REP 1994-017 AUTHOR FILE

Pergamon

Environmental Toxicology and Chemistry, Vol. 13, No. 2, pp. 333-341, 1994
Printed in the USA
0730-7268/94 $6.00 + .00

ENVIRONMENTAL EFFECTS ON WETLANDS OF QUELETOX® APPLIED TO PLOCEID ROOSTS IN KENYA

JAMES O. KEITH,*† JOHN G. NGONDI,‡ RICHARD L. BRUGGERS,†
BRUCE A. KIMBALL† and CLIVE C.H. ELLIOTT§
†Denver Wildlife Research Center, USDA/APHIS, P.O. Box 25266, Denver, Colorado 80225-0266
‡Kenya Crop Protection Division, Nairobi, Kenya
§Food and Agriculture Organization of the United Nations, Nairobi, Kenya

(*Received* 25 *January* 1993; *Accepted* 1 *July* 1993)

Abstract — Queletox® (Fenthion) is widely used in Africa to kill birds that eat cereal crops. Applications of Queletox have been reported to kill nontarget animals and contaminate areas used by livestock and humans. In 1988, we evaluated Queletox treatments to wetland roosts at the Njoro dam (2.88 kg/ha) and Gicheha farm (12.0 kg/ha) near Nakuru, Kenya. Fenthion deposits measured in the roosts ranged up to 1,100 g/ha, but were >1.0 g/ha at distances of 100 m or more from roosts. Following applications, 61 birds of 14 species at the Njoro dam and 22 birds of eight species at the Gicheha farm were found dead or severely debilitated. However, the general abundance of waterfowl, wading birds, plovers, doves, and passerines seemed unaffected. Residues in crop contents of 11 dead birds ranged up to 11.0 ppm, substantiating death from fenthion. Fenthion residues (2.2–750 μg) recovered from skin and feathers of 36 dead birds were sufficient to have been hazardous to predators and scavengers. Neither amphibians nor fishes were affected by treatments. At the Njoro dam, scarabids, dytiscids, and notonectids were killed, and their numbers decreased; many insects also were killed at the Gicheha farm. The abundance of these groups, however, had increased within 6 d post-treatment. Fenthion residues of 1.8 to 17 ppb were found in positive water samples for up to 5 d post-treatment. All sampled vegetation had temporarily hazardous residues; levels ranged up to 83 ppm on grasses but had decreased to <1.0 after 3 d.

Keywords — Fenthion Queletox® Nontarget effects Residues

INTRODUCTION

Fenthion (phosphorothioic acid *O,O*-dimethyl *O*-[3-methyl-4-(methylthio) phenyl] ester) is an organophosphate insecticide that can cause cholinesterase inhibition, debility, and death in vertebrate animals exposed to field applications. Fenthion is widely used in Africa under the trade name Queletox® to kill red-billed quelea (*Quelea quelea*) and other ploceid weaver birds that feed on maturing cereal crops. These species are extremely abundant and can cause considerable losses to crops. Red-billed quelea, for instance, may well be "the most destructive and possibly the most numerous bird in the world" [2, p. 173].

During 1985 in the eastern African countries of Tanzania, Sudan, Somalia, Kenya, and Ethiopia, 39,417 L Queletox was sprayed on 277 quelea nesting and roosting concentrations, totaling 23,370 ha [3]. Treated roosts often are in uniquely productive habitats that serve as concentration points for a variety of wildlife, livestock, and humans. Fenthion is used in bird control because it is highly toxic to birds but less toxic to mammals, including humans and livestock. However, effects on nontarget birds are of great concern in the use of fenthion. Queletox (60% a.i. fenthion) is often applied to roosts and colonies at rates of 4 to 10 L/ha. Such heavy treatments could adversely affect organisms other than target birds.

Research on nontarget effects of fenthion treatments to quelea breeding colonies in the dry savanna east of Tsavo National Park was undertaken in 1985 [4]. The study was stimulated by concern over the high mortality in 1984 of raptors and scavengers that had eaten dead and debilitated birds at treated colonies near Mount Kenya [5]. Results of the 1985 study showed that treatment of breeding colonies with fenthion killed many insectivorous birds in the area and seriously exposed about 70% of raptors examined to cholinesterase-inhibiting levels of fenthion. Wetlands used by depredating birds for nighttime roosts in grain-producing areas often support varied and dense wildlife populations. The current study evaluated the environmental effects of fenthion applications to wetland roosts in the highlands of Kenya, where ploceid weavers traditionally feed in maturing wheat.

METHODS

Study areas

Two wetland roosts were treated with fenthion in August 1988. Fish-eating birds, waders, waterfowl, raptors, shorebirds, doves, and passerines were present at one or both sites. Some 47 species of 22 families were seen at the Njoro dam, and 26 species of 17 families were recorded at the Gicheha farm. The relative abundances of these species at the two

*To whom correspondence may be addressed.

The current address of John G. Ngondi is International Red Locust Control Organization for Eastern, Central and Southern Africa, P.O. Box 72751, Ndola, Zambia.

The current address C.C.H. Elliott is FAO/AGPP, Via Delle Terme di Caracalla, 00100 Rome, Italy.

Reference to trade names does not imply endorsement by the U.S. government.

Scientific names of birds follow Williams and Arlott [1].

roosts before fenthion treatments and at the Njoro dam roost after treatment are given in Keith et al. [6]. The roosts, located at the Njoro dam and Gicheha farm, were 5.0 and 0.5 ha in size and located 24 km southwest and 26 km west of Nakuru, Kenya, respectively. These areas also contained an abundance of nontarget birds and a diverse community of terrestrial and aquatic organisms.

The Njoro dam was constructed early in this century to store water for livestock and irrigation (Fig. 1). The source of water is a spring on the western edge of the pond. Over time the pond has filled with silt and now is almost completely covered with dense stands of cattails (*Typha* sp.). Small, isolated areas of shallow, open water were scattered along the edge of the pond. The dam had a spillway at the eastern end, and overflow water was used to irrigate croplands downstream. The pond was bounded by crops (maize and green peas), open pasture, and a steep escarpment on the west. The pasturelands were heavily grazed by livestock, which drank from open water in the stream and at the end of the pond. Villagers lived near the pond and used open water at the spillway and at the spring for washing laundry and household use. The area received heavy rains during most afternoons before spraying, but no rain fell during the first 4 d post-treatment.

Water areas contained abundant tadpoles, frogs, and invertebrates, but no fish. Some 3,000 to 4,000 ploceids roosted in the cattails, including a few Reichenow's weavers (*Ploceus baglafecht reichenowi*) and rufous sparrows (*Passer motitensis*), and a greater abundance of chestnut weavers (*Ploceus rubiginosus*), black-headed weavers (*Ploceus cucullatus*), Jackson's widowbirds (*Euplectes jacksoni*), yellow bishops (*Euplectes capensis*), grosbeak weavers (*Amblyospiza albifrons*), and red-billed quelea. Control of such low numbers of pest birds would not normally be undertaken. Fenthion was applied primarily for this study. The Njoro dam pond was observed and sampled for 5 d before treatment on August 10, 1988, and for 6 d thereafter.

The Gicheha farm was a large private farm that was not used by villagers. The bird roost on the farm was in a 0.5-ha stand of flooded napier grass (*Pennisetum purpureum*), a tall (2- to 4-m), coarse grass being grown for livestock fodder. A stream flowing north immediately to the west of the napier grass had overflowed due to high water from heavy rains and had flooded the general area (Fig. 2). The flood water rejoined the stream north of the napier grass near a structure used to divert water into a large, deep pond. Overflow water from the pond returned to the stream north of the pond. Heavy rainfall during the study period greatly increased the speed and volume of water in the stream and the water that overflowed across the roost site. Pasturelands and fields of maize and wheat adjoined the stream, roost, and pond. Human and livestock use of the area at the time of treatment was negligible.

The pond had fishes (*Tilapia zilli*) but contained little other animal life. The stream and napier grass contained abundant insects and other arthropods. An estimated 10,000 ploceids roosted in the grass, including chestnut weavers (85%), black-headed weavers (5%), red-billed quelea (5%), and grosbeak weavers (5%). Such concentrations of pest birds are routinely controlled in this roost. The Gicheha farm roost was observed and sampled for 2 d before and 6 d after application of fenthion on August 19, 1988.

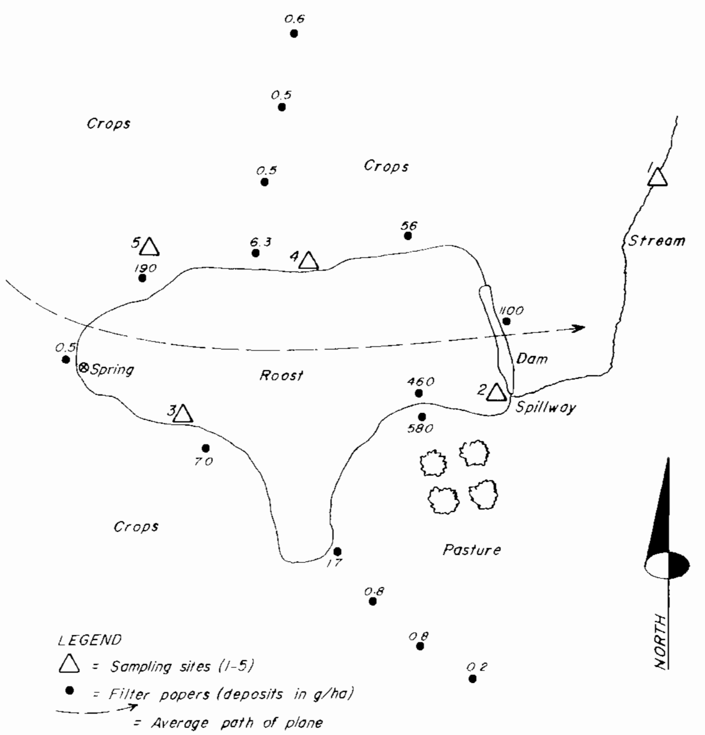

Fig. 1. The Njoro dam roost.

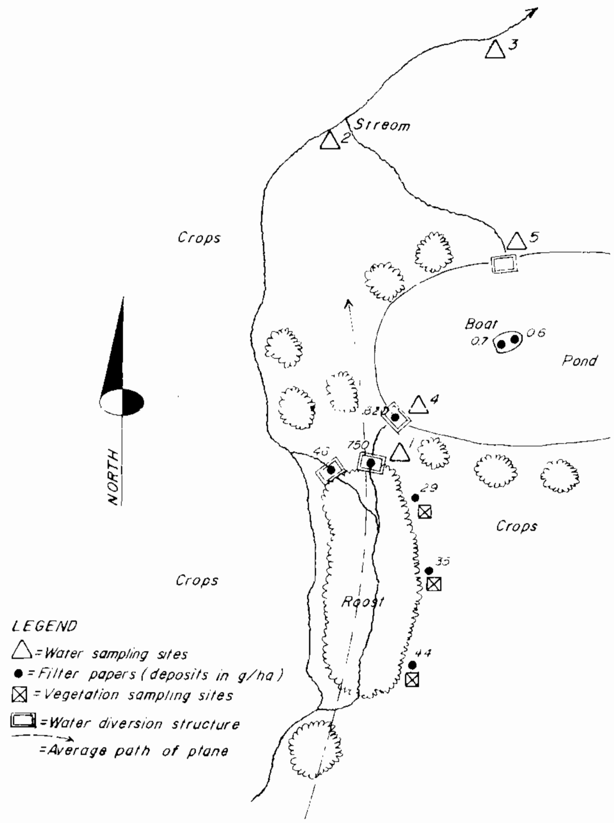

Fig. 2. The Gicheha farm roost.

Fenthion applications

The Njoro dam roost site was sprayed by a Desert Locust Control Organization of Eastern Africa (DLCO-EA) aircraft. DLCO-EA is a regional organization that treats bird concentrations in Kenya and other eastern African countries. The aircraft was a DeHavilland Beaver fitted with a twin micronair Au 4000 spray pod system. The blade angle was set at 30° and the variable restrictor unit was set at 13. Flight speed was 167 kilometers per hour (kph). A total volume of 24 L Queletox (60% a.i. fenthion) was applied during a 12-min period between 1830 and 1845 h on August 10, 1988. The aircraft made five passes over the roost site. There was a slight, variable wind that changed directions several times during the spray application.

The Gicheha farm roost site was treated by a contract spray operator flying a Piper Pawnee fitted with boom and nozzle spray gear with 22 nozzles and size D6 jets. Flight speed was 150 kph. A total volume of 10 L Queletox (60% a.i. fenthion) was applied during a 5-min period between 1845 and 1850 h on August 19, 1988. The aircraft made three passes over the roost site. There was a light wind from the southeast during treatment.

Assessments of fenthion deposits

Fenthion deposits in each roost were monitored by placing filter papers (diameter 24 cm) at various points in and around the roost sites (Figs. 1 and 2). All filter papers were picked up immediately after spraying. Filter papers were rolled, placed into a long glass vial that was wrapped in aluminum foil to exclude light, and later stored for one month at ambient temperature and up to four months under refrigeration until analyzed for fenthion residues. Samples of Queletox formulations were refrigerated and saved until analyzed.

Collection of environmental samples

Samples of water, plants, and animals were collected from both study areas before and after fenthion applications. Fenthion residues were subsequently determined in some samples to help assess the intensity of fenthion contamination; the persistence of residues; and the potential hazards to humans, livestock, and wildlife. Other samples were used to depict the relative abundance of aquatic organisms before and after treatments. Carcasses of affected target and nontarget animals were collected within and around both roost sites for 5 d postspray.

At the Njoro dam roost (Fig. 1), five sampling sites were established. At sites 2, 3, and 4, amphibians, invertebrates, water, and three types of vegetation were collected. At the stream site (site 1), only water was sampled. Site 5 did not have water, but all other materials were collected. Samples were obtained from all sites before treatment and daily afterward for up to 6 d.

At the Gicheha farm roost (Fig. 2), samples of water, vegetation, fishes, and aquatic and terrestrial invertebrates were collected before treatment. After fenthion applications, water was collected from five sites for up to 3 d; samples of vegetation (three sites), invertebrates (three sites), and fishes (one site) were obtained for up to 5 d post-treatment.

Water was obtained from streams and ponds by partially submerging the mouth of a collection bottle below the water surface and letting the bottle slowly fill. A sample of 75 ml was extracted immediately after collection by shaking the water vigorously for 3 min with 50 ml of petroleum ether in a separatory funnel. After separation of water and solvent, sufficient ethanol (5.0–10.0 ml) was added to eliminate an emulsion that formed in the solvent. Petroleum ether extracts were sealed in vials that were covered with aluminum foil to exclude light and stored for one month at ambient temperature and up to five months under refrigeration until analyzed for fenthion. As time permitted in the field, some extracts were concentrated or taken to dryness in vials by placing them in a hot water bath.

Vegetation for residue analysis was taken from common plants growing throughout treated areas. At the Njoro dam, leaves of grasses (*Chloris virgata* and *Pennisetum setaceum*), sedge (*Cyperus rigidifolius*), and an emergent aquatic (*Hydrocotyle ranunculoides*) were clipped with scissors and saved. Napier grass was collected from the roost at the Gicheha farm. Ten grams of each sample was finely macerated, placed in a small bottle with 15 ml of methanol, and shaken vigorously for 3 min. The methanol was drained from samples, and the process was repeated with an additional 15 ml methanol. The two extracts were combined and stored in wrapped vials for one month at ambient temperature and up to six months under refrigeration until analyzed for fenthion. As time permitted in the field, some extracts were taken to dryness in vials before storage.

Ploceid weavers, the target species, were used to determine amounts of fenthion present externally on feathers and carcasses. These residues represent most of the fenthion that raptors and scavengers ingest when they swallow whole carcasses of these small birds. Dead weavers were collected only from the Gicheha farm; dense vegetation prohibited searches for carcasses in the Njoro dam roost. Whole chestnut weavers (about 30 g) and red-billed quelea (about 18–20 g), found dead on the Gicheha farm, were each placed in a wide-mouth jar with 30 ml methanol and shaken vigorously for 3 min. After the methanol was drained off, the recovered volume was measured and placed in a wrapped vial until analyzed for fenthion. Vials were stored at ambient temperature for one month and up to eight months under refrigeration. Because feathers absorbed methanol, often only 15 to 20 ml methanol was recovered. Recovered amounts contained only a proportion of total fenthion present on birds; therefore, amounts of fenthion collected in washings were corrected to amounts that would have been present in 30 ml.

Crop contents were removed from nine nontarget birds killed by fenthion applications. These samples were placed in vials and frozen for four to seven months before analyses. Liquid nitrogen was used to freeze samples while in the field.

At the Njoro dam, aquatic dip nets and seines were used to sample the abundance of invertebrates and amphibians in open water areas. An experimental gill net was used in the pond on the Gicheha farm to collect fish before, and at 1, 3, and 5 d after, the roost was treated. A drift net was placed in the stream below the roost to monitor invertebrate kill, and sweep-net samples were collected to document the presence or absence of insects on vegetation after spraying.

Analyses for fenthion residues

Methanol was used to extract fenthion from all samples except water, which was extracted with petroleum ether. Some extracts were evaporated partially or to dryness in Kenya; the remainder were taken to dryness in the chemistry laboratory in Denver, Colorado. All dried extracts were reconstituted with isooctane, whereas samples of spray formulations were diluted with isooctane, for analyses.

Analyses for fenthion were performed by capillary GC with a methyl silicone capillary column (15 m × 0.25 mm i.d.) and a nitrogen–phosphorus detector (NPD). Fenthion was identified by its chromatographic retention time on the column and quantified by an external standard.

Most sample materials were fortified in Kenya with known amounts of a fenthion standard. These spiked samples were later analyzed to determine how much fenthion could be recovered after shipment and storage of samples. Percentage of recovery of fenthion was low, but recovery of fenthion from samples fortified with fenthion in the laboratory also was low. Residues were not corrected for recovery, and reported amounts should be viewed as minimal.

RESULTS

Both treated roosts were ecologically rich and diverse. Many nontarget birds were present at both sites, in addition to the abundant ploceids that were causing damage to the ripening wheat crop in the two areas. Based on changes in bird abundance after treatments, fenthion applications were estimated to have killed most ploceids in the Njoro dam roost but <25% of those in the Gicheha farm roost.

Spray formulations

Labels on the commercial drums containing Queletox listed the fenthion concentration as 640 mg fenthion per milliliter xylene. Chemical analyses of samples from drums indicated the fenthion concentration to be 640 mg/ml for the formulation used at the Njoro dam site, and 713 mg/ml for that applied to the Gicheha farm roost.

Fenthion deposits

Residues of fenthion on filter papers showed that deposits were greatest at the edges of the roost near the end of airplane spray swaths (Fig. 1). At the Njoro dam roost, four of five passes were flown from west to east and terminated over the dam. Deposits at the dam were 1,100 g/ha, and those nearby to the southwest were about one-half as great. The highest deposit elsewhere (190 g/ha) was at the northwestern edge, where swaths were begun. There was little drift onto crops up to 300 m north and south of the roost, as filter papers there contained <1.0 g/ha.

At the Gicheha farm roost, the spray plane flew south to north, with swaths ending at the diversion dam south of the pond (Fig. 2). Highest deposits on filter papers were 750 g/ha at the dam and 619 g/ha on the nearby concrete structure where water entered the pond. Filter papers along the edges of the roost had much lower fenthion deposits (29–46 g/ha). Two filter papers placed on the seats of a boat anchored in the pond 100 m away had low deposits (0.6 and 0.7 g/ha), again indicating minimal spray drift.

Nontarget bird mortality

At the Njoro dam roost, a total of 61 dead or debilitated nontarget birds were found during the first 4 d after fenthion was applied (Table 1). None were found thereafter. Most were located under trees south of site 2 at the southeastern corner of the roost (Fig. 1). Superb starlings (*Spreo superbus*, 15), red-capped larks (*Calandrella cinerea*, 12), and fiscal shrikes (*Lanius collaris*, 11) were affected in the greatest numbers, but one or more individuals of 11 other species were killed. One black crake (*Limnocorax flavirostra*) was found debilitated, and one young flightless crowned crane (*Balearica regulorum*) was reported to be sick. Other marsh birds may have been affected but were not found in the dense cattails covering the roost site. These cattail stands were practically impenetrable and were searched only on the edges. Few ploceids were recovered, but most were presumed to have died in the middle of the cattail roost.

At the Gicheha farm roost, all 22 dead or debilitated nontarget birds were found during the first 3 d post-treatment (Table 2). Nontarget birds were found primarily north of the roost and south of the pond under trees (Fig. 2). Speckled mousebirds (*Colius striatus*, seven), yellow-vented bulbuls (*Pycnonotus barbatus*, five), and fiscal shrikes (three) were the most commonly affected birds. One or two individuals of five other species also were found. Affected ploceids, the

Table 1. Nontarget birds found dead or debilitated in or near the Njoro dam roost after treatment with fenthion

Species	Days post-treatment[a] 1	2	3	4	Total
Black crake	—	—	—	1	1
Speckled mousebird	—	1	2	1	4
Green wood hoopoe	—	—	—	1	1
Fawn-colored lark	3	—	—	—	3
Red-capped lark	3	3	5	1	12
Gray-rumped swallow	1	—	—	—	1
Wells's wagtail	1	—	—	—	1
Richard's pipit	5	1	1	—	7
Fiscal shrike	3	4	—	4	11
Olive thrush	—	—	1	—	1
Pale flycatcher	—	1	—	—	1
Rufous sparrow	1	—	—	—	1
Blue-eared glossy starling	—	1	1	—	2
Superb starling	2	9	3	1	15
Total	19	20	13	9	61

[a]Roost was treated on August 10, 1988, at 1830 h.

Table 3. Fenthion residues in crop contents of birds found dead or debilitated[a]

Species, crop contents, and day found	Crop contents wt. (g)	Fenthion residues (μg)[b]	(ppm)
Superb starling, insects (day 1)	0.20	0.66	3.3
Hartlaub's turaco, mulberries (day 2)	3.5	2.8	0.8
Superb starling, insects (day 2)	0.55	2.1	3.8
Red-capped lark, insects (day 2)	0.10	LOD	<0.40
Glossy starling, insects (day 2)	0.17	1.6	9.4
Fiscal shrike, insects (day 2)	0.56	5.6	10
Speckled mousebird, vegetation (day 3)	0.47	5.1	11
Fiscal shrike, insects (day 4)	0.35	LOD	<0.11
Grosbeak weaver, insects (day 6)	0.13	LOD	<0.31

[a]Hartlaub's turaco was from the Gicheha farm; others were from the Njoro dam.
[b]Limit of detection (LOD) was 0.04 μg.

target species, were picked up for 5 d after the fenthion application. They were primarily chestnut weavers and red-billed quelea, and their carcasses were used to determine residues on the feathers of individuals killed by fenthion. Effects on raptors were not evaluated as few raptors were seen near treated roosts during this study.

Fenthion residues in crop contents

A Hartlaub's turaco (*Tauraco hartlaubi*) found dead at the Gicheha farm had been eating mulberries (*Morus alba).* Contents from its crop contained 0.80 ppm fenthion, whereas mulberries picked from a tree near the roost had residues of 0.56 ppm fenthion. All other birds whose crop contents were analyzed were from the Njoro dam area. Crops containing insects had levels of fenthion ranging from <0.11 to 10 ppm (Table 3). Unidentified vegetation in the crop of a speckled mousebird contained 11 ppm fenthion. Fenthion residues measured in crop contents were not corrected for efficiency of extraction from samples.

Table 2. Nontarget birds found dead or debilitated in or near the Gicheha farm roost after treatment with fenthion

Species	Days post-treatment[a] 1	2	3	Total
Hartlaub's turaco	1	—	—	1
Speckled mousebird	—	4	3	7
African pied wagtail	—	1	—	1
Yellow-vented bulbul	1	2	2	5
Fiscal shrike	—	2	1	3
Olive thrush	1	1	—	2
Robin chat	—	1	—	1
Common waxbill	—	2	—	2
Total	3	13	6	22

[a]Roost was treated on August 19, 1988, at 1845 h.

External fenthion residues on ploceids

Ploceids found affected the day after the fenthion application at the Gicheha farm had contamination on their feathers and bodies that averaged 330 μg (SE 66 μg) fenthion (Table 4). Affected birds found on days 2 through 5 post-treatment had fenthion residues that decreased daily from 140 to 24 μg. These were the highest residues measured on any plant or animal sample and were exceeded only by fenthion levels on filter papers. As previously indicated, no contaminated ploceid birds were collected from the Njoro dam roost. Fenthion residues measured in washings of birds were not corrected for efficiency of recovery from samples. However, because less than one-half of the solvent often was recovered from skin and feathers, reported fenthion levels were corrected for solvent recovery.

Fenthion residues in water

At the Njoro dam, residues in water varied over time and among sites (Table 5). The flow of water from the spring and from rain runoff moved slowly through the marsh to the dam spillway. Thereafter, it moved rapidly downstream, where residues were still relatively high (8.2 ppb) on day 4 post treatment. Residues were equally high in three samples at the spillway on days 2 and 3 (15, 9.7, and 12 ppb) but were usually lower in marsh water samples. The variability in residues at a site among days and time of day suggests that water was not adequately sampled to obtain a reliable value for fenthion residues. Results do show that roost treatment with fenthion resulted in a contamination in water of 2.2 to 15 ppb fenthion for several days post-treatment. Residues were still detected in water samples after 5 d.

Table 4. Fenthion (μg) washed from carcasses of chestnut weavers and red-billed quelea found dead or dying after spraying at the Gicheha farm roost[a]

Statistics	Hours post-treatment				
	14	24	48	60	108
n	14[b]	10	10	1	1
Range (μg)	12-750	18-330	2.2-180	—	—
Mean (μg)	330	140	65	58	24
SE	66	35	18	—	—

[a]Measured fenthion residues were increased to amounts that would have been present if all solvent had been recovered from washed bird carcasses.
[b]Four birds were red-billed quelea; all others were chestnut weavers.

Post-treatment fenthion residues in water (1.8-17 ppb) at the Gicheha farm (Table 6) were initially about equal to those at the Njoro dam. Water was still contaminated (1.9 ppm) in the fast-moving stream at about 14 h post-treatment. Results suggested fenthion contamination in water was somewhat lower downstream than that at the roost. Levels of fenthion in water from the pond did not indicate it ever became as contaminated as stream water. Amounts of fenthion reported in water at roosts were not corrected for extraction efficiency.

Fenthion residues on vegetation

Initial fenthion levels on vegetation at Njoro dam (Table 7) correlated with levels measured on filter papers at the same sites (Fig. 1). Highest residues were found at the spillway and in the northwestern corner of the area; levels elsewhere were much lower. At the spillway, the high initial residues decreased rapidly during the first 4 d post-treatment; however, they were high enough to be of concern during the first 3 d. Levels of 20 to 40 ppm on vegetation could be hazardous to livestock that consumed it and to barefooted humans—especially children, because of their size.

At the Gicheha farm, fenthion residues on napier grass were never high (Table 8). However, no grass samples were obtained in the area where filter papers showed highest deposits of fenthion. Amounts of fenthion reported from vegetation at roosts were not corrected for extraction efficiency.

Changes in animal abundance

Tadpoles and frogs at the Njoro dam and fishes at the Gicheha farm were neither affected nor perceived to be less abundant after fenthion applications. Similarly, the general abundance of ibis, waterfowl, herons, egrets, doves, plovers, and passerines seemed unaffected. Although many dead birds were found, treatments clearly did not cause massive mortality of vertebrates or noticeable reductions in populations.

Fenthion is an insecticide; it is not surprising, therefore, that fenthion was particularly effective in killing a variety of invertebrates. Dead and dying mosquitoes in shallow water and dead grasshoppers in grasslands were visible the day after spraying. Scarabids (*Hetronychus* spp. and *Onthophagus* sp.), dytiscids (*Laccophilus* sp. and *Hydaticus capicola*), and notonectids (*Anosops* sp.) were largely eliminated at the Njoro dam sampling points. Snails (*Balinus natalensis*) and a large Hemiptera (*Laccotrephes fabricii*) appeared unaffected. Some species reduced by spraying, such as the notonectids, reappeared within 6 d.

An impressive number of dead adult and larval Hemiptera, Odonata, Coleoptera, Araneae, and Lepidoptera were recovered in drift nets set in the stream at the Gicheha farm. However, sweeps of vegetation 1 d after treatment with an insect net showed that many insects either survived treatment or immediately reinvaded the roost.

Table 5. Fenthion residues (ppb) in individual water samples from four sites after treatment of the Njoro dam roost[a]

Days post-treatment[b]	Sites			
	Stream below dam (site 1)	At spillway (site 2)	Upper marsh on south (site 3)	Upper marsh on north (site 4)
Day 1				
a.m.	4.2	3.0	<LOD[c]	6.0
p.m.	8.1	3.6	4.8	4.2
Day 2				
a.m.	6.8	15	4.6	2.4
p.m.	<LOD	9.7	<LOD	5.0
Day 3				
a.m.	14	3.6	<LOD	<LOD
p.m.	<LOD	12	2.2	<LOD
Day 4				
a.m.	8.2	<LOD	2.6	12
Day 5				
a.m.	3.9	2.7	<LOD	3.0

[a]Water at sites ranged in temperature from 13.6 to 17.5°C and in pH from 6.7 to 7.0 during collections.
[b]Fenthion was applied on August 10, 1988, at 1830 h.
[c]Limit of detection (LOD) was 1.3 ppb.

Table 6. Fenthion residues (ppb) in individual water samples from five sites after treatment of the Gicheha farm roost

	Sites				
Periods post-treatment[a]	At diversion dam	Downstream 200 m	Downstream 400 m	At pond entrance	At pond discharge
10 min	17	3.4	<LOD[b]	1.8	–[c]
20 min	7.7	7.4	5.4	<LOD	–
30 min	15	2.0	7.3	<LOD	–
Day 1	2.7	<LOD	1.9	–	<LOD
Day 2	–	–	–	–	<LOD
Day 3	–	–	–	–	<LOD

[a]Fenthion was applied on August 19, 1988, at 1845 h.
[b]Limit of detection (LOD) was 1.3 ppb.
[c]No sample was obtained.

DISCUSSION

Currently control of pest birds in Africa is accomplished with the use of large quantities of fenthion. At the Njoro dam, 24 L Queletox (60% fenthion formulation) was used to treat the 5-ha roost (4.8 L/ha), and 10 L of the same formulation was applied to the 0.5-ha roost at the Gicheha farm (20 L/ha). These volumes represented applications of 2.88 kg fenthion per hectare (2.56 lb/acre) at the Njoro dam and 12.0 kg/ha (10.68 lb/acre) at the Gicheha farm. The 24 L used at the Njoro dam roost probably was applied to <5 ha, which was the size of the total impounded area covered with cattails. Birds roosted in only a small area and flew over less than one-third of the 5 ha during fenthion applications.

Treatments did not result in uniform deposits, as implied by terms of liters per hectare or grams per hectare. Pilots released the spray over swarms of birds flying low over roosts. The intent was to deposit fenthion on the birds, not to treat their roost habitat uniformly. Sprayed birds are likely killed primarily from dermal exposure [7] as a result of intercepting fenthion droplets while flying. Calculations of fenthion applied in grams per hectare were made only to allow comparison with other studies in which fenthion was uniformly applied to vegetative cover.

Maximum fenthion deposits on filter papers at the Njoro dam roost (460, 580, and 1,100 g/ha near the dam and spillway) were similar to those at the Gicheha farm roost (620 and 750 g/ha). However, these deposits were much lower than the average deposits (2.88 and 12.0 kg/ha) calculated from the amounts of fenthion applied and the areas treated at the two roosts. If the total applied amount of fenthion did not reach the ground in roosts, some may have been carried away as drifting particles. Filter papers placed up to 300 m on the northern and southern sides of the Njoro dam roost showed no evidence of heavy deposits, as they each intercepted <1.0 g/ha. If drift was a factor, airborne particles must have remained aloft for distances >300 m. In treatment of quelea nesting colonies [4], deposits on filter papers indicated <10% of sprayed fenthion reached the ground. But again, filter papers placed up to 700 m downwind showed only low deposits that decreased with distance from the colony.

The two roosts treated with fenthion were rich wetland habitats that supported an abundant and diverse vertebrate and invertebrate fauna. Nine target species and over 50 nontarget species of birds were identified. Based on counts of target species before and after fenthion applications, treatments were effective at the Njoro dam roost (most birds were killed) but not at the Gicheha farm roost (<25% killed). At the

Table 7. Fenthion residues (ppm) on vegetation at four sites after treatment of the Njoro dam roost

	Sites											
	Spillway (site 2)			Upper marsh on south (site 3)			Upper marsh on north (site 4)			Northwestern corner (site 5)		
Days post-treatment[a]	Grasses	Sedges	Emergent dicot	Grasses	Sedges	Emergent dicot	Grasses	Sedges	Emergent dicot	Grasses	Sedges	Emergent dicot
Day 1	83	20	42	0.12	0.012	0.046	0.059	0.069	0.31	3.4	2.3	1.5
Day 2	16	18	19	0.029	0.11	<LOD[b]	0.012	0.012	0.033	0.011	0.010	0.19
Day 3	5.7	1.3	7.5	0.012	0.009	<LOD	0.008	0.029	0.12	0.12	0.25	0.56
Day 4	0.088	3.6	0.74	0.023	0.029	<LOD	0.010	<LOD	0.048	0.20	0.020	0.20
Day 5	0.023	0.50	0.88	0.011	<LOD	<LOD	<LOD	0.045	0.089	<LOD	<LOD	0.015
Day 6	0.19	0.024	2.1	<LOD	0.012	0.008	<LOD	<LOD	0.022	0.024	<LOD	0.061

[a]Fenthion was applied on August 10, 1988, at 1830 h. No fenthion was detected on pretreatment samples of vegetation from four sites.
[b]Limit of detection (LOD) was 0.008 ppm.

Table 8. Fenthion residues (ppm) on napier grass after treatment of the Gicheha farm roost

	Sites		
Days post-treatment[a]	Northern end (site A)	Midroost (site B)	Southern end (site C)
Day 1	0.096	1.2	0.30
Day 2	<LOD[b]	0.12	<LOD
Day 3	<LOD	<LOD	<LOD
Day 4	<LOD	0.010	<LOD
Day 5	0.054	<LOD	<LOD

[a]Roost was sprayed on August 19, 1988, at 1845 h.
[b]Limit of detection (LOD) was 0.008 ppm.

Njoro dam, 61 individual birds of 14 species were found dead or debilitated (Table 1), whereas 22 individuals of eight species were recovered on the Gicheha farm (Table 2). There was no mortality in many of the nontarget species, and in species with individuals suffering mortality, many other individuals survived and appeared unaffected.

Much heavier mortality in birds has been reported in wetlands treated with considerably lower amounts of fenthion in North America. Fenthion applied to flooded pastures at 0.045 to 0.056 kg/ha (0.04–0.05 lb/acre) for mosquito control in Wyoming caused morbidity in 99 birds of 12 species and 15 mammals of six species [8]. Fenthion treatments of 0.09 kg/ha (0.08 lb/acre) to 600 ha (1,440 acre) of parkland for mosquito control in North Dakota resulted in a high bird mortality. A total of 453 birds of 37 species were recovered from just a small portion of the sprayed area. Overall bird mortality was estimated in the thousands [9]. Therefore, losses of birds in these Kenya roosts treated with fenthion at 2.88 to 12.0 kg/ha were surprisingly modest when compared with the greater mortality in the United States following larval mosquito control using <0.10 kg/ha fenthion.

Fenthion residues in crop contents of debilitated, nontarget birds found at the Njoro dam and Gicheha farm were 2.8 and 5.1 μg for vegetation and from 0.7 to 5.6 μg for insects (Table 3). This finding suggests that vegetation contaminated with fenthion can be just as hazardous as contaminated animal food. In other studies, insectivorous or predaceous birds usually have suffered the greatest mortality from fenthion use [8–10]. However, the blue-naped mousebird (*Colius macrourus*), a frugivore, was the most common debilitated bird found in quelea breeding colonies treated with fenthion [4].

Fenthion is highly toxic to a variety of birds; the acute, oral LD50 of tested birds has ranged from 1.3 to 24.9 mg/kg [11–13]. Fiscal shrikes (13) and speckled mousebirds (seven) were among the nontarget birds most commonly found dead in this study. Their crops were often full of food. The weight of shrikes and mousebirds averaged about 32 and 48 g, and individual crops examined from these species contained 5.6 and 5.1 μg of fenthion, respectively. Fenthion in crops was about one-tenth of the acute, oral LD50 (1–2 mg/kg) reported for small birds but probably did not represent the total exposure of birds to fenthion.

Fenthion washed from the carcasses of dead and dying chestnut weavers and red-billed quelea averaged 330 μg on the day after roosts were sprayed (Table 4). Such fenthion levels could be lethal to raptors, but raptors were seldom seen near treated roosts during the study period. The LD50 of fenthion to American kestrels (*Falco sparverius*) is 1.3 mg/kg [12]. Consumption of four dead birds could expose equally susceptible raptors weighing 1.0 kg to a lethal dose, and raptors often engorge themselves on quelea killed with fenthion [14]. Based on other studies, organophosphate treatments can present a real hazard to raptors and scavengers [4,5,15]. In two treated nesting colonies, flightless quelea debilitated by fenthion carried average levels of 44.0 and 83.7 μg, respectively; several raptors feeding on debilitated young quelea were affected, but none died [4]. Thomsett [5] found 39 dead raptors of nine species following quelea control with fenthion in the Kenya highlands. Numbers of steppe buzzards (*Buteo buteo*) and other birds were reportedly killed by fenthion applications in South Africa [16].

Sublethal effects of fenthion exposure have not been thoroughly studied, but research has not indicated any persistent impairment of individuals or populations of birds. Fenthion applied at mosquito larvicide rates had no real effects on nest abandonment, clutch size, hatching success, or fledgling success in red-winged blackbirds [17]. Fenthion reduced the abundance of the principal food organism but not nestling growth rates or fledgling success [17]. Adult male northern bobwhite quail (*Colinus virginianus*) maintained on diets containing 7 ppm fenthion made fewer errors than controls during the acquisition phase of behavior testing, and no residual adverse effects were seen after they had been fed plain diets for 73 d [18].

As in terrestrial habitats, fenthion in aquatic habitats has different intensities of effects on different animals. Fenthion is not highly toxic to tadpoles. Hall and Kolbe [19] reported tadpoles (*Rana catesbeiana*) survived a 96-h exposure to 5 ppm fenthion in water; however, all mallard ducks (*Anas platyrhynchos*) that fed on those tadpoles died. Most fish can survive exposure in water containing up to 1.0 ppm fenthion [20]. Probably for these reasons, fenthion contamination in water at the Njoro dam (15 ppb or less) and at the Gicheha farm (17 ppb or less) did not create hazards or cause mortality to fishes and amphibians.

In contrast, fenthion is very highly toxic to many aquatic invertebrates [20]. Levels in water found in treated roosts (1.3 ppb or higher) exceed the LC50 values for most invertebrates that have been tested. Fenthion concentrations in water at roosts debilitated most invertebrates, and many were killed. Still, invertebrate populations were already recovering within two weeks of fenthion applications, and rapid repopulation could be expected.

Fenthion concentrations in water were not high enough to pose hazards to larger animals such as livestock and humans. In natural waters, fenthion degradation is more rapid in mangrove water (half-life 2.9 d) than in ocean water (half-life 21.1 d). Degradation of fenthion in water increases directly with the biological activity present in water [21]. Water from the Njoro roost had high biological activity, whereas dilution probably was more responsible for disappearance of residues in Gicheha farm waters.

Initial residues on vegetation were high enough (>5 ppm) to be hazardous to both humans and livestock. Livestock consuming vegetation with 10 to 20 ppm fenthion could become poisoned over time. In the United States, fenthion residues above 5 ppm are not legal in grasses to be grazed by livestock [22]. The tolerance in meat is only 0.1 ppm. Likewise, humans coming in contact with such high residues on vegetation could be affected by dermal exposure. The high deposits on forage grasses should be eliminated by developing better strategies for fenthion applications. Fenthion should be applied so that vegetation adjacent to roosts is not contaminated. Spray from the aircraft should be terminated well before the plane crosses roost boundaries.

Fenthion treatments for bird control are sometimes made with little apparent impact on nontarget organisms. At other times, treatments kill a variety of nontarget animals, including individuals of sparse populations such as raptors that are of particular concern to ornithologists and other conservationists. Such lethal control lacks specificity because fenthion at currently applied rates is toxic to many animals. Although development of nontoxic methods for reducing bird damage is certainly desirable and needs to be pursued, until an effective alternative to lethal control is identified, roost and colony sprays are likely to be continued throughout much of Africa. Therefore, attempts should be made to identify species-specific toxicants and develop delivery systems and procedures for target species that do not expose nontarget animals and associated habitat to harmful levels.

Acknowledgement — This study was a cooperative effort of the Food and Agriculture Organization of the United Nations (FAO); the Crop Protection Division, Department of Agriculture, Ministry of Agriculture and Livestock Development (MOA), Kenya; and the Denver Wildlife Research Center, APHIS, U.S. Department of Agriculture (USDA). We thank Dr. J.K. Wanjama and the staff at the National Plant Breeding Station, Njoro, for their assistance and the use of laboratory facilities; F.M. Kitonyo, Crop Protection Division, for organizing and supervising fenthion applications; and the staff of the National Museum of Kenya for identification of insects, plants, and several birds. V.M. Kega and C. Thiong'o of the Crop Protection Division and Berniece Keith participated in fieldwork and processed most of the samples. Funding for technical participants involved in the research program was provided by FAO, Rome; MOA, Kenya; the U.S. Agency for International Development; and the USDA.

REFERENCES

1. **Williams, J.G.** and **N. Arlott.** 1980. *A Field Guide to the Birds of East Africa.* William Collins Sons, London, UK.
2. **Ward, P.** 1965. Feeding ecology of the black-faced dioch *Quelea quelea* in Nigeria. *Ibis* **107**:173–214.
3. **Nurein, M.O.M.** and **J.O. Ndege,** eds. 1986. *Proceedings,* First Quelea Technical Meeting, Desert Locust Control Organization for Eastern Africa, Nairobi, Kenya, May 5–9.
4. **Bruggers, R.L., M.M. Jaeger, J.O. Keith, P.L. Hegdal, J.B. Bourassa, A.A. Latigo** and **J.N. Gillis.** 1989. Impact of fenthion on nontarget birds during quelea control in Kenya. *Wildl. Soc. Bull.* **17**:149–160.
5. **Thomsett, S.** 1987. Raptor deaths as a result of poisoning quelea in Kenya. *Gabar* **2**:33–38.
6. **Keith, J.O., J.G. Ngondi, R.L. Bruggers, B.A. Kimball** and **C.C.H. Elliott.** 1991. Fenthion contamination and effects on wetland roosts treated for bird control in Kenya. FAO Crop Protection Project KEN/85/009. Final Report. Denver Wildlife Research Center, Denver, CO.
7. **Driver, C.J., M.W. Ligotke, P. VanVories, B.D. McVetty, B.J. Greenspan** and **D.B. Drown.** 1991. Routes of uptake and their relative contribution to the toxicologic response of northern bobwhite (*Colinus virginianus*) to an organophosphate insecticide. *Environ. Toxicol. Chem.* **10**:21–33.
8. **De Weese, L.R., L.C. McEwen, L.A. Settimi** and **R.D. Deblinger.** 1983. Effects on birds of fenthion aerial application for mosquito control. *J. Econ. Entomol.* **76**:906–911.
9. **Seabloom, R.W., G.L. Pearson, L.W. Oring** and **J.R. Reilly.** 1973. An incident of fenthion mosquito control and subsequent avian mortality. *J. Wildl. Dis.* **9**:18–20.
10. **Zinkl, J.G., D.A. Jessup, A.I. Bischoff, T.E. Lew** and **E.B. Wheeldon.** 1981. Fenthion poisoning of wading birds. *J. Wildl. Dis.* **17**:117–119.
11. **Hudson, R.H., R.K. Tucker** and **M.A. Haegele.** 1984. Handbook of toxicity of pesticides to wildlife. *U.S. Fish Wildl. Serv. Resour. Publ. 153.*
12. **Schafer, E.W.** 1972. The acute oral toxicity of 369 pesticidal, pharmaceutical and other chemicals to wild birds. *Toxicol. Appl. Pharmacol.* **21**:315–330.
13. **Schafer, E.W., Jr., R.B. Brunton, N.F. Lockyer** and **J.W. De Grazio.** 1973. Comparative toxicity of seventeen pesticides to the quelea, house sparrow, and red-winged blackbird. *Toxicol. Appl. Pharmacol.* **26**:154–157.
14. **Thiollay, J.-M.** 1975. Example de predation naturelle sur une population nicheuse de *Quelea qu. Quelea* L. au Mali. *Terre Vie* **29**:31–45.
15. **Henny, C.J., L.R. Blus, E.J. Kolbe** and **R.E. Fitzner.** 1985. Organophosphate insecticide (Famfur) topically applied to cattle kills magpies and hawks. *J. Wildl. Manage.* **49**:648–658.
16. **Callahan, B.D.** and **N.A. Ferreira.** 1989. Steppe buzzards killed in the course of quelea spraying in the Orange Free State, South Africa. *Gabar* **4**:17.
17. **Powell, G.V.N.** 1984. Reproduction by an altricial songbird, the red-winged blackbird, in fields treated with the organophosphate insecticide fenthion. *J. Appl. Ecol.* **21**:83–95.
18. **Kreitzer, J.F.** and **W.J. Fleming.** 1988. Effects on monocrotophos and fenthion on discrimination acquisition and reversal in northern bobwhite (*Colinus virginianus*). *Environ. Toxicol. Chem.* **7**:237–240.
19. **Hall, R.J.** and **E. Kolbe.** 1980. Bioconcentration of organophosphorus pesticides to hazardous levels by amphibians. *J. Toxicol. Environ. Health* **6**:853–860.
20. **Johnson, W.W.** and **M.T. Finley.** 1980. Handbook of acute toxicity of chemicals to fish and aquatic invertebrates. *U.S. Fish Wildl. Serv. Resour. Publ. 137.*
21. **Wang, T., R. Lenahan** and **T. Kadlac.** 1989. Persistence of fenthion in the aquatic environment. *Bull. Environ. Contam. Toxicol.* **42**:389–394.
22. **Office of the Federal Register.** 1991. Code of Federal Regulation. Protection of the Environment. 40 CFR 180.214.