	4	3	INS	-3.7
Chlorpyrifos	9W	S	2	2	0	1	1	0	PRED	-0.7
Chlorpyrifos	9W	S	8	1	4	2	3	3	GRAN	-1.7
Chlorpyrifos	9W	S	0	0	0	50	45	41	UNK	+45.3
			25	6	20	69	53	47	TOTAL	+39.3
Chlorpyrifos	9W	W	34	9	23	3	0	3	INS	-20.0
Chlorpyrifos	9W	W	0	1	0	0	1	0	PRED	0.0
Chlorpyrifos	9W	W	0	0	0	0	0	3	GRAN	+1.0
Chlorpyrifos	9W	W	0	0	0	0	56	1	UNK	+19.0
			34	10	23	3	57	7	TOTAL	0.0
Fenitrothion	11W	NW	3	0	9	36	26	28	INS	+26.0
Fenitrothion	11W	NW	1	1	3	1	0	0	PRED	-1.3
Fenitrothion	11W	NW	1	2	15	18	1	6	GRAN	+2.3
Fenitrothion	11W	NW	0	0	0	6	4	0	UNK	+3.3
			5	3	27	61	31	34	TOTAL	+30.3
Fenitrothion	11W	S	82	1	2	17	0	0	INS	-22.7
Fenitrothion	11W	S	0	0	1	2	0	0	PRED	+0.3
Fenitrothion	11W	S	1	3	0	2	1	0	GRAN	-0.3
Fenitrothion	11W	S	0	75	0	3	27	0	UNK	-15.0
			83	79	3	24	28	0	TOTAL	-37.7
Fenitrothion	13W	N	6	5	46	7	0	5	INS	-15.0
Fenitrothion	13W	N	0	0	1	0	2	0	PRED	+0.3
Fenitrothion	13W	N	1	5	1	6	0	4	GRAN	+1.0
Fenitrothion	13W	N	0	0	0	0	5	3	UNK	+2.7
			7	10	48	13	7	12	TOTAL	-11.0
Fenitrothion	13W	W	7	36	59	13	3	0	INS	-28.7
Fenitrothion	13W	W	0	0	0	1	2	0	PRED	+1.0
Fenitrothion	13W	W	2	0	0	14	0	0	GRAN	+4.0
Fenitrothion	13W	W	0	2	0	17	0	0	UNK	+5.0
			9	38	59	45	5	0	TOTAL	-18.7
Fenitrothion	2E	W	6	18	5	35	24	29	INS	+19.7
Fenitrothion	2E	W	2	13	6	2	3	5	PRED	-3.7
Fenitrothion	2E	W	9	6	7	2	2	2	GRAN	-5.3
Fenitrothion	2E	W	0	16	3	0	7	21	UNK	+3.0
			17	53	21	39	36	57	TOTAL	+13.7
Fenitrothion	2E	S	6	5	1	16	15	7	INS	+8.7
Fenitrothion	2E	S	12	1	1	0	2	6	PRED	-2.0
Fenitrothion	2E	S	2	1	3	1	0	2	GRAN	-1.0
Fenitrothion	2E	S	0	0	1	0	4	4	UNK	+2.3
			20	7	6	17	21	19	TOTAL	+8.0

Table 5-5. (Continued)

Treatment	Plot	TR	Day relating to treatment -8	-5	-2	+1	+4	+7	Bird guild*	Posttreatment numerical change per treatment
L-cyhalothrin	2W	NW	8	3	9	30	8	16	INS	+11.3
L-cyhalothrin	2W	NW	2	5	2	2	2	4	PRED	-0.3
L-cyhalothrin	2W	NW	1	1	2	1	3	8	GRAN	+2.7
L-cyhalothrin	2W	NW	0	2	0	0	0	0	UNK	-0.7
			11	11	13	33	13	28	TOTAL	+13.0
L-cyhalothrin	2W	NE	10	5	11	53	5	15	INS	+15.7
L-cyhalothrin	2W	NE	1	6	0	1	0	2	PRED	-1.3
L-cyhalothrin	2W	NE	3	8	0	1	0	0	GRAN	-3.3
L-cyhalothrin	2W	NE	0	1	1	0	0	4	UNK	+0.7
			14	20	12	55	5	21	TOTAL	+11.7
L-cyhalothrin	4W	N	16	3	2	7	2	4	INS	-2.7
L-cyhalothrin	4W	N	1	1	1	1	0	2	PRED	0.0
L-cyhalothrin	4W	N	3	0	0	0	0	0	GRAN	-1.0
L-cyhalothrin	4W	N	0	3	16	1	4	1	UNK	-4.3
			20	7	19	9	6	7	TOTAL	-8.0
L-cyhalothrin	7W	NE	2	77	54	8	14	3	INS	-36.0
L-cyhalothrin	7W	NE	0	0	1	3	1	0	PRED	+1.0
L-cyhalothrin	7W	NE	8	4	0	1	4	1	GRAN	-2.0
L-cyhalothrin	7W	NE	0	50	9	35	0	0	UNK	-8.0
			10	131	64	47	19	4	TOTAL	-45.0
L-cyhalothrin	7W	S	2	26	10	11	0	0	INS	-9.0
L-cyhalothrin	7W	S	0	4	1	2	0	0	PRED	-1.0
L-cyhalothrin	7W	S	0	1	2	32	0	0	GRAN	+9.7
L-cyhalothrin	7W	S	2	0	6	3	0	0	UNK	-1.7
			4	31	19	48	0	0	TOTAL	-2.0
Malathion	12E	S	3	6		6	8	1	INS	+0.5
Malathion	12E	S	0	0		0	0	0	PRED	0.0
Malathion	12E	S	1	11		1	1	7	GRAN	-3.0
Malathion	12E	S	1	1		0	0	1	UNK	-0.7
			5	18		7	9	9	TOTAL	-3.2
Malathion	12E	E	1	3		5	18	1	INS	+6.0
Malathion	12E	E	0	1		0	0	0	PRED	-0.5
Malathion	12E	E	2	4		6	0	1	GRAN	+0.7
Malathion	12E	E	3	4		0	0	0	UNK	-3.5
			6	12		11	18	2	TOTAL	+1.3
Malathion	5W	S	5	2		28	10	4	INS	+10.5
Malathion	5W	S	1	1		0	1	0	PRED	-0.7
Malathion	5W	S	1	2		0	2	2	GRAN	-0.2
Malathion	5W	S	0	8		1	3	0	UNK	-2.7
			7	13		29	16	6	TOTAL	+7.0

Table 5-5. (Continued)

Treatment	Plot	TR	Day relating to treatment -8	-5	-2	+1	+4	+7	Bird guild*	Posttreatment numerical change per transect
Malathion	5W	W	4	14		33	6	5	INS	+5.6
Malathion	5W	W	1	1		3	0	0	PRED	0.0
Malathion	5W	W	0	0		3	6	1	GRAN	+3.3
Malathion	5W	W	2	0		0	0	3	UNK	0.0
			7	15		39	12	9	TOTAL	+9.0
Malathion	8W	W	9	0		4	3	16	INS	+3.2
Malathion	8W	W	0	4		0	1	0	PRED	-1.7
Malathion	8W	W	4	2		4	2	4	GRAN	+0.3
Malathion	8W	W	2	2		0	0	0	UNK	-2.0
			15	8		8	6	20	TOTAL	-0.2
Malathion	8W	N	3	7		8	11	13	INS	+5.6
Malathion	8W	N	0	2		1	0	0	PRED	-0.7
Malathion	8W	N	1	1		2	0	1	GRAN	0.0
Malathion	8W	N	0	2		0	0	0	UNK	-1.0
			4	12		11	11	14	TOTAL	+4.0

Abbreviations:

INS = Insectivorous birds; PRED = predatory birds; GRAN = granivorous birds; UNK = unknown.

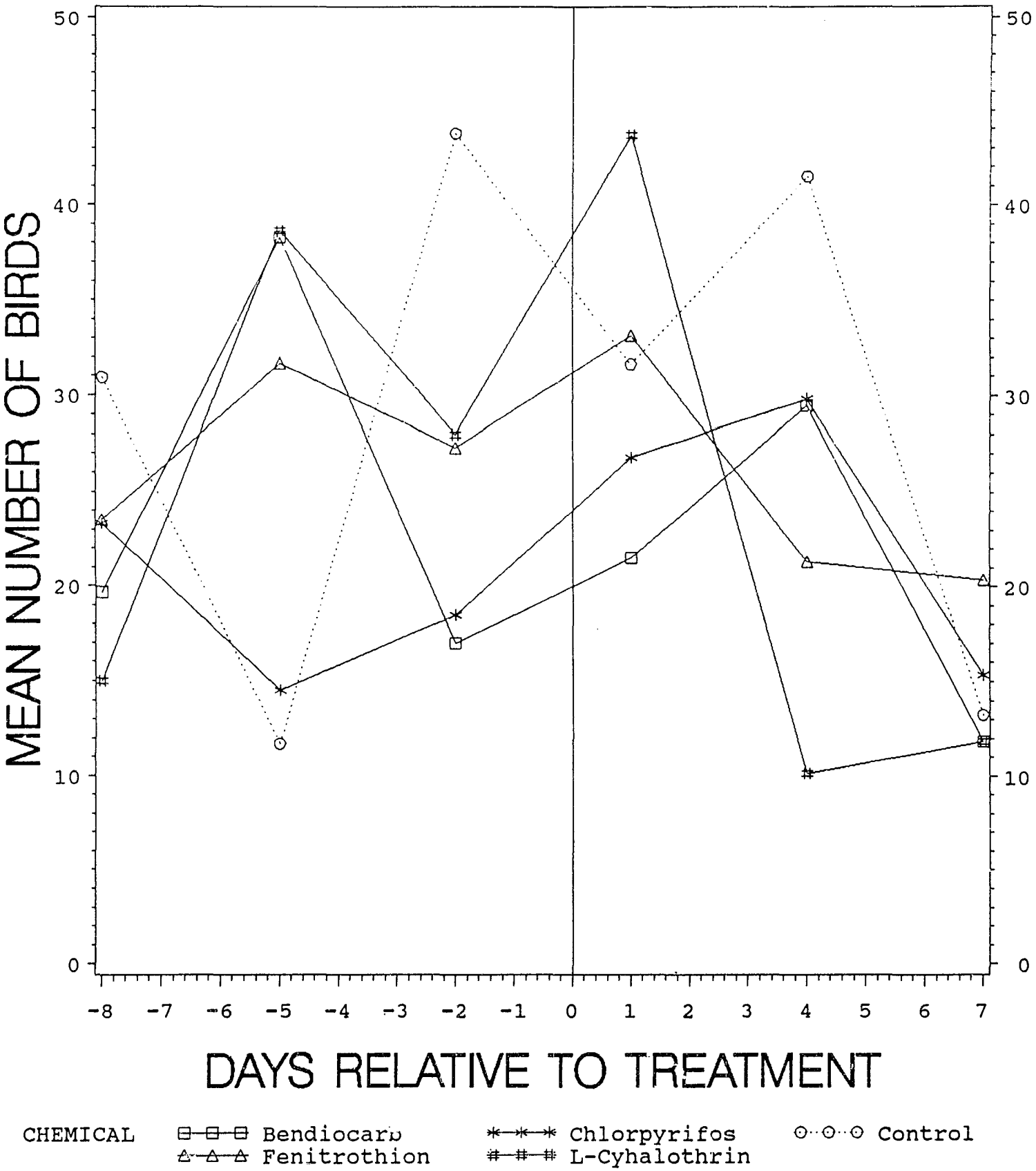


Figure 5-4. Mean bird counts from replicate plots for the first four treatments with ULV pesticides.

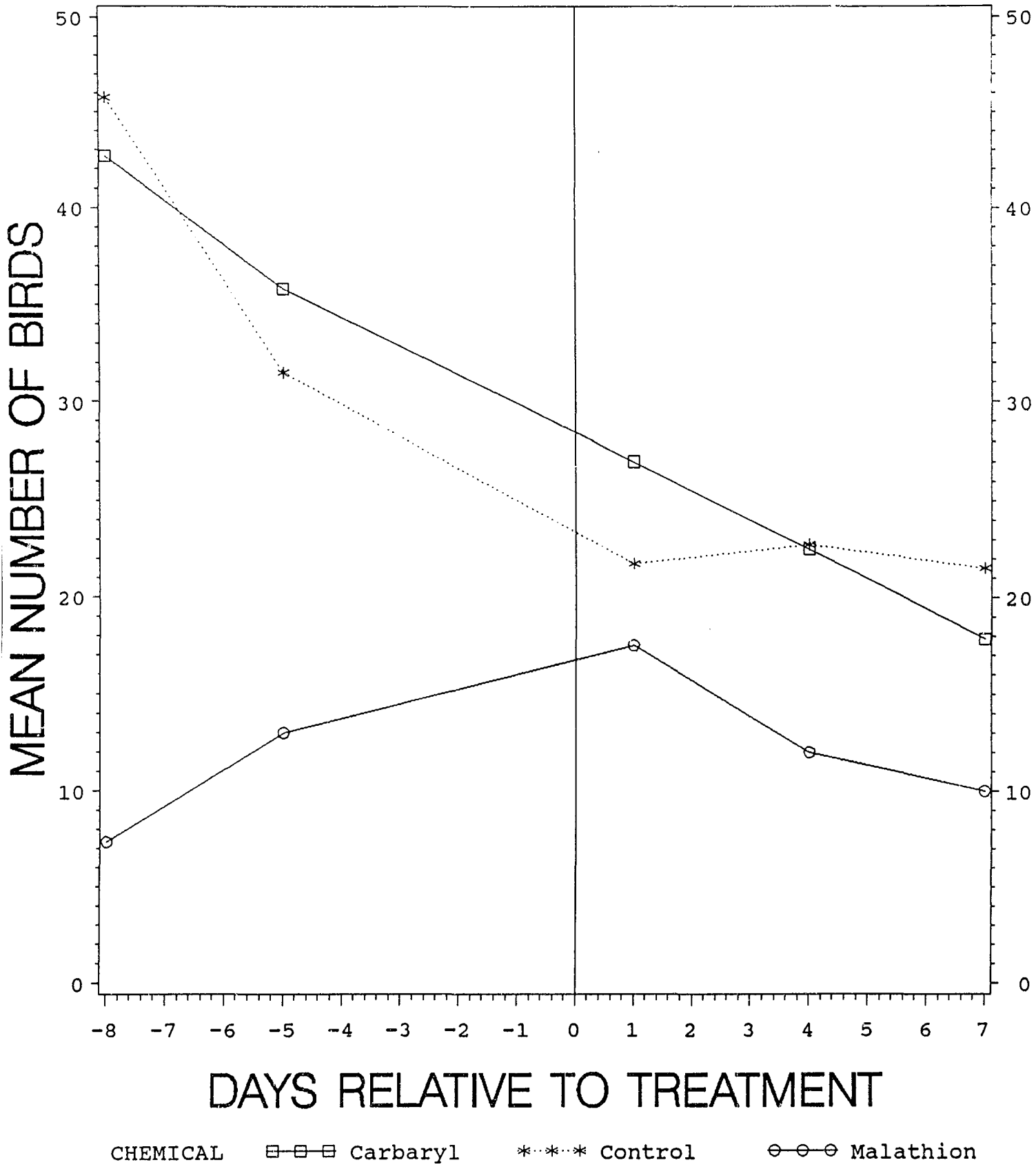


Figure 5-5. Mean bird counts from replicate plots for the last two treatments with ULV pesticides.

and abnormal individual behavior. In observations of over 5000 individual birds from 56 species, no instances of flight impairment or unnatural behavior were observed. This includes cases of birds observed in the spraypath and those known to have received direct exposure to the ULV pesticides. Although migratory species were present and considerable movement within and among plots undoubtedly occurred, the use of marked transects for replicate counts before and after pesticide treatment increased the likelihood of recording accurate numbers of nesting birds, especially weaver species. Unfortunately, the timeframe of this study did not permit the measurement of reproductive parameters. However, the substantial data obtained on species presence and relative abundances in the Tokar Delta should provide a valuable resource for future impact assessments. Figure 5-6 demonstrates both the magnitude of the avian contribution to this ecosystem and the variability of bird numbers with time.

5.6 IMPACTS ON NONTARGET ARTHROPODS

5.6.1 Results

Between March 2 and April 12, 705 separate samples of the arthropod fauna were collected. This total included 84 pitfall samples (grid totals measured as per cup captures), 92 sticky-trap samples (plot totals measured as per board captures), and 152 sweep-net samples (one collection per plot visit). From these samples, a total of 44,093 individual arthropods were identified to taxonomic order and counted. Spiders constituted 3.7% of the total, with the remaining 96.3% divided among eight orders of insects. The thrips, or Thysanoptera, made up 64.1% of the individuals counted, with the other orders constituting less than 10% each. When the Thysanoptera were excluded, the remaining eight orders of arthropods showed relative abundances as follows: true flies (Diptera) 23.9%, leafhoppers and aphids (Homoptera) 21.0%, true bugs (Hemiptera) 17.1%, beetles (Coleoptera) 13.9%, bees and wasps (Hymenoptera) 12.4%, spiders (Araneae) 10.3%, grasshoppers and crickets (Orthoptera) 0.9%, and butterflies and moths (Lepidoptera) 0.6% (Figure 5-7).

Although the quantity of data obtained from the samples was quite large (29,243 individual arthropods pretreatment and 14,850 posttreatment), the complexity of the design necessitated that each comparison be evaluated for confounding factors. To do this, the data set

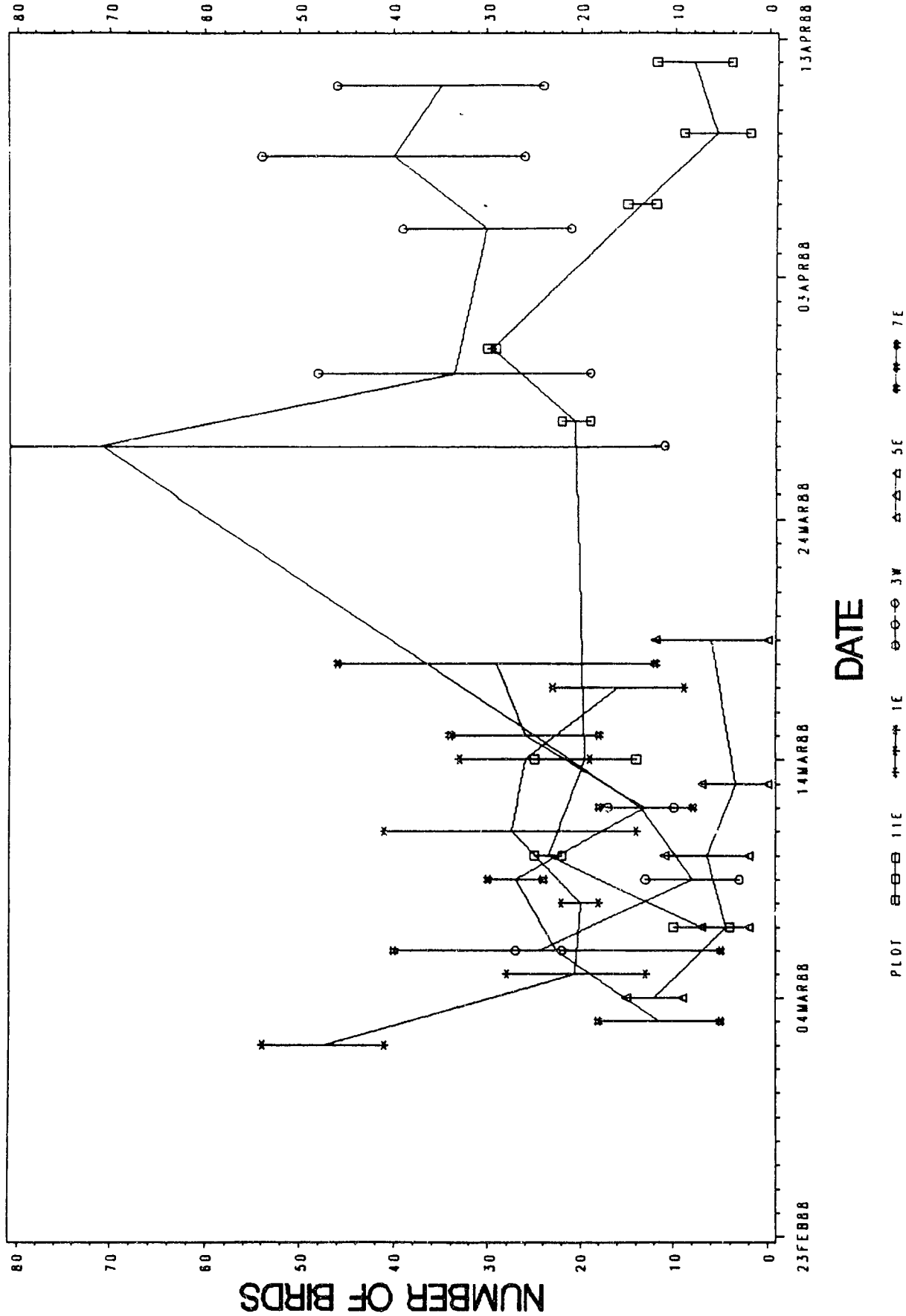
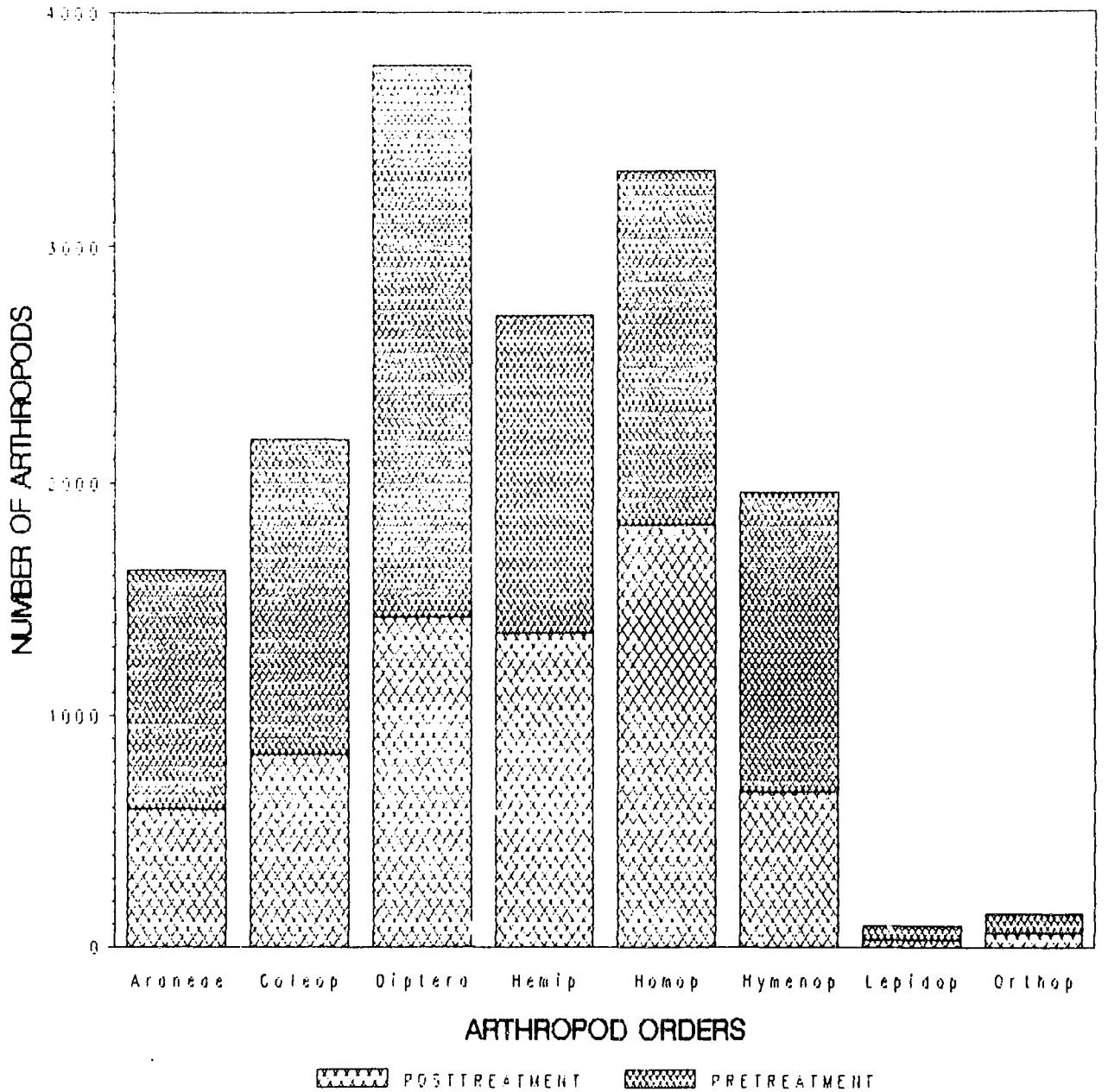


Figure 5-6. Mean bird counts from replicate transects on five control plots during environmental impact trials, Tokar, Sudan.



Thysanoptera samples are omitted from the graph. The total numbers for Thysanoptera are 28,277 (Pretreatment 20,219 and Posttreatment 8,058).

Figure 5-7. Total numbers of arthropods by order sampled during environmental impact trials, February-April 1988, Tokar, Sudan.

was dissected into units defined by a single chemical, sample type, and arthropod order. The experimental trials were designed so that each of these 180 smaller data sets would contain both three replicate treatment plots and a simultaneous control plot, with values for a minimum of two pretreatment and two posttreatment sample periods per plot. No data were shared across units; therefore, each data set was statistically independent. Not surprisingly, the vagaries of field data collection resulted in missing values for some data sets, so that valid comparisons could not be made in all cases. However, in most cases one of the three sampling techniques provided adequate numbers for each chemical to be evaluated for its effect on that order of arthropod.

Because of the naturally high variability in the distribution and abundance of terrestrial arthropod populations, all data were evaluated in the context of control values that were collected at the same time as each treatment sample. Preliminary graphical comparisons and an overall analysis of variance were used to identify trends in control values with time. The direction and magnitude of changes in arthropod abundance on controls were noted, and significant differences between control values and groups of treatment values were recorded. In general, the control values did not exhibit strong upward or downward trends with time, but did show considerable fluctuations on a daily basis (Figures 5-8 and 5-9). For this reason, subsequent analyses were done for time-averaged values covering two to three sample periods. This procedure likely obscured the most severe reductions in abundance often occurring at 1 day posttreatment. However, it provided a reasonable and conservative method of demonstrating pesticide-induced reductions in arthropod abundance.

The statistical technique used was the Before-After-Treatment-Control (BACI) procedure (Stewart-Oaten and Murdoch, 1986), which determines the significance of the changes ($p < 0.05$) in the treatment-control relationship when compared before and after treatment. While abundant, two orders, Thysanoptera and Hemiptera, were too variable for confident conclusions as to pesticide effect. Two other orders, Orthoptera and Lepidoptera, were too rare for an adequate comparison of effects among all the pesticide treatments. However, significant reductions in Orthoptera numbers did occur following treatment with the test standard organophosphorus chemicals malathion and fenitrothion. Lepidoptera numbers were

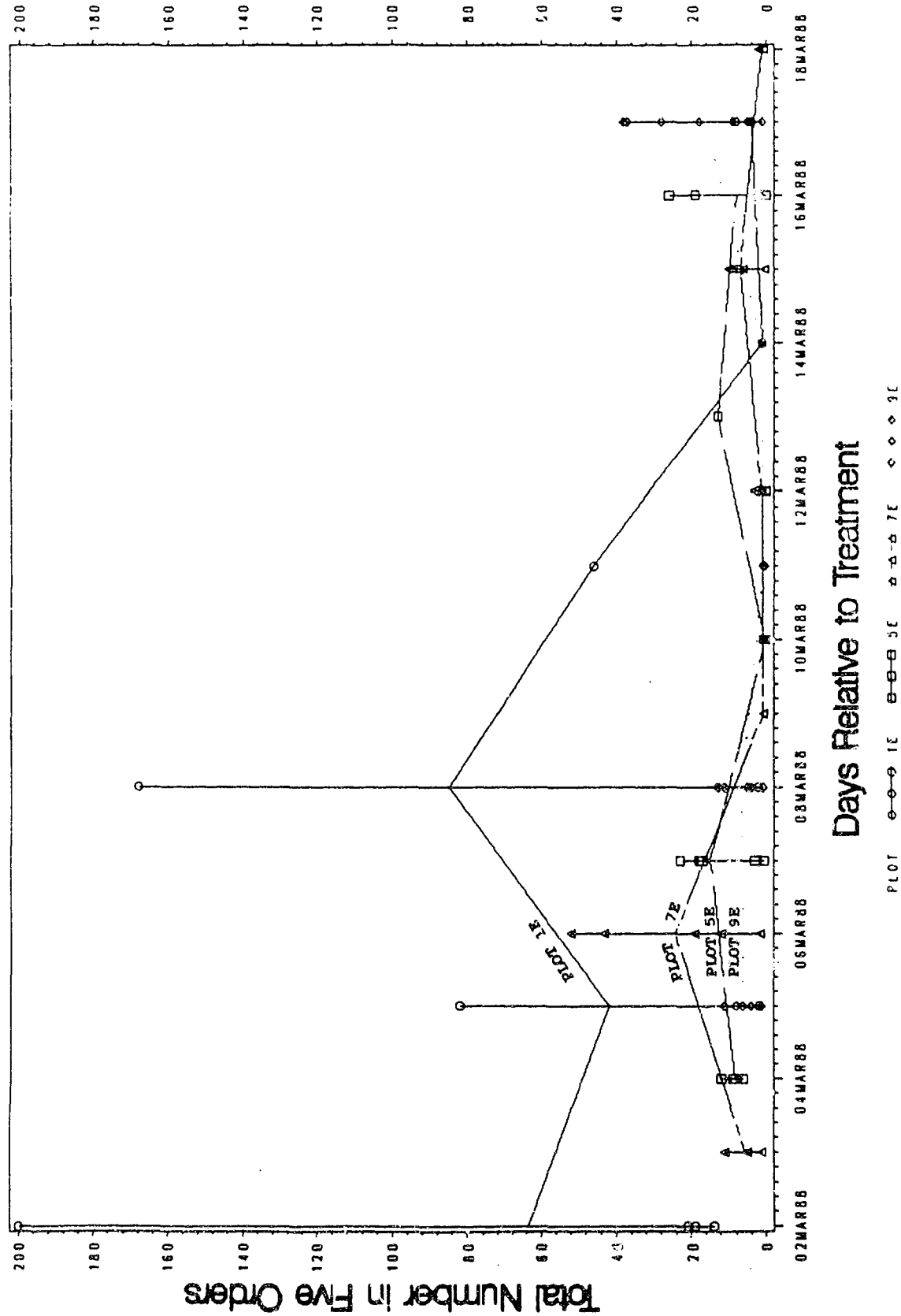


Figure 5-8. Total arthropod numbers from five orders (Araneae, Hemiptera, Coleoptera, Diptera, Hymenoptera) sampled on four control plots during environmental impact trials, March 2-18, 1988, Tokar, Sudan.

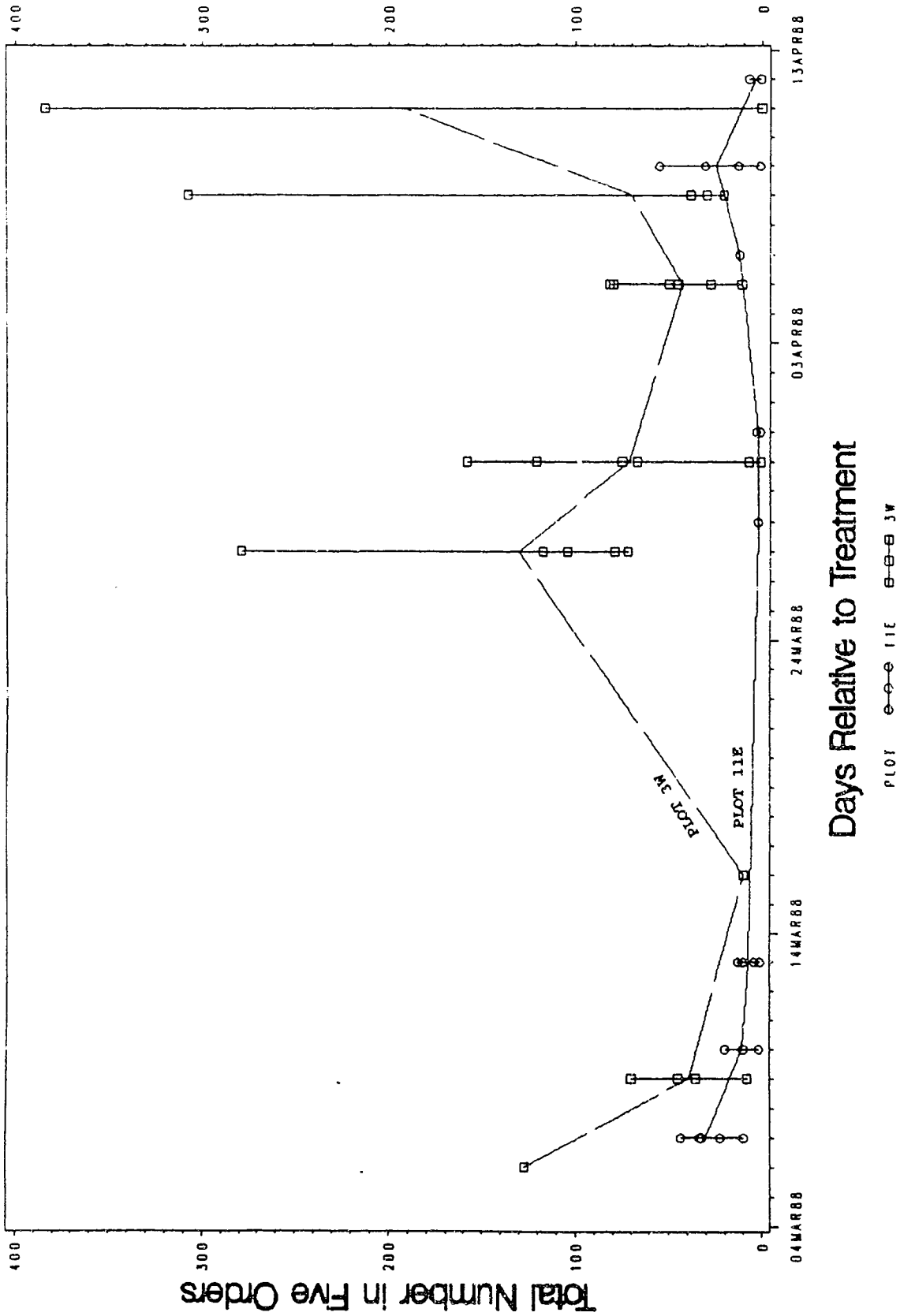


Figure 5-9. Total arthropod numbers from five orders (Araneae, Hemiptera, Coleoptera, Diptera, Hymenoptera) sampled on two control plots during environmental impact trials, March 7-April 12, 1988, Tokar, Sudan.

significantly reduced following treatment with the organophosphorus compounds malathion and chlorpyrifos. For the remaining five orders, a minimum sample of 100 individuals was collected pretreatment and, therefore, a reasonable comparison of effect among all six pesticides could be made.

The numbers of Hemiptera, Hymenoptera, and Araneae were each significantly ($p < 0.05$) reduced by four pesticides, including at least one of each of the three chemical classes: organophosphorus, carbamate, and pyrethroid (Table 5-6). The average reductions in arthropod abundance (calculated for the full 7-day posttreatment period), given as the change in percentage of control values, were 77.8% for Hemiptera, 69.8% for Hymenoptera, and 61.6% for Araneae. The abundance of both Hemiptera and Araneae was affected by the test standard organophosphorus compounds malathion and fenitrothion; the carbamate carbaryl; and the synthetic pyrethroid lambda-cyhalothrin. While neither test standard significantly reduced Hymenoptera numbers, the third organophosphorus compound, chlorpyrifos, and the second carbamate, bendiocarb, demonstrated an effect. Three pesticides significantly reduced the numbers of Coleoptera and Diptera, with only bendiocarb affecting both orders. The average percent reduction was 68.7 for Coleoptera and 59.2 for Diptera.

The pyrethroid lambda-cyhalothrin produced a significant reduction in four of the five arthropod orders; malathion, fenitrothion, bendiocarb, and carbaryl produced reductions in three orders each; and chlorpyrifos produced reductions in two orders (Table 5-6). The average percent reductions adjusted for controls followed the same pattern, with a 76.2% reduction for lambda-cyhalothrin, 71.2% for malathion, 70.1% for fenitrothion, 68.3% for bendiocarb, 59.5% for carbaryl, and 54.2% for chlorpyrifos. The variability of the data does not permit a determination of significant differences among the magnitudes of these reductions in arthropod numbers. Nonetheless, the presence and absence of effects on specific orders gives an indication of the range of possible impacts that each chemical might cause under locust control conditions.

5.6.2 Discussion

As with the intended target species, *Shistocerca gregaria*, other potential pest species could not be collected in adequate numbers for a comparison of effects among the pesticide treatments. As mentioned, however, significant reductions in numbers of Orthoptera (the order

TABLE 5-6. Significantly Reduced Arthropod Abundances[a]

Pesticide	Chemical class	Arthropod order				
		Araneae	Hemiptera	Coleoptera	Diptera	Hymenoptera
Fenitrothion	OP	62.3	58.3	89.6	NS	NS
Malathion	OP	88.0	99.5	NS	26.0	NS
Chlorpyrifos	OP	NS	NS	55.8	NS	52.7
Bendiocarb	C	NS	NS	60.8	85.9	58.1
Carbaryl	C	28.8	80.9	NS	NS	68.8
L-cyhalothrin	SP	67.2	72.3	NS	65.8	99.5

OP = Organophosphorus.
C = Carbamate.
SP = Synthetic pyrethroid.
NS = Nonsignificant results.

[a]Compared as the ratio of treatment numbers to control numbers both before and after pesticide application. Percent reductions adjusted for controls are indicated for each significant effect ($p < 0.05$).

including grasshoppers and locusts) were observed following treatment with the test standards fenitrothion and malathion. In addition, the flight impairment and rapid death of an individual Senegalese grasshopper, Oedaleus senegalensis, was observed within the first 20 minutes following a malathion application. In the case of three orders that possess numerous pest species (i.e., Hemiptera, Coleoptera, and Diptera), pesticides from all three chemical classes were shown to significantly reduce the abundance of each order. It is likely that all six of these pesticides would be effective against a variety of pests, including grasshoppers and locusts.

The only pesticide that did not show a significant effect on either Diptera or Coleoptera was carbaryl. In contrast, the only pesticide to show an effect on all three orders of locust predators and parasites was the other carbamate, bendiocarb. If it is anticipated that an array of beneficial species (antagonistic to desert locusts) will be present during control operations, then consideration should be given to the use of carbaryl. If there is concern about a specific hymenopteran parasitoid, such as that often used in biocontrol efforts, then malathion and fenitrothion should be considered. In each case, the pesticide of choice should be tested against the specific beneficial insect of concern.

To infer possible effects on the entire arthropod ecosystem, it is important to look at the effects on the higher trophic levels. Spiders (Araneae) are representative of a predatory taxon that can regulate arthropod abundances but that is not an agricultural pest. Significant reductions in spider numbers followed the application of pesticides from all three chemical classes, with only chlorpyrifos and bendiocarb failing to show an effect. In each case, plant-dwelling or arboreal spiders (as represented by sweep and sticky-trap samples), rather than ground-dwelling spiders (as represented by pitfall samples), were affected. It appears likely that all six pesticides will have a depressing effect on higher arthropod trophic levels, but that the ground-dwelling fauna will be relatively less affected. Indeed, fenitrothion was the only pesticide to show a significant effect on a ground-dwelling taxon (beetles in pitfalls). Malathion was the only pesticide to show a significant overall depressive effect on total arthropods, and it was a result based on the aboreal species captured in sweep samples. Again, 17 of the 18 reductions occurred among plant-dwelling and arboreal species (9 with the sweep samples and 8 with the sticky-trap samples), indicating incomplete penetration of the grasses by the pesticides.

An examination of the graphical results of the statistically significant effects mentioned above revealed a consistent pattern of sharply reduced arthropod numbers immediately following pesticide application (Figures 5-10 through 5-14). For the five orders analyzed, the average reduction in abundance from pesticides causing a significant effect ranged from 67% to 89% of the pretreatment levels. The first posttreatment samples were not substantially lower than the last pretreatment samples in only 2 of the 18 cases. Another characteristic of these graphs was the rapid increase in arthropod numbers following the initial posttreatment reduction. In 16 of the 18 cases, arthropod numbers rebounded by the second or third post-treatment sample to mean pretreatment levels. Instances of zero rebound were observed only in the Hemiptera samples, i.e., after treatment with fenitrothion and malathion.

The overall effect of these aerially applied ULV pesticides on nontarget arthropods appears to be limited due to rapid reinvasion by most arthropod groups. Repeated applications or treatments over large areas may have more severe effects not apparent in these results.

5.7 RESIDUAL ACTIVITY IN THE ENVIRONMENT

5.7.1 Results

In addition to the assessments of immediate pesticide effects based on mortality measures for birds and arthropods, the fate of the aerially applied pesticides in the environment was monitored for potential long-term effects. Although the pesticide spray from the aircraft was visible, direct examination of plants did not reveal a noticeable residue or instances of phytotoxicity. Although the small mammals (shrews, gerbils, and mice) collected for pesticide residue analysis were misplaced by the laboratory, the 46 bird specimens that were captured were analyzed for residues as reported in section 5.2.2. The results of the comprehensive sampling of soils and grasses over time (see Appendix R) were used to provide the best indication of delayed or indirect effects on the environment.

The soil samples spiked with each pesticide in the field did not give 100% recoveries owing to the uneven distribution of pesticide in the large soil samples. Given the unavoidable heterogeneity of particle size in the samples, reasonable recoveries were obtained: lambda-cyhalothrin 88.2%, malathion 85.5%, bendiocarb 74.2%, chlorpyrifos 56.7%, carbaryl 55.3%, and fenitrothion 52.4%. Because the pesticides known to degrade most rapidly

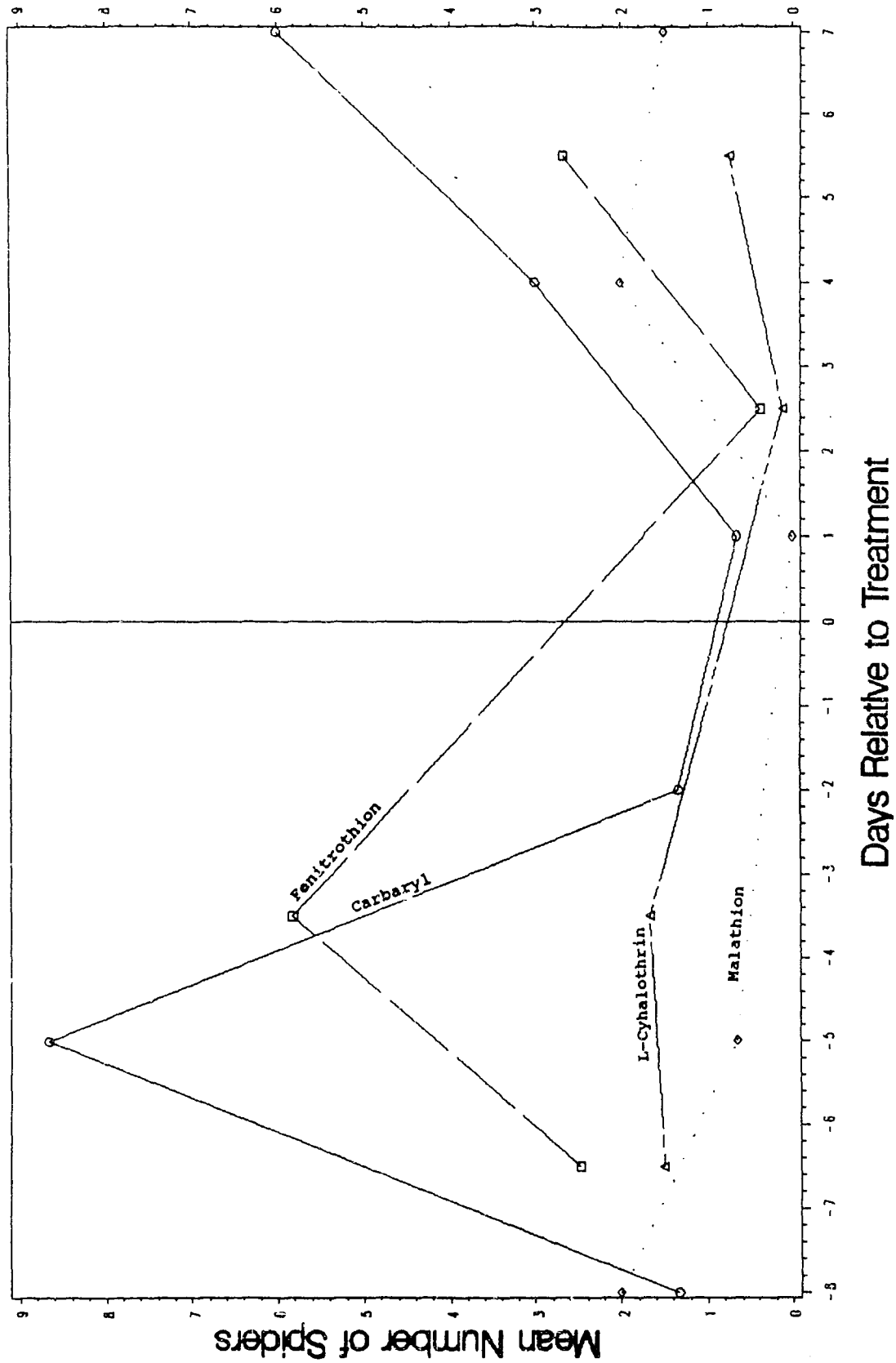


Figure 5-10. Mean numbers of Araneae (spiders) sampled from replicate plots both before and after treatment with ULV pesticides. Only significant reductions relative to controls are shown for environmental impact trials conducted in Tokar, Sudan.

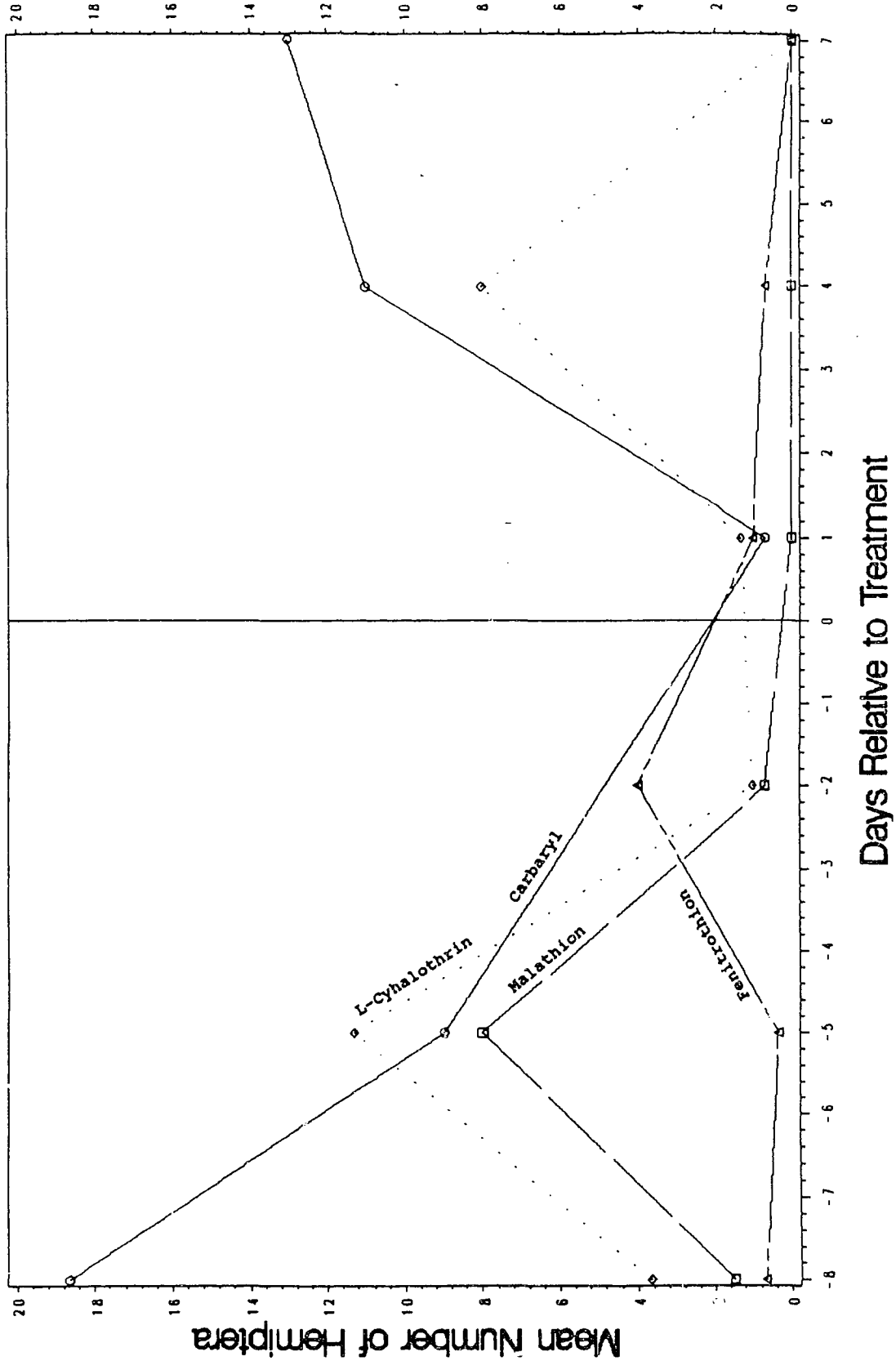


Figure 5-11. Mean numbers of Hemiptera (true bugs) sampled from replicate plots both before and after treatment with ULV pesticides. Only significant reductions relative to controls are shown for environmental impact trials conducted in Tokar, Sudan.

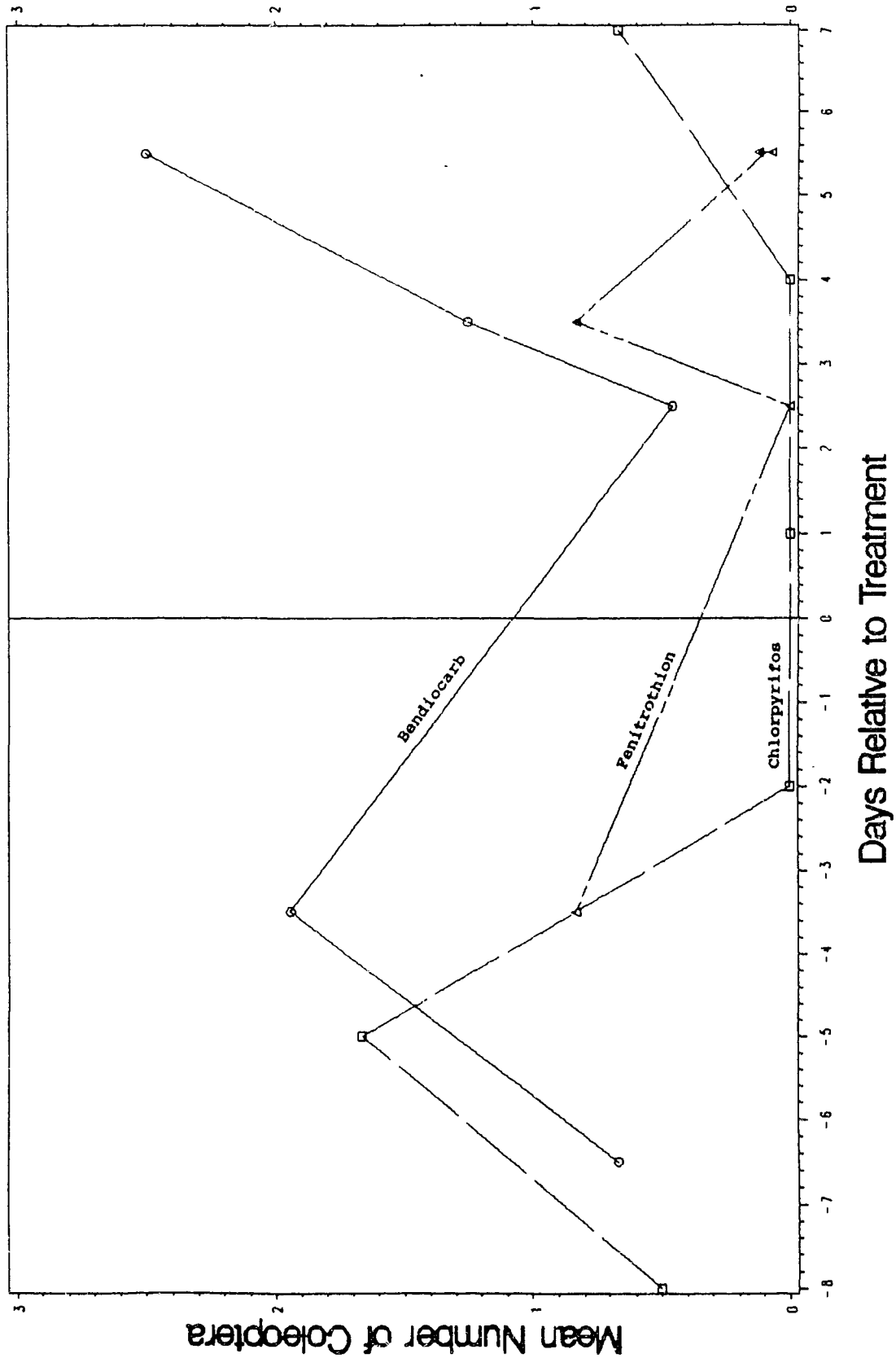


Figure 5-12. Mean numbers of Coleoptera (beetles) sampled from replicate plots both before and after treatment with ULV pesticides. Only significant reductions relative to controls are shown for environmental impact trials conducted in Tokar, Sudan.

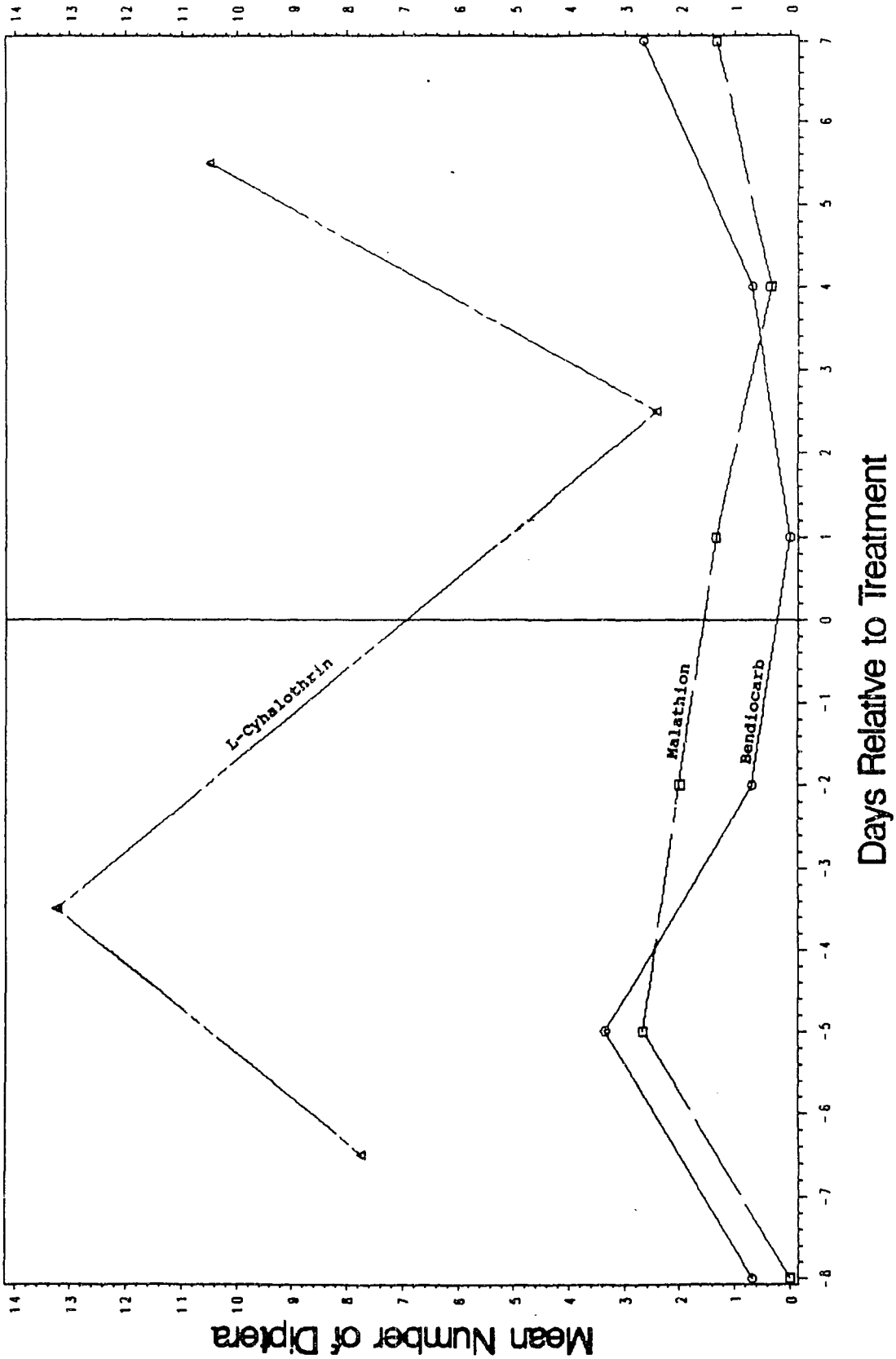


Figure 5-13. Mean numbers of Diptera (true flies) sampled from replicate plots both before and after treatment with ULV pesticides. Only significant reductions relative to controls are shown for environmental impact trials conducted in Tokar, Sudan.

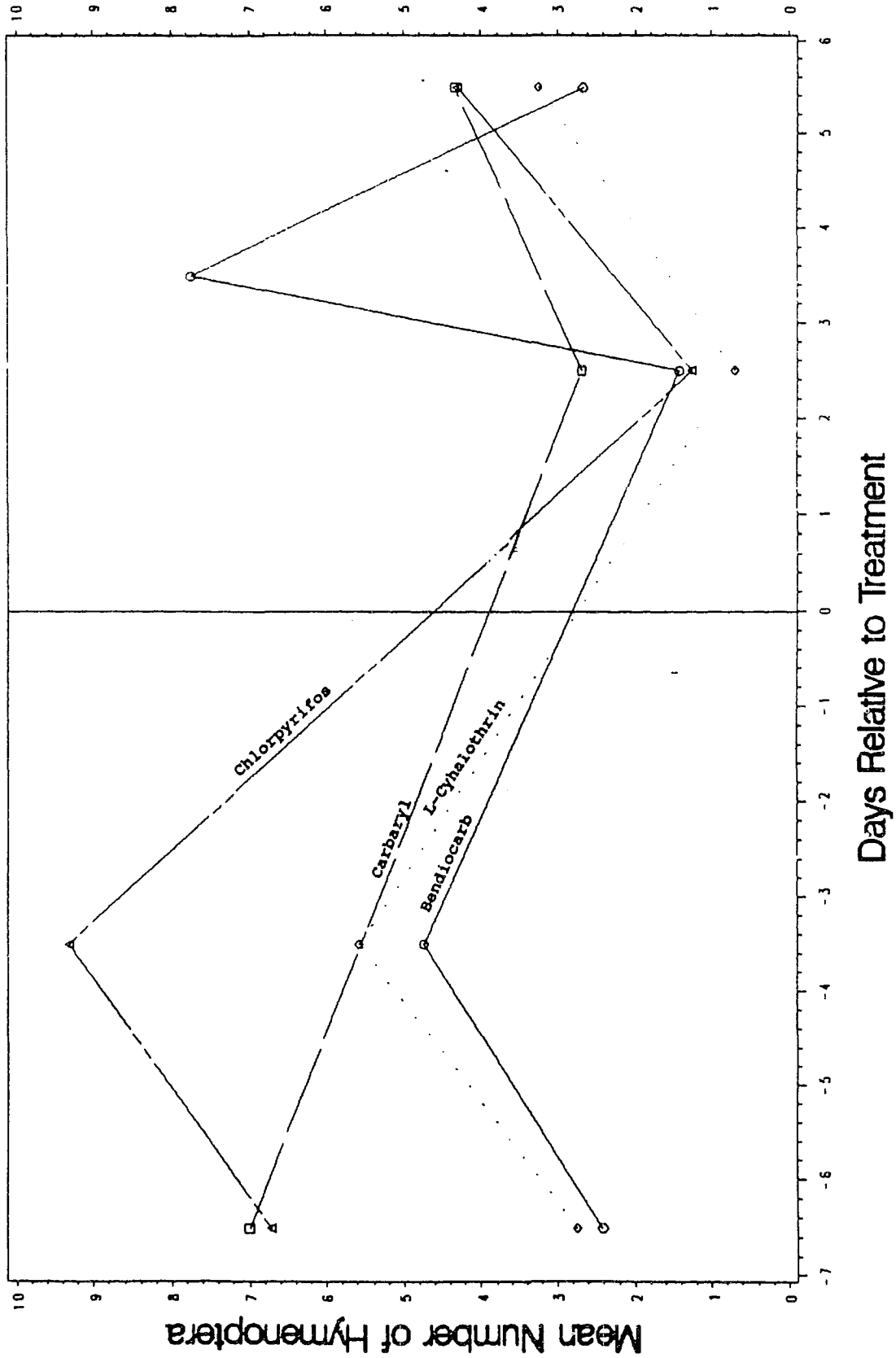


Figure 5-14. Mean numbers of Hymenoptera (bees and wasps) sampled from replicate plots both before and after treatment with ULV pesticides. Only significant reductions relative to controls are shown for environmental impact trials conducted in Tokar, Sudan.

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possessed the highest percent recoveries (lambda-cyhalothrin and malathion), it can be concluded that very little or no degradation of the residue samples occurred during storage or shipping prior to the analysis.

For quality control in the residue analysis, an average of three laboratory spikes of "PRE" samples were conducted for each pesticide. Good recoveries (in the range 92 to 114%) were obtained from the spikes of five pesticides. The low recoveries of the carbaryl spikes can be attributed to the lack of cleanup column use. The following mean recoveries were obtained for grass sample spikes: fenitrothion 101%, malathion 113%, chlorpyrifos 113%, bendiocarb 99.6%, carbaryl 66.0%, and lambda-cyhalothrin 114%. The following mean recoveries were obtained for soil sample spikes: fenitrothion 104%, malathion 106%, chlorpyrifos 92.8%, bendiocarb 99.5%, carbaryl 75.0%, and lambda-cyhalothrin 92.8%.

Mean pesticide residue levels differed significantly ($p < 0.05$) among the six pesticides and between the environmental substrates, soil, and grass (Table 5-7). The greatest difference was the relatively higher (greater than tenfold) residue levels found on the grass as compared to the soil.

The rate of residue decline was significant for all six pesticides. The shapes of each pesticide's decline curves were similar, with only three cases of apparent increases in residue levels on subsequent sampling days (see Figures 5-15 and 5-16). These cases can be attributed to sampling variability. The typical pattern of rapid initial decline followed by decreasing decline rates was most striking in the residue results of chlorpyrifos and fenitrothion. After a comparable initial decrease on day 1, carbaryl showed the slowest rate of decay to day 7, i.e., the greatest persistence. In theoretical decay functions fit to the residue data, the very rapid degradation of malathion is accentuated (Figures 5-17 and 5-18). Slower decay rates were evident for all six pesticides at residues below 5 ppm.

5.7.2 Discussion

The pesticide residue levels found in the Sudan trials were substantially higher than those found in the Mali trials for two reasons: (1) the application rates used in Sudan were those recommended for desert locust control, rather than for Senegalese grasshopper control, and were approximately twice as high as those used in Mali; and (2) the integrity of the samples was maintained from collection to analysis so that none of the degradation that likely occurred in the Mali samples could have occurred.

Table 5-7. Mean Residue Levels of Six Pesticides Found in Grass, Soil, and Birds and Relevant Tolerance Levels[a]

Pesticide (application rate)	Days[b]	Mean Residues (ppm) Forage grass	Soil	Bird[c]	U.S. tolerance or FAO/WHO Codex Maximum Residue Limit (MRL)[d] for related commodity
Fenitrothion (520 g/ha)	0	34.8	1.48	--[e]	10.00 cereal grain[d]
	1	12.8	1.08	0.158	
	3	1.7	0.89	--	
	7	1.3	0.66	--	
Malathion (1300 g/ha)	0	104.5	5.0	--	135.00 grass forage
	1	101.8	3.0	0.316	
	3	28.2	4.0	--	4.00 poultry
	7	1.9	2.6	--	
Chlorpyrifos (225 g/ha)	0	6.20	0.158	--	4.00 alfalfa forage
	1	1.47	0.093	0.154	1.50 sorghum forage
	3	1.03	0.032	--	0.50 poultry
	7	0.25	0.008	--	
Bendiocarb (124 g/ha)	0	2.22	0.38	--	0.05 cereal forage[d]
	1	2.62	0.34	N.D.[f]	
	3	0.68	0.27	--	
	7	0.57	0.23	--	
Carbaryl (576 g/ha)	0	73.3	2.35	--	100.00 grass forage
	1	31.3	1.23	1.216	100.00 sorghum forage
	3	29.9	1.87	--	5.00 poultry
	7	24.1	0.97	--	
L-cyhalothrin (20 g/ha)	0	0.343	0.018	--	0.50 pome fruit[d]
	1	0.298	0.020	0.005	
	3	0.061	0.013	--	
	7	0.042	0.010	--	

[a]Each value represents the average of three samples taken from replicate plots that received identical aerial applications.
[b]Number of days following pesticide application (0 = 6-hour sample).
[c]Live birds caught in mist nets.
[d]United Nations, Food and Agricultural Organization/World Health Organization pesticide residue limit for importation of commodities.
[e]Not applicable.
[f]Not detectable. Level of detection = 0.1 ppm.

Nonetheless, the substantially higher levels of malathion and carbaryl residues found in forage grass were still below the respective U.S. tolerances (see Table 5-7). As in the Mali trials, the mean chlorpyrifos residue level in or on grass samples harvested the same day (6 hours posttreatment) exceeded the U.S. tolerance for alfalfa. Subsequently harvested samples bore residues below this tolerance level. The remaining three pesticides do not have U.S. tolerances for residues in or on forage grass, but international Codex tolerances for other commodities may be compared with the observed levels. For example, the lambda-cyhalothrin residues found in or on forage grass were below the Codex Maximum Residue Limit (MRL) for pome fruit. In contrast, fenitrothion residue levels in or on grass harvested 6 hours and 1 day posttreatment exceeded the Codex MRL for cereal grain. As forage grass residue tolerances are usually much higher than grain or seed tolerances, these fenitrothion residues are probably of no concern. On the other hand, bendiocarb residues in or on grass samples harvested 0-7 days posttreatment exceeded the Codex MRL of 0.05 ppm for bendiocarb residues in or on forage, fodder, and straw of cereal grain crops by ten- to fiftyfold.

These results support the general conclusion that single applications of these pesticides (with the exception of bendiocarb) on semiarid grasslands of the Sahel pose little hazard to the local population or to the environment. It is possible, however, that crop harvesting and livestock grazing should be restricted for 1 to 3 days after spraying with chlorpyrifos, lambda-cyhalothrin, or fenitrothion.

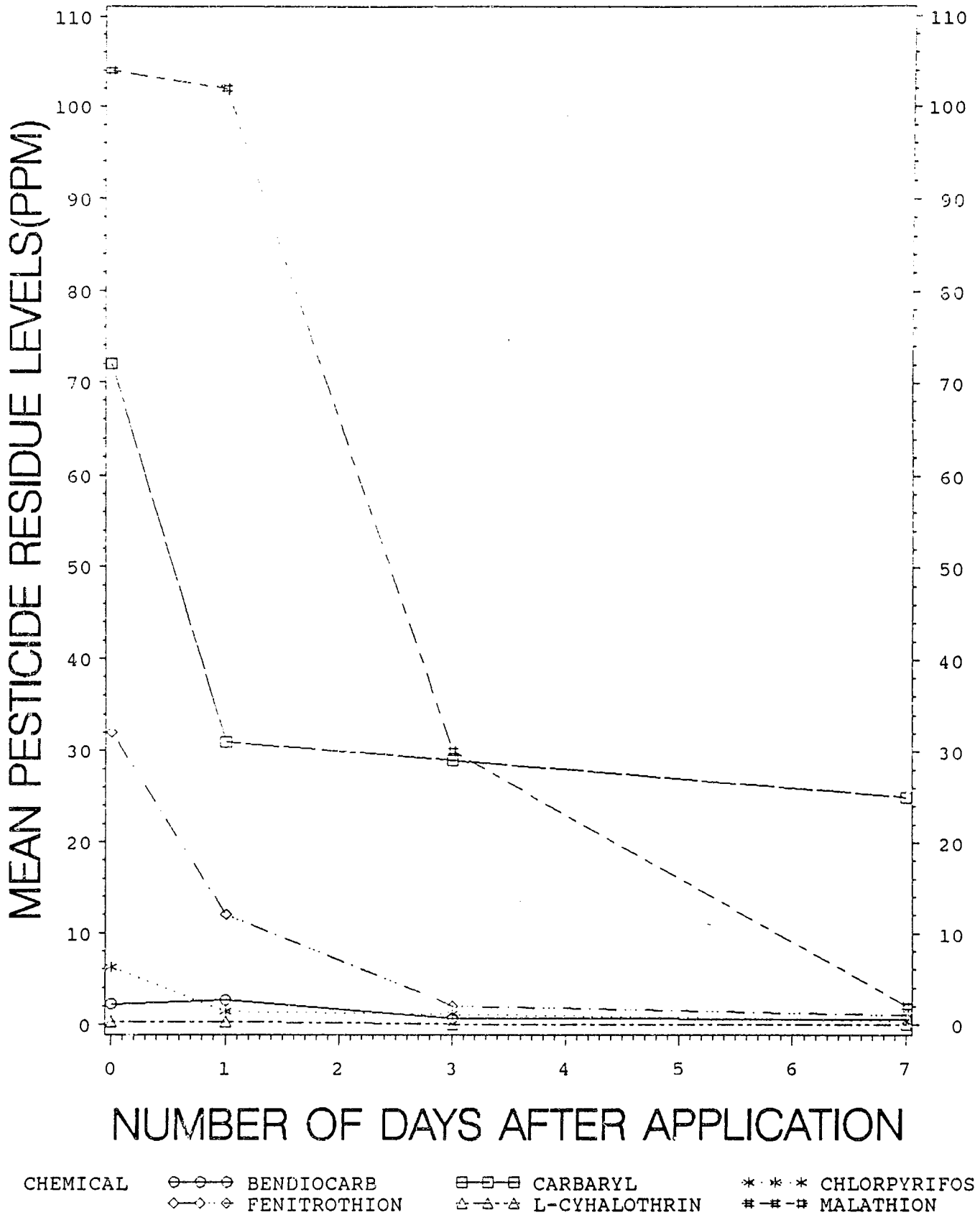


Figure 5-15. Mean residue levels (ppm) in grass obtained from replicate plots treated with aerial applications of six ULV pesticides during field trials in Tokar, Sudan.

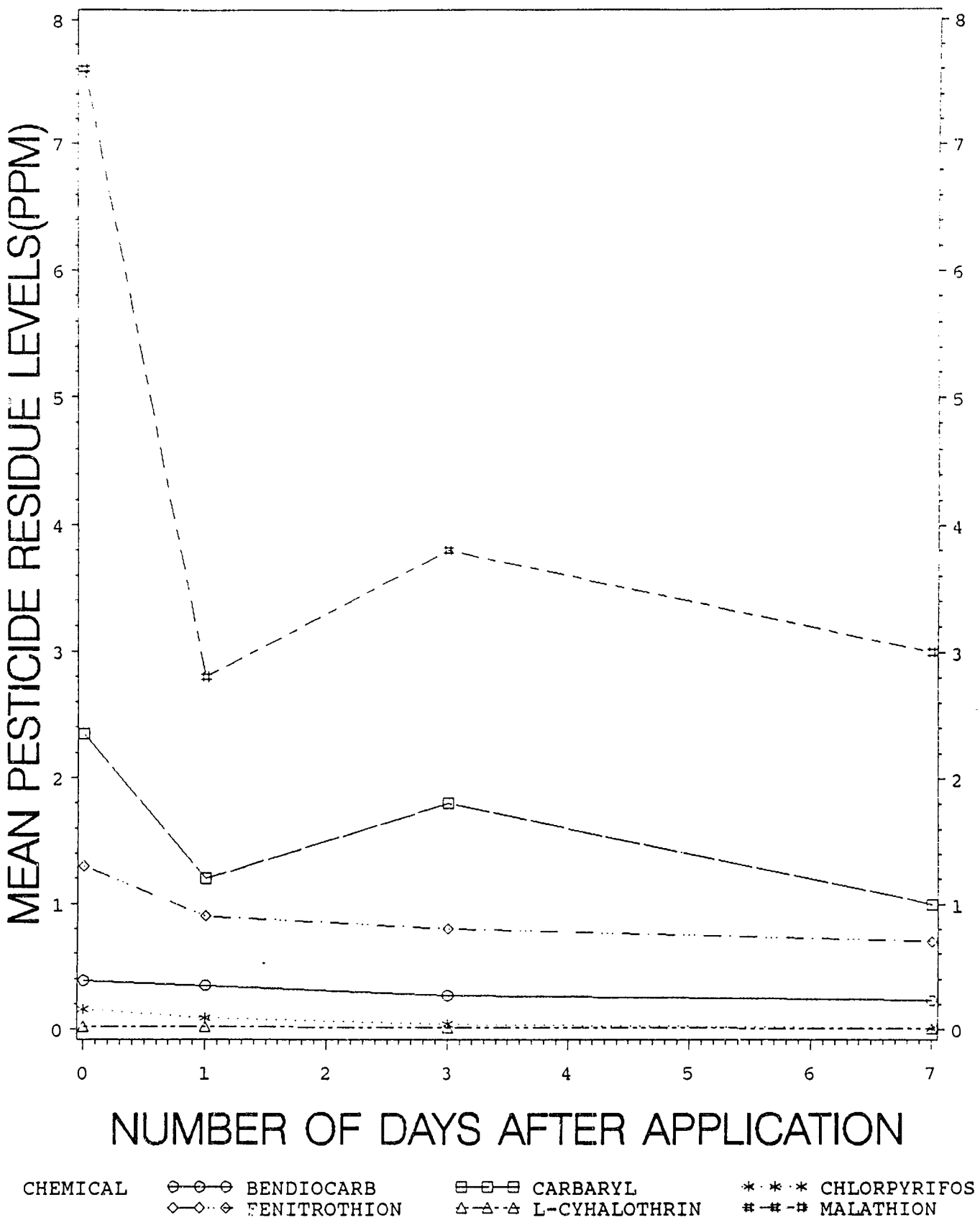


Figure 5-16. Mean residue levels (ppm) in soil obtained from replicate plots treated with aerial applications of six ULV pesticides during field trials in Tokar, Sudan.

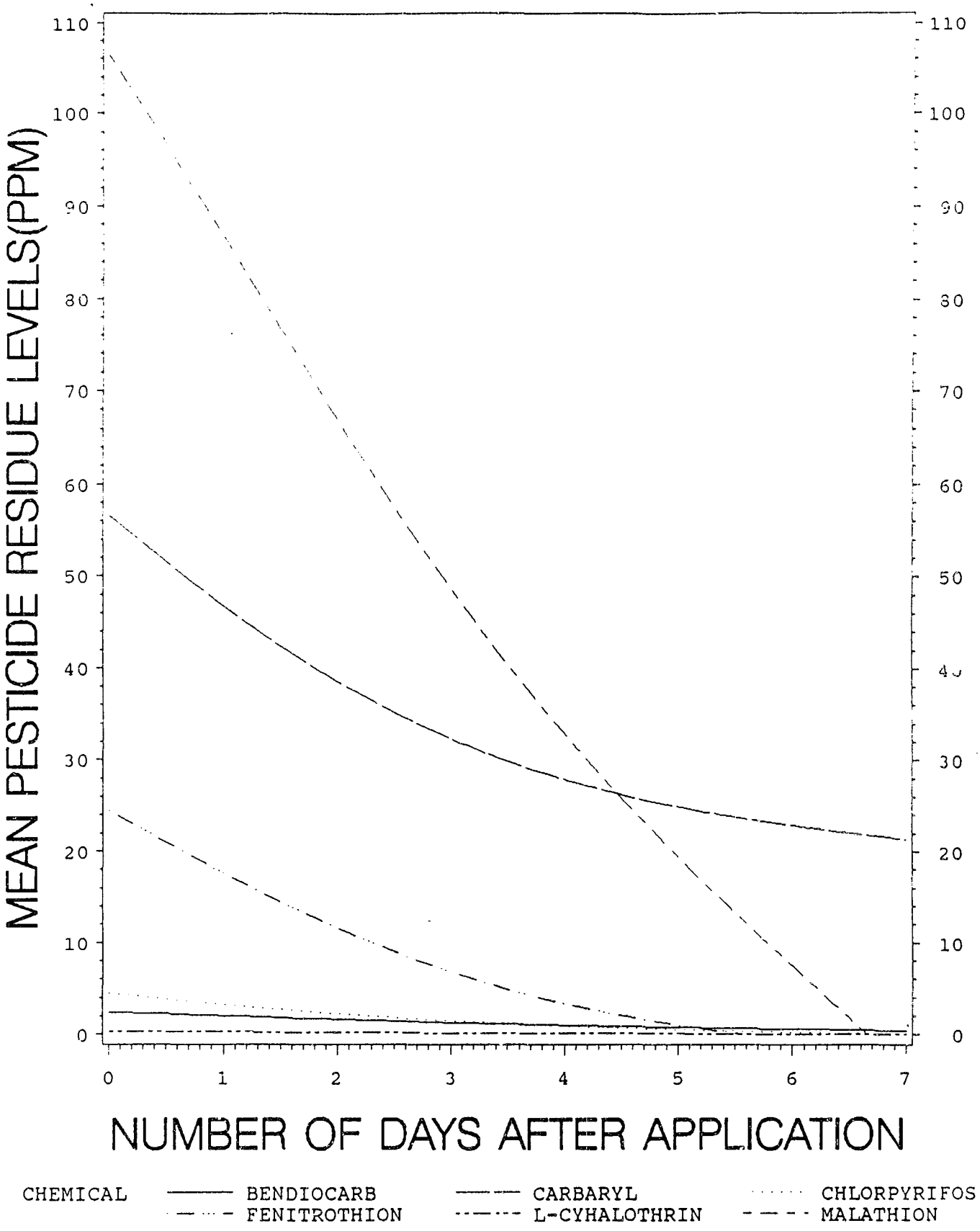


Figure 5-17. Theoretical pesticide decay rates fit to data from replicated grass samples following aerial ULV application in Tokar, Sudan.

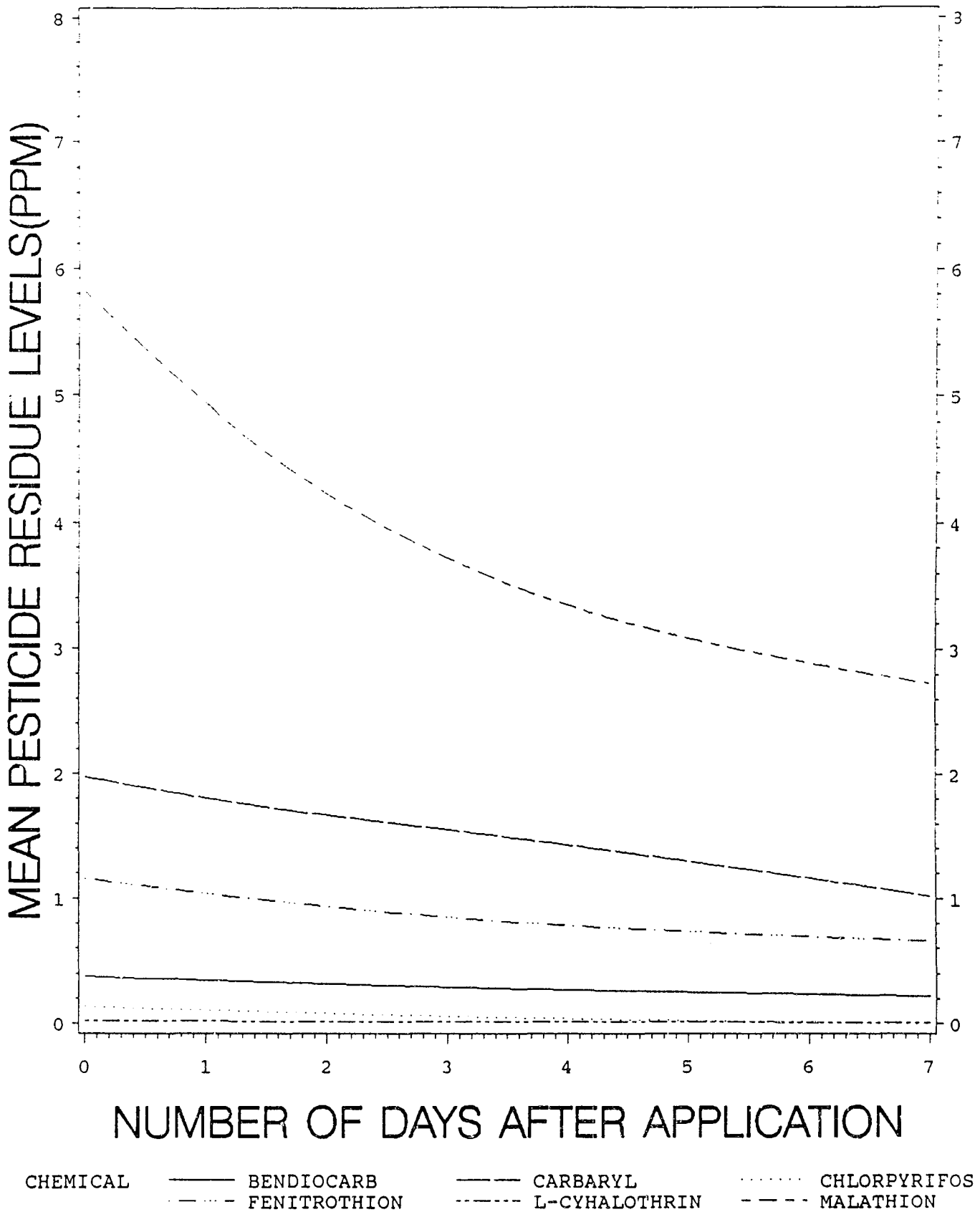


Figure 5-18. Theoretical pesticide decay rates fit to data from replicated soil samples following aerial ULV application in Tokar, Sudan.

6. SUMMARY AND CONCLUSIONS

These conclusions are based solely on the results of the Sudan field trials.

6.1 SUMMARY

The planned environmental impact trials, but not the locust efficacy trials, were successfully completed in Tokar, Sudan, during the months of March and April 1988. Although desert locusts were not present in the Tokar Delta at this time, this site was an appropriate place for the environmental impact trials for three reasons: (1) the delta is the prime agricultural area along the Red Sea coast and it attracts the greatest numbers and diversity of nontarget species; (2) this area has been the site of past locust control campaigns (Appendix L) and, as part of the traditional Red Sea winter breeding grounds of the desert locust, will almost certainly be the site of future control efforts; and (3) weather records for previous locust infestation years (Appendix W) indicate that environmental conditions in the delta during our trials were comparable to periods of high locust densities.

The efficacy trials against the desert locust could not be conducted because of the absence of testable locust populations in Sudan. In addition, grasshoppers were too scarce on the environmental test plots for a comparison among pesticides for effects on species related to the desert locust (Orthoptera). However, significant reductions in Orthoptera numbers were observed following treatments with malathion and fenitrothion. The difficulties in conducting an efficacy trial on the desert locust point to several recommendations for future projects. Chief among these is an increased amount of locust tracking and infestation prediction based on in-field surveys by project scientists. In addition, it is likely that efficacy trials in the Red Sea coast region should be targeted at locust hopper populations that hatch in December and congregate in areas of newly emerged short grass.

All six pesticide formulations were correctly applied to replicate plots following the best available procedures. The use of flagging vehicles and the computerized monitoring of flow rate and revolutions per minute (rpm) assured that the aerial applications corresponded to the pesticide manufacturers' specifications. Although the best available weather conditions were chosen for each spray, moderate winds were present throughout the trials. The spray

deposition cards demonstrated that the applications achieved good coverage, and the results suggest that windspeeds greater than those usually recommended are acceptable when spraying in the hot Sahelian conditions.

6.2 CONCLUSIONS

6.2.1 No Effects on Mortality or Behavior of Vertebrates

The highly replicated design of the environmental trials (three replicate treatment plots per pesticide and two to four repeated samples per treatment period) and the extensive set of controls used (matched controls for each pesticide treatment and control plot samples for every day of sampling) permit a confident assessment of no major adverse environmental impacts. No dead or moribund reptiles, birds, or mammals were observed during exhaustive searches of all treatment plots. Although other vertebrate taxa were too uncommon to sample effectively, investigators counted over 5000 birds without observing any abnormal behaviors or reductions in bird activity. One result, mildly depressed brain cholinesterase levels in carbaryl-exposed birds, points to potentially adverse, although likely transient, effects on the avifauna.

6.2.2 Initial Reduction but Rapid Rebound of Arthropod Numbers

All six pesticides produced significant reductions in at least half of the arthropod orders studied. None of the four major orders of insects sampled (Hemiptera, Coleoptera, Diptera, and Hymenoptera) and none of the spiders (Araneae) are likely to be unaffected by any of the classes of pesticides. However, in nearly every instance of a significant reduction in abundance, arthropod numbers rebounded quickly within the first week posttreatment. Given the potential for dispersal and reinvasion, none of these pesticides appears likely to dramatically affect the nontarget arthropod fauna. Although specific locust predators and parasite species were not identified, carbaryl appears to be the pesticide least likely to adversely affect groups that contain beneficial insects. The difficulty in making an adequate assessment of the adverse impact on nontarget insects cannot be overstated. We recommend that specific sampling procedures be developed for the grasshopper predators and parasites whose ecology has been adequately described.

6.2.3 Rapid Pesticide Breakdown but High Initial Residues on Forage Grass

The soil and forage grass residue samples were replicated within and among plots and were kept frozen throughout storage and transport. Thus, the residue results represent accurate measures of pesticide residues to be expected from locust control operations in the Sahel. All of the residue measures for malathion and carbaryl were below established U.S. tolerance levels. Without relevant established tolerances for the other pesticides it is difficult to determine their potential hazards. However, the only restrictions that appear to be needed are (1) cautions against 1-day postspray harvesting or grazing following chlorpyrifos and fenitrothion applications, and (2) strict limitations against spraying bendiocarb on lands subject to harvesting or grazing. The most important result of the residue study was the demonstration of substantial pesticide breakdown within 7 days. This result precludes the possibility of biomagnification and ensures that if local inhabitants and their domestic animals can be kept off treated lands as required (note, however, that even in the United States, the EPA considers grazing restrictions for open rangeland to be unenforceable), adverse effects on the human population can be avoided.

6.2.4 Recommendations

The lack of dramatic acute effects within the ecosystem and the evidence of rapid breakdown of the pesticides suggest that single applications of fenitrothion, malathion, chlorpyrifos, carbaryl, lambda-cyhalothrin, and possibly bendiocarb can be performed safely in grassland areas subject to desert locust infestation.

However, because our trials used careful application methods and because we did not treat aquatic or other sensitive habitats, we cannot assess the potential impacts of careless locust control programs. For this reason, we recommend that future pesticide control strategies give priority to ensuring that the selected pesticides are properly applied and that sensitive habitats, such as wetlands, are carefully avoided.

APPENDIX A

Guidelines for Operation of Micronair Aerial Application System

NOTES ON OPERATION OF SPRAY SYSTEM ON CESSNA AGTRUCK ST-AJZ

1.0 Calibration

Before use, the spray system must be calibrated for the chemical to be sprayed. The calibration is divided into two separate parts; setting the correct chemical application rate and setting the droplet size. Unlike a conventional spray nozzle, these are largely independent and are adjusted separately.

1.1 Setting Chemical Application Rate

The required chemical flow rate from the aircraft is given by:

$$\text{FLOW (l/min)} = \frac{\text{SWATH (m)} \times \text{SPEED (Km/hr)} \times \text{APPN RATE (l/Ha)}}{600}$$

Where:

SWATH = Distance between successive spray runs of the aircraft (lane separation), <u>not</u> maximum effective swath width.

SPEED = Groundspeed of aircraft (typically 105 mph (169 Km/hr) for Cessna Agtruck).

The flow is controlled by the setting of the Variable Restrictor Units (VRUs) on the atomisers and by the system (boom) pressure. The VRUs must be adjusted on the ground for the approximate flow rate and the exact flow rate set in flight by adjusting the boom pressure.

The attached graph shows anticipated flow rate against pressure for VRU settings #3 and #5. This graph should be used to decide which VRU setting is appropriate for the flow rate to be used.

Final adjustment of output rate is made by the pilot in flight with reference to the Application Monitor (see later).

IMPORTANT: The relationship between chemical flow rate and pressure will vary according to the viscosity of the chemical being used. Because of this, the attached graph must be used as a guide only. The Application Monitor must always be used for the final adjustment.

1.2 Setting Droplet Size

The Volume Median Diameter (VMD) of the spray droplets produced by each atomiser with a given chemical is determined by the rotational speed (RPM) of the atomiser. The RPM is in turn determined by the angle of the fan blades driving the atomiser.

The angle of the fan blades must be set on the ground to ensure the correct rotational speed. This speed should be checked by the pilot in flight using the RPM function of the Application Monitor.

The attached graph has been prepared to assist with the setting of the fan blade angle. It is based on flight tests with the

/continued ...

aircraft under typical operating conditions (105 mph airspeed, 5 l/min chemical output).

Before setting the fan blades, the required atomiser RPM must be known. This should be based either on chemical manufacturer's recommendations or earlier trials during which droplet size on the target was measured.

To determine the blade angle for each atomiser, refer to the graph and read off the angle for atomisers 1 - 4. Note that the angles for each unit will differ slightly due to the varying airflow over different parts of the wing.

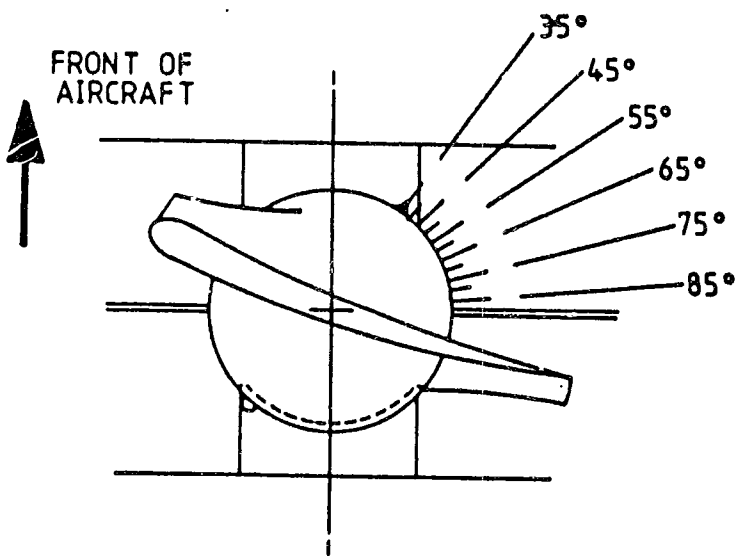
The atomisers are numbered 1 - 4 counting from the left-hand outboard unit to the right-hand outboard unit.

Having determined the blade angle for each atomiser, adjust the blades as follows:

i) Slacken the three clamp ring securing bolts with a 3/8" wrench.

ii) Adjust all three blades to the same angle as shown in the diagram below.

iii) Re-tighten the three bolts just sufficiently to trap the fan blades. DO NOT OVERTIGHTEN THE CLAMP RING BOLTS.



ADJUSTMENT OF FAN BLADES ON AU5000 ATOMISER

Note: If atomiser is fitted with new type EX1772/2 fan blades the setting is made with reference to the extreme anti-clockwise pip on the blade.

/continued ...

2.0 Pre-flight checks on Spray System:

i) Check atomisers for damage and contamination.
ii) Check condition of all atomiser bearings.
iii) Check for leaks from diaphragm check valves (possible chemical damage to diaphragms).
iv) Check VRU setting on each atomiser.
v) Check blade angles on all atomisers.
vi) Check condition of all hoses, booms and boom supports.

3.0 Setting-up of Application Monitor

i) Start aircraft engine.
ii) Check that display reads:

USE LAST SET-UP? (YES/NO)

If the display does not show this, switch the master switch off and on again to reset the Application Monitor.

iii) If the swath width, speed and turbine calibration have not changed since the unit was last used, respond by pressing the YES button. The unit is now ready for use.

If a parameter has been changed, press the NO button and enter the new data as prompted on the display.

Note that TURBINE #1 should be selected for flows above 5.5 l/min and TURBINE #2 should be selected for flows below this figure.

4.0 In Flight

i) Press the FLOW button on the Application monitor if output rate is being expressed as chemical flow; otherwise, press the VOL/AR button to display output in terms of application rate in litres/Ha.

ii) When in the spraying area, start the chemical pump, open the spray valve and adjust the pressure until the Application Monitor shows the correct flow or application rate. Note the boom pressure required to achieve this output.

iii) Open and close the spray valve in the normal way when making each spray run.

iv) Towards the begining of the first spray run, press the RPM button on the Application Monitor and select atomiser #1. Check that its speed corresponds to the required RPM. Select atomisers #2, #3 and #4 and check their speeds in the same way.

Press the RESET button on the Application Monitor to leave RPM mode and select FLOW or VOL/AR again.

v) Use the VOL A and VOL B functions to measure the total amount of chemical used if required. Note that VOL A can be reset by pressing the VOL A button and then RESET. VOL B cannot be reset in flight.

vi) Whilst spraying, note the reading of flow or application rate on the Application Monitor and the boom pressure. If the flow or application rate should start to fluctuate or become zero, it is possible that the flowmeter turbine could have become blocked. If this is the case, the output can be maintained by reference to the boom pressure noted in (ii) above.

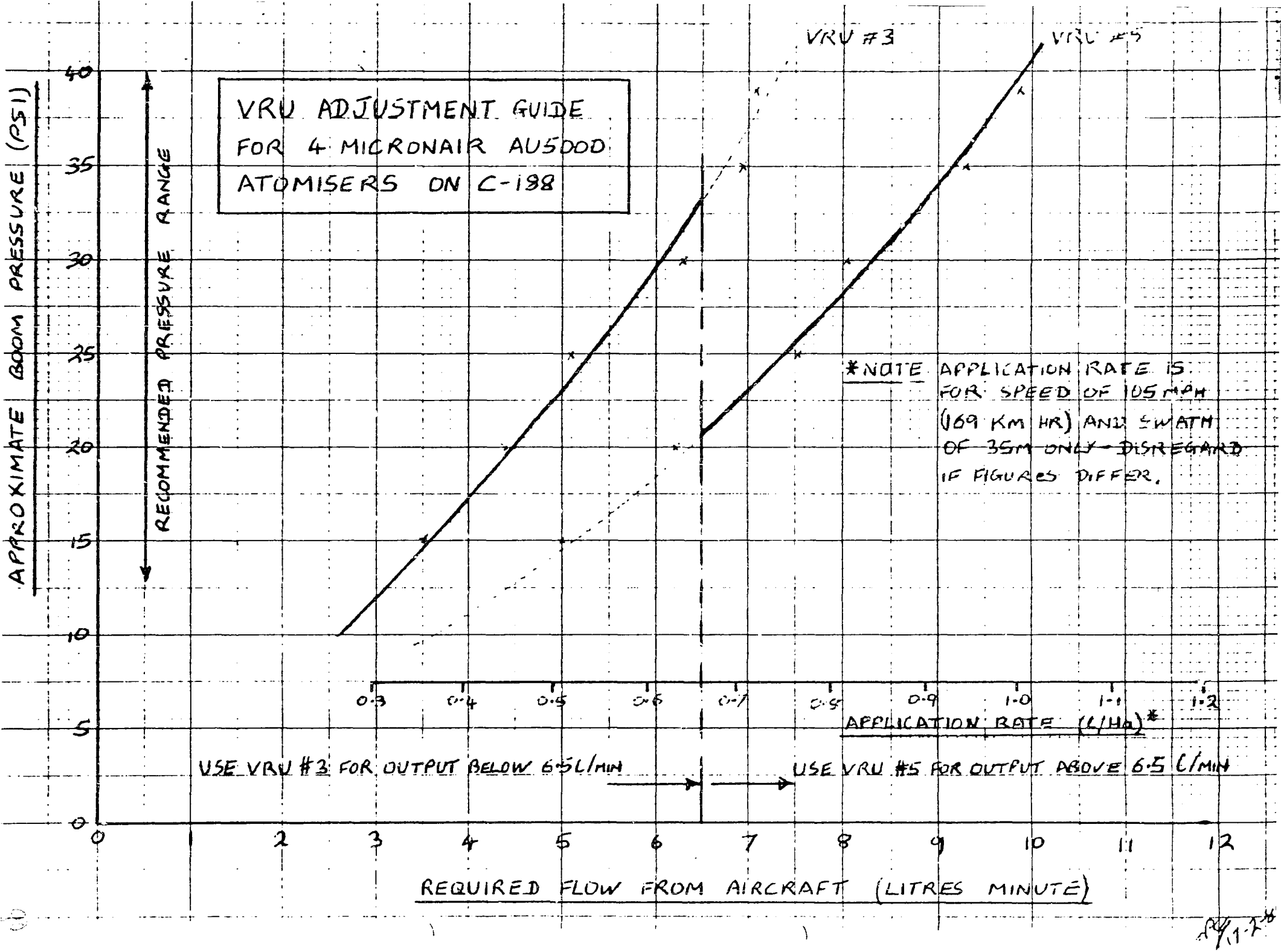
IMPORTANT: If a large change in pressure or spray valve opening is required in flight, this probably indicates a major blockage (possibly in the filter) and the spray run should be aborted.

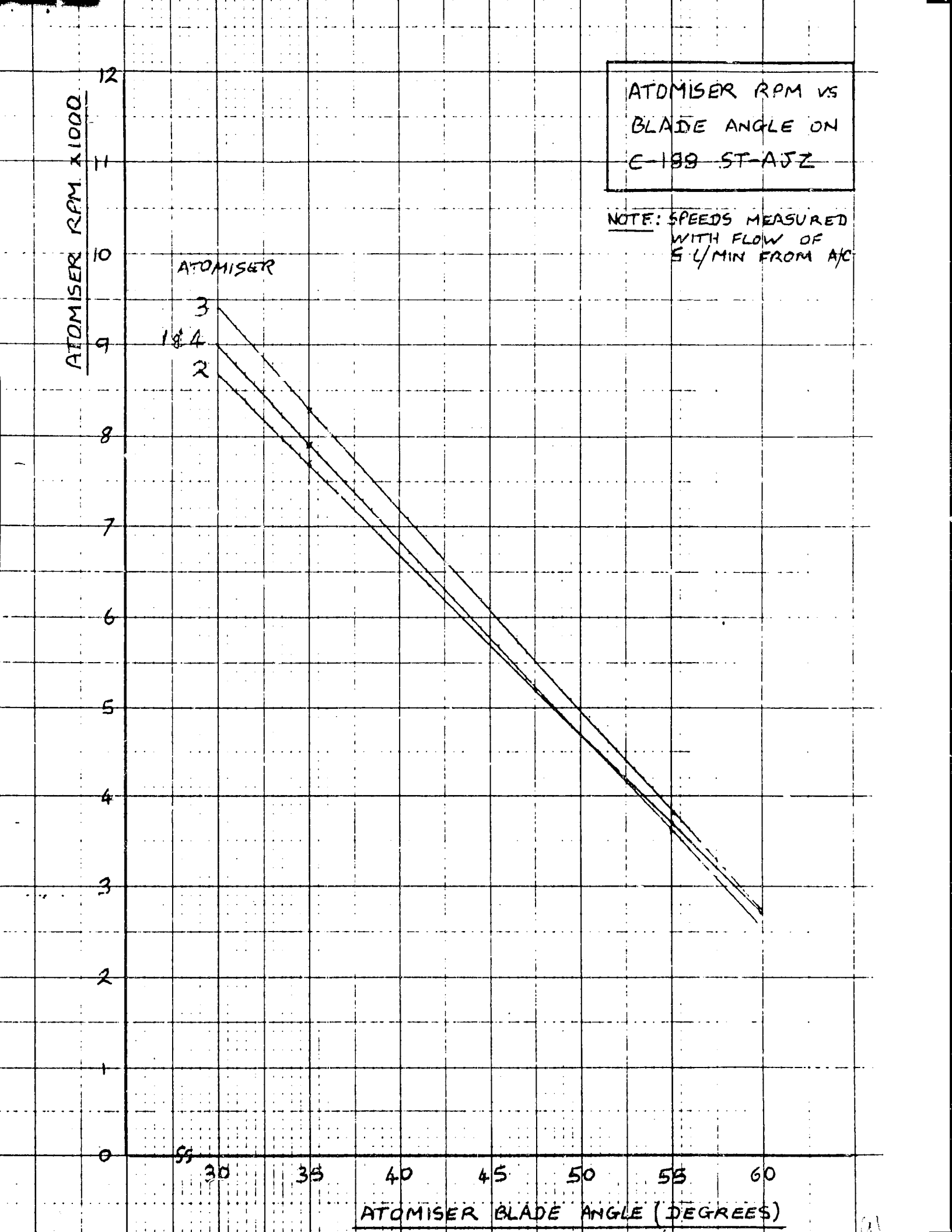
5.0 After Completion of Flights

The entire spray system should be washed out by pumping a suitable solvent through the booms and atomisers. Diesel would probably be a suitable solvent for most ULV chemicals. Use water with caution as it can form a gel with some formulations.

Pay particular attention to the atomisers. Ensure that there is no chemical build-up on the gauze screens or fan blades. If conditions are likely to be dusty and windy, it is suggested that all atomisers are wrapped in cloth whilst the aircraft is left on the ground for a significant time.

T P Y Sander
Feb 18 1988


VRU ADJUSTMENT GUIDE
FOR 4 MICRONAIR AU5000
ATOMISERS ON C-188
VRU #3
VRU #5
APPROXIMATE BOOM PRESSURE (PSI)
RECOMMENDED PRESSURE RANGE
40
35
30
25
20
15
10
5
0
0
2
3
4
5
6
7
8
9
10
11
12
REQUIRED FLOW FROM AIRCRAFT (LITRES MINUTE)
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
1·1
1·2
APPLICATION RATE (L/Ha)*
*NOTE APPLICATION RATE IS FOR SPEED OF 105 MPH (169 KM HR) AND SWATH OF 35M ONLY - DISREGARD IF FIGURES DIFFER.
USE VRU #3 FOR OUTPUT BELOW 6·5 L/MIN
USE VRU #5 FOR OUTPUT ABOVE 6·5 L/MIN


ATOMISER RPM VS BLADE ANGLE ON C-188 ST-AJZ
NOTE: SPEEDS MEASURED WITH FLOW OF 5 L/MIN FROM A/C
ATOMISER
3
1 & 4
2
ATOMISER RPM X1000
12
11
10
9
8
7
6
5
4
3
2
1
0
30
35
40
45
50
55
60
ATOMISER BLADE ANGLE (DEGREES)

APPENDIX B

Species List of Birds Observed Near the Test Site, Tokar, Sudan

APPENDIX B

Species List of Birds Observed Near the Test Site, Tokar, Sudan

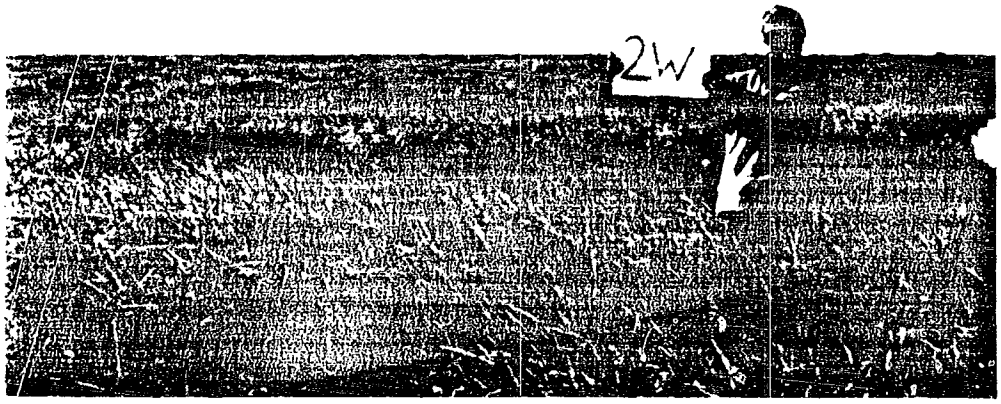
Common Name	Scientific Name	Location
PELICANIDAE (Pelicans and their allies)		
Pink-backed Pelican	*Pelecanus rufescens*	Trinkatat
PHOENICOPTERIDAE (Flamingos)		
Greater Flamingo	*Phoenicopterus ruber*	Trinkatat
AREIDAE (Herons and Egrets)		
Yellow-billed Egret	*Egretta intermedia*	Tokar
Reef Heron	*Egretta gularis*	Trinkatat
Cattle Egret	*Ardeola ibis*	Tokar
Goliath Heron	*Ardea goliath*	Tokar
THRESKIORNITHIDAE (Ibises)		
Bald Ibis	*Geronticus eremita*	Tokar
ACCIPITRIDAE (Vultures, Eagles, Hawks)		
Hooded Vulture	*Necrosyrtes monachus*	Tokar
Egyptian Vulture	*Neophron percnopterus*	Tokar
Nubian Vulture	*Torgos trachelitois*	Tokar
Griffon Vulture	*Gyps fulvus*	Tokar
Tawny Eagle	*Aquila rapax*	Tokar
Augur Buzzard	*Buteo rufofuscus*	Tokar
Black Kite	*Milvus migrans*	Tokar
Osprey	*Pandion haliaetus*	Trinkatat, Suakin
Grasshopper Buzzard	*Butastur rufipennis*	Tokar
Pale Chanting Goshawk	*Melierax matabates*	Tokar
Pallid Harrier	*Circus macrourus*	Tokar
Montagu's Harrier	*Circus pygargus*	Tokar
FALCONIDAE (Falcons)		
Peregrine Falcon	*Falco peregrinus*	Tokar
Lanner Falcon	*Falco biarmicus*	Tokar
PHASIANIDAE (Gamebirds)		
See-see Partridge	*Ammoperdix griseogularis*	Tokar
Quail	*Coturnix coturnix*	Tokar
SCOLOPACIDAE (Sandpipers)		
Temmink's Stint	*Calidris temminckii*	Suakin
Common Sandpiper	*Tringa hupoleucos*	Trinkatat
LARIDAE (Gulls)		
Sooty Gull	*Larus hemprichii*	Suakin
PTEROCLIDAE (Sandgrouse)		
Chestnut-bellied Sandgrouse	*Pterocles exustus*	Tokar

Common Name	Scientific Name	Location
COLUMBIDAE (Doves)		
Rock Dove	Cloumba livia	Tokar
Namaqua Dove	Oena capensis	Tokar
Collared Dove	Streptopelia decaocto	Tokar
Red-eyed Dove	Streptopelia semitorquata	Tokar
UPUPIDAE (Hoopoes)		
African Hoopoe	Upupa epops africana	Tokar
CORACIIDAE (Rollers)		
Abyssianian Roller	Coracias abyssinica	Tokar
MEROPIDAE (Bee-eaters)		
Eurasian Bee-eater	Merops apiaster	Tokar
Carmine Bee-eater	Merops nubicus	Tokar
APODIDAE (Swifts)	Apus sp.	Tokar
Swift		
ALUADIDAE (Larks)		
Black-crowned Finch-lark	Eremopterix nigriceps	Tokar
Hoopoe Lark	Alaemon alaudipes	Tokar
Desert Lark	Ammomanes deserti	Tokar
Crested Lark	Galerida cristata	Tokar
HIRUNDINIDAE (Swallows)		
Swallow	Hirundo rustica	Tokar
MOTACILLIDAE (Wagtails)		
Pied Wagtail	Motacilla alba	Tokar
African Pied Wagtail	Motacilla aguimp	Tokar
Yellow Wagtail	Motacilla flava	Tokar
TURDIDAE (Thrushes)		
Stonechat	Saxicola torquata	Tokar
Desert Wheateaer	Oenanthe deserti	Tokar
Black-eared Wheateaer	Emberiza striolata	Tokar
SYLVIIDAE (Warblers)		
Garden warbler	Sylva borin	Tokar
LANIIDAE (Shrikes)		
Great Grey Shrike	Lanius excubitor	Tokar
Masked Shrike	Lanius nubicus	Tokar
Isabelline Shrike	Lanius isabellinus	Tokar
Taita Fiscal Shrike	Lanius dorsalis	Tokar
Yellow-billed Shrike	Corvinella corvina	Tokar
White-crowned Shrike	Eurocephalus ruppelli	Tokar
EMBERIZIDAE (Buntings)		
Golden-breasted Bunting	Emberiza flaviventris	Tokar
Striped Bunting	Emberiza striolata	Tokar

Common Name	Scientific Name	Location
FRINGILLIDAE (Finches)		
Silverbill	*Euodice malabarica*	Tokar
Golden Sparrow	*Passer luteus*	Tokar
Northern Masked Weaver	*Ploceus taeniopterus*	Tokar
Vitelline Masked Weaver	*Ploceus velatus*	Tokar
Black-headed Weaver	*Ploceus cucullatus*	Tokar
Grey-headed Social Weaver	*Pseudonigrita arnaudi*	Tokar
Common waxbill	*Estrilda astrild*	Tokar

APPENDIX E

Photographs of Each 100-ha Plot Used in the Environmental Impact Trials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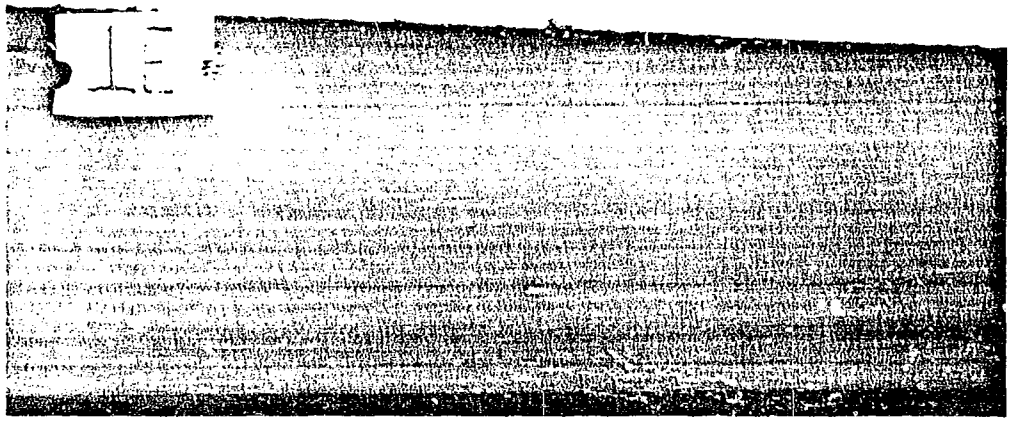
3W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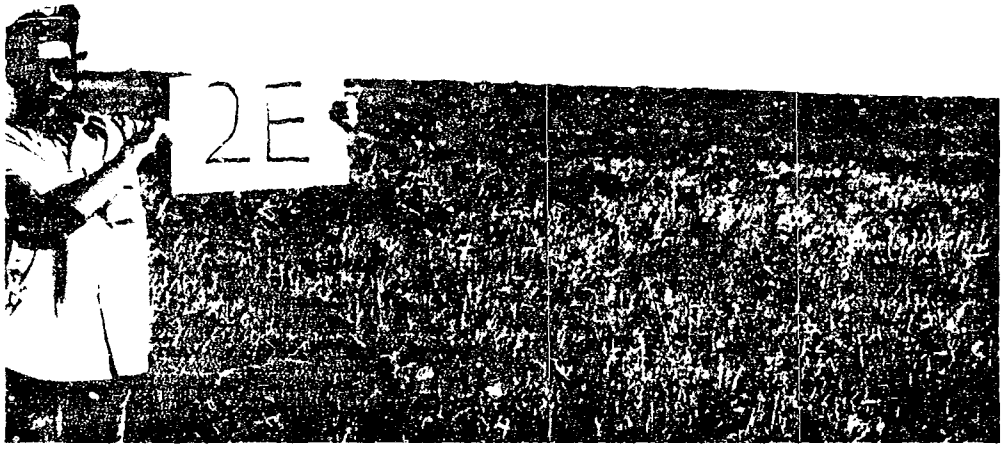
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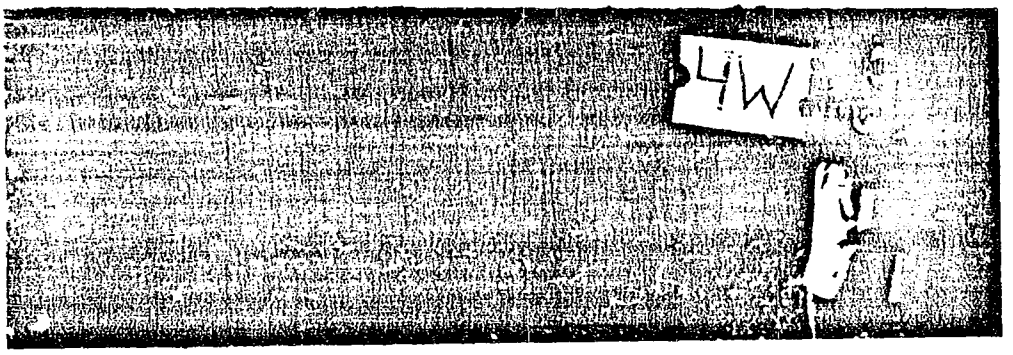
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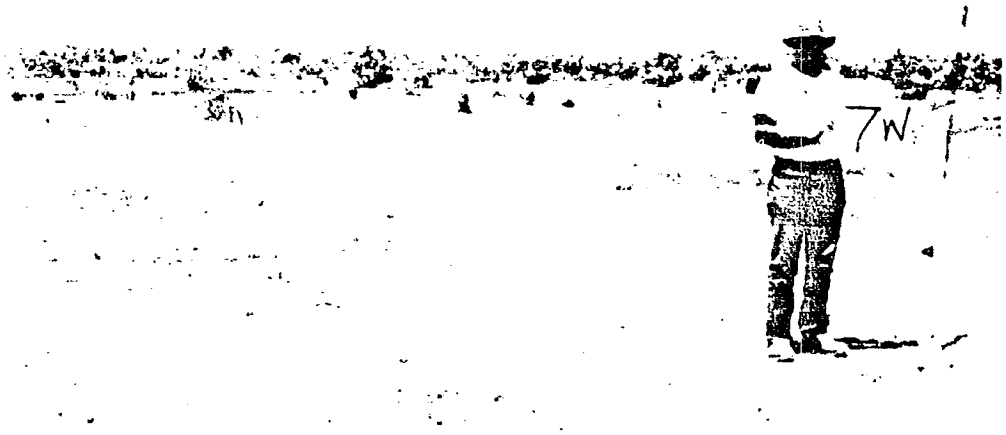
4E

5E

GE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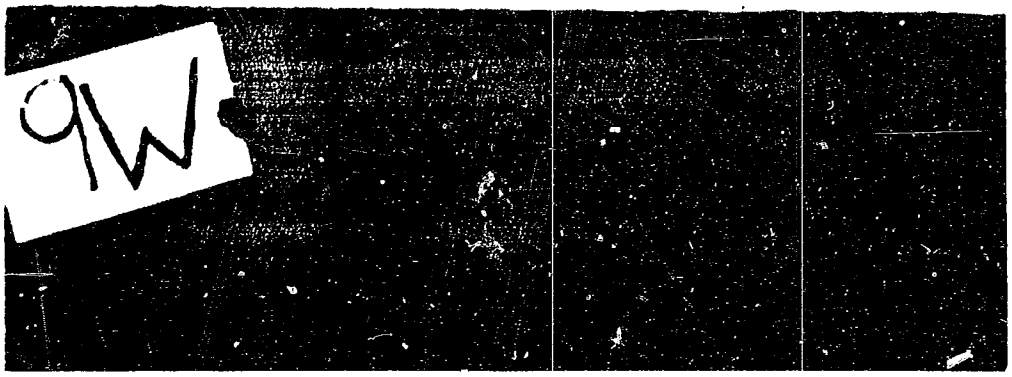
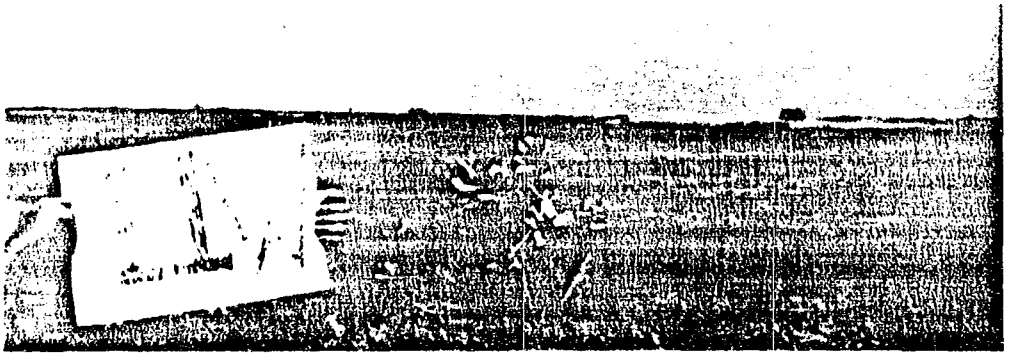
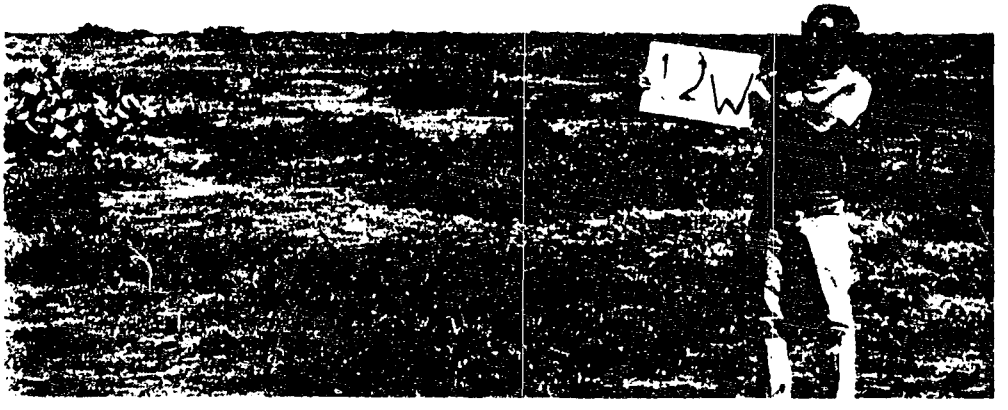
8W


9W

8E

9E

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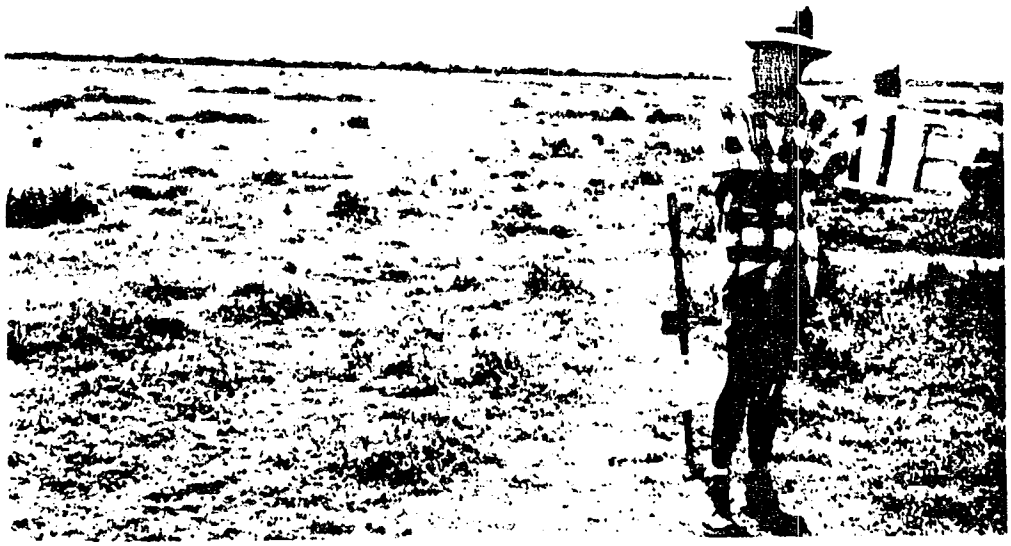
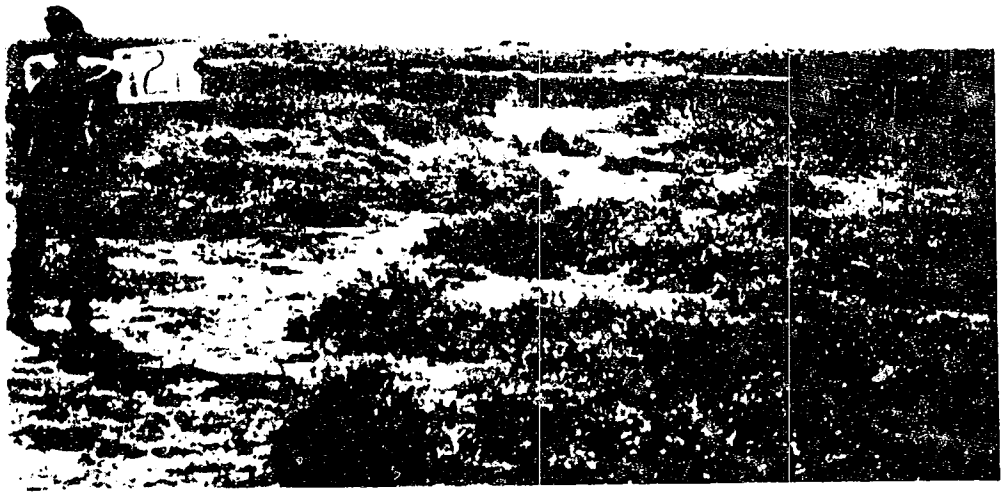
10E





13W

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APPENDIX L

Desert Locust Control Operations in the Tokar Delta, Sudan

DOCUMENT SUMMARY

Document Id: 3012s
Document Name: Appendix & Title Pages
Operator: sh
Author: southerland

Comments: 1174/020

STATISTICS

OPERATION	DATE	TIME	WORKTIME	KEYSTROKES
Created	07/26/88	11:59	:54	2724
Last Revised	01/13/89	10:48	:08	59
Last Printed	01/13/89	11:21		
Last Archived	01/05/88	14:55	onto Diskette 0302s	

Total Pages: 19
Total Lines: 200
Total Worktime: 6:24
Total Keystrokes: 23639

Pages to be printed 1

APPENDIX L. Desert Locust Control Operations in the Tokar Delta, Sudan*

Year	Desert Locust Infestation	Pesticides Applied for Locust Control in the Tokar Delta
1984-85 and earlier	Dry conditions resulted in no sizable infestations	None
1985-86	Seven locust swarms from Derudeb and locust escapes from Eritrea reached the delta	Fenitrothion Diazinon BHC
1986-87		
December 86	28 locust swarms and infestations of hoppers covered 46,000 ha in the delta	Fenitrothion ULV (1,000 L) Fenitrothion EC 50% (3,370 L) Diazinon ULV 100% (1,600 L) Diazinon EC 60% (17,500 L) BHC bait & 2.6 dust (400 kg)
January 87	Locusts infested 315 ha in the delta	Diazinon EC 60% (1,120 L) BHC bait & dust (1,450 kg)
March 87	Breeding locusts and swarms from Eritrea infested 20,700 ha in the delta	BHC bait & dust (500 kg)
April 87	Locusts infested 10,692 ha in the delta	Fenitrothion ULV (5,400 L) Fenitrothion EC 50% (300 L) Diazinon EC 60% (240 L) BHC bait & dust (1,450 kg)
1987-88	No sizable infestations occurred in the delta	None

*Information provided by Shabban Shahata, Director of Locust Control Operations, Red Sea Province.

APPENDIX M

Analytical Methodologies Used in the Determination of Pesticide Residues in Soils, Grasses, and Animals.

METHODOLOGY

Fenitrothion, Malathion and Chlorpyrifos were extracted from Forage using the official AOAC* method 29.011(d), from animals using AOAC* method 29.011(a), and from Soil using the official EPA** method 3540. The analyses were made without clean-up by G.L.C.-F.P.D. using a 525 nm filter specific for Phosphorus, a 5% OV-210 column and the parameters designated by EPA***.

Karate was extracted from Forage using AOAC* method 29.011(d), from animals using AOAC* Method 29.011(a) and from Soil using EPA** method 3540, then cleaned up using AOAC* method 29.015 (Florisil column). The analyses were made by G.L.C.-E.C.D. using a 4%SE-30/6%OV-210 column and the parameters designated by EPA***.

Carbaryl was extracted from Forage using JAOAC(*) method, from animals using AOAC* Method 29.011(a), and from Soil using EPA** method 3540, then cleaned up using EPA*** Section 10,A,page 9 (Silica Gel column). The analyses were made using G.L.C.-E.C.D. after derivatization as in EPA*** Section 10,A,page 10.

Calculations

SOIL 10 grams analyzed.

$$\frac{\text{peak height sample(mm)}}{\text{peak height standard(mm)}} \times \frac{\text{Standard mcl injected x concentration(pg/mcl)}}{\text{mcl sample injected x sample weight(gm)}}$$

$$\times \frac{\text{Final dilution sample(mls) x 1000 mcl/ml}}{\text{1000 pg/ng x 1000 ng/ug}} = \text{mcg/gm} = \text{PPM}$$

Forage

$$\frac{\text{25 gm sample X Filtrate extracted(mls)}}{\text{350 mls ACN : water}} \times \frac{\text{mls Recovered}}{\text{100 mls Pet Ether}} = \text{Sample Wgt}$$

Same formula as Soil analysis

ANIMAL total weight analyzed

$$\frac{\text{Sample weight X Mls ACN recovered}}{\text{200 mls ACN}} \times \frac{\text{Mls P.E. recovered}}{\text{100 mls Pet Ether}} = \text{Sample Wgt}$$

Same formula as Soil analysis

*"Official Methods of Analysis", Association of Official Analytical Chemists.
**"Test Methods for Evaluating Solid Waste", U.S. Environmental Protection Agency.
***"Manual of Analytical Methods for the Analysis of Pesticides in Human and Environmental Samples", U.S.Environmental Protection Agency.
(*)"Journal of the Association of Official Analytical Chemists (Vol. 64, No.5, 1981) pp. 1187-1195.

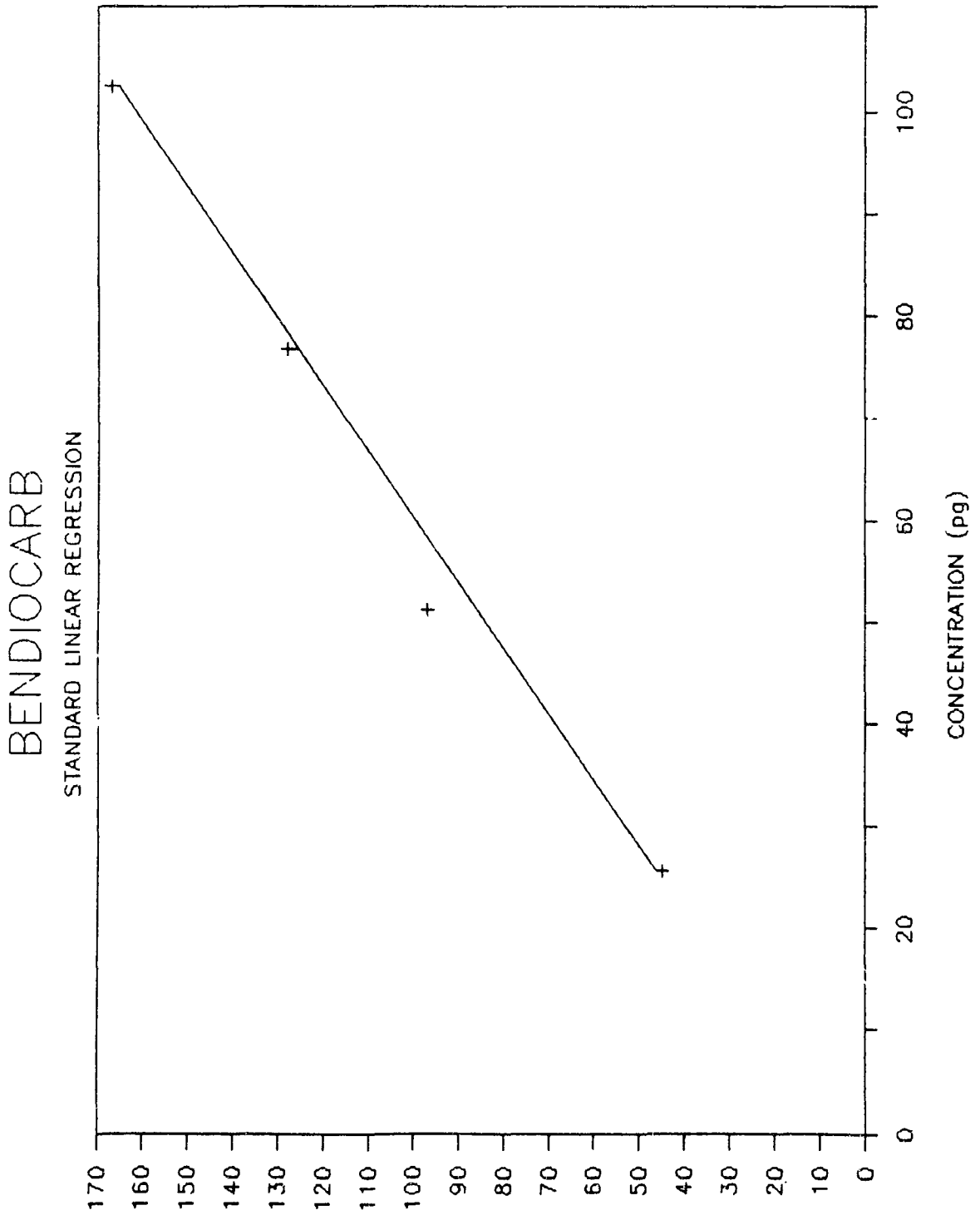
BENDIOCARB was analyzed by the Nor-Am Chemical Company method provided by Mr. Louis Borghi. A standard curve(see Standard Linear Regression chart) was prepared to show linearity in the range used.

Calculations

SOIL 10 grams extracted, 1 gram derivatized for analysis.

FORAGE 10 grams extracted, 1 gram or 0.1 gram derivatized for analysis depending on expected concentration.

ANIMALS total weight extracted, 1/10 th derivatized for analysis.



APPENDIX P

Descriptions of Plant Species Occurring on the Test Plots in the Tokar Delta, Sudan

APPENDIX P. Description of Plant Species Occuring on the Test Plots in the Tokar Delta, Sudan

Family	Species	Description
AMARANTHACEAE	Amaranthus augustifolus	Annual weed with growth form varying from entirely spreading to partly or wholly ascending. Common in sandy plains and entrances of wadis.
	Avera javanica	White woolly undershrub found in deserts.
ASCLEPIADACEAE	Calotropis procera	Shrub or small tree 3 to 5 meters, high. Broad, ovate, fleshy leaves. Spongy bark, strong indicator of overgrazing.
CHENOPODIACEAE	Suaeda pruinosa	Shrub indicative of saline conditions. Bluish green with very small leaves.
CRUCIFERAE	Dipterygium glaucum	Perennial plant with erect branches and yellow greenish flowers. Not eaten by cattle.
CYPERACEAE	Cyperus rotundus	Creeping rhizomes, producing rows of small rosettes along the ground. Stolons thin, but occasionally swollen into black ellipsoid tubers which are collected as a drug. Found in sandy places near springs, wells, or moist areas.
GRAMINEAE	Paspalidium geminatum	Tall, glabrous, robust grasses of subaquatic habitat. Although the main grass on our plots, it is considered an undersirable invading weed in channels, marshes, rice fields, river shores, and wells.
	Cynodon dactylon	Common weed grass cultivated in some areas as a turf grass.
LEGUMINOSAE	Acacia nilotica v. adansonii	Tree with dark stems, numerous leaflettes, and yellow flowers. Glabrous legumes not, or only slightly, constricted between the seeds.

Family	Species	Description
OROBANCHACEAE	*Cistanche phelypaea*	Parasitic plant. Large robust species with yellow flowers. Often associated with shrubs of the Chenopodiaceae family.
PALMAE	*Hyphanea* sp.	Fan palm. Leaves 10 to 20 in terminal crown. Species in plots never more than 1 to 3 branches. Very short.
PAPACERACEA	*Argemone mexicana*	Prickly herb with yellow juice, clasping, spiny-white veined blue green leaves. Flowers yellow. Introduced from America, completely naturalized.
RHAMNACEA	*Ziziphus lotus*	Forms large bushy impenetrable thickets up to 2 to 5 meters in height. Branches are zigzag. Spines occur in pairs, one hooked and minute the other straight and needle-like.
SOLANACEAE	*Datura metel*	Leaves broadly ovate, few-toothed solitary white flower up to 16 cm long.

APPENDIX R

Pesticide Residue Levels Detected in
326 Samples of Soil and Grass

FENITROTHION

SPL. NO.	PLOT	PRODUCT	DAY	FENITROTHION(ppm)
1101	2E	Soil	Pre.	N.D.(<0.001)*
1102	2E	Soil	0	1.53
1103	2E	Soil	0	1.18
1104	2E	Soil	1	1.53
1105	2E	Soil	1	0.32
1106	2E	Soil	3	1.14
1107	2E	Soil	3	1.73
1108	2E	Soil	7	0.84
1109	2E	Soil	7	0.34
1110	11W	Soil	Pre.	N.D.(<0.001)*
1111	11W	Soil	0	0.37
1112	11W	Soil	1	0.10
1113	11W	Soil	3	0.25
1114	11W	Soil	7	0.88
1115	13W	Soil	Pre.	N.D.(<0.001)*
1116	13W	Soil	0	2.44
1117	13W	Soil	0	1.90
1118	13W	Soil	1	0.80
1119	13W	Soil	1	2.63
1120	13W	Soil	3	0.50
1121	13W	Soil	3	0.81
1122	13W	Soil	7	0.74
1123	13W	Soil	7	0.52

RECOVERIES

1110 Spiked (2ug = 0.2 ppm)	99.0% Rec.
1115 Spiked (2ug = 0.2 ppm)	107.0% Rec.
1101 Spiked (2ug = 0.2 ppm)	104.0% Rec.

SPL. NO.	PLOT	PRODUCT	DAY	FENITROTHION(ppm)
1001	2E	Forage	Pre.	N.D.(<0.006)
1002	2E	Forage	0	54.1
1003	2E	Forage	0	56.2
1004	2E	Forage	1	17.3
1005	2E	Forage	1	18.5
1006	2E	Forage	3	1.02
1007	2E	Forage	3	1.00
1008	2E	Forage	7	0.37
1009	2E	Forage	7	0.50
1010	11W	Forage	Pre.	N.D.(<0.006)
1011	11W	Forage	0	22.1
1012	11W	Forage	1	9.52
1013	11W	Forage	3	2.16
1014	11W	Forage	7	2.11
1015	13W	Forage	Pre.	N.D.(<0.006)
1016	13W	Forage	0	21.2
1017	13W	Forage	0	20.5
1018	13W	Forage	1	9.85
1019	13W	Forage	1	8.79
1020	13W	Forage	3	2.73
1021	13W	Forage	3	1.66
1022	13W	Forage	7	1.23
1023	13W	Forage	7	2.38

Formulation 84.7% wt./vol

RECOVERIES

1001 Spiked (2ug = 0.12 ppm)	84.9% Rec.
1015 Spiked (2ug = 0.12 ppm)	117% Rec.

*Nothing Detected Above Limit of Detection

MALATHION

SPL NO	PLOT	PRODUCT	DAY	MALATHION(PPM)	SPL NO	PLOT	PRODUCT	DAY	MALATHION(PPM)
4101	5W	SOIL	PRE	N.D.(<0.005)*	4001	5W	FORAGE	PRE	N.D.(<0.006)*
4102	5W	SOIL	0	4.16	4002	5W	FORAGE	0	190
4103	5W	SOIL	0	2.63	4003	5W	FORAGE	0	34.6
4104	5W	SOIL	1	5.48	4004	5W	FORAGE	1	109
4105	5W	SOIL	1	3.08	4005	5W	FORAGE	1	19.1
4106	5W	SOIL	3	1.53	4006	5W	FORAGE	3	5.4
4107	5W	SOIL	3	3.72	4007	5W	FORAGE	3	24
4108	5W	SOIL	7	1.24	4008	5W	FORAGE	7	0.19
4109	5W	SOIL	7	1.03	4009	5W	FORAGE	7	4.33
4110	8W	SOIL	PRE	N.D.(<0.005)*	4010	8W	FORAGE	PRE	N.D.(<0.006)*
4111	8W	SOIL	0	10.4	4011	8W	FORAGE	0	219
4112	8W	SOIL	0	4.96	4012	8W	FORAGE	0	88.9
4113	8W	SOIL	1	1.7	4013	8W	FORAGE	1	223
4114	8W	SOIL	1	4.46	4014	8W	FORAGE	1	134
4115	8W	SOIL	3	7.36	4015	8W	FORAGE	3	21.8
4116	8W	SOIL	3	3.56	4016	8W	FORAGE	3	53
4117	8W	SOIL	7	3.08	4017	8W	FORAGE	7	0.72
4118	8W	SOIL	7	2.35	4018	8W	FORAGE	7	0.59
4119	12E	SOIL	PRE	N.D.(<0.005)*	4019	12E	FORAGE	PRE	N.D.(<0.006)*
4120	12E	SOIL	0	4.38	4020	12E	FORAGE	0	69.7
4121	12E	SOIL	0	3.63	4021	12E	FORAGE	0	24.7
4122	12E	SOIL	1	1.87	4022	12E	FORAGE	1	120
4123	12E	SOIL	1	1.33	4023	12E	FORAGE	1	5.71
4124	12E	SOIL	3	2.86	4024	12E	FORAGE	3	13.9
4125	12E	SOIL	3	5.03	4025	12E	FORAGE	3	51.1
4126	12E	SOIL	7	4.44	4026	12E	FORAGE	7	1.24
4127	12E	SOIL	7	3.75	4027	12E	FORAGE	7	4.26

RECOVERIES

4101 SPIKED (1mcg = 0.10ppm) 101% REC.
4110 SPIKED (1mcg = 0.10ppm) 113% REC.
4119 SPIKED (2mcg = 0.20ppm) 103% REC.

*NONE DETECTED ABOVE LIMIT OF DETECTION

FORMULATION 87.3%WT./VOL.

RECOVERIES

4001 SPIKED (4mcg = 0.16ppm) 115% REC.
4019 SPIKED (4mcg = 0.16ppm) 110% REC.
4010 SPIKED (4mcg = 0.16ppm) 115% REC.

CHLORPYRIFOS

SPL. NO.	PLOT	PRODUCT	DAY	CHLORPYRIFOS (ppm)
0101	9W	Soil	Pre.	N.D.(<0.001)*
0102	9W	Soil	0	0.37
0103	9W	Soil	0	0.15
0104	9W	Soil	1	0.07
0105	9W	Soil	1	0.15
0106	9W	Soil	3	0.07
0108	9W	Soil	7	0.009
0109	9W	Soil	7	0.003
0110	12W	Soil	Pre.	N.D.(<0.001)*
0111	12W	Soil	0	0.22
0112	12W	Soil	0	0.09
0113	12W	Soil	1	0.04
0114	12W	Soil	1	0.13
0015	12W	Soil	3	0.03
0116	12W	Soil	3	0.02
0117	12W	Soil	7	0.008
0119	13E	Soil	Pre.	N.D.(<0.001)*
0120	13E	Soil	0	0.07
0121	13E	Soil	0	0.05
0122	13E	Soil	1	0.08
0123	13E	Soil	1	0.09
0124	13E	Soil	3	0.03
0125	13E	Soil	3	0.02
0126	13E	Soil	7	0.01
0127	13E	Soil	7	0.01

RECOVERIES

0101 Spiked (50 ng = 0.005 ppm)	69.0% Rec.
0110 Spiked (50.0ng = 0.005 ppm)	108.0% Rec.
0119 Spiked (500ng = 0.05 ppm)	94.8% Rec.
0110 Spike (500ng = 0.05 ppm)	99.6% Rec.

*Nothing Detected Above Limit of Detection

SPL. NO.	PLOT	PRODUCT	DAY	CHLORPYRIFOS (ppm)
0001	9W	Forage	Pre.	N.D.(<0.006)
0002	9W	Forage	0	3.70
0003	9W	Forage	0	7.94
0004	9W	Forage	1	2.48
0005	9W	Forage	1	0.94
0006	9W	Forage	3	0.83
0008	9W	Forage	7	0.55
0009	9W	Forage	7	0.25
0010	12W	Forage	Pre.	N.D.(<0.006)
0011	12W	Forage	0	3.03
0012	12W	Forage	0	10.4
0013	12W	Forage	1	2.49
0014	12W	Forage	1	1.09
0015	12W	Forage	3	1.43
0016	12W	Forage	3	1.49
0017	12W	Forage	7	0.08
0018	12W	Forage	7	0.03
0019	13E	Forage	Pre.	N.D.(<0.006)
0020	13E	Forage	0	6.14
0021	13E	Forage	0	6.02
0022	13E	Forage	1	0.78
0023	13E	Forage	1	1.06
0024	13E	Forage	3	0.59
0025	13E	Forage	3	0.79
0026	13E	Forage	7	0.19
0027	13E	Forage	7	0.41

FORMULATION 43.4% wt./vol.

RECOVERIES

0001 Spiked (500ng = 0.02 ppm)	115% Rec.
0010 Spiked (500ng = 0.02 ppm)	110% Rec.
0019 Spiked (500ng = 0.02 ppm)	115% Rec.

BENDIOCARB

SPL NO	PLOT	PRODUCT	DAY	BENDIOCARB(PPM)	SPL NO	PLOT	PRODUCT	DAY	BENDIOCARB(PPM)
3101	3E	SOIL	PRE	N.D.(<0.10)*	3001	3E	FORAGE	PRE	N.D.(<0.10)*
3102	3E	SOIL	0	0.38	3002	3E	FORAGE	0	2.65
3103	3E	SOIL	0	0.11	3003	3E	FORAGE	0	2.06
3104	3E	SOIL	1	0.49	3004	3E	FORAGE	1	2.87
3105	3E	SOIL	1	0.34	3005	3E	FORAGE	1	2.09
3106	3E	SOIL	3	0.36	3006	3E	FORAGE	3	0.89
3107	3E	SOIL	3	0.26	3007	3E	FORAGE	3	0.57
3108	3E	SOIL	7	0.1	3008	3E	FORAGE	7	0.49
3109	3E	SOIL	7	0.26	3009	3E	FORAGE	7	0.87
3110	8E	SOIL	PRE	N.D.(<0.10)*					
3111	8E	SOIL	0	0.45	3010	8E	FORAGE	PRE	N.D.(<0.10)*
3112	8E	SOIL	0	0.6	3011	8E	FORAGE	0	2.22
3113	8E	SOIL	1	0.45	3012	8E	FORAGE	0	1.93
3114	8E	SOIL	1	0.1	3013	8E	FORAGE	1	2.06
3115	8E	SOIL	3	0.2	3014	8E	FORAGE	1	3.44
3116	8E	SOIL	3	0.25	3015	8E	FORAGE	3	0.43
3117	8E	SOIL	7	0.3	3016	8E	FORAGE	3	0.85
3118	8E	SOIL	7	0.26	3017	8E	FORAGE	7	0.73
					3018	8E	FORAGE	7	0.2
3119	10E	SOIL	PRE	N.D.(<0.10)*					
3120	10E	SOIL	0	0.64	3019	10E	FORAGE	PRE	N.D.(<0.10)*
3121	10E	SOIL	0	0.94	3020	10E	FORAGE	0	3.09
3122	10E	SOIL	1	0.22	3021	10E	FORAGE	0	1.6
3123	10E	SOIL	1	0.55	3022	10E	FORAGE	1	3.08
3124	10E	SOIL	3	0.3	3023	10E	FORAGE	1	2.92
3125	10E	SOIL	3	0.04	3024	10E	FORAGE	3	2.96
3126	10E	SOIL	7	0.13	3025	10E	FORAGE	3	2.02
3127	10E	SOIL	7	0.33	3026	10E	FORAGE	7	0.21
					3027	10E	FORAGE	7	0.33

FORMULATION 18.6%WGT/VOL 19.6%WGT/WGT

3110 SPIKE(1MCG - 10GM = 0.1PPM) 99.5% REC

SEP-PAK RECOVERY 95.3% REC

3019 SPIKE(10MCG - 10GM = 1PPM) 104% REC

* NONE DETECTED ABOVE THE LIMIT INDICATED.

CARBARYL

SPL NO	PLOT	PRODUCT	DAY	CARBARYL(PPM)	SPL NO	PLOT	PRODUCT	DAY	CARBARYL(PPM)
5001	1W	FORAGE	PRE	N.D.(<0.10)*	5101	1W	SOIL	PRE	N.D.(<0.06)*
5002	1W	FORAGE	0	66.2	5102	1W	SOIL	0	3.06
5003	1W	FORAGE	0	19.7	5103	1W	SOIL	0	3.36
5004	1W	FORAGE	1	28.8	5104	1W	SOIL	1	0.7
5005	1W	FORAGE	1	32.7	5105	1W	SOIL	1	0.76(0.72)
5006	1W	FORAGE	3	42.1	5106	1W	SOIL	3	4.43
5007	1W	FORAGE	3	24.9	5107	1W	SOIL	3	2.07
5008	1W	FORAGE	7	1.88	5108	1W	SOIL	7	2.29
5009	1W	FORAGE	7	19.5	5109	1W	SOIL	7	0.693
5010	4E	FORAGE	PRE	N.D.(<0.10)*	5110	4E	SOIL	PRE	N.D.(<0.060)*
5011	4E	FORAGE	0	118	5111	4E	SOIL	0	2.63
5012	4E	FORAGE	0	130	5112	4E	SOIL	0	3.43
5013	4E	FORAGE	1	50	5113	4E	SOIL	1	0.81
5014	4E	FORAGE	1	9.49	5114	4E	SOIL	1	0.21(0.29)
5015	4E	FORAGE	3	21.3	5115	4E	SOIL	3	1.15
5016	4E	FORAGE	3	67.9	5116	4E	SOIL	3	1.34
5017	4E	FORAGE	7	26.3	5117	4E	SOIL	7	0.53
5018	4E	FORAGE	7	73	5118	4E	SOIL	7	0.979
5019	6E	FORAGE	PRE	N.D.(<0.10)*	5119	6E	SOIL	PRE	N.D.(<0.060)
3020	6E	FORAGE	0	52.7(55.6)	5120	6E	SOIL	0	0.85
5020	6E	FORAGE	0	51.4	5120	6E	SOIL	0	0.77
5022	6E	FORAGE	1	20.1	5122	6E	SOIL	1	1.59
5022	6E	FORAGE	1	46.6	5122	6E	SOIL	1	3.27
5024	6E	FORAGE	3	10.2	5124	6E	SOIL	3	1.34
5024	6E	FORAGE	3	12.8	5124	6E	SOIL	3	0.91
5026	6E	FORAGE	7	7.37	5126	6E	SOIL	7	0.814
5026	6E	FORAGE	7	16.7	5126	6E	SOIL	7	0.5

5001** SPIKE(NO CLEAN-UP COLUMN USE 95% REC
5001 SPIKE(1mcg = 0.04ppm) 68% REC
5010 SPIKE(1mcg = 0.04ppm) 65% REC
5019 SPIKE(1mcg = 0.04ppm) 65% REC

5101 SPIKE(1mcg = 0.10ppm) 63% REC
5110 SPIKE(1mcg = 0.10ppm) 87% REC

FORMULATION 43.3% WGT/WGT

*NONE DETECTED ABOVE LIMIT OF DETECTION INDICATED
**CLEAN-UP NOT USED ON SAMPLES

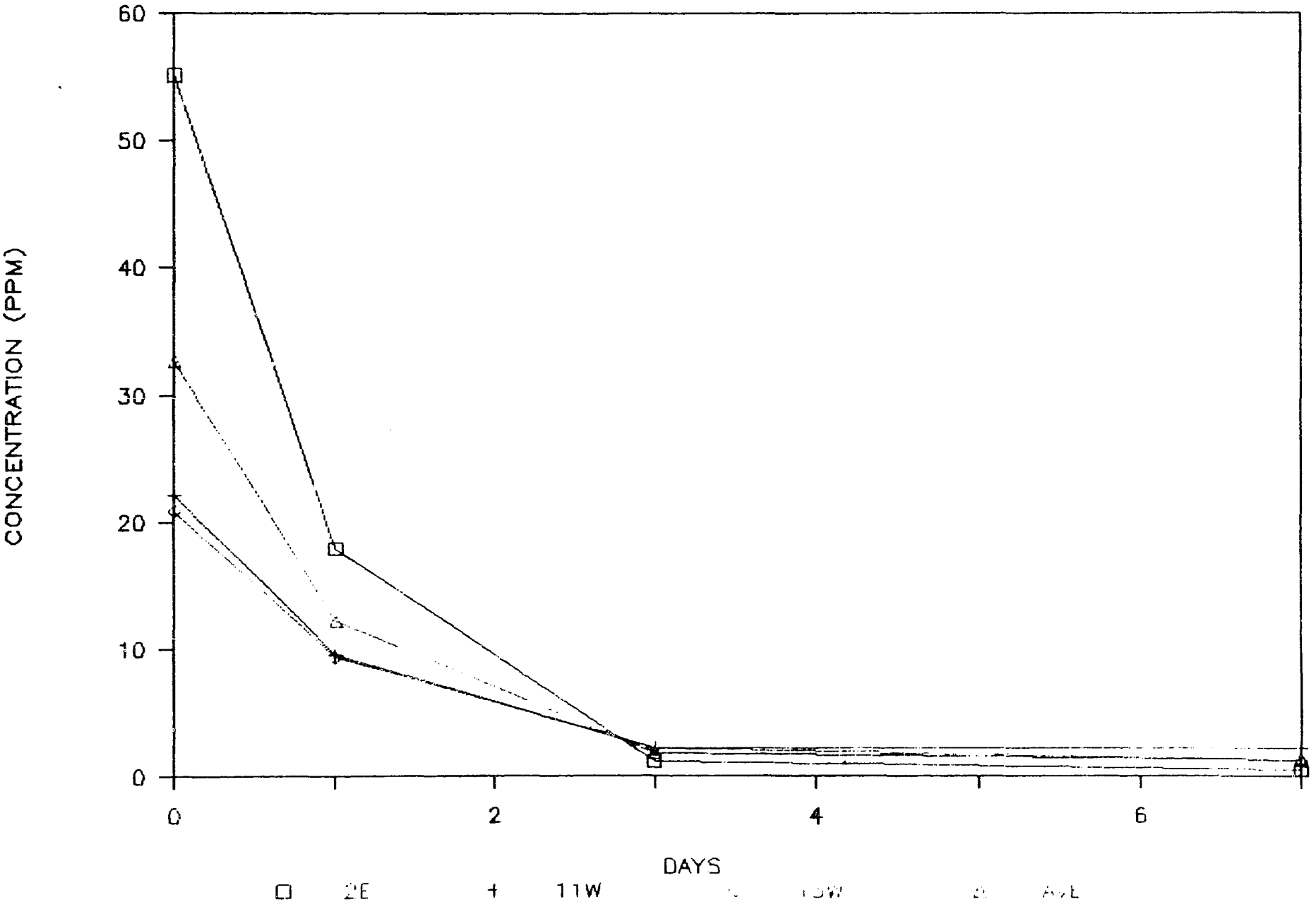
KARATE (Lambda-cyhalothrin)

SPL NO	PLOT	PRODUCT	DAY	KARATE(PPM)	SPL NO	PLOT	PRODUCT	DAY	KARATE(PPM)
2001	2W	FORAGE	PRE	N.D.(<0.001)*	2101	2W	SOIL	PRE	N.D.(<0.001)*
2002	2W	FORAGE	0	0.012(0.011)**	2102	2W	SOIL	0	0.046
2003	2W	FORAGE	0	0.274	2103	2W	SOIL	0	0.011
2004	2W	FORAGE	1	0.055	2104	2W	SOIL	1	0.041
2005	2W	FORAGE	1	0.011	2105	2W	SOIL	1	0.02
2006	2W	FORAGE	3	0.027	2106	2W	SOIL	3	0.016
2007	2W	FORAGE	3	0.114(0.020)**	2107	2W	SOIL	3	0.006
2008	2W	FORAGE	7	0.091	2108	2W	SOIL	7	0.016
2009	2W	FORAGE	7	0.007	2109	2W	SOIL	7	0.007
2010	4W	FORAGE	PRE	N.D.(<0.001)*	2110	4W	SOIL	PRE	N.D.(<0.001)*
2011	4W	FORAGE	0	0.158	2111	4W	SOIL	0	0.007
2012	4W	FORAGE	0	0.432	2112	4W	SOIL	0	0.013
2013	4W	FORAGE	1	0.08	2113	4W	SOIL	1	0.004
2014	4W	FORAGE	1	0.191	2114	4W	SOIL	1	0.006
2015	4W	FORAGE	3	0.044	2115	4W	SOIL	3	0.004
2016	4W	FORAGE	3	0.001	2116	4W	SOIL	3	0.018
2017	4W	FORAGE	7	0.017	2117	4W	SOIL	7	0.004
2018	4W	FORAGE	7	0.007(0.006)**	2118	4W	SOIL	7	0.01
2019	7W	FORAGE	PRE	N.D.(0.001)*	2119	7W	SOIL	PRE	N.D.(<0.001)*
2020	7W	FORAGE	0	0.84	2120	7W	SOIL	0	0.02
2021	7W	FORAGE	0	3.64	2121	7W	SOIL	0	0.013
2022	7W	FORAGE	1	1.14	2122	7W	SOIL	1	0.026
2023	7W	FORAGE	1	0.311	2123	7W	SOIL	1	0.025
2024	7W	FORAGE	3	0.114	2124	7W	SOIL	3	0.027
2025	7W	FORAGE	3	0.105	2125	7W	SOIL	3	0.008
2026	7W	FORAGE	7	0.147(0.059)**	2126	7W	SOIL	7	0.01
2027	7W	FORAGE	7	0.015(0.026)**	2127	7W	SOIL	7	0.012
					2119 SPIKE(1mcg = 0.10 ppm)				97.5% REC.
2001 SPIKE(1mcg = 0.04ppm)				115% REC.	2101 SPIKE(1mcg = 0.10ppm)				83% REC.
2019 SPIKE(1mcg = 0.04ppm)				112.5% REC.	2119 SPIKE(1mcg = 0.10ppm)				98% REC.
					FORMULATION		2% WT/WT		1.7% WT/VOL

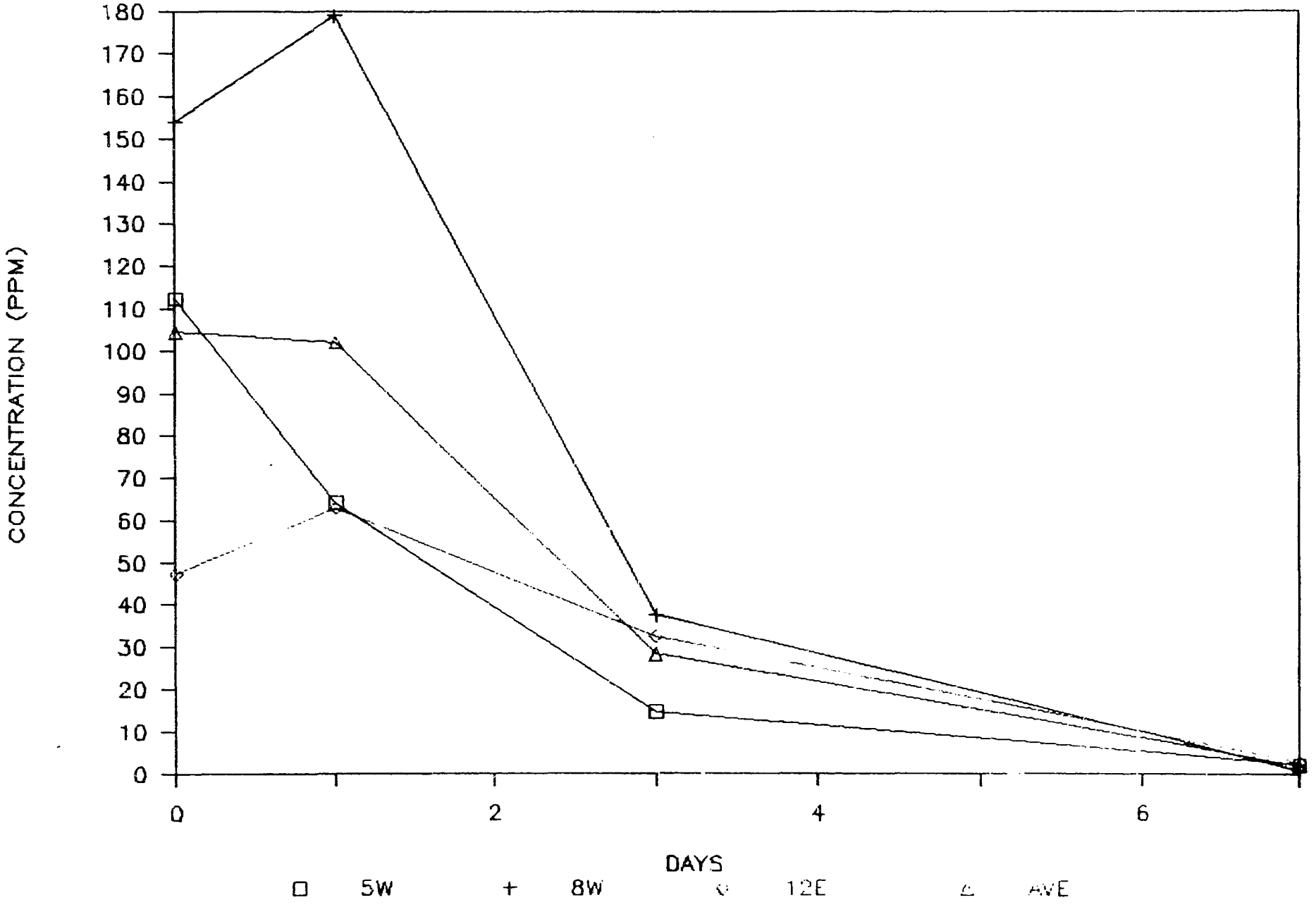
* None Detected Above Limit of Detection Indicated

** Duplicate Analysis

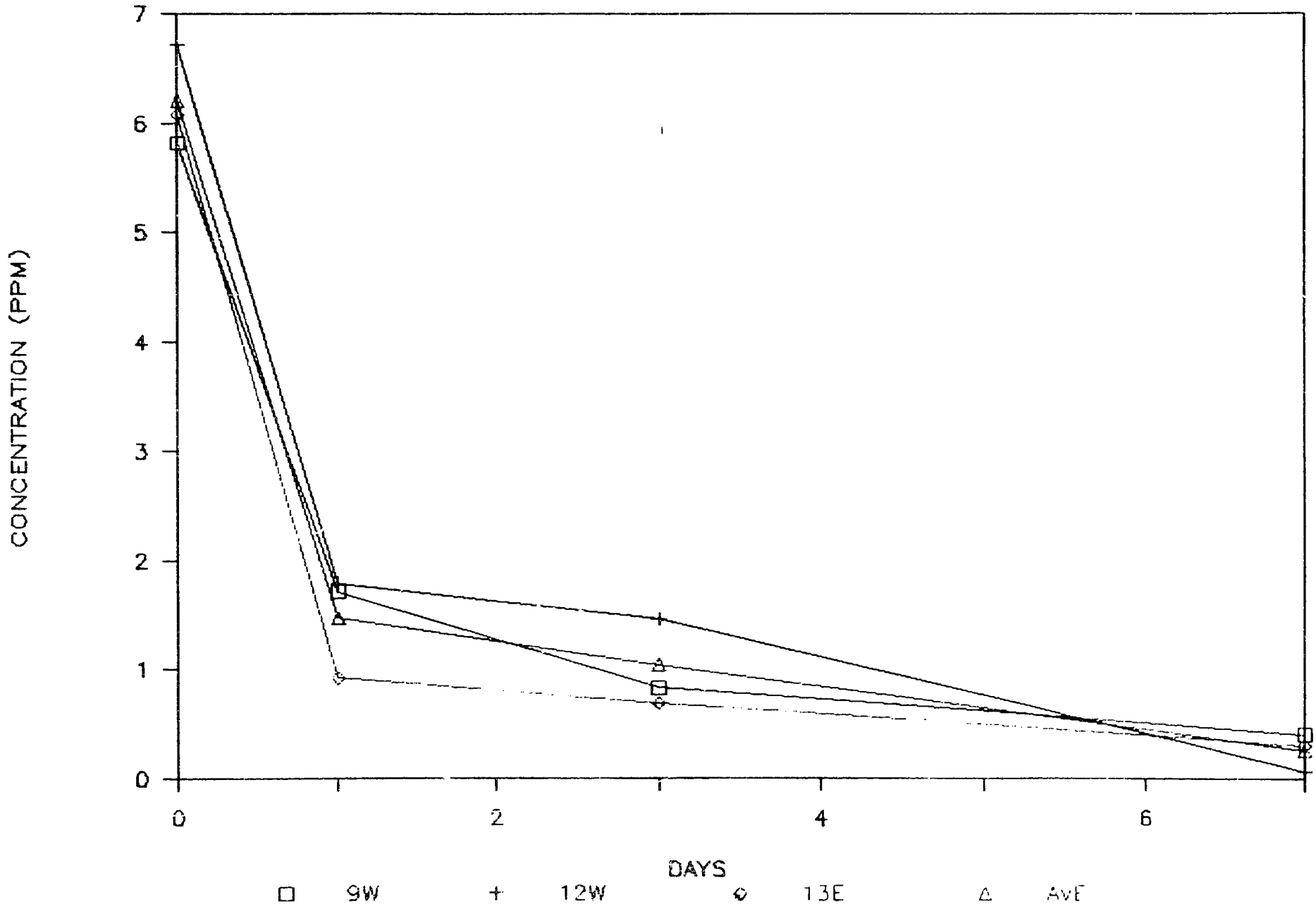
FENITROTHION FORAGE



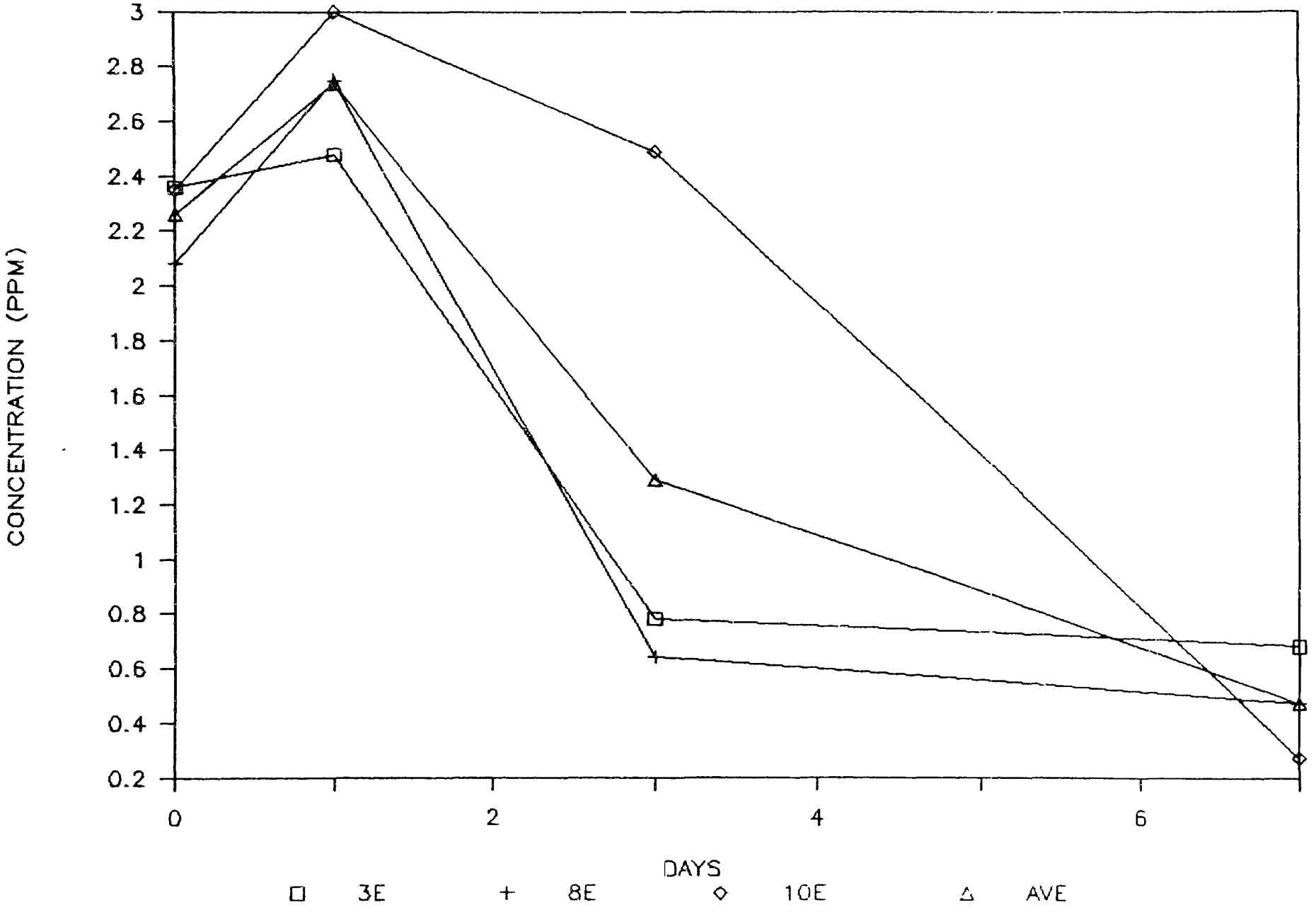
MALATHION FORAGE



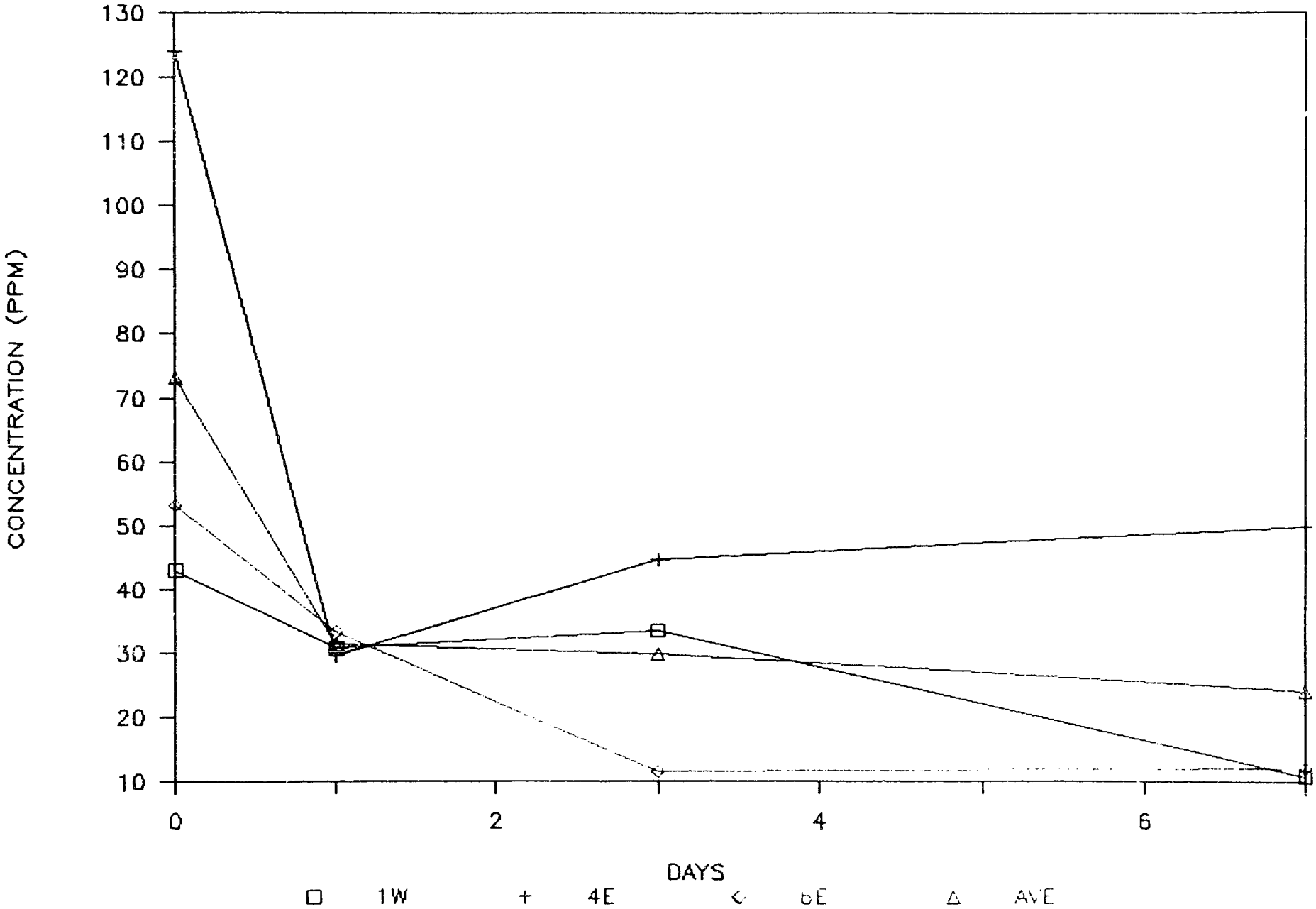
CHLORPYRIFOS FORAGE



BENDIOCARB FORAGE

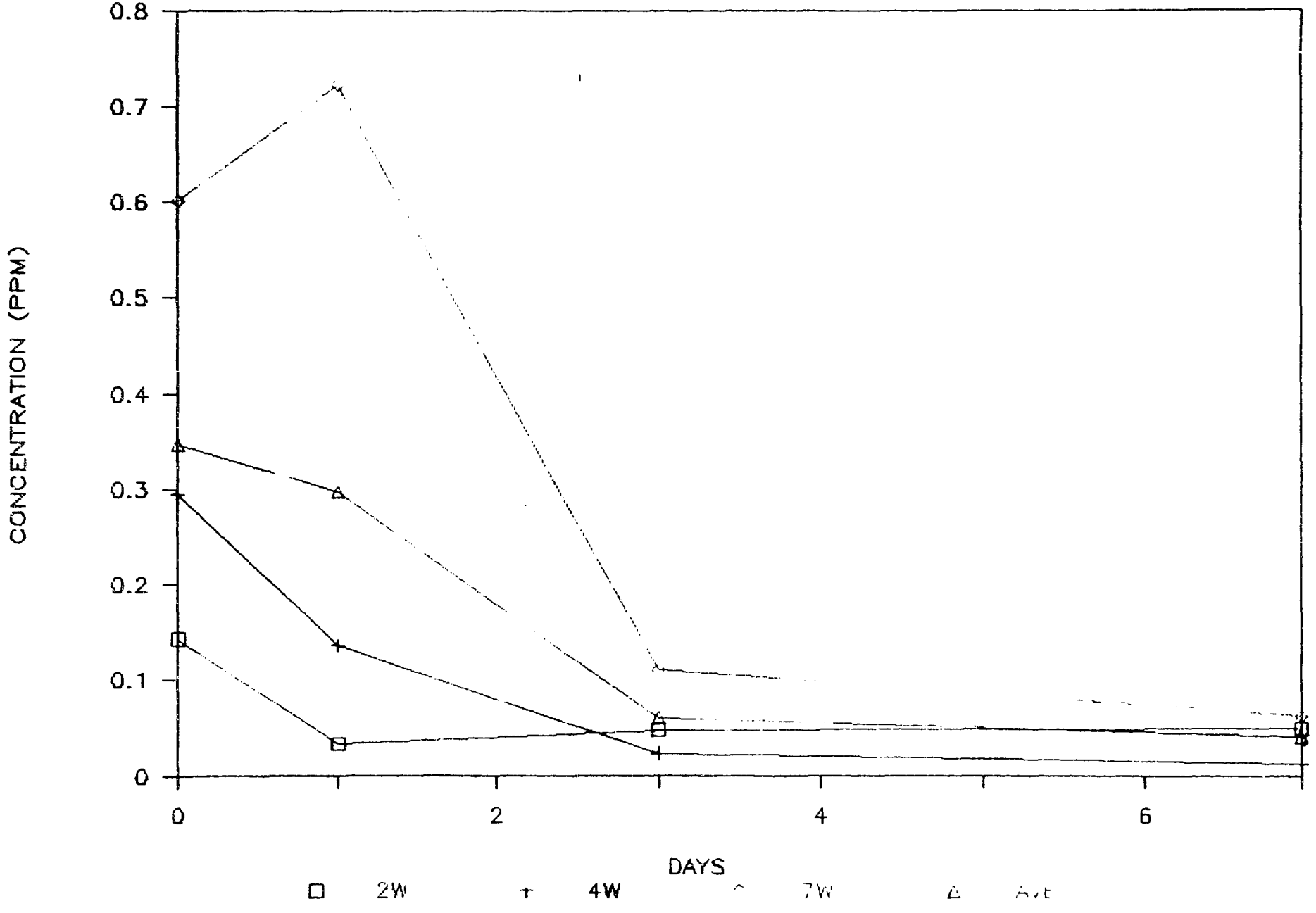


CARBARYL FORAGE

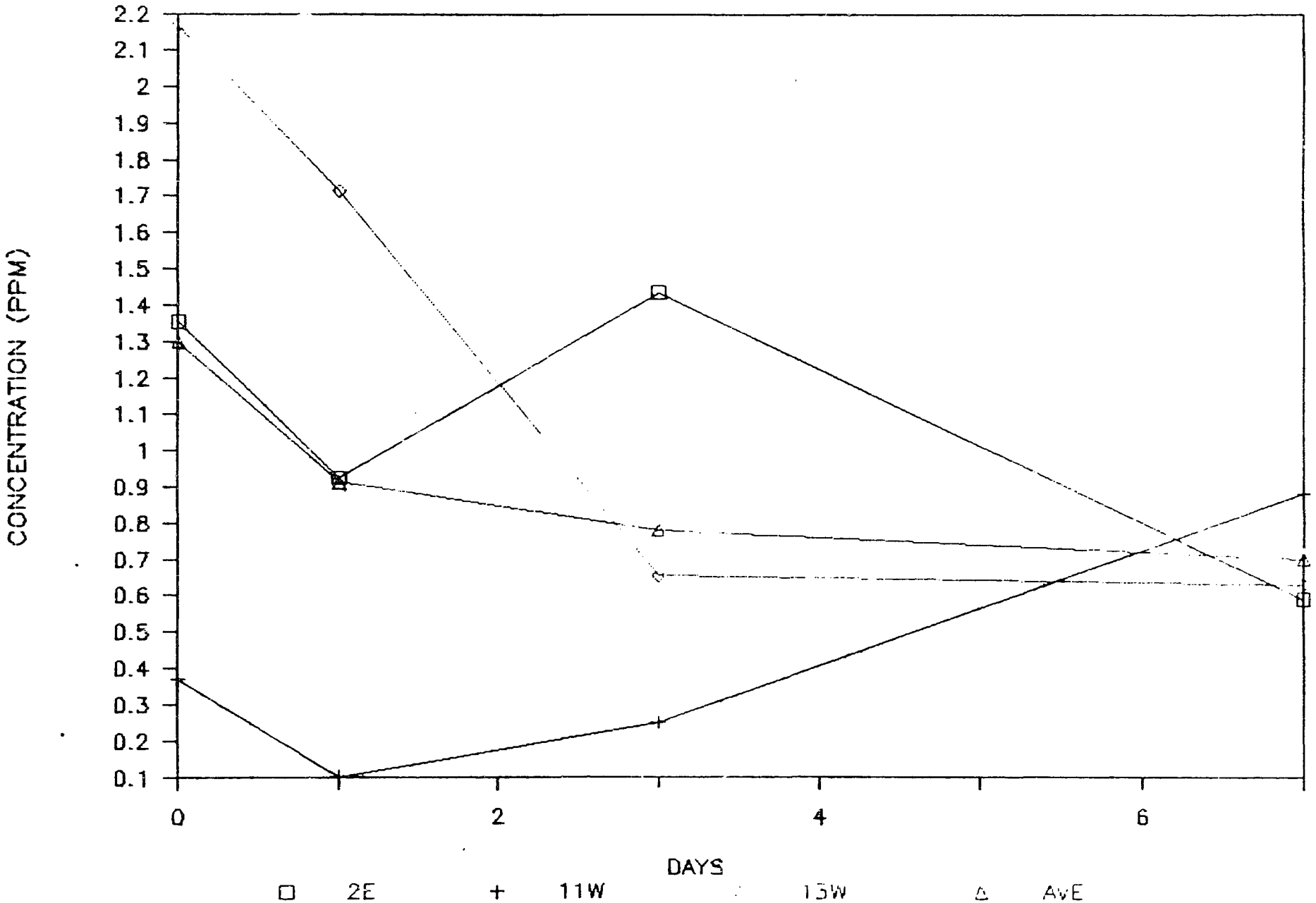


KARATE FORAGE

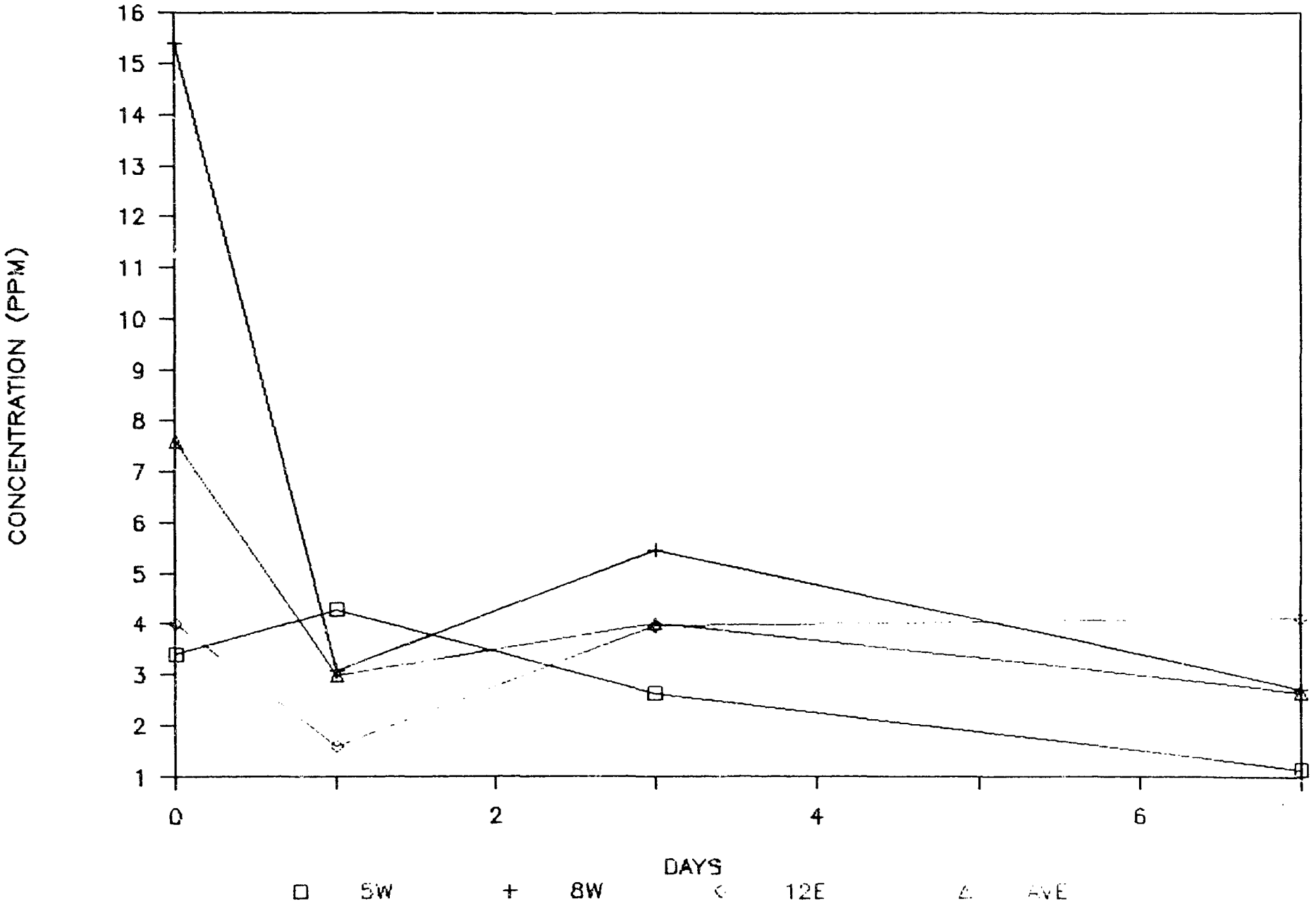
(Lambda-cyhalothrin FORAGE)



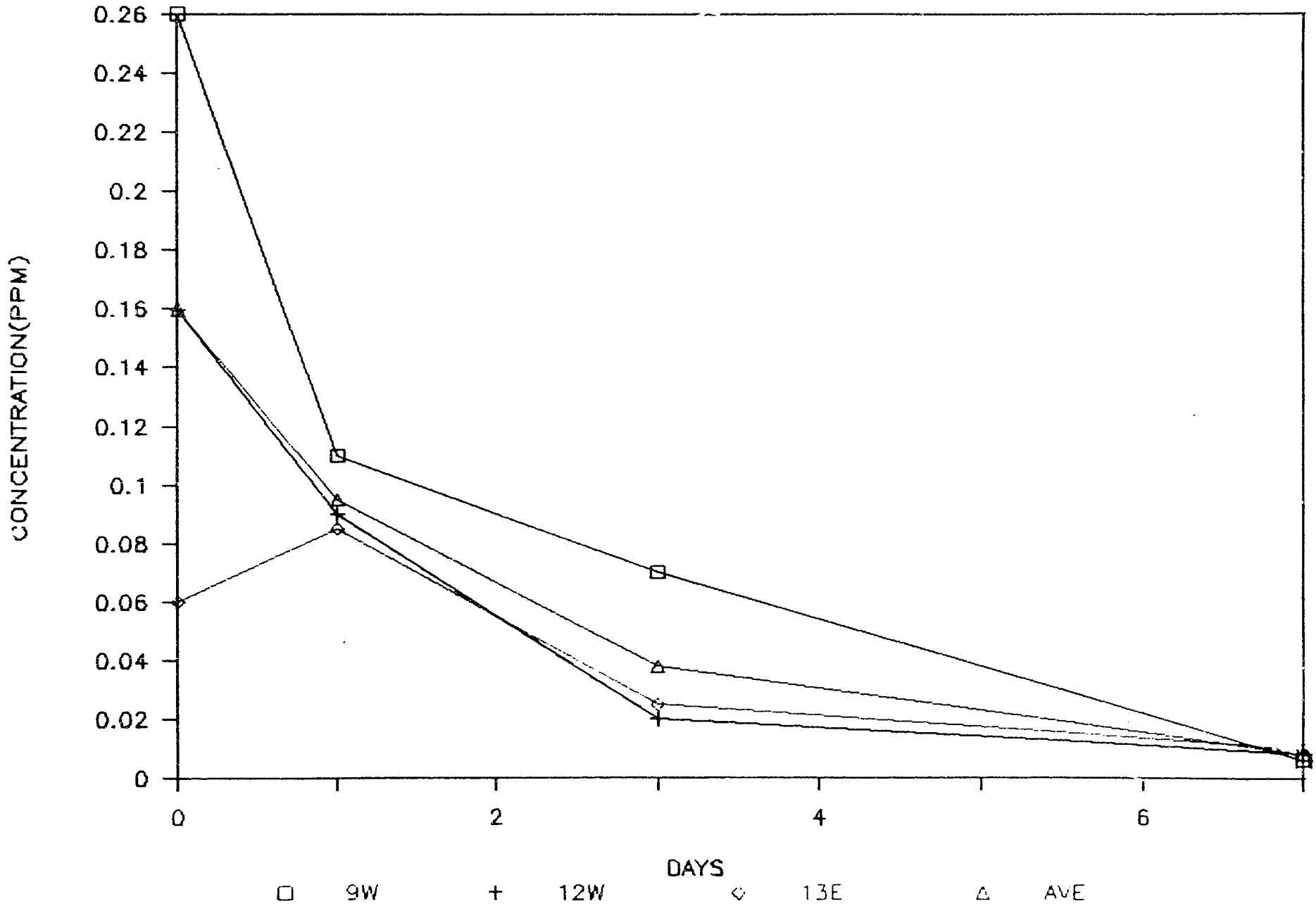
FENITROTHION SOIL



MALATHION SOIL



CHLORPYRIFOS SOIL



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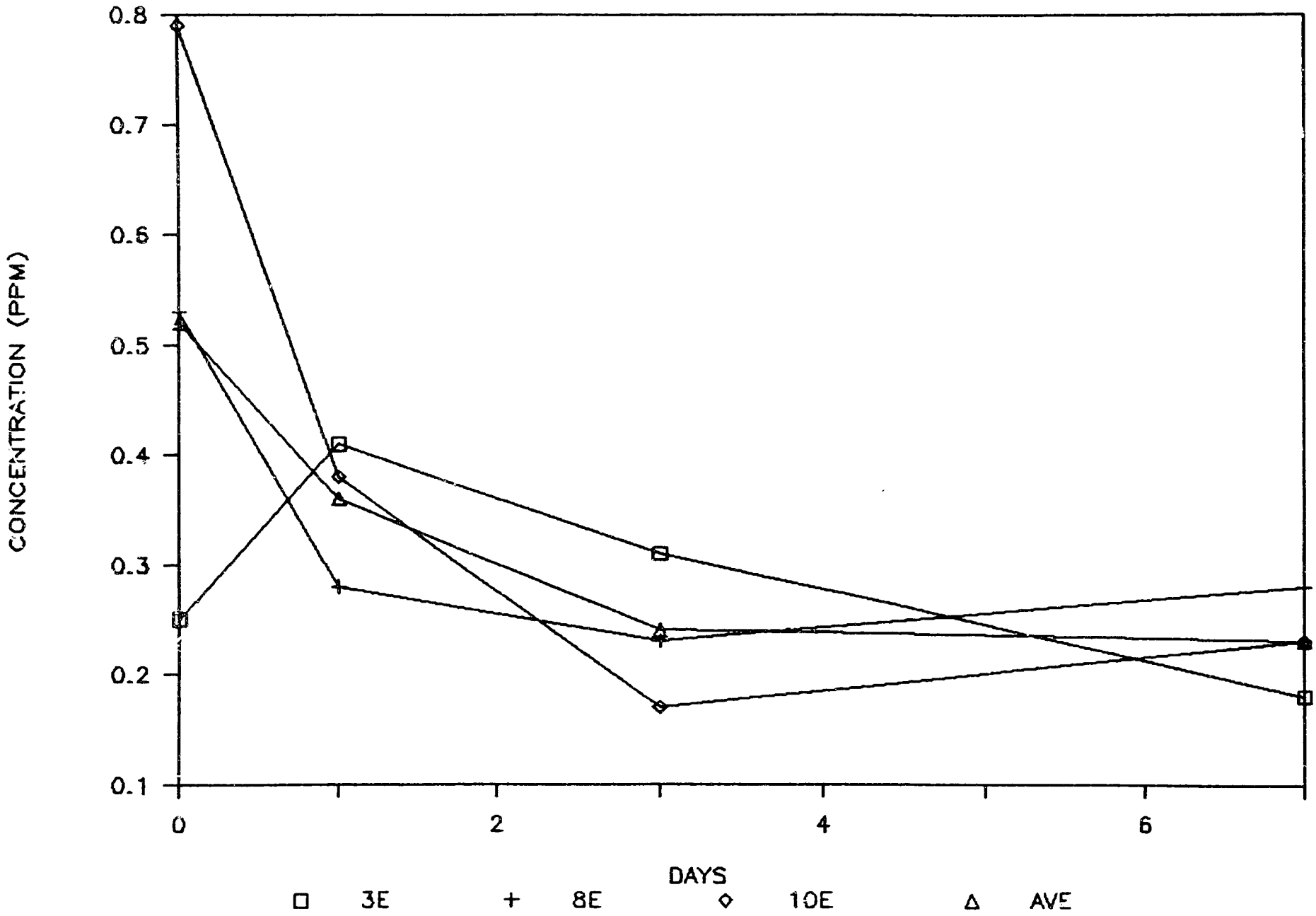
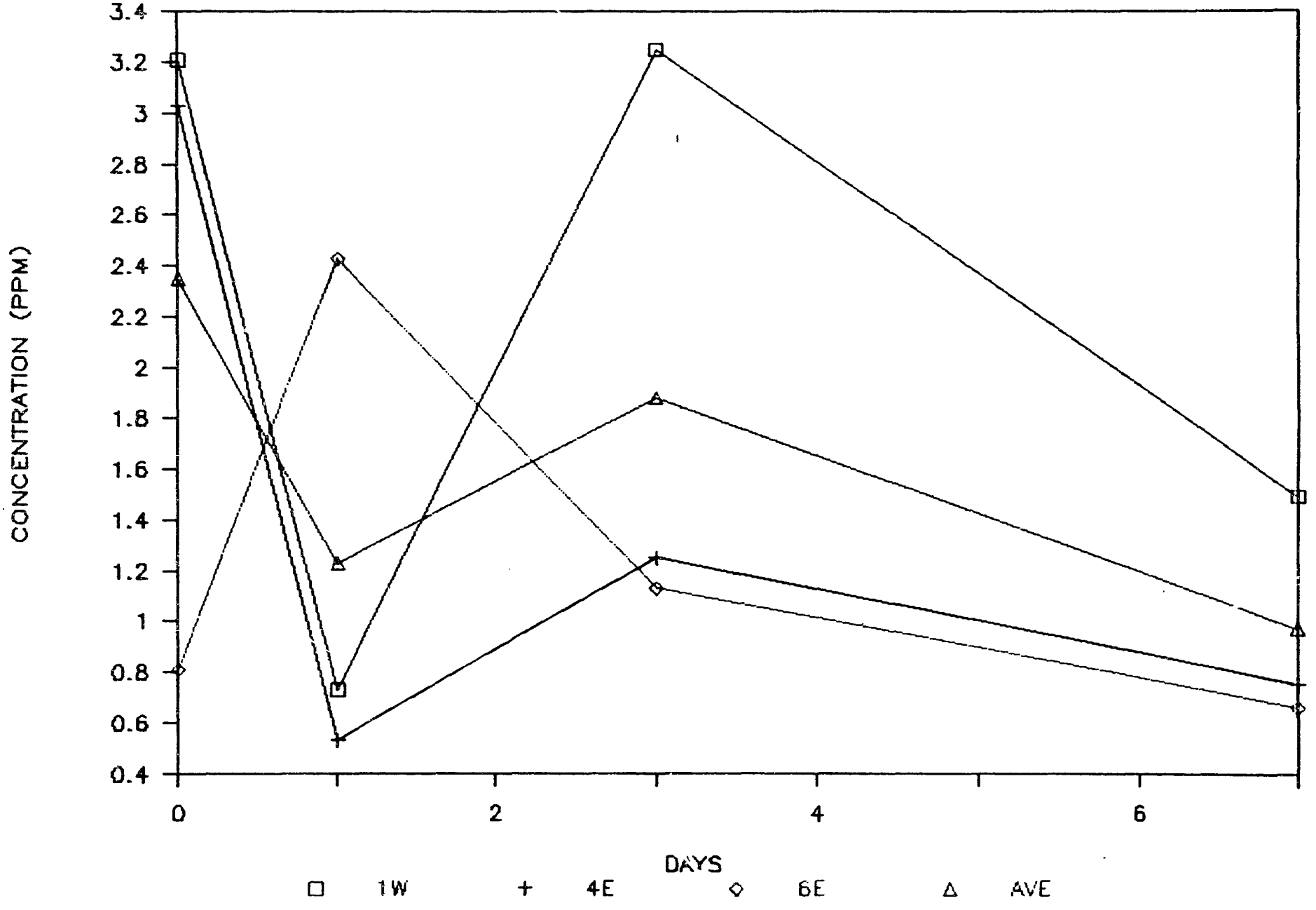
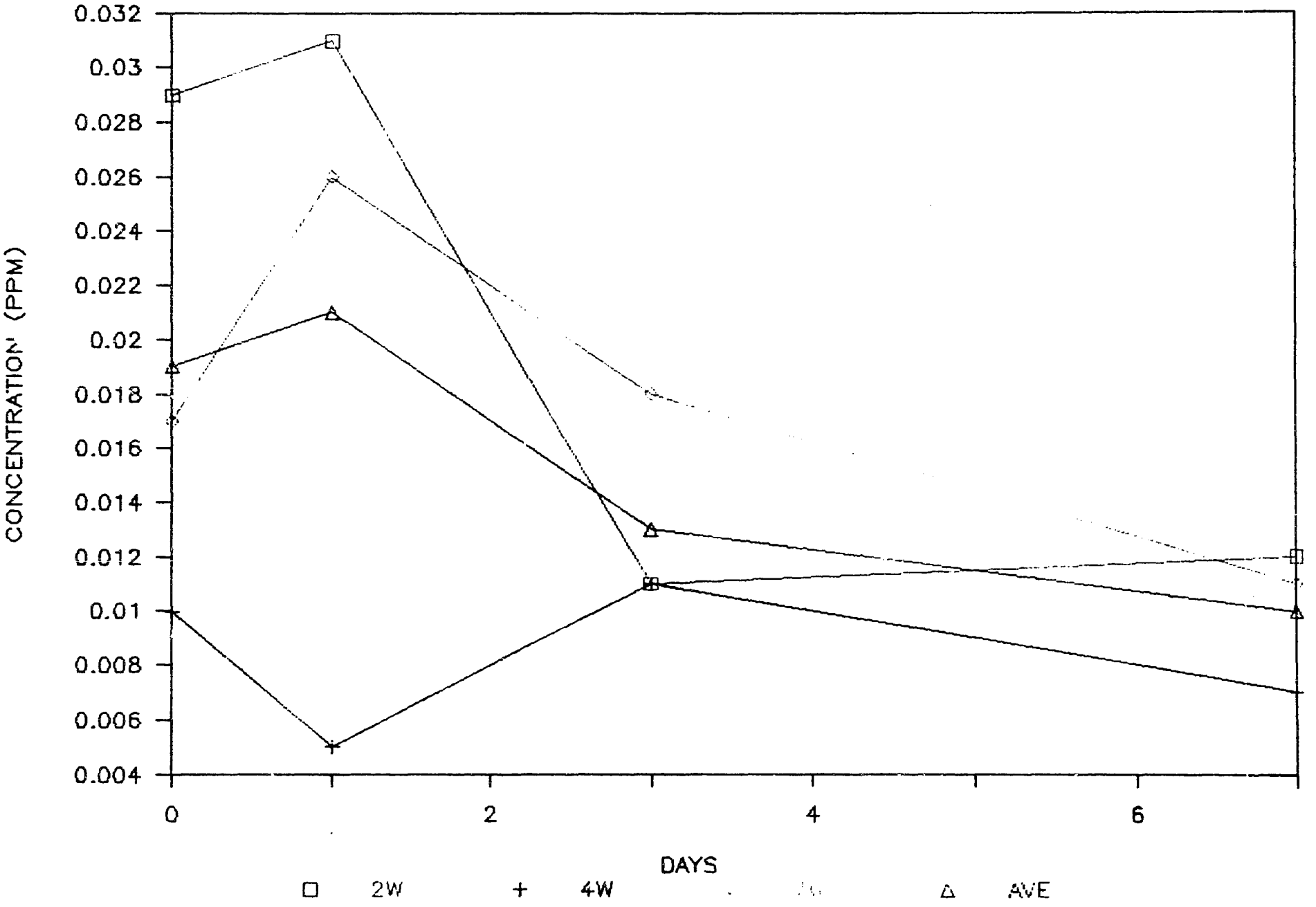


CARBARYL SOIL



KARATE SOIL

(Lambda-cyhalothrin soil)



APPENDIX S

Species List and Notes on Mammals, Reptiles, and Amphibians Observed Near the Test Site, Tokar, Sudan

APPENDIX S. Species list and Notes on mammals, reptiles, and amphibians observed near the test site, Tokar, Sudan.

Common Name	Scientific Name	Notes
MAMMALS		
Shrew	*Crocrodura reliosa*	Collected in pitfall traps on plots
Hedgehog	*Paraechinus aethiopicus*	Observed on plots
Bat	*Taphozous perforatus*	Observed and collected around camp
House Mouse	*Mus musculus praetextus*	Observed and collected around camp
Brown Hare	*Lepus capensis*	Seen in auto headlights, seen in *Calotropis* thicket
Caracal	*Caracal caracal*	Two observed around camp one night
African Wild Cat	*Felis silvestris*	Seen in auto headlights
Sand Fox	*Vulpes pallida*	Seen in auto headlights
Jackal	*Canis* sp.	Heard at night around camp
Spotted Hyena	*Crocuta crocuta*	Heard at night in garbage dump, den observed on plot
Wart Hog	*Phacochoerus aethiopicus*	Seen in auto headlights
Dorcas Gazelle	*Gazelle dorcas*	Seen on road to Trinkatat
REPTILES		
Clifford's Snake	*Spalerosophis dismema cliffordi*	At base of acacia tree in camp
Carpet Viper	*Echis pyramidum*	In acacia thicket near camp
Ocellated Skink	*Chalcides levitoni*	Collected in camp
Lacertid	*Acanthodactylus* sp.	Common on sand dunes near plot 11W
Mediterranean Gecko	*Hemidactylus turcicus*	Collected in camp
Spotted Gecko	*Stenodactylus sthenodactylus*	Collected in pitfalls on plot 6E
Desert Monitor	*Varanus griseus*	Two seen fighting on plot 6E
AMPHIBIANS		
Toad	*Bufo* sp.	Found buried in soil, seen hopping in grass

APPENDIX T

Technical Plan for Testing Pesticides Against the Desert Locust, *Schistocera gregaria*, for Both Efficacy and Environmental Impact in the Republic of Sudan

DRAFT TECHNICAL PLAN
FOR
TESTING PESTICIDES AGAINST THE DESERT LOCUST, *SCHISTOCERCA GREGARIA*, FOR BOTH EFFICACY AND ENVIRONMENTAL IMPACT IN THE REPUBLIC OF SUDAN

PREPARED BY:

DYNAMAC CORPORATION
ROCKVILLE, MARYLAND

FOR:

USAID
BUREAU FOR AFRICA

JANUARY 13, 1988

This report outlines a technical plan for testing the efficacy of eight pesticides on the desert locust (Schistocerca gregaria) in the Tokar region of Sudan and for monitoring the effects on beneficial flora and fauna, determining pesticide residue levels, and assessing possible effects of bioaccumulation and magnification.

The plan is organized as follows:

I. Purpose

II. Selection of Test Chemicals

III. Schedule

IV. Design of the Testing Program

V. Efficacy

VI. Environmental Impact

- Nontarget Arthropods (Beneficial Insects)
- Plants and Vertebrates
- Residues

VII. Safety Procedures

VIII. Staffing

IX. Reporting

I. PURPOSE

The project proposed for Sudan is part of a larger USAID scientific program to test the efficacy and environmental effects of certain pesticides used, or being considered for use, by the U.S., other international donors, and African countries to combat the threat of grasshoppers and locusts.

The project is being coordinated with other pesticide testing programs through the Food and Agriculture Organization, Rome. The findings are expected to contribute to decisions concerning the use of pesticides in future AID-funded control projects and will also contribute information for use by other donors and African countries.

The project consists of programs in two zones of Africa: West Africa and East Africa. Mali was the site of the 1987 West African testing program. The Republic of Sudan has been chosen as the site of the East African program.

The program will work on the desert locust and the Senegalese grasshopper. It will:

A. Test the efficacy of eight pesticides; and

B. Monitor the environmental impact by

1) determining the effects of the pesticides on nontarget organisms, including locust predators and parasites and other fauna and flora, and

2) estimating any impact of residues of the pesticides in the environment.

II. SELECTION OF TEST CHEMICALS

Eight pesticides were selected for the Mali test program from a list of candidates supplied by AID (see Mali Technical Plan, July 1987). All eight chemicals proved to be efficacious against the Senegalese grasshopper and warrant inclusion in the test program against the desert locust. In Sudan, the biology of the target organism and the environment in which it is lives differ substantially from that encountered in the Mali program.

For this reason the Sudan trials will provide new information on all eight pesticides. In addition, testing of the same suite of chemicals will permit direct comparison among pesticides and assure consistency in the overall AID African Grasshopper/Locust Pesticide Testing Project. The following pesticides will be tested at the manufacturers recommended rates for efficacy and environmental impact:

Compound	Chemical Class	Tradename	Formulation
Fenitrothion	organophosphorus	Sumithion	L50
Malathion	organophosphorus	Malathion	96% ULV
Chlorpyrifos	organophosphorus	Dursban	450 ULV
Diazinon	organophosphorus	Basudin	90 SCO
Bendiocarb	carbamate	Ficam	20% ULV
Carbaryl	carbamate	Sevin	4-Oil
Lambda-cyhalothrin	pyrethroid	Karate	4% ULV
Tralomethrin	pyrethroid	Scout	3.75% ULV

An additional interest in the testing of pesticides against the desert locust is the identification of persistant compounds which remain effective against locusts for two weeks or longer. If timing and testing conditions permit, a second efficacy trial will be performed on selected compounds to determine their persistence as control agents. Carbaryl, because it exhibited the greatest persistence in the Mali trials, will be included. Three as yet undetermined microencapsulated compounds will complete the list of four chemicals to be tested for continuing control of the desert locust.

III. SCHEDULE

The test program has been designed as two parallel tests to determine efficacy and environmental impact, respectively. Each test phase will involve site survey and delineation, spray activities, and the actual efficacy (Phase I) or environmental (Phase II) sampling. The efficacy test trials will use locust bands as the treatment units and likely will require spraying areas of 4 to 8 ha. The environmental impact test trials will require the spraying of 100 ha plots. The timeframe of the efficacy trials is 8 days for survey and pretest sampling, 20 days for spraying and simultaneous posttreatment sampling. The environmental test trials will take approximately 30 days to complete. These numbers are approximations and could vary by as much as 20 percent. We believe though, that the Dynamac field team would be in the country on the order of 60 days.

The field operations manager, the logistics coordinator, and the scientific coordinator will arrive in Khartoum in January to make arrangements for the earliest initiation of field trials in the Tokar Delta.

The field testing schedule, which is governed by rainfall patterns and subsequent locust outbreaks, is expected to be approximately as follows:

- efficacy trials: February
- environmental trials: March

This period has been selected because winter breeding populations of locust that are suitable for testing are expected to be present and because it encompasses the ecological conditions that exist during normal winter locust control campaigns.

IV. DESIGN OF THE TESTING PROGRAM

The testing program in Sudan has been designed to include a number of options to take into account the uncertain conditions facing field trials. Manpower and resources have been allocated so that the principal objective of determining the efficacy and environmental effects of the eight pesticides at the recommended rate will be accomplished under the expected field conditions. The inclusion of a second rate and additional testing are planned where the target densities and sampling options permit.

An initial assessment of the magnitude and distribution of testable locust populations will be made when the field team first arrives at the site. If testable hopper bands are numerous over a large area, a single trial using 100 ha plots will be conducted for both efficacy and environmental impact determinations. If, as expected, the distribution of hopper bands does not cover an area adequate for large plot (100 ha) efficacy testing, full effort will be applied to the identification of single hopper bands that can be used to test the efficacy of all eight pesticides at the manufacturers' recommended rate. This will require the designation of 36 hopper bands as test replicates to be sprayed in a randomized design. If the hopper bands prove to be numerous enough, a second lower rate will be tested simultaneously in a design of 68 distinct bands. If no testable locust populations can be found, trials for environmental impact will be undertaken immediately.

Assuming that the efficacy trials are initiated on plots unsuitable for the environmental test, a second search will be made for plots to assess environmental impact. Thirty 100 ha plots will be designated as treatment or control plots to determine the effects on nontarget arthropods and

vertebrates. Two pretreatment sample dates will be used for each plot so that adequate baseline data can be obtained. If conditions for efficacy testing remain favorable, the efficacy team will conduct a separate trial to test for the persistent control effects of certain pesticides, including microencapsulated forms, while the environmental impact sampling continues. This environmental sampling will be conducted in grassland areas usually exposed during normal locust control operations. If potentially sensitive areas such as cropland and aquatic habitats are available and can be sprayed safely, they will be included in the environmental test design.

V. EFFICACY

A. Objectives

The testing of pesticides against the desert locust presents many practical obstacles which must be dealt with by decisions made in the field. In doing so, cooperation with other organizations (PPD/MOA/GOS, DLCO-EA, FAO) operating in the region will prove invaluable. To the extent possible USDA testing protocols will be used and all modifications will be directed by the need to maintain scientific validity. In particular, the following factors must be taken into account when determining efficacy: the developmental stage of the pest, the stage in the outbreak cycle, and the severity of the infestation. The principal objective will be to determine which pesticides, applied at their recommended rate, achieve 90% mortality of the desert locust.

B. Experimental Design

The initial survey for testable populations of desert locusts will be especially important in determining the test design, treatment method, and sampling protocol. It is assumed that nymphal locusts will be abundant and

that distinct hopper bands can be identified. Once an area with a sufficient number of hopper bands has been selected, we will layout a grid (5 x 5 km) with markers every 500 m. Daily surveys of this grid will provide information on the location of hopper bands that can be designated as four replicate target areas for treatment with a single chemical the following day. While the treated area should never be less than 0.5 ha we plan to spray buffer areas surrounding the hopper band so that the treatments will cover between 4 and 8 ha each. The arrangement of these target areas will be randomly chosen and adequately spaced to ensure the integrity of each test area.

Upon the discovery of each hopper band a transect or area counting method will be used to determine the density of hoppers per square meter. The application of the pesticide will be completed the following morning and 8 hr counts of live and dead hoppers will be made that afternoon. The sprayed area will be marked and eliminated from further consideration as a testing area. Counts of live and dead hoppers will be made the next morning (24 hr) and on day 3 (72 h), using collapsible cages to prevent emigration if necessary. At each sampling period, untreated hopper bands designated as controls will be counted. Surveys and treatments will continue until all eight pesticides have been sprayed.

When the primary efficacy testing trials have been completed, the efficacy team will develop a plan for testing the persistance of four compounds. A second area will be identified with predictable marching hopper bands that lend themselves to barrier spraying. Three replicate strips of 1 km length and 300 m width will be sprayed for each pesticide. These will be oriented perpendicular to the direction of the march of the hopper bands and

spaced (1 km) so that bands do not contact different treatments. As the bands approach the treated areas, density counts will be done in each band. Counts within the treated strip will be done at 8 hr and 24 hr. As successive bands contact the sprayed strips, hopper counts will reflect control at varying times postspray. Counts for mortality will continue for 2 to 3 weeks. Although the fundamental approach of these persistence trials will be to duplicate normal barrier spraying techniques and to measure the effect of free-ranging hopper bands, an alternative caging experiment has been planned. Where bands are not available, individual hoppers will be collected and caged on smaller areas (1 ha) of sprayed vegetation. Additional hoppers will be captured and caged at different times postspray. Complete mortality counts will be conducted within each cage.

C. Application Procedure

All treatments will be applied aerially from micronair-mounted fixed-wing aircraft. Before the efficacy and environmental impact trials are initiated, an application testing trial will be conducted to assure that all materials are being applied consistently and according to manufacturers recommendations. The team's application specialists, cooperative scientists from DLCO or other agencies, and manufacturers' technical representatives will be involved whenever possible. This test session should assure standardization in flying speed and height, swath width, and rate of output as determined by blade angle setting and flowmeter calibration.

We will use the deposition cards recommended by the manufacturers to verify that the prescribed droplet sizes and densities have been achieved in each spray run. Specifically, a grid of nine cards will be placed in the

target area before spraying. They will be collected for analysis of droplet size (volume median diameter) and droplet density (per square cm). All spray runs will be confined to favorable weather conditions (winds of about 3 m/sec and minimal convective turbulence). Temperature, wind speed and direction, and relative humity will be recorded and a line of seven spray cards will be placed in the direction of potential drift to assure plot integrity.

D. Data Analysis

Data will collated in the field to assure complete records of all sampling dates. The numbers of locusts per sampling unit will be analyzed in a completely randomized or blocked design ANOVA (analysis of variance) with mean separations determined for each sample date using an experimentwise probability level of 0.05. The efficacy results will be presented in tabular and graphical form as percent reductions adjusted for simultaneous control counts.

VI. ENVIRONMENTAL IMPACT

A. Objectives

The goal of ascertaining the environmental impact of these eight pesticides when used for desert locust control requires three efforts: 1) an evaluation of the overall effect on the nontarget invertebrate fauna, especially beneficial insects, 2) a determination of direct effects on plants and vertebrates, and 3) an analysis of the levels and persistence of pesticide residues in the important environmental substrates. Our objective is to characterize the effect on the grassland ecosystem usually exposed to control efforts against the desert locust. If the environments are available and can be sprayed safely, we will also undertake to assess the environmental

impact on croplands or aquatic habitats that might infrequently or inadvertantly be sprayed during a control campaign.

In particular, each pesticide will be reviewed and evaluated for its potential adverse effects on locust parasites and predators, parasites and predators that control other pest species, and other insects that directly affect the agricultural and grazing ecosystems. Principal known natural enemies of the desert locusts are listed below:

Stomorhina lunata, fly larva predatory on eggs

Systoechus somali, bombyliid fly predatory on eggs

Blaesoxipha filipjevi, sarcophagid fly parasitic on nymphs/adults

Sarcophaga destructor, sarcophagid fly parasitic on adults

Symmictus sp., internal parasite of hoppers

predatory ants.

B. Experimental Design

The environmental team will survey the surrounding region for areas large enough to include thirty 100 ha plots spaced at distances of no less than 500 m. As mentioned above, sensitive habitats may be included and they will be incorporated into a blocked or stratified design. Once the plots have been identified and their boundaries marked, preliminary sampling for baseline data will begin. Two or three sample dates will be used for each of 24 treatment plots (3 replicates for 8 pesticides) and 6 control plots. All treatments will be assigned randomly and the topography and vegetation of each plot will be recorded.

The evaluation of impacts on beneficial insects will involve two parts. First, a search for the natural enemies listed above in areas with substantial locust populations (the efficacy trials). Second, an assessment of the results of broad-taxa sampling for effects on families of insects that include known beneficial species (the environmental impact trials). The beneficial insect specialist will work with the efficacy team to discover instances of mortality among beneficial species in the treatment areas. If one or more beneficial species are abundant enough to include in the general sampling program, special efforts will be made to collect them during the large plot (environmental) nontarget insect sampling or the persistence efficacy trials. Special attention will be paid to the life cycles and habitats of these species so that possible mitigation of adverse effects can be recommended. It is expected that a large part of the results will be unreplicated so the best possible records will be kept.

Although nontarget invertebrate sampling will concentrate on arthropods, especially insects, the top 5 cm of soil in each plot will be sieved for oligochaetes and other soil fauna. General sampling for the arthropods will be divided into ground-dwelling and flying components. Pitfall traps in grids of 16 small (500 ml) cans will be placed in each treatment and nondestructively sampled to obtain pre- and posttreatment abundance of beetles, hemipterans, spiders, and scorpions. Sticky traps will be deployed at two heights to obtain 48 hr counts of flying insects. Transects will also be used to gather measures of live and dead arthropods for each sample period. A second method for assessing the impact of nontarget arthropods is the selection of indicator species which are abundant enough to

demonstrate adverse effects as they exist. Two taxa important in the normal functioning of the ecosystem are proposed for sampling as indicator species, harvester ants and web-building spiders. In both cases permanent foraging sites can be marked for repeated sampling. Where available, anthills and shrubs with spider webs will be sampled in each plot. Direct mortality and foraging success will be measured.

A preliminary faunal survey utilizing mist nets and rodent and pitfall traps will be conducted to identify the existing vertebrates and document their abundance. This characterization will help us develop scenarios of potential effects. It is expected that although most vertebrate groups will be rare, at least birds and possibly lizards will be abundant enough to include in our test by sampling all plots with transect walks. Two transects of 400 m each will be walked in each plot while recording all carcasses and live lizards seen within 10 m and all birds seen within 50 m. As with the arthropod sampling, 2-3 samples both pre- and posttreatment will be taken. All carcasses will be collected for cholinesterase and pesticide residue analysis. In addition, six live birds from each treatment will be sacrificed for determination of possible cholinesterase inhibition.

Residue samples of up to four media will be taken from each plot: soils, grasses, shrub foliage, and animals. In order to obtain a measure of residue persistance, samples will be taken the day of spraying (8 hr), and day 1, day 7, and day 14. All samples will be immediately chilled and frozen upon return to the camp. Where possible, split samples will be taken so that the Sudanese lab in Wad Medni can carry out immediate analysis while duplicate samples are shipped to the United States. The sampling procedure will employ

composited samples taken over a grid large enough to encompasses a minimum of two swath widths. Sterile procedures will be followed to guard against contamination of the samples. The use of control plots will provide baseline data for the cholinesterase and residue results. Procedures for conducting the residual sampling are set forth in Appendix I of the Mali Technical Plan. It should be noted that all the crops and substrates listed in Appendix I will not be directly applicable to the tests in the Tokar region.

C. Data Analysis

As with the efficacy results, the environmental data will be collated in the field to guarantee that all treatments have been equally sampled for a balanced test design. Where possible, abundant species will be analyzed separately; in any case, complete faunal numbers will be analyzed for each group. Analysis of variance (ANOVA) techniques and appropriate multiple comparison methods will be used. If the data is extremely variable, all pretreatment samples will be pooled and compared directly with pooled posttreatment samples in a Before-After-Control-Impact (BACI) design.

VII. SAFETY PROCEDURES

The following provisions will be made to assure safety of the project personnel and the Sudanese population in adjacent areas:

A. The pilots and applicator are certified for spray application of pesticides. As certified operators, they will be required to adhere to approved practices in handling and applying the pesticides.

B. All project staff will receive on-site training in safety procedures. The field operations manager will be responsible for providing the training.

C. During the spray operations, we will work with the representatives of the Plant Protection Department to assure that the population in the area concerned is aware of the activity and takes proper precautions to minimize exposure of humans and domestic animals. The test plots will be selected to avoid spraying in close proximity to villages, and pilots will be instructed to avoid spraying large herds of domestic animals.

VIII. STAFFING

Staffing for the Tokar operation will be as follows:

A. Management and Coordination

- o Field Operations Manager - M. Brown
- o Logistics Coordinator - P. Bernard
- o Scientific Manager - M. Southerland

B. Efficacy and Beneficials Team

- o Leader - T. Schwartz (Efficacy)
- o Members - R. Kepner (Beneficials)
  H. Khoury (Efficacy)
  W. Yates (Application)

C. Environmental Impact Team

- o Leader - M. Southerland
- o Members - J. Evans (Residues)
  A. Giraldi (Sampling)

D. Aerial Spraying

- o Pilots (2)
- o Mechanic

E. Participation by Government of Sudan

It has been proposed that the Government of Sudan participate by:

- o Provision of six counterpart personnel (agricultural and environmental scientists) from appropriate ministries.
- o Assignment of an administrative liaison officer to work with the field operations manager in maintaining communications and expediting clearances.
- o Assignment of a scientific liaison officer to work with the scientific manager in providing needed technical advice and resources.

F. Other

We anticipate some additional on-site personnel, such as observers from chemical companies and FAO.

IX. REPORTING

All field results will be fully documented. Summary updates of the progress of the field research will be provided every two weeks. A full report on the field tests will be prepared for USAID by June 1988. Copies will be provided to the Government of Sudan. The findings of both the West and East African programs will be incorporated into a comprehensive final report of the overall testing project.

APPENDIX W

Weather Data from the Test Site, (Tokar, Sudan)
for the Years, 1980-1988

Instrument Observation	1987 June	July	Aug	Sep	Oct	Nov	Dec	1988 Jan	Feb	Mar	April	May	Season Total
Mean Daily High Temp °C	--	--	43.0	40.9	37.5	33.6	36.5	27.8	28.3	--	--	--	
Maximum Daily High Temp °C	--	--	45.5	44.0	41.6	37.0	36.4	23.0	31.7	--	--	--	
Minimum Daily High Temp °C	--	--	40.2	37.6	31.8	36.5	23.5	22.8	25.1	--	--	--	
Mean Daily Low Temp °C	--	--	29.8	25.1	26.4	22.2	20.4	19.2	19.8	--	--	--	
Maximum Daily Low Temp °C	--	--	34.7	27.0	27.7	27.5	24.0	23.5	23.0	--	--	--	
Minimum Daily Low Temp °C	--	--	26.8	24.2	23.7	22.0	15.0	15.5	16.7	--	--	--	
Mean 0800 hr Relative Humidity(%)	--	--	41	47	71	73	70	75	73	--	--	--	
Total Rainfall (mm)	--	--	--	--	6.2	20.7	22.8	12.8	Trace	--	--	--	62.5 (m
Highest Daily Rainfall (mm)	--	--	--	--	5.8	13.5	5.4	10.5	Trace	--	--	--	
Mean Daily Piche Evaporation (t)*	--	--	20.1	11.5	7.2	6.0	20.9	5.0	0.5	--	--	--	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

Instrument Observation	1987 June	July	Aug	Sep	Oct	Nov	Dec	1988 Jan	Feb	Mar	April	May	Seaso Total
Mean Daily High Temp °C	--	--	43.0	40.9	37.5	33.6	36.5	27.8	28.3	--	--	--	
Maximum Daily High Temp °C	--	--	45.5	44.0	41.6	37.0	36.4	23.0	31.7	--	--	--	
Minimum Daily High Temp °C	--	--	40.2	37.6	31.8	36.5	23.5	22.8	25.1	--	--	--	
Mean Daily Low Temp °C	--	--	29.8	25.1	26.4	22.2	20.4	19.2	19.8	--	--	--	
Maximum Daily Low Temp °C	--	--	34.7	27.0	27.7	27.5	24.0	23.5	23.0	--	--	--	
Minimum Daily Low Temp °C	--	--	26.8	24.2	23.7	22.0	15.0	15.5	16.7	--	--	--	
Mean 0800 hr Relative Humidity(%)	--	--	41	47	71	73	70	75	73	--	--	--	
Total Rainfall (mm)	--	--	--	--	6.2	20.7	22.8	12.8	Trace	--	--	--	62.5 (m
Highest Daily Rainfall (mm)	--	--	--	--	5.8	13.5	5.4	10.5	Trace	--	--	--	
Mean Daily Piche Evaporation (t)*	--	--	20.1	11.5	7.2	6.0	20.9	5.0	0.5	--	--	--	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

Instrument Observation	1986 June	July	Aug	Sep	Oct	Nov	Dec	1987 Jan	Feb	Mar	April	May	Season Total
Mean Daily High Temp °C	--	43.0	43.2	46.5	36.6	32.3	27.6	27.0	29.6	31.0	31.6	--	
Maximum Daily High Temp °C	--	46.5	45.0	42.5	41.0	35.3	31.0	30.0	33.2	37.2	38.2	--	
Minimum Daily High Temp °C	--	24.0	46.5	36.0	34.5	26.5	23.5	22.7	26.5	26.5	29.5	--	
Mean Daily Low Temp °C	--	29.4	28.8	26.6	26.6	24.0	20.8	19.7	20.9	19.7	21.6	--	
Maximum Daily Low Temp °C	--	32.0	31.6	29.0	28.5	26.2	23.3	23.0	24.0	24.0	27.2	--	
Minimum Daily Low Temp °C	--	26.5	36.0	23.4	26.6	20.0	18.0	17.0	15.5	13.0	16.3	--	
Mean 0800 hr Relative Humidity (%)	--	37.0	--	56	63	71	67	72	73	69	69	--	
Total Rainfall (mm)	--	--	--	7.5	Trace	60.2	4.3	36.4	Trace	4.0	--	--	112.4 (mm
Highest Daily Rainfall (mm)	--	--	--	--	--	28.2	4.0	13.5	Trace	4.0	--	--	
Mean Daily Piche Evaporation (t)*	--	22.5	18.9	13.6	9.1	5.5	3.6	4.4	6.3	6.1	5 7	--	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

Instrument Observation	1985 June	July	Aug	Sep	Oct	Nov	Dec	1986 Jan	Feb	Mar	April	May	Season Total
Mean Daily High Temp °C	41.9	--	--	41.0	35.7	32.5	29.9	28.5	29.2	31.2	34.7	35.4	
Maximum Daily High Temp °C	45.0	--	--	43.5	39.0	37.0	41.5	30.3	34.7	37.3	42.2	37.7	
Minimum Daily High Temp °C	29.0	--	--	36.7	34.5	31.0	25.7	25.7	26.2	29.3	29.4	32.2	
Mean Daily Low Temp °C	24.9	--	--	26.7	25.8	25.1	21.8	21.6	20.0	22.3	26.6	26.8	
Maximum Daily Low Temp °C	32.5	--	--	31.5	27.5	27.0	25.8	24.3	23.7	25.4	27.8	24.0	
Minimum Daily Low Temp °C	30.4	--	--	22.0	23.2	22.5	17.8	15.3	14.5	18.3	17.5	18.5	
Mean 0800 hr Relative Humidity (%)	40	--	--	53	67	69	71	74	75	74	68	56	
Total Rainfall (mm)	3.5	--	--	--	--	8.5	20.4	--	5.6	1.6	--	--	36.1 (mm)
Highest Daily Rainfall (mm)	3.5	--	--	--	--	8.4	20.4	--	5.3	1.2	--	--	
Mean Daily Piche Evaporation (t)*	17.3	--	--	12.4	8.4	8.1	7.0	5.7	4.2	5.7	8.4	9.2	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

Instrument Observation	1984 June	July	Aug	Sep	Oct	Nov	Dec	1985 Jan	Feb	Mar	April	May	Season Total
Mean Daily High Temp °C	43.1	43.4	43.9	40.3	36.9	33.2	--	30.0	28.2	31.3	34.6	38.5	
Maximum Daily High Temp °C	46.5	45.0	45.6	44.5	38.3	35.0	--	32.2	33.3	39.3	39.0	45.0	
Minimum Daily High Temp °C	39.8	40.7	34.5	35.5	34.2	29.5	--	25.0	25.3	25.8	30.3	33.1	
Mean Daily Low Temp °C	24.5	28.3	25.5	26.6	25.4	23.9	--	22.8	19.3	22.1	22.5	24.8	
Maximum Daily Low Temp °C	28.5	21.5	30.0	30.5	27.0	26.0	--	26.5	24.0	25.8	27.3	28.4	
Minimum Daily Low Temp °C	20.6	22.7	23.0	22.5	23.0	21.7	--	19.0	15.5	15.0	16.7	20.7	
Mean 0800 hr Relative Humidity (%)	47	34	35	78	72	2.0	--	--	7.6	7.5	72	62	
Total Rainfall (mm)	--	--	--	--	--	--	--	--	4.0	--	3.8	11.7	19.5 (mm
Highest Daily Rainfall (mm)	--	--	--	--	--	--	--	--	4.0	--	3.8	11.5	
Mean Daily Piche Evaporation (t)*	15.2	15.3	14.0	24.7	9.6	--	--	--	7.4	6.6	8.5	9.9	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

Instrument Observation	1983 June	July	Aug	Sep	Oct	Nov	Dec	1984 Jan	Feb	Mar	April	May	Season Total
Mean Daily High Temp °C	42.5	44.1	43.9	42.6	35.5	33.6	30.3	28.1	29.7	30.8	33.4	38.0	
Maximum Daily High Temp °C	47.5	49.5	45.7	45.7	39.4	36.8	34.4	30.8	34.9	37.2	37.2	44.5	
Minimum Daily High Temp °C	38.0	38.5	40.5	37.0	34.2	31.0	--	24.7	--	27.0	30.5	34.5	
Mean Daily Low Temp °C	26.0	27.6	29.8	25.7	24.3	23.3	22.2	20.3	22.3	22.2	22.4	23.6	
Maximum Daily Low Temp °C	30.5	32.4	33.0	30.3	27.2	26.3	17.0	23.0	--	26.4	26.6	27.7	
Minimum Daily Low Temp °C	21.5	21.2	26.0	23.0	20.7	20.3	--	16.0	19.4	17.5	15.8	17.5	
Mean 0800 hr Relative Humidity (%)	40	34	41	44	67	67	79	69	74	71	66	61	
Total Rainfall (mm)	--	3.0	--	--	--	1.00	1.2	1.0	Trace	Trace	--	--	6.2 (mm)
Highest Daily Rainfall (mm)	--	3.0	--	--	--	3.00	0.4	0.3	--	--	--	--	
Mean Daily Piche Evaporation (t)*	--	--	21.9	16.0	9.4	9.7	7.4	7.1	6.8	6.9	15.5	8.8	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

Instrument Observation	1982 June	July	Aug	Sep	Oct	Nov	Dec	1983 Jan	Feb	Mar	April	May	Season Total
Mean Daily High Temp °C	42.1	43.6	43.7	40.9	35.4	31.1	--	26.7	26.0	26.0	32.6	37.4	
Maximum Daily High Temp °C	46.5	46.1	45.0	44.5	38.5	34.8	--	33.0	31.0	32.6	36.4	46.0	
Minimum Daily High Temp °C	36.3	41.6	40.2	37.0	31.3	28.5	--	22.2	23.4	25.4	30.0	33.0	
Mean Daily Low Temp °C	25.2	32.9	32.1	31.4	25.4	22.4	--	18.9	17.5	15.6	19.5	23.8	
Maximum Daily Low Temp °C	30.2	36.0	35.1	33.0	28.5	26.0	--	24.5	22.0	25.0	26.0	30.0	
Minimum Daily Low Temp °C	20.7	29.0	24.0	29.5	21.0	17.0	--	12.0	12.5	14.3	14.5	19.2	
Mean 0800 hr Relative Humidity (%)	32	33	40	51	62	63	--	68	61	73	61	55	
Total Rainfall (mm)	--	--	0.2	--	7.0	0.3	--	Trace	Trace	0.4	--	--	7.7 (mm)
Highest Daily Rainfall (mm)	--	--	0.2	--	7.0	0.3	--	--	--	0.2	--	--	
Mean Daily Piche Evaporation (t)*	15.6	21.2	21.4	12.7	11.8	10.2	--	11.1	7.0	7.0	--	--	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

Instrument Observation	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	May	Season Total
	1981							1982					
Mean Daily High Temp °C	42.6	43.2	43.9	42.1	36.8	32.4	31.3	29.1	28.1	29.4	35.0	36.3	
Maximum Daily High Temp °C	47.0	46.4	45.8	44.6	40.5	36.5	33.0	33.3	32.1	34.8	43.2	42.4	
Minimum Daily High Temp °C	35.3	40.2	41.6	39.0	35.0	25.6	27.8	25.7	33.8	25.8	27.2	34.9	
Mean Daily Low Temp °C	25.0	30.2	29.4	26.0	26.3	27.1	22.1	21.1	19.0	19.4	23.1	24.6	
Maximum Daily Low Temp °C	34.2	35.4	33.6	22.5	29.0	26.7	25.1	25.1	21.7	26.0	27.5	28.3	
Minimum Daily Low Temp °C	31.0	25.6	25.8	32.5	22.6	21.5	18.5	15.9	13.4	15.0	16.1	20.0	
Mean 0800 hr Relative Humidity (%)	77	40	41	44	62	66	75	71	63	67	61	59	
Total Rainfall (mm)	--	--	17	Trace	--	31.1	0.9	2.3	--	1.9	Trace	--	53.2 (n
Highest Daily Rainfall (mm)	--	--	17	--	--	26.6	0.5	2.3	--	1.9	Trace	--	
Mean Daily Piche Evaporation (t)*	18.8	25.8	20.1	14.7	6.5	7.2	6.3	5.8	6.6	7.3	8.6	8.9	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

Instrument Observation	1980 June	July	Aug	Sep	Oct	Nov	Dec	1981 Jan	Feb	Mar	April	May	Season Total
Mean Daily High Temp °C	44.6	43.3	43.4	40.5	36.5	33.6	29.9	28.1	27.7	31.2	34.3	37.8	
Maximum Daily High Temp °C	46.5	45.6	45.7	44.3	40.2	28.2	33.2	34.0	31.4	35.6	41.3	46.3	
Minimum Daily High Temp °C	31.6	40.5	39.2	36.5	35.0	28.0	23.0	23.2	23.3	27.7	30.8	33.5	
Mean Daily Low Temp °C	30.1	34.8	29.7	26.2	25.6	24.1	21.0	21.1	19.7	22.6	25.8	23.3	
Maximum Daily Low Temp °C	36.7	36.2	33.5	28.8	24.2	26.4	24.3	24.5	24.5	26.3	29.3	29.0	
Minimum Daily Low Temp °C	22.9	25.0	24.5	22.3	23.0	21.8	19.2	18.1	15.5	16.2	22.0	18.8	
Mean 0800 hr Relative Humidity (%)	44	30	42	56	67	72	73	72	69	35	64	49	
Total Rainfall (mm)	--	Trace	Trace	Trace	Trace	7.8	9.6	Trace	Trace	Trace	--	--	17.4 (m
Highest Daily Rainfall (mm)	--	--	--	--	--	6.4	2.9	Trace	Trace	--	--	--	
Mean Daily Piche Evaporation (t)*	--	--	--	--	--	--	--	7.0	7.2	7.7	9.8	10.7	

*To obtain an approximate value for evaporation from a free water surface multiply the piche evaporation (t) by 32.

APPENDIX X

List of Staff and Cooperating Personnel Involved in the Field Trials

APPENDIX X. List of staff and cooperating personnel involved in the field trials.

STAFF

Ali Mohamad, Ickhlas	Pesticide Residue Specialist, PPD
El Bashir, Sayed	Locust Biologist, University of Khartoum
Bernard, Paul	Logistics and Camp Manager, Dynamac Corp.
Bettendorf, David	Field Biologist, Dynamac Corp.
Brown, Michael	Field Operations Manager, Dynamac Corp.
Duszkiewicz, Jozef	Mechanic, Pezetel
Edien Abdel Rahman, Nezam	Locust Officer, PPD
Evans, Jeffrey	Scientific Coordinator, Dynamac Corp.
Gabra Butrous, Munir	Project Liaison, PPD
Giraldi, Al	Field Biologist, Dynamac Corp.
El Hag, Ismail	Chief Vertebrate Officer, PPD
Hajjar, Nick	Project Negotiator, Dynamac Corp.
Hamid Yousif, Hassan	Inspector, Tokar Delta Agricultural Corp.
Hemming, Chris	Locust Specialist, CICP
Hiemid Mohamad, Abdel Rhaman	Locust Officer, PPD
Hirsch, Allan	Vice-President, Dynamac Corp.
Kepner, Rodney	Beneficial Insects Specialist, CICP
El Khidir Taha, Abdel Moneim	Locust Officer, PPD Sudan
El Mahdi, El Safie	Vertebrate Officer, PPD
Mydtowski, Antoni	Pilot, Pezetel
Nabri, Assad	Logistician, Dynamac Corp.
El Nigoumi, Ebraheem	Pilot, BanAir
Rafe, Abdel	Mechanic, BanAir
Sander, Timothy	Application Specialist, Micronair, Ltd.
Schwartz, Thomas	Efficacy Team Leader, CICP
Skromny, Marek	Flight Mechanic, Pezetel
Southerland, Mark	Scientific Manager, Dynamac Corp.
Stancioff, Andrew	Project Manager, Dynamac Corp.
Yates, Wesley	Application Specialist, CICP

COOPERATING PERSONNEL

Ali, Babiker	Acting Director, Tokar Delta Agric. Corp.
Farnsworth, Kate	Acting Project Officer, AID/Sudan
Fee, Sharon	Project Officer, AID/Sudan
Ghobrial, George	Agronomist, AID/Sudan
Karrar, A.H.	Head, Grasshopper and Locust Section, PPD
Mackie, Anita	Head, General Development Office, AID/Sudan
Mohamad El Amin, Abdel Rahman	Director, Tokar Delta Agricultural Corp.
Shahata Barsi, Shabban	Chief Locust Officer, PPD
Shams El Deen, Hayder	Locust Technician, PPD
Tingari, Omar	Locust Officer, PPD
Zaroug, Abdel Latif	Acting Director, PPD

Note: CICP - Consortium for International Crop Protection
PPD - Plant Protection Directorate, Ministry of Agriculture, Government of Sudan