

1 A REVIEW OF ALTERNATIVES TO FENTHION FOR QUELEA BIRD CONTROL

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17 Keywords: red-billed quelea, *Quelea quelea*, fenthion, fire-bombs, integrated pest
18 management.

19

20 ABSTRACT

21 The red-billed quelea (*Quelea quelea*) is the most important avian pest of small grain crops in
22 semi-arid zones of Africa. Fenthion, an organophosphate, is the main avicide used for
23 controlling the pest but it is highly toxic to non-target organisms. The only readily available
24 pesticide that could replace fenthion is cyanophos, but this chemical is also highly toxic to
25 non-target organisms, although less so than fenthion, and may be more expensive; however,
26 more research on its environmental impacts is needed. Apart from chemical avicides, the only
27 rapid technique to reduce the numbers of quelea substantially is the use of explosives
28 combined with fuel to create fire-bombs but these also have negative effects on the
29 environment, can be dangerous and have associated security issues. The technique is labour
30 intensive and in practice can only be deployed against small (<5 ha) colonies and roosts. An
31 integrated pest management (IPM) approach is the most environmentally benign strategy but,
32 apart from when circumstances permit cultural control measures, most IPM activities only
33 have realistic chances of succeeding in controlling quelea in small (<10 ha) areas. For
34 instance, mass-trapping, which also has the advantage of providing a food source, is suitable
35 when quelea roosts and colonies are less than 5 and 10 hectares in area, respectively.
36 Nevertheless with both traps and mist nets, care is needed to minimise non-target casualties.
37 Other IPM measures are also reviewed and the advantages and disadvantages of different
38 methods tabulated. A related figure provides a decision tree for choosing appropriate
39 measures for different circumstances. If fenthion has to be used, means of minimising its use
40 include ensuring that spraying is only conducted when crops are threatened and that the
41 lowest dosages necessary are applied. Regular training of pest control workers in how to use

42 equipment correctly and in what to do in the case of accidental contamination of operators,
43 and training of farmers on IPM principles and quelea biology through farmer field schools are
44 recommended.

45

46 1. Introduction

47 The red-billed quelea (*Quelea quelea* Linnaeus) is the most important avian pest of small
48 grain crops in Africa, causing damage up to the equivalent of US\$ 88.6 million per annum at
49 2018 prices throughout semi-arid zones (Elliott, 1989a,b). At present, control is mostly by
50 aerial and / or ground-spraying of organophosphate avicides, with fenthion (Queletox®)
51 being the pesticide of choice. As the red-billed quelea is recognised as a migratory pest, such
52 control is conducted by international agencies, Governments and commercial companies,
53 although subsistence farmers can undertake other measures, included in this review, to reduce
54 the birds' depredations. Regrettably, fenthion is toxic to humans and to other non-target
55 organisms so alternatives to its use, reviewed here, are urgently sought. The red-billed
56 quelea feeds principally on native grasses but when these are scarce the birds will attack the
57 seed heads of crops. Principal amongst the latter are millet, sorghum, wheat, rice and teff.
58 There are three subspecies of red-billed quelea: the nominate form *Q. q. quelea* occurs in
59 West Africa from Senegal in the west to Sudan in the east; *Q. q. aethiopica* (Sundevall)
60 ranges in East Africa from Ethiopia to southern Tanzania and *Q. q. lathamii* (Smith) is
61 restricted to southern Africa (Cheke, 2014). All three of the subspecies are migrant pests
62 which follow rainfall systems. As meteorological conditions vary from year to year, the
63 locations and severity of quelea infestations also vary between seasons. In general, the birds
64 breed 2 or 3 times a year, but up to 5 times per annum in East Africa, during and just after
65 rainy seasons. Quelea coming from huge communal breeding colonies may attack crops.
66 Damage also occurs in dry seasons when the birds continue to flock together and may roost in
67 very high numbers. Both breeding colonies and roosts are the targets of control operations
68 that take place after dark when the birds have settled down for the night. The birds also
69 collect in "day-roosts" or "secondary roosts" during daytime (Ward and Zahavi, 1973) when
70 they are susceptible to mass-trapping.

71 As the birds are migrant pests, responsibility for their control rests in some zones with
72 international organisations. Thus, the Desert Locust Control Organization for Eastern Africa
73 (DLCO-EA) uses its aircraft to treat member countries' infestations and the International Red
74 Locust Control Organisation for Central and Southern Africa (IRLCO-CSA) has a similar
75 role for its areas of responsibility. However, some countries such as Botswana, the Republic
76 of South Africa and affected West African countries now undertake their own control duties.
77 Although fire-bombs are used to destroy quelea breeding colonies and roosts in Botswana,
78 South Africa, Kenya and elsewhere, the principal control agent in all areas is currently the
79 organophosphate avicide fenthion (Queletox®; 640 UL; thiophosphoric acid or *O,O*-
80 dimethyl-*O*-[3-methyl-4-(methylthio) phenylphosphorothioate], also known as Baytex,
81 Lebaycid, Tignvon and OMS-2).

82 Fenthion, like other organophosphate compounds, acts by inhibiting acetylcholinesterase,
83 which is essential for normal nerve function. When acetylcholinesterase is inhibited a build-
84 up of acetylcholine results causing prolonged transmission of nerve impulses leading to death
85 from respiratory failure. Fenthion can therefore injure or kill indiscriminately, with
86 consequent adverse effects on non-target organisms (McWilliam and Cheke, 2004) including
87 humans. Fenthion residues are now known to have a half-life of 45 days, almost twice a
88 previous figure given by Meinzingen et al. (1989), and rainfall after sprays can cause fenthion
89 to leach out of the soil and still be detectable five months later (Cheke et al., 2013).
90 Additionally, persistence of fenthion residues in the air for 64 hours and in soil for 46 days
91 was reported by van der Walt (2000).

92 To date, measures to control quelea birds without using fenthion have included the use of
93 (a) alternative pesticides; (b) explosives/fire-bombs; (c) a variety of mass trapping methods,
94 sometimes keeping the birds for food; (d) cultural control; (e) quelea resistant crops; (f)
95 protecting vulnerable crops with repellents and netting and (g) scaring the birds, including the

96 use of falcons. These will be described and discussed below under main headings of
97 Chemical Control, Mechanical Control, Cultural Control and Biological Control. The
98 information for this review is based on published and unpublished documents, obtained
99 following library and internet-based literature searches for relevant terms, and the authors'
100 own observations that were collated for presentation at a workshop to discuss the subject of
101 this paper organised by the FAO's Rotterdam Convention Secretariat. The meeting was
102 attended by representatives of 11 African countries and held in Khartoum, Sudan, on 4-5
103 April 2017 (see
104 <http://www.pic.int/Implementation/TechnicalAssistance/Workshops/WorkshopSudanApr2017/tabid/5895/language/en-US/Default.aspx>). The workshop was convened following concerns
105 over human safety and a proposal to list fenthion in Annex 3 of the Rotterdam Convention
106 which, if accepted, would have led to the pesticide being subject to the Prior Informed
107 Consent (PIC) procedure (see
108 <http://www.pic.int/Procedures/PICProcedure/tabid/1364/language/en-US/Default.aspx>). The
109 Rotterdam Convention is a multilateral Environment Agreement. Its principal objective is
110 promotion of shared responsibility and cooperative efforts among parties in the international
111 trade of certain hazardous chemicals, in order to protect human health and the environment.
112 By its article 6, the convention allows developing countries and countries with economies in
113 transition that are experiencing problems caused by any specific pesticide formulation to
114 propose it for consideration as a Severely Hazardous Pesticide Formulation (SHPF). Such
115 SHPFs will then be subject to the Prior Consent Procedure (PIC) applicable to the 160 parties
116 of the Rotterdam Convention. Fenthion is scheduled for consideration for inclusion in 2019.
117 After the Khartoum meeting, the text of the initial review was revised to include additional
118 topics raised by the delegates, comments arising from the ensuing discussions and the
119 reflections of the attendees. A summary of the advantages and disadvantages of the various
120

121 methods is tabulated (Table 1) and, aiming to minimise pesticide usage, a decision tree
122 recommending different approaches according to circumstances is provided (Figure 1),
123 thereby collating current evidence about the various control methods available for use against
124 quelea.

125

126

127 **2. Alternatives to fenthion for quelea control**

128 *2.1. Chemical Control*

129 *2.1.1. Alternative pesticides*

130 The most commonly used alternative avicide is another organophosphate, cyanophos
131 (Falcolan 520 UL; OMS 226, $C_9H_{10}NO_3PS$ (*O*-(4-cyanophenyl) *O,O*-dimethyl
132 phosphorothioate). Cyanophos is not registered for use in the United States of America where
133 it is classified as an extremely hazardous substance. Similarly it is not registered for use in
134 the European Union. Nevertheless, it has been used for quelea control in Senegal, Mauritania,
135 Botswana, Ethiopia and elsewhere since it has lower toxicities (e.g. acute oral LD50 for rats
136 730 mg.kg^{-1} and 3 mg.kg^{-1} for quelea) than those of fenthion (acute oral LD50 for rats 250
137 mg.kg^{-1} and $6\text{-}10 \text{ mg.kg}^{-1}$ for quelea). Cyanophos was tested in Tanzania but was not
138 recommended for routine use. In contrast, it is a registered avicide in the Republic of South
139 Africa where it is used for the majority of quelea control operations since fenthion is no
140 longer available there (E. van der Walt, pers. comm., Nov. 2016). Cyanophos has the
141 disadvantage of a delayed effect on mortality in comparison with fenthion (Allan, 1997), so
142 use of cyanophos could lead to more secondary poisoning of non-target organisms than
143 control with fenthion but few studies of the effects of cyanophos use in the field have been
144 conducted. Mullié et al. (1999) studied non-target organisms after cyanophos spraying
145 against quelea in Senegal and concluded that it seemed to be as damaging as fenthion but that

146 the data were insufficient for adequate comparisons. Cheke et al. (2013) found that
147 cyanophos was still present in soil, at concentrations of from 0.009 to 0.169 $\mu\text{g.g}^{-1}$, 41 days
148 after a spray in Botswana (the maximum residue level for this compound is unknown but UK
149 pesticide authorities recommend a default maximum residue level on food of 0.01 $\mu\text{g.g}^{-1}$; see
150 <https://secure.pesticides.gov.uk/MRLs/>). Phoxim, also an organophosphate, has been tested
151 as an alternative to fenthion (Pope and King, 1973) and Allan (1997) listed some other
152 alternative chemicals such as mevinphos, another organophosphate. However, mevinphos is
153 even more toxic than fenthion (acute oral LD50 for rats 3-12 mg.kg^{-1} and 1.43 mg.kg^{-1} for
154 quelea), so it does not present a suitable alternative.

155

156 *2.1.2. Bird repellents including narcotics*

157 Alphachloralose is a narcotic agent added to bait grain or water that has been used in South
158 African trials (Garanito et al. 2000) which leaves birds so weak that they can be easily picked
159 up or killed, but its potential for affecting non-target organisms renders it unsuitable except,
160 perhaps, in urban areas. Other possible chemicals with repellent abilities that could be used,
161 but which have similar strictures against them, include 4-aminopyradine and aluminium
162 ammonium sulphate, curb (ammonium sulphate) and trimethacarb (predominantly
163 trimethylphenyl methylcarbamate). Use of mesurol, the carbamate methiocarb, a bird
164 repellent, molluscicide and insecticide, also listed by Allan (1997), doubled yields of
165 sorghum in Senegal and in Sudan reduced damage from 85 to 30% in experiments on
166 sorghum and wheat. It is now banned by the EU either for direct use on crops or as a seed
167 dressing. Use of repellents was reviewed by Bruggers (1989). The repellent 9,10
168 Anthraquinone is in use in Zimbabwe but it is not approved for use in the EU. Attempts have
169 been made in South Africa to spray birds with wetting agents such as dilute molasses to

170 prevent the birds from thermoregulating, but the large volumes required precluded regular
171 use of the technique (E. van der Walt, pers. comm.).

172

173 *2.2. Mechanical Control*

174 *2.2.1. Explosions*

175 Explosions/fire-bombs are or were used to control red-billed quelea in Botswana, the
176 Republic of South Africa, Kenya, Zimbabwe and elsewhere. They are often used in or near
177 wetlands, where spraying with organophosphates is contra-indicated. The technique requires
178 highly trained personnel, specialised equipment to transport the explosives safely, and time to
179 deploy the firebombs at the base of vegetation where the birds are either roosting or nesting.
180 This precludes their use except at small (<5 ha) sites. Cheke et al. (2013) described the
181 method used in Botswana as follows: “The technique involves the detonation of 5 L plastic
182 containers, filled with 2.5 L of a mixture of fuels: one-third diesel to two-thirds unleaded
183 petrol was used in 2009 and 2010, but a 50 : 50 mixture of 1 L of diesel and 1 L of petrol was
184 used in 2005; the addition of diesel keeps the flame alight longer than petrol alone, but also
185 gives rise to smoke. Each plastic container (white opaque containers were used in 2005–
186 2008, but green ones in 2009–2010) is placed beneath a bush where quelea birds are either
187 nesting or expected to roost. Each container has an explosive charge placed beneath it. In
188 2005, this consisted of 150 g of Trojan C150 cast boosters, 38 × 120 mm of pentolite and a
189 mixture of TNT and RDX, encased in yellow plastic [manufactured by Ensign-Bickford,
190 (Pty) Ltd, South Africa]. Each booster had a hole drilled in the middle, through which red
191 detonating cord (plastic cord, 8 g.m⁻¹; Auxim Tech. Ltd, China) was fed. At the ignition site,
192 about 120 cm of yellow safety fuse of slow-burning (8–10 mm.s⁻¹) gunpowder was placed at
193 the beginning of the cord, giving approximately 2.5 min between ignition and detonation for
194 1000 m of cord under >200 containers. The fuse was connected to an electric detonator cord

195 containing a white powdered high-explosive core to set off the detonator. This created a
196 shock wave to the detonating cord, along which it travelled at 6400 m.s^{-1} , exploding each
197 booster in turn. In 2009 and 2010 the explosive used was PowergelTM (see
198 [www.oricaminingservices.com/download/file id 4292/](http://www.oricaminingservices.com/download/file_id_4292/) for information on its toxicology), a
199 commercially available ammonium nitrate product, with a detonation velocity of 1780 m.s^{-1}
200 [$<6400 \text{ m.s}^{-1}$ for TNT (see above), and $<8400 \text{ m.s}^{-1}$ for pentaerythritol tetranitrate (PETN),
201 which was also used in years before 2006], mixed with aluminium powder to enhance its
202 performance. These charges were connected by cordex fuse cord, made of powdered PETN,
203 to a central electric detonator that started the reaction with 1 g of metallic-derived explosives
204 or after being activated by a slow-burning safety fuse of gunpowder (black powder). When
205 the explosion takes place, the fuel mixture is first splashed up onto the trees where it forms a
206 mist and then ignites.” In South Africa, the main explosions are preceded a few milliseconds
207 earlier by a small detonation to scare the birds into the air to improve control and, in reed
208 beds, the firebombs are raised on poles. In Kenya, small stones are sometimes placed in
209 packages above the explosive apparatus. Allan (1997) also describes the method with
210 particular reference to reed beds and he also discussed the drawbacks of the method including
211 its expense and dangers. There is also a security issue given the involvement of explosives
212 and suitably trained military personnel are often required to oversee the operations. This may
213 explain why explosions are not used in Tanzania, for instance.

214 The method has obvious dangers for the operators and the environment immediately
215 affected by the explosions, but provided that suitable precautions are taken threats to
216 personnel, villagers and livestock can be minimised. It was long thought that explosions were
217 less damaging to the environment than the use of fenthion (e.g. see Meinzingen et al., 1989,
218 Allan, 1997) and Jaeger and Elliott (1989) describe people eating the blown-up birds as
219 benefitting from “a much appreciated source of uncontaminated quelea for food”. However,

220 Cheke et al. (2013) showed that explosions are by no means environmentally benign. Many
221 non-target organisms can be killed or maimed (see also reports cited in McWilliam and
222 Cheke, 2004), soil is contaminated with concentrations of total petroleum hydrocarbons
223 (TPHs) and phthalates (from the plastic) ranging from 0.05 to 130.81 (mean 18.69) $\mu\text{g.g}^{-1}$
224 and from 0 to 1.62 (mean 0.55) $\mu\text{g.g}^{-1}$, respectively, in the craters formed by the explosions,
225 but the values declined to means of 0.753 and 0.027 $\mu\text{g.g}^{-1}$ at 10m away. Dead birds will also
226 be contaminated and thus unfit to eat. One year after an explosion, mean TPHs of 0.865 and
227 mean phthalates of 0.609 were still detectable in the soil. In addition, remains of the plastic
228 did not degrade and littered the sites for years after an explosion, bushes and other vegetation
229 were badly burnt, although the bushes tended to recover unless their trunks were broken, and
230 craters were formed at each firebomb location damaging the soil. More than 1% of the area
231 encompassed by the explosion was damaged in this way.

232

233 *2.2.2. Nest destruction and chick harvesting*

234 Bashir (1989) described how in some communities such as in western Sudan, quelea nests
235 are destroyed by pulling them out of trees with hooks on the ends of long poles or by cutting
236 down the nest trees or with fire including use of flame-throwers. Nest destruction is only
237 useful if conducted after the birds have laid their eggs, otherwise the birds simply repair nests
238 or move elsewhere to breed, and before any fledglings can fly. Amongst various control
239 methods tried against birds in reed beds where chemical control was prohibited, Garanito et
240 al. (2000) concluded that mechanical destruction of breeding and roosting habitat manually or
241 using tractors dragging brushing equipment was the most cost-effective technique.

242 Removal of chicks from nests for later consumption for food is also widely practised.
243 Pelham (1998) reported that up to 3.78 kg of chicks could be harvested per person per hour in

244 Zimbabwe. Reports of the use of quelea as a food source for the rural poor were reviewed and
245 their implications discussed by McWilliam and Cheke (2004).

246

247 *2.2.3. Trapping*

248 It is well known that in many parts of Africa, people eat quelea as the birds provide a
249 nutritious source of protein (Jaeger and Elliott 1989). Indeed quelea colonies are sometimes
250 not reported to pest control authorities when the villagers want to exploit them for food.
251 Various means of trapping the birds are described below. Quelea consumption for food varies
252 regionally and with the preferences of different ethnic groups but it is known to occur in parts
253 of Botswana, Cameroon, Chad, Ethiopia, Kenya, Nigeria, Senegal, Tanzania, Zambia and
254 Zimbabwe. With the exception of organised operations such as that described in Zimbabwe
255 (Pelham, 1998), most harvesting for food is restricted to small colonies (<10 ha), but see
256 section 2.2.3.1.

257

258 *2.2.3.1. Chad Traps*

259 In Chad, farmers adapted nets used for fishing to capture quelea. One of three types of nets
260 used were triangular, suspended on long hand-held poles, and held open in front of roosts and
261 closed to capture birds frightened into them. In this way, on moonless nights at tree roosts
262 about 1,200,000 birds were caught over nine weeks (Mulli  2000). As many as 20,000 could
263 be processed per day by a team of six men for later sale in markets as plucked, fried and dried
264 products. The trapping had a negligible effect on the quelea populations, although many such
265 actions conducted by teams can lead to 7,000,000 bird captures over the course of a year, but
266 the revenue from sale of the quelea as food partly compensated the villagers for their crop
267 losses.

268

269 2.2.3.2. *Kondoa basket traps*

270 In Kondoa District, near Dodoma in Tanzania, farmers catch quelea using basket traps
271 woven in star grass *Cynodon nlemfuensis* Vanderyst (Cheke, 2011). The technique is only
272 used in dry seasons when traps are usually placed with the funnel-shaped opening uppermost
273 near water where the birds come to drink when they are attending “daytime or secondary
274 roosts” or else they are placed in fields. Each basket is baited with grain and heads of millet
275 and, sometimes, with a decoy quelea bird to entice others into the traps. In this way 800 or
276 more birds can be caught per trap per day. The birds are then collected through the hole on
277 the opposite side of the trap after the lid has been removed. The birds are slaughtered,
278 plucked, de-gutted and then prepared as food in a variety of ways (Mtobesya, 2012). So
279 successful are the captures that surplus birds are sold at roadsides and elsewhere leading to
280 profits that help the farmers to buy goods and pay for school fees (Mtobesya, 2012, Manyama
281 et al., 2014).

282

283 2.2.3.3. *Kondoa basket traps made of wire mesh*

284 Given the success of the Kondoa basket traps in catching quelea, experiments were
285 conducted with artificial versions made of wire-mesh (Mtobesya, 2012). The traps were
286 deployed in the same manner as with the traditional model and found to be superior in their
287 catching ability. Also, wire-mesh traps with 3 entrance holes caught more birds than those
288 with 1 or 2 holes and all of the wire mesh versions caught more than traditional grass basket
289 traps, with peak catches of all traps between 0800 and 1000 hours and between 1500 and
290 1700 hours (Mtobesya, 2012).

291

292 2.2.3.4. *Funnel traps*

293 Mitchell (1963) described how very large funnel traps could be used to trap pest birds such
294 as red-winged blackbirds *Agelaius phoeniceus*, common grackles *Quiscalus quiscula*,
295 common starlings *Sturnus vulgaris* and brown-headed cowbirds *Molothrus ater* in the United
296 States of America by luring them in with very bright lights (five 1,000 W floodlights). In 101
297 operations, 672,000 birds were caught and the three best catches yielded 80,000 – 120,000
298 birds per night. Similarly, such methods have been used to capture common starlings *Sturnus*
299 *vulgaris* in Tunisia in stands of broad-leaved trees such as *Eucalyptus*, with up to 15,000
300 caught per night (Elliott et al. 2014). Trials of large funnel traps with attractant strong light
301 have been conducted in Tanzania but with limited success (Elliott et al., 2014).

302

303 2.2.3.5. *Miscellaneous indigenous trapping methods*

304 Allan (1997) illustrated a variety of basket trap and the means to catch termites to bait it
305 with. Other methods include stick and box traps for which a string is pulled to close the box
306 onto the birds eating bait below, sticky bird lime attached to branches and throwing sticks
307 into the midst of a quelea flock.

308

309 2.2.3.6. *Mist nets*

310 Mist nets are efficient means of catching flying birds but run the risk of catching non-target
311 birds too, which may be killed or injured if not removed quickly from the nets by trained
312 personnel. In a trial of mist-netting operations to catch quelea in Tanzania, nearly 4000 were
313 caught in 5 days using an average of 18 mist-nets (12m long x 3m tall) per day. Although this
314 total is minimal compared with the totals in pest flocks and is unlikely to be feasible except at
315 small colonies (<5ha), the villagers nevertheless reported that attacks on their crops did
316 decline during the catching (Elliott et al., 2014). If the method is used repeatedly near

317 colonies with eggs rather than chicks, the birds may desert the colony. Mist nets can also be
318 used to catch birds at roosts and have been deployed in Tanzania.

319

320 *2.2.3.7. Roost traps*

321 Mtobesya (2012) modified the trap roost concept (see section 2.3.6. below) by devising a
322 “roost trap” consisting of netting that could be drawn over a rigid frame erected over a “trap
323 roost” of *Typha* sp. grass. Once the birds had settled to roost the net was pulled over the roost
324 trapping the birds which could then be chivvied into a funnel at one end for capture.
325 Approximately 10,000 quelea were caught per night during trials conducted in Tanzania but
326 the catch also included some non-target species although the majority of these were weaver
327 bird species that sometimes also damage crops (Mtobesya, 2012).

328

329 *2.3. Cultural Control*

330 *2.3.1. Planting and harvest time manipulation*

331 Elliott (1979) and Bullard and Gebrekidan (1989) drew attention to how crop damage by
332 quelea can be minimised if the timings of planting and harvesting can be arranged such that
333 the crop can be harvested when there are few or no quelea present. This method is apt when
334 irrigation facilities are available. Thus in the lower Awash river valley in Ethiopia if irrigated
335 sorghum is planted in September it can be harvested in December when quelea are absent
336 (Bullard and Gebrekidan 1989). Similarly, irrigated rice can be timed for harvesting in mid-
337 May to mid-June in parts of Chad and Cameroon when there are no quelea pests there (Elliott
338 1979). Harvest time manipulation can also be achieved by growing early-maturing varieties
339 of crops. Even if the latter do not completely escape attack they will be vulnerable for shorter
340 periods than conventional crops (Bullard and Gebrekidan 1989).

341

342 2.3.2. *Weeding*

343 It is important for farmers to keep their fields as weed-free as possible since quelea are
344 attracted to weed seeds and may thus attack crops that they might otherwise ignore (Luder,
345 1985, Rodenburg et al., 2014).

346

347 2.3.3. *Alternative Crops*

348 Crop substitution whereby a crop such as maize, which quelea birds do not attack, is
349 planted instead of vulnerable crops such as millet or sorghum. As maize requires more water
350 to thrive than do millet or sorghum, this measure will only succeed if there is adequate
351 rainfall or irrigation is possible. The socio-economic aspects of substituting for small grain
352 crops and the movement away from winter wheat and barley in Zimbabwe due to quelea
353 attacks has been discussed by Mundy (2000). Other crops that are not attacked by quelea such
354 as groundnuts could also be grown as substitutes.

355

356 2.3.4. *Quelea resistant crops*

357 Bullard and Gebrekidan (1989) described how plant breeders can produce crop cultivars
358 that have morphological or chemical characteristics that are unpalatable to quelea and Tarimo
359 (2000) reported how bird resistance in sorghum is imparted by the cyanogenic glycoside
360 known as dhurrin. However, unless the majority of farmers in an area plant resistant varieties
361 the birds will simply move away from them to seek more palatable cultivars nearby.
362 Furthermore, resistant varieties with high concentrations of tannins are less palatable to
363 people than conventional varieties. Gressel (2008) described possibilities for a genetic
364 engineering approach to either (a) make sorghum varieties that produce dhurrin only in the
365 developing seeds, thereby preventing livestock eating sorghum forage from being poisoned;
366 and then have dhurrin completely self-destruct on maturity or (b) manipulate the morphology

367 of the seed head such that seeds are more difficult to peck apart or less accessible. At present,
368 these suggestions remain unrealistic and (a) would not benefit subsistence farmers much.

369

370 2.3.5. *Protecting crops with netting*

371 Allan (1997) described a variety of methods whereby nets were used to cover crops and
372 thus prevent birds from attacking them and Elliott and Bright (2007) recommended covering
373 rice fields with nets to reduce quelea damage in Nigeria. This was tested and found to be
374 worthwhile, with damage varying from 0 to 4% with netting compared with 2.7 to 18.8 %
375 with bird scaring. Yields ranged from 565 to 1,448 kg.ha⁻¹ with netting, but were 296 to
376 1,250 kg.ha⁻¹ with bird scaring (Ajayi et al., 2007).

377 Allan (1997) illustrated how black cotton threads and metallic tapes can be deployed over
378 crops to deter quelea birds. Such methods may be appropriate for commercial farmers or for
379 small-scale cropping but the expense and labour needed to erect and maintain the systems
380 negates their value for subsistence farmers in general. There is also a tendency for quelea to
381 become habituated to such methods and after a few days they may ignore them.

382

383 2.3.6. *Trap roosts*

384 As it is known that quelea often roost in stands of sugar cane *Saccharum officinarum* L.
385 and Napier grass *Pennisetum purpurum* Schumach., these crops have been deliberately sown
386 to act as “trap roosts” (Jarvis and La Grange, 1989, Allan, 1997). After settling into roosts,
387 the birds then presented a discrete target that could be easily controlled with avicide. Ideally,
388 the roosts should be planted 100m x 100m, with tracks for access on each side. They should
389 also be grown within a few hundred metres of water where the birds can drink before roosting
390 and away from other thickets or similar vegetation that the birds could move to.

391

392 2.3.7. Scaring

393 2.3.7.1. Scaring by humans

394 Bird-scaring methods were reviewed by Bashir (1989). These include visual techniques
395 such as scarecrows, flag-waving and loud noises, created by elaborate systems of tins and
396 rattles activated by pulling a connecting string or by cracking whips. In addition, missiles
397 may be hurled at the birds or shot from catapults or mud is sometimes flicked at the pests
398 from the ends of sticks. All such methods are time-consuming, often conducted by children
399 who are thus absent from schools, and may be effective locally but scared birds will move to
400 other fields where there are no scaring activities. In Ogun State, Nigeria, scaring costs may
401 account for as much as 50% of production costs (Elliott and Bright, 2007).

402

403 2.3.7.2. Scaring with falcons

404 In Botswana, experiments have been conducted using lanner falcons (*Falco biarmicus*) to
405 scare quelea away from sorghum crops in the Pandamatenga area (H. Modiakgotla, pers.
406 comm., Gaemengwe, 2014). The farmers there reported that the method gave good results
407 and they supported use of the method as it had led to good and high tonnages due to reduced
408 bird damage (H. Modiakgotla, pers. comm., Oct 2016). The latter was estimated as 12.1% of
409 sorghum heads damaged on average in 13 fields where falcons were not deployed, but was
410 about half this figure at 6.3% in 6 fields where the falcons were flown (H. Modiakgotla, pers.
411 comm.). However, use of falcons has only been tested in the commercial farms in the
412 Pandamatenga area and has not been applied to protect crops grown by subsistence farmers.

413

414 [Table 1 near here]

415

416 2.3.7.3. Commercial bird-scaring devices

417 In Europe and elsewhere, machines that produce loud bangs at set intervals are available
418 commercially for farmers (e.g. the Bangalore bird-scarer,
419 <http://www.nomorebirds.co.uk/bangalore%2Dbird%2Dscarer%7E230>) and it is also possible
420 to purchase varieties that produce species-specific alarm calls or predator calls to scare bird
421 pests (e.g. http://www.birdstop.co.uk/bio-acoustic_bird_scarers.asp). This approach was
422 tested against quelea using Bird X-Pellers (<http://www.bird-x.com/>) by Garanito et al. (2000)
423 and trials with similar devices have been conducted at Pandamatenga in Botswana (H.
424 Modiakgotla, pers. comm.). However, such devices are expensive and the birds are likely to
425 become habituated to them, as they will to other noises used for scaring such as drum beats
426 and tractor horns. An additional possibility is to develop an unmanned aerial vehicle (UAV)
427 or drone that can fly over quelea gatherings and scare them with appropriate noises or with
428 predator-shaped machines. Two such devices have recently been developed for other bird
429 pests (BirdX, 2016). Other novel methods include use of laser beams such as the Agrilaser,
430 either fixed or hand-held, to scare birds off crops ([http://www.pestfix.co.uk/agrilaser-](http://www.pestfix.co.uk/agrilaser-autonomic-laser-bird-dispersal-system.asp)
431 [autonomic-laser-bird-dispersal-system.asp](http://www.pestfix.co.uk/agrilaser-autonomic-laser-bird-dispersal-system.asp)). However, they have a limited range (approx
432 600m) and are too expensive for use by subsistence farmers, but might be applicable in
433 commercial farms.

434

435 *2.4. Biological control*

436 Barre (1974) reviewed the parasitology of *Q. quelea* to seek potential biological control
437 agents, but failed to identify any pathogen capable of causing an epizootic that might limit the
438 bird's populations. Barre recommended a worldwide survey of avian viruses occurring
439 outside Africa and experimental checks to see if any were highly pathogenic to quelea.

440 *Q. quelea* are hosts to a variety of blood parasites (see Durrant et al., 2007 for surveys of
441 some found in *Q. q. lathamii*), but none seem to cause morbidity. However, some taxa may

442 be species specific and, if so, there is a possibility that future progress in genetic
443 manipulation might allow the introduction of lethal forms of haematozoa.

444 *Quelea* are taken by a variety of predators (Thiollay, 1989) but these have a negligible
445 effect on the huge numbers of the pest birds, except occasionally when flocks of storks and
446 birds of prey locate breeding colonies.

447 *Quelea* and their colonies have a sharp and distinct odour, quite unlike that of any other
448 bird's odour. Since many other species with acute olfactory abilities also have sharp odours,
449 this suggests that odour-based cues serve a communication function in quelea. Likely
450 functions include acting as either a group-specific identification mechanism and/or as a
451 colony- or roost-locating mechanism for either new entrants to colonies, or roosts, and birds
452 returning to their nests or roosts after foraging. In an attempt to identify any biologically
453 active odours that might show promise as attractants to traps or as repellents, samples from
454 birds of the nominate race *Q. q. quelea* were analysed but no compounds of interest were
455 found (R. A. Cheke, D. R. Hall and D. Farman, unpublished data). Samples from other
456 subspecies (*Q. q. lathamii* and *Q. q. intermedia*) were also analysed but again no promising
457 compounds were detected. However, none of these samples were from actively breeding
458 birds, which should be the subject of future research on this topic.

459 Feral pigeons (*Columba livia*) can now be controlled by using ncarbazine as a
460 contraceptive, dispensed in maize mixtures (Albonetti et al., 2015), but unless places where
461 only *Q. quelea* would be feeding this method would pose dangers to non-target birds.

462

463 **3. Comparison of red-billed quelea control methods with the desert locust** 464 **preventive control approach**

465 Control of quelea is only advised when the birds are posing a direct threat to a crop (Ward
466 1972, 1973, 1979). The mere presence of the bird does not justify lethal control as they are

467 often innocuous, especially when their preferred grass food is plentiful. Thus, strategies for
468 dealing with the birds differ markedly from the “preventive control” approach (FAO 2001,
469 van Huis et al., 2007, Magor et al., 2008) applied to other migrant pests such as the desert
470 locust (*Schistocerca gregaria*), and the “strategic control” policy for control of the African
471 armyworm (*Spodoptera exempta*) (Rose et al., 2000, Cheke and Tucker, 1997). For locusts
472 and armyworm, control strategies require “off the crop monitoring” and lethal control as soon
473 as the pest’s populations rise. In this way, if all proceeds according to plan, the pest’s
474 population is prevented from reaching numbers high enough to cause severe damage to crops.
475 Also, locusts and armyworm are remarkable insofar as they change “phase” from the
476 solitary state to the gregarious condition, a change associated with accelerating population
477 growth (Cheke, 1978, 1995) that does not occur in birds. One of the aims of the strategic
478 approach to locust and armyworm control is to ensure that the pests do not succeed in
479 changing phase to become gregarious and swarm.

480 Elliott (2000a) pointed out that FAO’s approach to quelea control was to adopt Integrated
481 Pest Management (IPM) approaches whenever possible and only to use lethal control as a last
482 resort. IPM approaches include many of the options listed above such as “modifying crop
483 husbandry, planting time, weed reduction, crop substitution, bird scaring, exclusion netting
484 etc.” Elliott (2000b), in discussing management practices prevalent at the time in Eastern and
485 Southern Africa, also emphasised that economic constraints and the environmental impact of
486 pesticides were leading to consideration of more sustainable IPM approaches.

487

488 **4. Recommendations for quelea control minimising the extent of fenthion use**

489 *4.1. Forecasting and control planning*

490 Quelea breeding colonies are often not located in time to control them before the fledgling
491 birds, the juveniles responsible for much of the crop damage at this stage in the birds’ life

492 cycles, have left their nests. Similarly, if birds which are attacking crops can breed
493 successfully then the populations available to attack crops will be augmented. However, if the
494 efficiency of control operations could be improved, then the quantities of fenthion used could
495 be reduced. One way of improving the efficiency of control strategies is to detect the
496 presence of suitable quelea breeding areas by satellite imagery (Wallin et al., 1992) or to
497 forecast where the birds are likely to breed. Given that the birds' migrations and breeding
498 opportunities are determined by patterns of rainfall (Ward, 1971), it is possible to devise
499 forecasting systems to predict where the birds are likely to breed and, thus, to concentrate
500 activities in search of the colonies to areas where the birds are likely to be for control
501 purposes (Cheke et al., 2007). A scheme based on the model described by Cheke et al. (2007)
502 that used satellite-derived rainfall data and knowledge of the threshold amounts of rainfall
503 needed to (a) initiate the migrations at the start of seasons ("early rains migrations") and (b)
504 to permit the birds to breed was maintained online as a forecasting system from 2001 to 2009,
505 but fell into disuse when the funding for it ceased. That system was for southern Africa only,
506 dealing with populations of *Q. q. lathamii*, but it is possible to develop a similar system for a
507 pan-African set of forecasts and a prototype model for East Africa was developed (J. Venn
508 and R. A. Cheke, unpublished, Mtobesya, 2012). Regrettably, no system of forecasting where
509 quelea roosts will appear in dry seasons has been devised, other than a recommendation to
510 survey sites known to be traditional insofar as they are used regularly year after year.

511

512 4.2. Fenthion dosages

513 There is marked variation in the dosages used by different control organisations. For
514 instance at a workshop in Machakos, Kenya during May 2005, it was reported that Sudan
515 controlled their birds successfully at rates of 1 l.ha⁻¹ (occasionally only 0.5 l.ha⁻¹), DLCO-EA
516 usually used 2-4 l.ha⁻¹ but South Africa reported use of dosages ranging from 7 l.ha⁻¹ up to as

517 high as 14 l.ha⁻¹. Clearly, less fenthion will be used if the dosage is minimised, with 2-4 l.ha⁻¹
518 recommended. Amounts used by Tanzania during the 2012-2016 period were mostly within
519 this range and were generally lower in the later years (Table 2), a difference which was
520 significant for the roosts (ANOVA, $p < 0.0001$) so an encouraging trend of gradual dosage
521 reductions was achieved. Interestingly the dosages sprayed on colonies (sample mean 2.66)
522 were consistently and significantly less than those deposited on roosts (sample mean 3.51;
523 Welch two sample t test, $t = 8.82$, d.f. = 171, $p < 0.0001$), so if this result is also true
524 elsewhere other control teams could probably minimise potential environmental damage by
525 reducing dosages sprayed on roosts to the levels used on colonies without affecting control
526 rates.

527

528 [Table 2 near here]

529

530

531 *4.3. Fenthion application methods*

532 Studies of environmental effects of fenthion applications revealed that in some cases
533 sprays were conducted incorrectly with regard to speeds and directions of movements of
534 ground-sprayers in relation to wind directions, failing to cease sprays when turning vehicles,
535 incorrect nozzle positioning, equipment maintenance and missed targets during aerial
536 applications (Cheke et al., 2013). Therefore regular training and supervision of pest control
537 workers is recommended, as is correct use of equipment to minimise excessive contamination
538 of the environment and risks to personnel. Furthermore use of the most appropriate
539 equipment may reduce quantities of fenthion needed. For instance, in Tanzania use of
540 ground-based sprays with Micronair AU8000 sprayers required 10% of the volume used by
541 aircraft (B. Mtobesya, pers. comm., October 2016). Training of farmers in quelea biology and
542 IPM principles for damage avoidance and minimisation through farmer field schools is
543 advised. Spray operators also need to know what to do in the case of accidental

544 contamination, which involves washing any affected area immediately with soap and water
545 and discontinuing any further operations until the cause of the contamination has been
546 corrected.

547 The use of unmanned aerial vehicles (drones) for spraying operations would ensure
548 accurate targeting but to date the size of maximum possible payloads has precluded their use.
549 Recent developments have succeeded in increasing payload possibilities up to 80 litres (E.
550 van der Walt, pers. comm., Nov. 2016) so in future this technique may become usable.

551

552 **5. Recommendations for quelea control without fenthion: a strategy for bird**
553 **control using selected methods of control**

554

555 The appropriate control measure to be adopted against quelea will vary depending upon the
556 circumstances (Table 1). Most of the IPM measures described above will seldom be effective
557 on their own, except at scales when infestations are small relative to massive swarms of
558 millions of birds or huge breeding colonies: one colony in March 1998 at Malilangwe in
559 Zimbabwe was 20km long and 1km wide, with nests at densities of 30,000 nests per hectare
560 (Dallimer, 2000). Ideally, an economic cost-benefit analysis should be made prior to each
561 control operation as the overall objective is to find the optimal level of pesticide use, taking
562 into account the availability of non-pesticide alternatives and even compensation for crop
563 losses. As proposed by Agne et al. (1995), an economic assessment of pesticide use needs to
564 be considered within a framework that covers both the farmer's and society's points-of-view.
565 Thus, the farmer would be expected to maximise expected net returns, with gross returns
566 from control equal to prevented crop losses in monetary terms. In contrast, the aim of society
567 in deciding how much pesticide or explosives to apply is to maximise net social benefit,
568 taking into account negative externalities such as environmental contamination and health.

569 However, by combining judicious planning of crop choice and of planting and harvesting
570 times before any expected quelea arrivals with environmentally benign control methods, the
571 cultural control and IPM strategy will succeed under some circumstances. Nevertheless,
572 faced with crop raids by huge quelea flocks, farmers and those in their country responsible
573 for the control will have little choice other than to authorise lethal control with pesticides
574 (cyanophos or other alternatives to fenthion) or explosives. The scheme outlined in Figure 1
575 is an attempt to provide guidelines on how to minimise chemical use and their unintended
576 effects, together with suggestions on the circumstances under which alternative methods
577 would be appropriate within the context of subsistence agriculture rather than commercial
578 operations.

Table 1. Summary information on alternatives to use of fenthion for quelea control.

Method	Application	Mode of action	Advantages	Disadvantages	Socio-economic issues
<i>Chemical Methods</i>					
Cyanophos	Spray	Lethal organophosphate avicide.	Less toxic than fenthion. Colonies and roosts of any size can be treated	High risk of environmental impacts. (Mullié et al., 1999, Cheke et al., 2013) Killing action takes longer than fenthion, so could lead to more secondary poisoning than fenthion. (Allan, 1997)	More expensive than fenthion. (Fenthion costs approx. US\$10 per litre [www.yufull.com]). Requires trained personnel and expensive equipment, e.g. applied by Government personnel or international control agencies.
Alphachloralose	Narcotic added to bait grain or water (Garanito et al., 2000)	Immobilises birds.	Minimal pollution.	Risk to non-target birds. Requires birds to be found and killed. Only possible for small sites (< 5ha)	Labour intensive.

Mesurool (Bruggers 1989)	Sprayed on seed heads of crops or applied as seed dressing.	Carbamate pesticide, active ingredient methiocarb. Repellent. Deters birds from crops. (Allan, 1997)		Risk to non-target birds and mammals. Highly toxic to aquatic fauna. Now not recommended for direct use on crops, only as seed dressing. Now banned by the EU.	Expensive. Approx. US\$300 per litre. Labour intensive.
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Mechanical Methods

Explosions (Cheke et al., 2013)	Diesel/petroleum firebombs detonated beneath birds.	Lethal	No organophosphates or aircraft involved.	Risk to non-target birds and mammals. Petroleum product residues pollute soil. Vegetation damage. Fire and security risks. Only possible for small sites (< 5ha)	Expensive. Requires trained personnel and expensive equipment, e.g. applied by Government personnel.
Nest destruction and chick harvesting (Bashir 1989, Jaeger and Elliott, 1989)	Human intervention with sticks on poles or flame throwers	Lethal	No pollution. Provides source of protein.	Labour intensive. Often possible only on small scale (colonies <10ha) but see Pelham (1998).	Profits possible, if surplus chicks sold as food or livestock feed.

Trapping with Chad or basket traps or other trapping methods (Mullié et al., 2000, Mtobesya, 2012)	Human intervention with various trap designs.	Lethal	No pollution. Provides source of protein.	Labour intensive. Often possible only on small scale (areas <10ha).	Profits possible, if surplus birds sold as food or livestock feed, e.g. annual value of US\$50,000 to 100,000 in Chad (Mullié et al., 2000).
Trapping with mist nets (Elliott et al., 2014)	Human intervention with various trap designs.	Lethal	No pollution. Provides source of protein.	Labour intensive. Often possible only on small scale (areas <10ha). Needs supervision to avoid non-target mortalities.	Profits possible, if surplus birds sold as food or livestock feed. Locally sourced nets at cost of only US\$5 each.
Roost traps (Jarvis and La Grange, 1989, Allan, 1997, Mtobesya, 2012).	Planting of fodder crops to attract birds to roost, followed by spraying.	Lethal		High risk of environmental impacts. Possible only on small scale (areas <10ha).	Loss of area where crops could be planted.

Cultural Methods

Planting and harvest date manipulation (Elliott, 1979,	Planting of fast-maturing crop varieties or early	Avoidance of quelea attacks on crops.	No pollution. Can be done on large scale	Not always possible. Requires knowledge of likely quelea movements into and out of cropped	Agronomic advice needed.
--	---	---------------------------------------	---	---	--------------------------

Bullard and Gebrekidan 1989)	harvesting to minimise risk of quelea at harvest. Planting of crops that are not susceptible to attacks.			zone. Alternative crops may not flourish in zone, especially in very arid areas.	
Netting crops (Elliott & Bright, 2007)	Covering crops with netting	Protective	No pollution.	Only on small scale. May just divert birds to crops with no netting present.	Expenditure on nets and poles or gantry to rig them on
Scaring by people (Bashir, 1989)	Farmers and their children scare birds	Birds frightened away from crops by waving and noise.	No pollution.	Labour intensive. Often possible only on small scale. May just divert birds to crops with no scarers present.	Prevents children attending school. Labour intensive.
Scaring with falcons (Gaemengwe, 2014)	Release of falcons near quelea flocks.	Birds frightened away from crops.	No pollution.	Requires trained birds and bird handlers. May just move quelea to fields where falcons not deployed.	So far only used by large scale commercial farmers not by subsistence farmers.

Biological Methods

No successful biological control

agents identified to date.

Table 2. Dosages of fenthion (litres.ha⁻¹) sprayed on quelea roosts and colonies in Tanzania during the 2012-2016 seasons. Means and standard deviations calculated from raw data on spraying operations reported by Mutahiwa (2016). n = sample size; SD = standard deviation.

Year	2012	2013	2014	2015	2016
<i>Roosts</i>					
Mean litres.ha ⁻¹	4.79	4.03	4.20	2.72	2.98
n, SD	21, 3.95	12, 2.50	10, 2.85	30, 0.56	31, 1.92
Range	1.25 – 15	1.5 – 10	1.67 – 10	2.22 – 4.76	0.55 – 10
<i>Colonies</i>					
Mean litres.ha ⁻¹	1.63	3.02	3.08	2.5	2.47
n, SD	11, 0.76	10, 2.92	33, 1.82	1, -	31, 1.92
Range	0.67 – 3.33	1.43 – 11.11	0.73 – 10	-	0.62 – 10

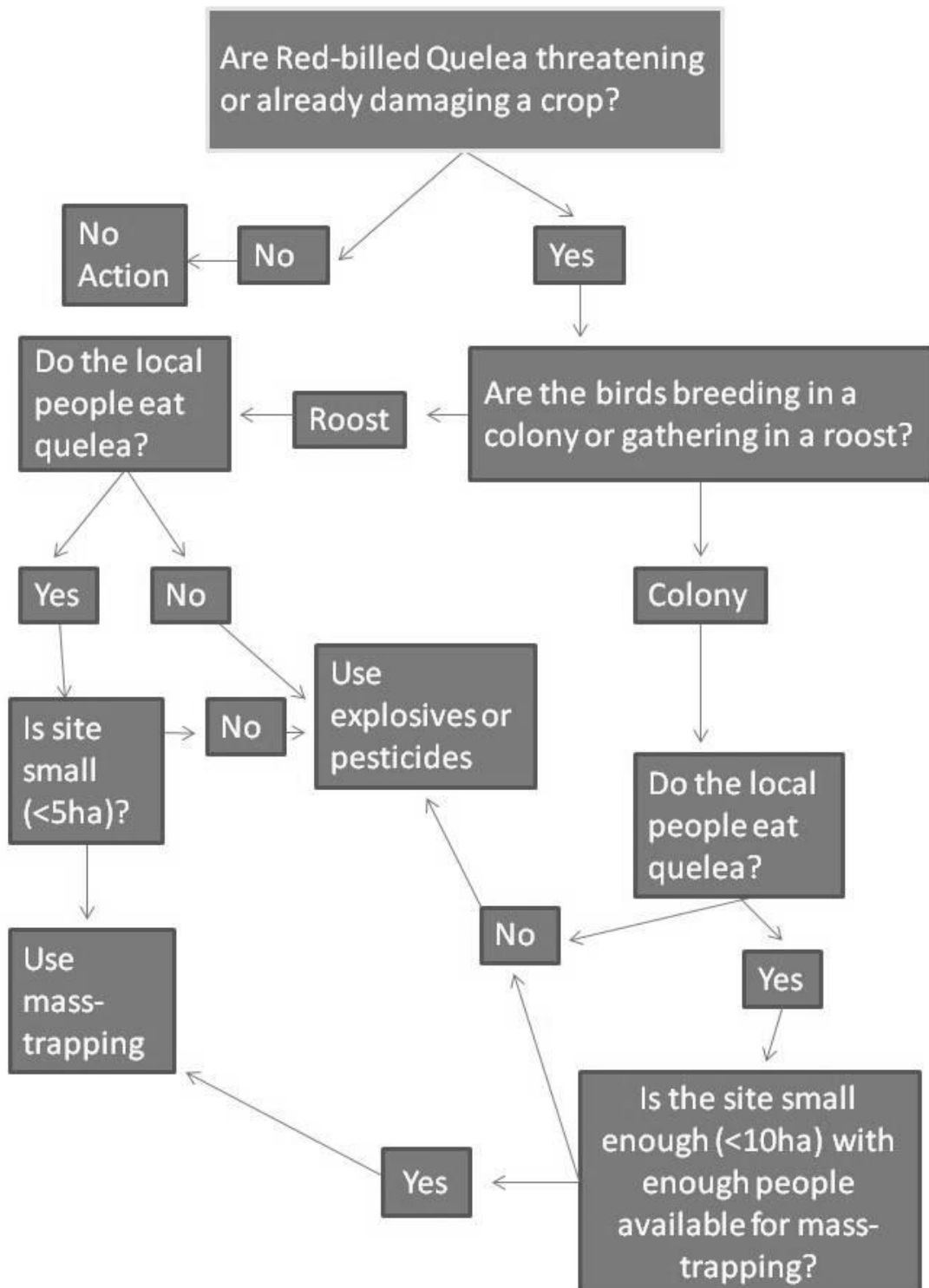


Figure 1. Flow diagram of decisions for planning quelea control by responsible authorities for subsistence farmers.

Disclaimer

The views expressed in this information product are those of the authors and do not necessarily reflect the views or policies of FAO.

Acknowledgements

We are grateful to Hendrick Modiakgotla, Boaz Mtobesya, Etienne van der Walt and the late Dr Clive Elliott for information and the latter for comments on an earlier draft. We thank Dr Stephen Young for statistical help and the Rotterdam Convention Secretariat in FAO for funding the preparation of this report. We are also grateful to Christine Fuell and Elisabetta Tagliati of the Secretariat's staff and to two anonymous referees for comments on an earlier draft.

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