Deterring Crop-Foraging Wildlife

Lessons from farms in north-western Uganda

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Introduction

Addressing interactions and conflict between subsistence farmers and crop-foraging wildlife is an increasingly crucial conservation issue. Crop foraging often compromises food security, reduces tolerance of wildlife, and undermines management efforts. Although many species in many regions consume crops regularly, there are relatively few accounts of systematic testing of techniques to protect crops from wildlife. Working in partnership with farmers in villages adjacent to Budongo Forest Reserve, Uganda, observational sampling, interviews, and focus groups were used to examine the dynamics of crop foraging. Data were collected across two consecutive crop-growing seasons. Total observational sampling time exceeded 4,000 hours over almost 800 sessions and was representative across farms, months, days of the week, and time of day. Baseline data were collected and analysed in the first year (Year 1) then used to develop and evaluate a series of deterrents to crop foraging during the second year (Year 2).

Primates were the predominant diurnal crop foragers and bush pigs (*Potamochoerus porcus*) were the main nocturnal foragers. Six species of primate were observed consuming crops on farms: chimpanzees (*Pan troglodytes schweinfurthii*), olive baboons (*Papio anubis*), black & white colobus (*Colobus guereza occidentalis*), vervet monkeys (*Chlorocebus aethiops*), blue monkeys (*Cercopithecus mitis sthuhlmannii*), and red-tailed monkeys (*Cercopithecus ascanius schmidti*). Patterns of crop foraging varied spatially and temporally, crop foraging behaviour differed across species, and losses were expensive for farmers. Rate of crop foraging events (CFEs) was aligned with crop availability and maturation, with maize (*Zea mays*) and beans (*Phaseolus vulgaris*) consumed most frequently. Number of individuals foraging, duration of foraging, and distance travelled onto farm determined the amount of crop loss that occurred during CFEs.

Farmers did not detect crop foraging completely and may underestimate foraging activity or extent of crop damage by wildlife. Farmers used a range of crop-protection methods, usually in combination but only intermittently effective. Deterrents implemented and tested by the project at study farms included alarm systems to improve early detection of wildlife, barriers (nets or fences) and border crops, natural repellents, systematic guarding, and alternative crop locations. Farmers identified benefits and shortcomings for each deterrent, which contributed to a comprehensive understanding of costs associated with each deterrent. Insights from the project inform intervention strategies to address crop-foraging issues and the development of affordable, locally-appropriate options to mitigate crop losses to wildlife.

Because wildlife and their habitats can only be protected effectively with support from local people, it was considered critical to work in partnership with stakeholders when developing and implementing deterrents. Actively involving all stakeholders in each stage of mitigation (a) provides a better understanding of perceptions and any differing perspectives, (b) ensures aims, actions, and outcomes are likely to be relevant for stakeholders and aligned with their interests or concerns, (c) ensures interventions will be locally appropriate and consistent with norms and customs, (d) increases ownership of key issues and the need to find solutions, and (e) maximises the probability that strategies will be effective, and hence used or adapted for the long term (see Hill, 2005; Osborn and Hill, 2005; Hill and Wallace, 2012; Wallace and Hill, 2012). Although many methods traditionally employed by farmers for protecting crops from wildlife are not legally sanctioned, it is unreasonable and impractical to expect farmers to stop using methods they perceive to be effective without providing access to alternatives aligned with conservation goals (Hill, 2004; Osborn and Hill, 2005; Hill, 2015).

Strategies to reduce crop damage by wildlife should not only deliver reduced crop loss for farmers through effective deterrent interventions, but also reduce the associated social costs and increase local tolerance of wildlife (Hill et al., 2002; Gillingham and Lee, 2003; Dickman, 2010; Mackenzie and Ahabyona, 2012). Primary application of the project's outputs is reducing crop foraging (and hence crop losses and costs for farmers) using non-lethal methods aligned with conservation goals. The project's central objective was developing effective, affordable, and locally-appropriate deterrents to crop foraging in partnership with farmers.

The aims for this document are to (1) review techniques reported to deter crop foraging by wildlife, including main considerations for planning deterrent interventions, (2) describe the series of deterrents tested at farms, including evaluating their efficacy, perceived benefits, or shortcomings, (3) detailing the materials and construction of each deterrent, and (4) explore factors to take into account when evaluating deterrents. For further project information see Wallace (2010), Hill and Wallace (2012), and Wallace and Hill (2012).

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Background

To develop effective and affordable methods of crop protection it is necessary to measure and understand crop-foraging activity occurring within an area, including the foraging behaviour of local animal species. Integral to this is a detailed record of the frequency and patterns of crop-foraging events (CFEs), the species involved, and the types of crop consumed, and key parameters of CFEs.

Observed and farmer-reported crop foraging

A total of 502 CFEs (249 in Year 1 and 253 in Year 2) involving fifteen animal species were observed during the project (Table 1).

Table 1 Frequency and proportion of CFEs observed during the project.

Species and species-group	CFEs during Year 1		CFEs during Year 2		CFEs over both seasons	
	n	%	n	%	n	%
Baboon	76	30.5	71	28.1	147	29.3
Blue monkey	26	10.5	41	16.2	67	13.3
B&W colobus	6	2.4	1	0.4	7	1.4
Chimpanzee	12	4.8	4	1.6	16	3.2
Red-tailed monkey	58	23.3	89	35.2	147	29.3
Vervet monkey	40	16.1	10	3.9	50	10.0
Primates	218	87.6	216	85.4	434	86.5
Banded mongoose	1	0.4	0	0.0	1	0.2
Casqued hornbill	1	0.4	0	0.0	1	0.2
Common duiker	1	0.4	0	0.0	1	0.2
Ground squirrel	5	2.0	0	0.0	5	1.0
Guineafowl	1	0.4	2	0.8	3	0.6
Other wildlife	9	3.6	2	0.8	11	2.2
Domestic chicken	5	2.0	0	0.0	5	1.0
Domestic duck	0	0.0	7	2.8	7	1.4
Domestic goat	13	5.2	28	11.0	41	8.1
Domestic pig	4	1.6	0	0.0	4	0.8
Farm animals	22	8.8	35	13.8	57	11.3
All	249	100.0	253	100.0	502	100.0

In addition to crop-foraging events observed directly by the project team, each participating farmer was trained to maintain records of CFEs occurring when the team were not present on the farm. A total of 345 CFEs (153 in Year 1 and 192 in Year 2) involving nine species were reported by farmers (Table 2).

Table 2 Frequency and proportion of CFEs reported by farmers during the project.

Species and species-group	CFEs during Year 1		CFEs during Year 2		CFEs over both seasons	
	n	**%**	**n**	**%**	**n**	**%**
Baboon	72	47.1	68	35.4	140	40.6
Blue monkey	10	6.5	12	6.3	22	6.4
Chimpanzee	19	12.4	18	9.4	37	10.7
Red-tailed monkey	21	13.7	16	8.4	37	10.7
Vervet monkey	8	5.2	7	3.6	15	4.4
Primates	130	84.9	121	63.1	251	72.8
Bush pig	20	13.1	58	30.2	78	22.6
Common duiker	0	0.0	2	1.0	2	0.6
Ground squirrel	0	0.0	7	3.6	7	2.0
Porcupine	3	2.0	4	2.1	7	2.0
Other wildlife	23	15.1	71	36.9	94	27.2
All	153	100.0	192	100.0	345	100.0

Examples of crop damage on participating farms during Year 1 are shown in Figures 1 and 2.

Figure 1 Extensive damage by baboons to maize stems at a study farm in Year 1.

Figure 2 Extensive damage by bush pigs to stems of sweet cassava at a study farm in Year 1.

Crops consumed during CFEs during the project are summarised in Tables 3 and 4.

Table 3 Proportion of observed crop-foraging events involving each type of crop compared to availability of the crop during the project. Availability is expressed as a proportion of the total area within 100m of the forest edge planted with the crop species.

	Year 1			Year 2		
	Proportion of CFEs (%)		Proportion of farm area planted with crop (%)	Proportion of CFEs (%)		Proportion of farm area planted with crop (%)
Crop consumed	*Primates only*	*All wildlife*		*Primates only*	*All wildlife*	
Maize	59.1	60.5	60.5	78.2	77.8	64.2
Beans	34.0	33.0	13.2	18.4	18.4	16.9
Bananas	5.9	5.7	5.1	1.9	1.9	3.0
Greens	5.4	5.3	< 0.1	1.9	1.9	< 0.1
Mangos	2.0	1.9	< 0.1	1.0	1.0	< 0.1
Papaya	1.0	1.0	< 0.1	0.5	0.5	< 0.1
Millet	0.5	0.5	2.3	0.0	0.5	1.3
Eggplant	0.5	0.5	< 0.1	0.0	0.0	< 0.1
Pumpkin	0.5	0.5	< 0.1	0.0	0.0	< 0.1
Passionfruit	0.0	0.0	< 0.1	1.0	1.0	< 0.1
Sweet potato	0.0	0.0	0.2	0.5	1.0	1.2
Cassava	0.0	0.0	4.0	0.5	0.5	2.8
Jackfruit	0.0	0.0	< 0.1	0.5	0.5	< 0.1

Table 4 Proportion of reported crop-foraging events involving each type of crop compared to availability of the crop during the project. Availability is expressed as a proportion of the total area within 100m of the forest edge planted with the crop species.

	Year 1			**Year 2**		
	Proportion of CFEs (%)		**Proportion of farm area planted with crop (%)**	**Proportion of CFEs (%)**		**Proportion of farm area planted with crop (%)**
Crop consumed	*Primates only*	*All wildlife*		*Primates only*	*All wildlife*	
Maize	64.3	69.2	60.5	60.0	65.1	64.2
Beans	20.6	17.8	13.2	27.0	24.9	16.9
Bananas	8.7	7.5	5.1	0.9	0.6	3.0
Mangos	7.9	6.8	< 0.1	3.5	2.4	< 0.1
Papaya	4.0	3.4	< 0.1	2.6	1.8	< 0.1
Cassava	1.6	1.4	4.0	4.3	6.5	2.8
Sugar cane	1.6	1.4	1.0	1.7	1.2	2.0
Rice	0.8	0.7	0.7	0.0	0.0	2.4
Sweet potato	0.8	0.7	0.2	3.5	3.6	1.2
Eggplant	0.8	0.7	< 0.1	0.0	0.0	< 0.1
Passionfruit	0.8	0.7	< 0.1	0.9	0.6	< 0.1
Jackfruit	0.0	0.0	< 0.1	3.5	2.4	< 0.1

Vulnerability to crop foraging, and therefore patterns of CFEs across an area can depend on many variables, including (a) ranging and habitat use by crop-foraging species, (b) types of vegetation or refuge adjoining crop fields, (c) species' diets and/or nutritional requirements, (d) proximity of crop fields to human settlements, especially sites of high population density, (e) whether farmers reside on their farms, (f) hunting or guarding activity by neighbouring farmers, and (g) the number of farms between a farm and wildlife habitat. CFE probability is often tied to proximity to forest or other wildlife habitat; most crop loss occurs within 200m (and particularly 100m) of a forest edge and decreases with greater distance from forest (see Naughton-Treves, 1998; Hill, 2000; Chism, 2005; Priston, 2005; Wallace, 2010). In practice, the methods used by farmers for crop protection may be the only variable in vulnerability to crop foraging that they can feasibly control.

Because deterrent effectiveness is ultimately linked to reduced crop loss per unit of cost and farmer effort, the primary characteristics of CFEs will be those determining how many stems are damaged. These characteristics include how many individuals forage, how far they travel onto farms while foraging, and how long they forage for (see Wallace and Hill, 2012). Each parameter will probably differ between species and across prevailing circumstances, and are likely to reflect tactics or strategies used by crop-foraging animals. Understanding foraging behaviour, species-specific CFE parameters, and patterns of foraging at farms should enable development of reasonably targeted and fine-tuned, and hence effective, deterrents.

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Figure 3 Sub-adult baboon being vigilant while consuming greens at a farm.

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Figure 4 A pair of vervet monkeys being vigilant in a field of mature beans at a farm.

Types of Deterrents

Farmers are known to use a wide range of methods to protect their crops from wildlife; these are often used in combination and perceptions about effectiveness are frequently mixed (Sitati and Walpole, 2006; Graham and Ochieng, 2008; Hill and Wallace, 2012). Deterrents can be categorised according to how they operate (such as passive, active, physical, sensory, lethal, vigilant, barrier, alarm, repellent) and most can be assigned to two or more categories. Some methods, such as burning pepper dung to deter elephants (Osborn and Parker, 2002) or using monofilament lines and flags to deter ducks (Lane and Higuchi, 1998), are species-specific; methods such as guarding or using traps and wire fences may deter a broad range of species.

Guarding crops and responding to wildlife

Guarding crops, including vigilance and patrolling crop fields, is frequently the primary crop protection technique used by subsistence farmers (Webber, 2006; Hill and Wallace, 2012). In addition to requiring one or more humans to be near crops during the times crop foragers are active, guarding ideally involves active vigilance such as scanning farm-forest edges as well as regular patrolling through crop fields. Although presence and patrolling can deter wildlife, guarding usually also involves active responses towards animals detected within or near crop fields. Common responses are chasing (often with dogs), throwing objects (usually rocks and sticks), waving a spear or tool in a threatening manner, making a loud noise (such as banging drums or tins, shouting, and clapping hands), waving arms, using torches or whistles to alert others, or using a catapult or bow and arrows (see Wallace, 2010). Many guarding responses can kill or injure wildlife if caught. Most responses are used in combination; if consistently well-executed they may enhance guarding efficacy over time by maintaining a high level of risk for crop foragers (Osborn and Hill, 2005).

Because guarding is labour-intensive and requires substantial regular effort it often involves social and opportunity costs for farmers. All family members may be expected to assist with guarding crops, particularly during busy planting and harvesting stages of growing seasons, and when crop foraging can occur during the day and night. Farming families might forego social, education, and/or work activities to guard their crops unless they can afford to hire external labour (Hill, 2004; Dickman, 2010; Mackenzie and Ahabyona, 2012). Costs may be greater for female-only families at farms damaged by elephants or bush pigs at night, because it can be considered unsafe for women to actively respond to these animals or to be in fields at night (Osborn and Hill, 2005). Other hidden costs of guarding are risk of injury, exposure to malaria, and illness from cold or rain (Hill, 2004; Webber and Hill, 2014).

Fences, buffers, and trenches

Barriers such as fences, walls, hedges, trenches, and buffer areas may deter crop foraging by impeding or excluding access to fields or farms (see Hygnstrom et al., 1994; Conover, 2002). Barriers to wildlife have been built using diverse materials and at a range of scales. Although barriers are typically passive deterrents, they can also be used to bring potential crop foragers into contact with alarms or repellents, such as bells, tin cans, or chilli grease on fences (see Hill et al., 2002). The ability of a barrier to impede or prevent crop foraging varies according to foraging species and how well it is constructed and maintained (Conover, 2002; CARE et al., 2003). Farmers may perceive barriers as more effective than other deterrents because they physically and visibly separate people from wildlife (Webber, 2006); however, some barriers simply shift foraging to crop fields that are less protected, or may only be effective for small areas (Geisser and Reyer, 2004).

Most non-vegetation barriers are built with wire, mesh, or nets, or are stone walls (see CARE et al., 2003). Although wire fences can be most effective when electrified or enclosing crop fields, this is usually expensive and requires frequent maintenance (Hygnstrom et al., 1994; Sitati and Walpole, 2006). Compared to wire or mesh barriers, live barriers constructed from crops or plants unpalatable to foraging wildlife should be less costly for farmers because the required materials are often present or readily grown in agricultural areas. These are usually built as hedges or buffers at the edge of crop fields; they can be self-propagating or farmers can increase their length or width regularly from seeds or cuttings (Conover, 2002; Wallace, 2010). Ideally, plants comprising a barrier will also have direct economic value for farmers. Crops or plants often considered effective as a hedge, buffer, or repellent are Mauritius thorn (*Caesalpinia decapetala*), varieties of prickly pear such as *Opuntia exaltata*, chilli (*Capsicum* sp.), sisal (*Agave letonae*), soya beans (*Glycine max*), sunflower (*Helianthus annuus*), tobacco (*Nicotiana tabacum*), rice (*Oryza sativa*), tea (*Camellia sinensis*), or coffee (*Coffea* sp.).

Buffer areas are usually located along farm boundaries closest to wildlife habitat, and either cleared of vegetation to improve view of approaching wildlife or planted with crops aversive and/or unpalatable for wildlife (Hygnstrom et al., 1994; CARE et al., 2003). A buffer planted with a crop that is (a) low-growing or easily trimmed as well as (b) aversive or unpalatable to wildlife should be particularly useful for a farmer. The greater a buffer's length or width the more likely it will be effective (Nyhus and Tilson, 2004). Although it is frequently suggested that buffer crops be economically profitable for farmers to justify using land that otherwise could be planted with cash or food crops, this can undervalue the primary aim of generating savings in crop loss. If crop damage is a major problem, the deterrent properties of a buffer should have priority in farmers' considerations.

Although trenches or ditches, including moats filled with water, have been reported as useful barriers to wildlife in various contexts (see Hygnstrom et al., 1994; Conover, 2002; Hill et al., 2002; CARE et al., 2003; Sitati and Walpole, 2006), they can be costly and labour-intensive to construct and maintain, particularly at large scales or in high-rainfall areas. These factors can undermine the utility and/or value of trenches for subsistence farmers. A trench must be sufficiently deep and wide to prevent target species from climbing in it, jumping across it, or filling it by digging (Conover, 2002; Sitati and Walpole, 2006).

Alarms and repellents

Alarms, such as bells, metal objects, and motion-activated lights or sound, are usually used in conjunction with a barrier to signal animal presence when interacting with the barrier. Alarms are intended to provide early warning of crop foraging activity so farmers can respond before damage occurs or becomes substantial; neighbours can be warned using whistles or torches (Osborn and Parker, 2002; Sitati and Walpole, 2006). Alarms require farmers to be on-farm and respond to wildlife: for example, being vigilant and/or guarding. Although an alarm can repel wildlife when initially activated, animals may re-test alarms over time; alarms usually lose deterrent properties if farmers fail to respond (Conover, 2002). Dogs can be most useful to detect and signal the presence of wildlife, and respond alongside farmers (Warren et al., 2007; Priston et al., 2012).

A diverse range of actions, objects, substances, or sensory stimuli have been reported to deter crop foraging wildlife by scaring and/or repelling them (see Hygnstrom et al., 1994; Conover, 2002; CARE et al., 2003). Repellents operate by inducing fear or causing discomfort or pain. Primary repellents are inherently and directly noxious or aversive (such as chemical sprays);

secondary repellents acquire deterrent properties through learned association with a noxious or aversive stimulus (such as sounds paired with a chemical spray) (Bryant et al., 2000).

Animals usually habituate quickly to auditory repellents, such as firing guns, beating drums, or using whips or firecrackers, unless paired with chasing (Osborn, 2002); remote exploders can be effective if activated by animal motion rather than on timed or programmed cycles (Belant et al., 1996). Similarly, many visual repellents, such as flashing lights, pyrotechnics, coloured lasers, flags, bright or reflective objects, monofilament lines, and scarecrows, often fail to deter wildlife unless tied to active responses (Lane and Higuchi, 1998; Conover, 2002; Gorenzel et al., 2002; VerCauteren et al., 2006a; VerCauteren et al., 2006b).

Conditioned taste aversion techniques attempt to make a target food noxious for animals by associating the food with symptoms of ingesting mild poison (Conover, 2002; Forthman et al., 2005). Although these methods apply basic learning principles and may alter food preference for numerous species, they can be difficult to implement and maintain because animals often detect emetics and learn to avoid treated food items (Forthman et al., 2005; Lee and Priston, 2005). Compounds stimulating satiation have reduced crop damage by rodents (Cotterill et al., 2005), while aversive conditioning and predator simulation has repelled deer and elk that were habituated to other methods (Kloppers et al., 2005; Seward et al., 2007).

Chilli

Fruits of *Capsicum* species such as chilli contain capsaicin, which produces a hot and burning sensation when ingested (Osborn, 2002); the sensation can also occur on contact with moist skin, and dry skin if chilli is moist. Chilli is unpalatable and potentially noxious to numerous vertebrates. Chilli applied to rope fences, burned, or sprayed in aerosol solution has repelled elephants (Hoare, 2001; Parker and Osborn, 2006; Graham and Ochieng, 2008). Although the low strength of rope fences used with elephants confirms deterrent effects are derived from the chilli (Osborn and Parker, 2002), the ropes are a key means of bringing chilli into contact with elephants. Chilli has also been effective as a repellent when added to liquid and sprayed, mixed with dung and burned to create smoke, or scattered along paths used by wildlife; it is also possible to link chilli with sounds or lights as a secondary repellent (Osborn, 2002). Natural chemicals or synthetic commercial compounds have been used with mixed success to repel elk, deer, caribou, beavers, badgers, prairie dogs, gophers, and birds (Nolte et al., 1993; Hygnstrom et al., 1994; Hygnstrom et al., 1998; Nolte, 1998; Stevens and Clark, 1998; Baker et al., 2005; Werner et al., 2007). Duiker can be repelled by soap or goat dung at field edges (Hill, 1997; Webber, 2006), while a predator's scent, dung, urine, or hair often repels a prey species (Epple et al., 1993; Epple et al., 1995; Conover, 2002; Seamans et al., 2002). Chilli can also be a valuable cash crop for farmers due to high yield and usually high market prices, particularly where grown by farmer cooperatives at larger scale to meet commercial demand. Most farmers can produce chilli in sufficient quantity for use as a deterrent to wildlife, even where grown in small plots (Osborn and Parker, 2002).

Indirect crop-protection methods

The frequency or extent of crop foraging at a farm might also be reduced by methods that do not involve active responses by humans or direct interaction between animals and deterrents. Planning land uses, allocating crop zones, or growing key crops in places less accessible for wildlife (such as in dispersed fields, more than 100m from forest edges, or near housing on farms) may inherently deter foragers and minimise the resources required for crop protection. However, this will depend on farm size, area required for fallow fields, the land's suitability for specific crops, and required crop yields. It can be effective to synchronise planting and maturation of crops with neighbouring farms to ensure availability of crops does not differ between farms during the growing season; this might also make cooperative guarding more feasible for farmers because they would be farming on shared schedules (CARE et al., 2003; Warren et al., 2007). Growing alternative crops less palatable to wildlife may reduce losses, but is typically not economically viable for farmers (Hill, 2005). Providing alternative food sources (i.e. provisioning), and/or ensuring natural foods are not depleted except in seasonal patterns, could also reduce crop foraging (Conover, 2002; Geisser and Reyer, 2004).

Removing crop foragers

More extreme methods of crop protection involve removing or reducing crop foragers using relocation, fertility control, hunting or eradication, or destruction of habitat (Osborn and Hill, 2005; Southwick et al., 2005; Treves and Naughton-Treves, 2005). Although translocation of problem animals can be effective, notably large carnivores to reduce livestock depredation, it is often expensive and logistically complex, and might simply transfer the problem to another area (Dublin and Niskanen, 2003; Bradley et al., 2005; Goodrich and Miquelle, 2005; Strum, 2005). Lethal removal of crop foraging wildlife can occur through hunting or use of traps, snares, weapons, baits, or poisons by farmers, and in many areas these are probably the most traditional of farmers' responses to crop damage (Hill et al., 2002; Hill, 2004). Trapping may involve catching animals then releasing them away from farms (Webber et al., 2007). Lethal control does not always produce the desired outcome: it might not deter conspecifics (Sitati and Walpole, 2006), animals can learn to avoid traps and baits (Morgan et al., 2001), traps, baits, or poisons are often not species-specific and could impact non-target animals (Osborn and Hill, 2005), other individuals or groups usually expand into a vacated territory to replace those removed (Osborn and Hill, 2005), and removal frequently alters or skews the structure of animal populations (Hill et al., 2002; WWF, 2005). Lethal methods are also often illegal, can carry penalties for farmers, and usually conflict with long-term conservation goals.

Deterrent Attributes

Although a method of crop-protection may operate to impede, prevent, repel, deter, or signal crop foraging (see Conover, 2002), the term *deterrent* refers here to any technique intended to protect crops from damage by animals, irrespective of how and/or at what stage of a CFE the technique influences animal behaviour.

A deterrent could be a sensory stimulus, structure, apparatus, tool, or set of actions, therefore encompassing (a) alarms, repellents, and barriers, (b) indirect methods such as synchronised planting or alternate locations for crops, and (c) traditional techniques such as guarding crop fields or chasing wildlife (CARE et al., 2003; Osborn and Hill, 2005; Hill and Wallace, 2012). While crop-foragers can adapt to deterrents over time, any activity that reduces the severity or frequency of crop foraging may acquire ongoing deterrent properties (Hygnstrom et al., 1994; Conover, 2002).

From the perspective of wildlife, an effective deterrent increases the perceived risks of crop foraging to exceed and override the benefits of consuming crops (Lee and Priston, 2005). Deterrent effectiveness is reflected in the presence or absence and behaviour of crop foraging animals, and may be measured through the frequency, patterns, and parameters of species' foraging activity. Because many animals can habituate to crop-protection methods, the most effective deterrents over longer terms are likely to be adaptive and locally-appropriate rather than complex, expensive, or all-encompassing (see Osborn and Hill, 2005; Hill and Wallace, 2012). The utility of an effective deterrent can typically be derived in quantitative terms by comparing savings in crop losses with costs of the deterrent over time. However, deterrent utility also has a qualitative dimension, and is influenced by farmers' perceptions about the effort and costs, including any opportunity costs, to implement and maintain the deterrent (Graham and Ochieng, 2008; Wallace, 2010). Accordingly, a deterrent's value to a farmer is a function of how well it addresses the need to reduce or prevent crop foraging, relative to the time and resources the farmer is willing or able to invest in protecting crops. It is therefore productive to approach deterrent strategies as cost-benefit scenarios.

Planning Deterrents

Although a deterrent technique may be used frequently, widely, or over long periods of time, this does not necessarily mean it is effective; rather, farmers could perceive they lack feasible alternatives. This is often the case for subsistence farmers, where traditional crop protection methods can be labour-intensive, inefficient, and ineffective but the only options farmers can afford or access with available resources (Hill et al., 2002; Hill and Wallace, 2012). However, traditional deterrents such as basic fences, vigilance, guarding, throwing objects at wildlife, and chasing or (where permitted) culling wildlife may be appropriate in a range of contexts, especially when used systematically (see Osborn, 2002; Wallace, 2010). Traditional methods should be considered first when planning to address crop foraging: techniques that farmers are familiar with are likely to be locally acceptable and more-readily modifiable to suit changing circumstances, and also easier to build upon when greater efficiencies are required.

It is therefore important to understand the entire context of crop foraging and any associated conflict prior to implementing a deterrent intervention (Sitati and Walpole, 2006; Graham and Ochieng, 2008; Wallace and Hill, 2012). This includes knowing the behaviour and ecology of crop foragers, types of crop grown on farms, and the extent and frequency of crop foraging (Wallace, 2010; Wallace and Hill, 2012). Farmers' attitudes and perceptions about wildlife should be assessed to ensure actions and anticipated outcomes are likely to address farmers' concerns (Osborn and Hill, 2005; Hill and Wallace, 2012). Consulting with farmers and local leaders is imperative, particularly to agree plans and goals, and be informed about the steps, limitations, resources, or timeframes to be taken into account (Wallace, 2010; Mackenzie and Ahabyona, 2012). Interventions should fit with local social norms and constraints, age- and gender-specific roles on farms, and labour availability across agricultural seasons (Hill, 2005; Dickman, 2010). Involving farmers actively in planning, implementing, and evaluating crop protection often increases their ownership of methods and commitment to finding solutions, decreasing reliance on 'outsiders' (Sitati et al., 2005; Hill and Wallace, 2012; Hill, 2015). If deterrents provide crop-loss savings for farmers there should be fewer calls for compensation for damage by wildlife. Compensation can be counter-productive because it does not reduce crop foraging, diminishes incentives to protect crops, and can lead to deliberate damage and exaggerated claims (see Hoare, 1995; Bulte and Rondeau, 2005; Sitati and Walpole, 2006). Ideally, implementing deterrents should be part of a larger conflict-mitigation strategy to not only decrease the frequency and severity of crop loss, but also increase tolerance of wildlife by reducing the impacts of crop foraging for farming communities.

Approach and Rationale for Deterrents

It was considered important that the deterrents reported here had the following characteristics otherwise the techniques would be impractical and have little value for farmers.

- Relatively or potentially affordable for local farmers.
- Used materials that farmers could source locally.
- Easy for farmers to use.
- Requiring relatively low ongoing maintenance in terms of effort and cost.

However, in this context the primary objectives were to determine which deterrent methods reduced crop foraging, assess how these deterrents operated, establish why they were effective, and gauge how useful they might be for farmers. Therefore when an alternative crop was assessed as a deterrent the cash saleability or immediate profitability of the crop for a farmer was not the driving factor in deterrent evaluation. Because economic conditions and markets for specific crops will fluctuate over time, developing deterrents that were effective in terms of impacts on crop foraging took precedence over the short-term crop marketability. It is also likely that donor support will be available to help farmers defray the cost of deterrents if their efficacy has been demonstrated and can be measured.

Deterrent methods, experiences, and considerations were explored with farmers during focus group sessions before the crop-growing season. Focus groups supplemented discussions with individual farmers and generated a wide range of ideas and options for deterrents; most were uncomplicated and affordable, and could be readily implemented. Farmers were also positive about potential deterrent techniques suggested by the research team from analysis of wildlife crop foraging activity observed and reported at farms over the previous year. Results for the prior year were used to identify which deterrents would probably be (a) best evaluated and rigorously tested compared to baseline data for each farm, and also (b) of greatest benefit to individual farmers given the patterns and frequency of crop foraging observed at each farm. These data were used alongside each farmer's preferences to allocate deterrents to farms for implementation, and farmers agreed it was not feasible to test all deterrents at each farm. The effectiveness of a deterrent was evaluated by comparing frequency, patterns, and parameters of crop foraging with baseline values for the previous year, as well as the behaviour of crop foraging wildlife in each season.

Ongoing consultation with farmers ensured each deterrent was implemented, monitored, and evaluated in partnership with farmers. Farmers were advised that techniques to deter wildlife can operate in different ways and require different levels of farmer input. Techniques can be grouped into three categories that differ according to when a deterrent operates, is used by farmers, or has effect on animals during a crop foraging event (CFE):

Firstly, deterrents can impede or prevent entry to farms or crop fields. These deterrents (such as fences, trenches, or other barriers) operate before crop foraging occurs and are particularly valuable because they restrict CFE frequency or eliminate foraging. Deterrents that impede farm entry will also impede farm exits, which could reduce the duration of crop foraging if species learn they need to allow more time to escape. These deterrents usually require only minor input from farmers, other than construction and ongoing maintenance.

Secondly, deterrents can alert farmers to the presence of animals that are attempting to enter or have entered the farm, allowing the farmer to respond to their presence. These deterrents (such as alarms, bells, or other warning systems) have effect when foraging is attempted or when an animal travels on the farm, and limit the CFE parameters influencing the amount of stem damage sustained (see Wallace and Hill, 2012). These deterrents require a farmer to construct and maintain the deterrent, and actively respond when signalled.

Thirdly, deterrents can repel animals that have travelled on the farm and are foraging. These deterrents (such as guarding, dogs, using loud noises, or using chemical sprays) have effect when animals are already in fields and consuming crops, and also limit the CFE parameters determining stem damage. These deterrents require a farmer to be vigilant, allocate time for patrolling or monitoring, and actively respond when foraging animals are detected. However, deterrent construction or maintenance is typically not required unless the farmer uses a guard hut and/or provides food and care for dogs.

The categories of deterrent outlined above are not mutually exclusive. For example, farmer vigilance and guarding could also provide warning of crop foraging before or when animals enter the farm. Nets and bells used as an alarm may also act as a barrier to impede entry to a farm. Over time, effective guarding could deter animals from approaching a farm. Similarly, deterrents will probably reduce crop foraging frequency if they decrease the returns derived by wildlife. Deterrents can achieve this by improving farmers' ability to detect CFEs, which increases the risks of crop foraging, or by limiting the parameters determining crop loss.

Farmers were also advised that deterrents can differ in impact for different farms as well as for different animal species. Therefore, farmers' experiences of a deterrent may vary as part of determining whether and how a technique worked, and whether it operated specifically or broadly. Farmers were advised that it may be necessary to adjust or modify techniques over time because animals can habituate to deterrents and develop ways to bypass them. A broad range of tools, techniques, and structures to deter crop foraging were implemented at study farms, including barbed-wire fences, mesh fences, rope fences, solar lights, trenches, crop or vegetation barriers, chilli powder, nets, bells, systematic guarding, dogs, glasses for farmers, alternate crop locations and timing for planting crops, and synchronisation of crops. Some of the deterrents were used in combination.

Although reduced crop loss was the main measure of deterrent value, farmers also identified long-term effectiveness as an important consideration when deciding whether to invest in a deterrent. Deterrents that are more expensive in terms of cost and effort can still have value and warrant use if they provide returns for relatively long periods. Deterrents that are useful for short periods of time or less effective, such as scarecrows, warrant a smaller investment.

Because farmers measured deterrent value in costs and benefits over time, it was possible to evaluate techniques using relatively long-lasting but more-expensive materials that a farmer would need to plan to purchase (probably from savings) rather than access from the forest. It was important that forest resources were not relied on to construct or operate the deterrents. Additionally, because the project involved testing a wide range of deterrents and could not guarantee outcomes for farmers, all costs for materials or related expenses (such as transport of materials to farms) were paid from project funds. Although farmers incurred effort costs trialling deterrents, project funding meant they accrued any benefits without monetary risks, allowing them to focus on deterrent utility and effectiveness. Where feasible, materials and labour were sourced locally to benefit the local economy.

The deterrents evaluated during the project are reported in four categories:

(1) fences and non-crop barriers.

(2) crop and vegetation barriers.

(3) alarm systems and guarding.

(4) indirect deterrents.

FENCES AND NON-CROP BARRIERS

Barbed-wire fences were used to assess the efficacy of fencing along the edges of crop fields, to enclose crop fields, and between crop fields. Other barriers were solar-cell lights to address crop foraging at night, a trench at a farm-forest edge, and nets and ropes to protect rice from damage by birds.

Barbed-Wire Fences

Although primates foraged at study farms more often than other wildlife, most farmers stated they would benefit greatly from techniques to deter foraging by bush pigs. Farmers envisaged benefits could be two-fold. Firstly, less foraging by bush pigs would reduce total crop losses and increase maize yields considerably, potentially more than for any other wildlife species. Bush pigs usually caused extensive damage when they foraged, particularly over consecutive nights. Because most bush pig CFEs occur relatively late in growing seasons when crops are almost mature, the impact of damage on farmer livelihood is usually greater than early in the season with sufficient time to replant damaged crops. Secondly, deterring bush pigs would mean farmers did not need to guard their crops as extensively at night, when bush pigs were most active. This would allow farmers to sleep more and allocate more time to working or guarding during the day, especially in the latter stages of crop-growing seasons when diurnal crop foraging is most frequent. Additional sleep and less guarding at night would probably have general health benefits for farmers and reduce their exposure to malaria (see Hill, 2004; Osborn and Hill, 2005). Many farmers suggested strong low fences constructed of posts and strands of barbed wire could prevent bush pigs from entering fields; fences could be low in height because bush pigs do not climb or jump, although they regularly dig.

The indicative design of barbed-wire fences tested at farms is shown in Figure 5. Each fence comprised a series of pine (*Pinus pinnata*) posts to which three or four strands of barbed wire were attached. All posts were sourced from local plantations and immersed in chemical dips for six or seven days to increase their resistance to termites, other borers, and weather. Posts averaged 100mm in diameter and were 1.0m to 1.2m in length. Rolls of '16' gauge stainless steel (i.e. corrosion resistant) barbed wire were purchased locally. Galvanised 25mm U-nails were used to attach the barbed wire to the posts.

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Figure 5 Indicative design of barbed-wire fences constructed at farms to deter bush pigs.

Holes for posts were dug at 2.0m to 2.8m intervals along edges of fields to be fenced. Holes were 400mm to 500mm deep to ensure solid foundations for the fence. A pounding pole was used to pack soil and one post into each hole. Barbed wire was nailed to each post while the strand of wire was unrolled along the length of the fence. Nails were fixed to the side of the post facing where a bush pig would approach from; therefore if the wire was pushed it was against rather than away from the post and unlikely to detach. The wire was secured and cut at the last post in the fence and nailing of the next strand occurred in the opposite direction. Strands of wire were attached with a vertical spacing of 180mm to 220mm to ensure a bush pig would not be able to pass between any two strands. The lower strand of wire in a fence was secured 50mm to 70mm above ground level to deter bush pigs from attempting to dig under the fence. The upper strand of wire was secured 480mm to 580mm above ground level to ensure bush pigs could not step or jump over the fence. It took two or three people from three to five hours to construct each wire fence. It would be possible for a farmer to transport all materials for a barbed-wire fence with a bicycle and construct the fence with assistance from one or two people. If several farmers require a fence it could be beneficial to purchase materials together, and the farmers could also share transport and labour costs.

Fencing at the edge of crop fields

A 128m fence comprising four strands of barbed-wire was constructed along the edge of crop fields at one farm, extending over approximately 60% of the total length of the farm-forest interface. The fence bordered three of five fields along the farm-forest interface and crop availability was equivalent across years. Crop foraging (mainly by baboons or bush pigs) was extensive in these three fields previously but not in the other two fields. After the fence was constructed crop foraging only occurred in the two fields not bordered by the fence, which suggests the fence protected the fields it bordered by shifting foraging to adjacent fields. The fence not only deterred bush pigs but also primates, duikers, and porcupines, and accounted for a 72% decrease in CFE frequency over the farm-forest interface (see Wallace, 2010; Hill and Wallace, 2012). The farmer stated he gained more sleep at night, he could then work on the farm for more hours each day over most of the season (removing the need to pay people to help weed his crop fields), which allowed his wife more time on household tasks, and his family had lost less maize than in previous seasons. The farmer envisaged the fence would require only minor maintenance over three to four years; although the costs of replacing the barbed wire were potential shortcomings, he stated he had many years to accumulate funds and the fence would save him more money than this via better crop yields over future years.

Fencing to enclose a crop field

Extensive crop foraging by bush pigs during Year 1 of the project (see Figure 6) prompted a farmer to trial a three-strand barbed-wire fence to fully enclose a maize field in Year 2. The field was approximately 1,200m^2 in area and square in shape; it is considerably more cost effective to enclose a square rather than elongated area (i.e. when the ratio of perimeter units to area units approaches one) because it maximises the proportion of a farm protected by the fence (Conover, 2002). Figure 7 provides two views of the fence.

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Figure 6 Two views of a maize field following crop foraging by bush pigs during Year 1. The field was dense with maize before being damaged and the open areas indicate extent of crop loss; damaged stems have been cleared from the field.

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Figure 7 Two views of a three-strand barbed-wire fence constructed to fully enclose a maize field at a farm.

Crop availability was equivalent in the field over Years 1 and 2 of the project, and maize was predominant. Bush pigs did not forage within the field enclosed by the fence, even though all CFEs by bush pigs had previously been within this field. Signs of bush pig activity near the fence (such as tracks or digging near posts) were noted on several occasions, indicating pigs checked or tested the fence more than once; however, the posts or wire were not damaged. While bush pigs foraged at the farm more often in Year 2 than Year 1, the fence appeared to shift CFEs to unprotected fields very effectively. However, the fence did not deter primates from crop foraging within the protected field, suggesting fence height (three strands of wire versus four strands at the farm above) is a key factor when targeting primates.

Fencing between crop fields

A three-strand barbed-wire fence was constructed between two crop fields at another farm in Year 2 of the project, perpendicular to the farm-forest edge to partition fields along a central path: see Figure 8. The fence was 94m in length and oriented across on-farm trails used by bush pigs. The location of the fence was requested by the farmer due to a large increase in bush pig foraging in fields south of the fence, compared to very few north of the fence. Crop availability was equivalent across fields each year. Although incidence of crop foraging over

Year 2 was the same as Year 1, no CFEs occurred in fields south of the fence, indicating the fence was effective for deterring bush pigs from accessing crops within the protected fields. Also, even though the fence covered the corner of the south fields by only six metres at one end and followed a straight line, bush pigs did not appear to travel around either end of the fence to enter the south fields. This was probably mainly due to the long length of the fence.

Figure 8 Two views of a three-strand barbed-wire fence constructed between two crop fields.

Comparison of multiple-strand barbed-wire fences

Each barbed-wire fence described above deterred or shifted crop foraging by bush pigs very effectively. Results demonstrated that a barrier does not have to enclose a crop field entirely to be effective, particularly if it extends over a relatively long distance, is constructed along a large proportion of the farm-forest edge, and follows a relatively straight line. While the length and structural strength of a barbed-wire fence appeared to be important for deterring bush pigs, it did not matter whether the fence used three or four strands of wire; both were effective. Provided the wire strands have appropriate vertical spacing, using three instead of four strands reduces the costs of fence construction without compromising its effectiveness. Height above ground of the top wire in a fence seems to be influential for deterring primates. Although it was hoped that these fences might also deter some crop foraging by primates, it was not anticipated that they would deter primates or modify foraging patterns to the extent they did. The behaviour of primates during CFEs at farms with barbed-wire fences included frequent vigilance and travelling, indicating they were uncomfortable in fenced areas where barriers could impede escape from farmers.

Solar-Cell Lights to Deter Crop Foraging at Night

Farmers stated during interviews and focus group sessions that bush pigs and other nocturnal crop foragers could be deterred by signalling that a farmer was in fields and guarding at night. Farmers added that a common method of doing this was to light small fires along the farm edges; the rationale was that potential foragers would see a fire or smell the smoke, infer the farmer was guarding crops, and avoid the farm, which appeared sound. Because fires require an ongoing supply of wood and must be stoked regularly to remain alight, solar-cell lights (Figures 9 and 10) were used instead of fires to indicate human presence on-farm at night. It was envisaged the lights would be novel and possibly aversive stimuli for nocturnal wildlife, leading them to infer a farmer was guarding crops. The lights were made of weather-resistant materials, could be recharged daily by placing them in an open area, and easy to move; they were therefore likely to require a minimal time and maintenance investment from the farmer.

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Figure 9 Solar-cell lights used as deterrents at night.


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Figure 10 Solar lights recharging in sunlight at a farm during Year 2 of the project.

Each solar-cell light was portable and mounted on a short, spiked pole designed to be pushed into the ground. The bulb of each light was approximately 350mm above ground level when the light was in place. The cap of each light included a power cell that was rechargeable in sunlight. Either three to four hours of full sunlight or five to six hours of partial sunlight was sufficient to charge each light for eight to twelve hours of use. The lights became activated automatically under low light conditions, but not in daylight.

The solar lights were implemented at a farm where there had been a marked increase in bush pig CFEs, which were likely to continue and other deterrents targeting bush pigs were not in use at the farm. Efficacy of the lights was measured by comparing the frequency of nocturnal CFEs before and after introduction. Eight of ten lights were used for the trial and two were retained as spares to ensure the trial could continue if any lights were damaged. The lights were placed at each end of the 57m farm-forest edge, at approximately 12m intervals along the edge and also 12m from the edge on each side boundary of the farm. The row of lights activated automatically after dusk and emitted a surprising amount of illumination for the relatively small size of each light. The lights were an effective deterrent: whereas bush pigs crop foraged on twelve occasions and damaged more than 320 maize stems before using the lights, no further foraging was evident or reported by the farmer after their introduction. The farmer envisaged the lights may also be very useful as lighting in his house between growing seasons, saving the cost of other fuels. However, the farmer noted that while the lights were easy to use and flexible deterrents because they can be moved to other locations if required, they were easy to steal. Because the lights were useful and conspicuous, the farmer felt they were at risk of being stolen, particularly because they were not guarded at night. The farmer ensured the lights were collected at dawn, recharged adjacent to his house, and many people in the village knew they were his property. The lights may be equally effective if spaced at greater intervals, potentially reducing the number of lights required.

Using a Trench to Deter Crop Foraging

Farmers suggested a trench at least 600mm wide and 600mm deep along farm edges would probably prevent bush pigs from entering crop fields. To test this, one farmer spent 18 hours over three days digging a trench along the edges of a maize field prior to Year 2: Figure 11. The trench averaged 700mm in width and 750mm in depth; it was 45m in length, extending 30m along the farm-forest edge and 15m along a side boundary to enclose the corner of the farm where bush pigs were most likely to approach when attempting to enter crop fields.

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Figure 11 Partially completed trench in Year 2. On completion the trench was twice as deep and the (left) wall close to the forest was much steeper.

Bush pigs did not forage at the farm as regularly as anticipated for Year 2 (based on Year 1 data). This may have been linked to killing of a bush pig before the season, given that lethal removal of some crop foragers can reduce foraging by conspecifics over the short term. As a result, assessing trench impact was inconclusive. Only two bush pig CFEs were reported at the farm in Year 2 and on both occasions the trench was avoided when entering and exiting the farm. Surprisingly, all primates foraging the farm also avoided the trench when entering and exiting the farm. Primates entered from the other side of the farm or directly adjacent to the trench, and were regularly observed to take longer and less direct escape routes from the field to forest when fleeing from the farmer. This indicated the trench had a broad deterrent effect by shifting foragers' access and escape points to unprotected areas of the farm. Given primates' climbing and jumping abilities, the trench was not expected to influence foraging behaviour to the extent that it did. The width, depth, or steep walls of the trench could have been sufficient for primates to perceive it as a high-risk impediment to travel, particularly if pursued by a farmer. The main shortcoming of the trench was the regular need to clear it of leaves or dirt due to erosion, especially after rain.

Nets and Ropes to Protect Rice from Birds

Due to extensive crop foraging by wildlife in Year 1, one farmer elected to replace one field of maize with rice in Year 2, but was concerned stems might be damaged by birds, especially when the rice matured. This was an opportunity to assess whether nets and ropes suspended above the rice (see Figure 12) could deter birds, given that netting placed above grape vines can reduce damage by bats effectively (Verghese, 1998). Various objects that were brightly coloured, moved in light breeze, and/or reflected or shimmered in sunlight were attached to the ropes because these can also deter birds from crop fields (Hygnstrom et al., 1994; Nelms and Avery, 1997; Lane and Higuchi, 1998). Items used included colour tape, compact discs, tin cans and lids, and plastic package caps: Figure 13. The nets and ropes covered 300m^2 of rice, which included almost half of the estimated 14,030 rice stems planted within the field.

Figure 12 Nets and ropes attached to pine stakes to suspend them over rice at a farm.

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Figure 13 Objects that were attached to ropes over rice at a farm during Year 2.

The netting comprised eight 4m x 4m commercial small-mesh nets; although the larger mesh size nets used by local hunters would probably be equally suited to the purpose. The farmer suggested mosquito nets could be effective. The stakes to hold the netting were inexpensive pine off-cuts; four 50m rolls of local sisal were used as rope. Unfortunately, the farmer was unable to plant the rice until late in the season and it grew relatively slowly due to sporadic rain; therefore due to expiration of the project period there was insufficient time to evaluate the effectiveness of the nets and ropes via on-farm observations. The farmer was optimistic the technique would reduce damage to rice, although he planned to attach the objects to the ropes only when the rice was mature to minimise habituation.

Crop and Vegetation Barriers

A range of barriers utilising crops or vegetation were constructed at farms in Year 2 to deter crop-foraging wildlife. These were:

- A rope and post fence coated with chilli (*Capsicum*) paste.
- Jatropha (physic nut: *Jatropha curcas*) planted as a fence.
- Ocimum (camphor basil: *Ocimum kilimandscharicum*) planted as a three-row hedge.
- Ocimum planted in single row along a wire-mesh fence.

Chilli Paste Applied to a Rope Fence

A rope fence was constructed at one farm for Year 2 to evaluate whether chilli paste applied to the ropes (i.e. chilli paired with a barrier) could deter crop foraging by primates and other wildlife; this technique has repelled elephants effectively elsewhere (Osborn, 2002; Osborn and Parker, 2002; Sitati and Walpole, 2006). The fence was 82m in length and included four strands of sisal used as rope to enclose three sides of a bean field at the forest edge: Figure 14. Posts for the fence were pine off-cuts purchased locally. Posts averaged 1.0m in length, placed 300mm to 400mm into the ground and spaced at 3.0m to 3.5m intervals around the perimeter of the field. Four strands of sisal rope (also purchased locally) were secured to the posts using galvanised 25mm U-nails. Vertical space between ropes was 140mm to 160mm, with the lower strand 120mm to 150mm above ground level and the upper strand 550mm to 600mm above ground level. Two members of the project team carried all required materials and tools to the farm by bicycle, and constructed the fence in four hours.

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Figure 14 Four-strand sisal rope fence constructed to assess chilli paste as a deterrent when paired with a barrier.

Chilli powder for paste for the fence was bought from local farmers for US$1 per kilogram. The powder was made by drying, crushing, and pounding whole chillies. Approximately 500 grams of chilli powder, or 800 grams of whole chillies, made one litre of paste when mixed with water. Three litres of paste was sufficient for four applications to each post and rope of the fence. The paste was prepared by mixing either chilli powder (see Figure 15) or crushed whole chillies with water to enable the chilli to adhere to the sisal ropes and pine posts. The most adherent mix was three parts chilli powder, or five parts crushed whole chillies, to one part water by volume. Paste was applied twice weekly, using gloves to smear it along ropes and posts. The design of the fence ensured primates (or other wildlife) would need to touch and climb the ropes and/or posts to enter the crop field. Contacting or tasting the chilli was expected to be noxious and aversive, particularly if primates licked their hand(s) or rubbed their eye(s).


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Figure 15 Chilli powder (left) and whole chillies (right) used to prepare chilli paste.

The chilli paste barrier was trialled for six weeks because local chilli supplies were limited. Impact was assessed by comparing frequency of CFEs prior to versus after implementation. All crop-foraging events were by primates, mainly blue monkeys and red-tailed monkeys. A total of 23 CFEs occurred during the six week period before deterrent implementation while only one CFE occurred during the six weeks when chilli was used. CFE ratio for one month prior versus one month after implementation was 18 to 1. Because using the fence and chilli paste did not modify farmer vigilance or guarding behaviour, these CFE frequencies show a dramatic decrease in crop-foraging activity due to the barrier. After chilli was implemented both blue monkeys (twice) and red-tailed monkeys (twice) were observed near the fence or travelling adjacent to the fence; on each occasion one or more monkeys was rubbing hands vigorously and none entered the crop field. The farmer considered the chilli paste powerful, easy to mix, and key to the fence's effectiveness. The farmer added that up to one hour was required every three to four days to apply the paste to the fence, and this was a small time investment relative to benefits. While the barrier might be less useful in periods of heavy rain because this would remove the chilli, the farmer noted persistent rain usually only occurred during the early stages of the growing season before crops are targeted regularly by wildlife.

Jatropha Planted as a Fence

Jatropha (*Jatropha curcas*) or physic nut is a large shrub or small tree in the Euphorbiaceae family. The plant grows to almost five metres in height unless trimmed and is characterised by a straight trunk, grey-white patchy bark, thick spreading branches containing latex, and green leaves 12cm to 18cm in length and 6cm to 12cm wide, arranged alternately. Jatropha is insect-pollinated, monoicous, hardy, drought-resistant, and grows well in marginal soils; it is also non-invasive, does not exhaust natural nutrients in soil, and usually has a lifespan in excess of fifty years (Henning, 2000). Jatropha is easily established, grows rapidly, and can be propagated from seeds and seedlings, or cuttings from established plants (Figure 16). Seeds of jatropha plants (Figure 17) are toxic to many animals (Duke, 1983; Makkar et al., 1997); the plants also exude a noxious or aversive repellent odour, which can be detected by many animals (Henning et al., 1994; Henning, 2000).

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Figure 16 Jatropha three months after being planting as cuttings from established plants.

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Figure 17 Seeds of a jatropha plant. Seeds become coarse, grained, and darker as they ripen.

Because jatropha is toxic to many species, not browsed, and has repellent properties it should be useful planted as a hedge or fence along edges of crop fields to deter wildlife. While this has been demonstrated with livestock in several regions of Africa (Henning, 1998; Henning, 2000), there are few reports of jatropha being trialled systematically as a barrier to wildlife.

Subject to rainfall, it can take two to three years to establish a protective barrier if jatropha is grown from seeds; however, a hedge or fence can be established in four to five months when cuttings are planted. Seeds or cuttings should be planted when rains commence to maximise growth; if necessary, cuttings can be stored in shaded areas for three to four weeks without drying out. Seeds or cuttings should be placed 12cm to 20cm into soil and spaced at 6cm to 12cm intervals along a fence (SIRDC, 1998; Henning, 2000). If sufficient land is available, hedge density can be increased by planting several rows 30cm apart with alternating, offset stem spacing. Further cuttings can be taken from the hedge once established, to increase the length or width of the barrier without cost. Although jatropha cuttings may be susceptible to borer damage, conducive conditions are an uncommon combination of soil composition, low rainfall, high ambient temperatures, and proximity to specific vegetation; once the stems are established they are typically borer-resistant (see SIRDC, 1998; Henning, 2000).

Jatropha was planted as a fence along edges of crop fields at one farm in Year 2, including a farm-forest interface almost 100m in length. Throughout Year 1 crops within these fields had been damaged frequently by wildlife, especially baboons. The farmer was enthusiastic about jatropha and used cuttings to extend the barrier regularly. Based on observations of primate behaviour during Year 1, it was envisaged jatropha plants would have sufficient height and density to impede farm entry and exit for primates, particularly when fleeing from a farmer. The plants were also expected to obscure primates' view of crop fields from the forest, plus their view of forest while on-farm. It was anticipated that reducing the information primates can obtain about on-farm activity, or their prospects of escape, could increase the perceived risks of foraging on crops. Therefore, if primates were more likely to forage where they had an unobstructed escape route and direct line of sight to the forest, they should avoid fields protected by the fence. The inherent repellent properties of jatropha were expected to add to any deterrent impacts of the fence's structure.

The jatropha barrier was built with cuttings rather than seeds. Almost 1,500 cuttings ranging from 30mm to 80mm in diameter and 600mm to 900mm in length (Figure 18) were sourced from established plants in the region and transported to the farm. The fence was commenced in September of Year 1 to coincide with onset of peak annual rainfall, maximise growth rate, and ensure the plants were established as a hedge prior to Year 2.

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Figure 18 Cuttings of jatropha prior to planting in September of Year 1.

Cuttings were sorted by length to balance stem height over the length of the fence. The base of each cutting was then trimmed at an angle of 30 to 45 degrees to maximise cross-sectional surface area and promote growth on replanting (Figure 19). A 20cm trench was made along the fence line, including a vertical wall to lean each cutting against while being planted and support the plants while they developed roots. Cuttings were planted by packing soil firmly around them while being held against the trench wall (Figure 20), with gaps of only 6cm to 8cm between them to ensure the fence would be difficult for wildlife to pass through.

Figure 19 Jatropha cuttings being sorted by length (left) and trimmed at the base to promote faster growth when planted (right).

Figure 20 Trench used to plant jatropha cuttings (left) and packing soil around stems to form a fence (right).

A section of the initial jatropha fence is shown in Figure 21, together with the same section of fence in early December prior to Year 2 (less than three months after planting) showing rapid growth of the cuttings.

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Figure 21 Part-completion of the initial section of jatropha fence (top) and the same section of fence less than three months after planting (bottom).

Almost 1,000 additional cuttings were subsequently obtained from local farms and planted in February of Year 2 to extend the fence. Less than three percent of the jatropha stems died or had to be replaced during the period required to establish the fence. The fence was 135m in length over two sections when the Year 2 crop-growing season commenced; one section was 91m and the other 44m, joined at a corner to partially enclose half of the crop fields. By the third month of the season and before any crop-foraging activity at the farm, the jatropha had formed a dense, bushy, growing hedge from 1.2m to 1.8m in height (Figures 22 and 23); due to plant growth, the gap between stems averaged 4cm to 5cm.

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Figure 22 Section of the jatropha fence at a corner of the farm in March of Year 2.

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Figure 23 Section of the jatropha fence during May of Year 2. The barrier was dense and well-established, and many plants were producing seeds.

Figure 24 is a schematic diagram of the crop fields, showing location of the jatropha fence as well as the types of crop in each field. Maize and beans were predominant crops and mostly intercropped. Crop availability was almost equivalent between Year 1 and Year 2. Frequency of crop-foraging events during Year 1 and Year 2 is summarised in Table 5.

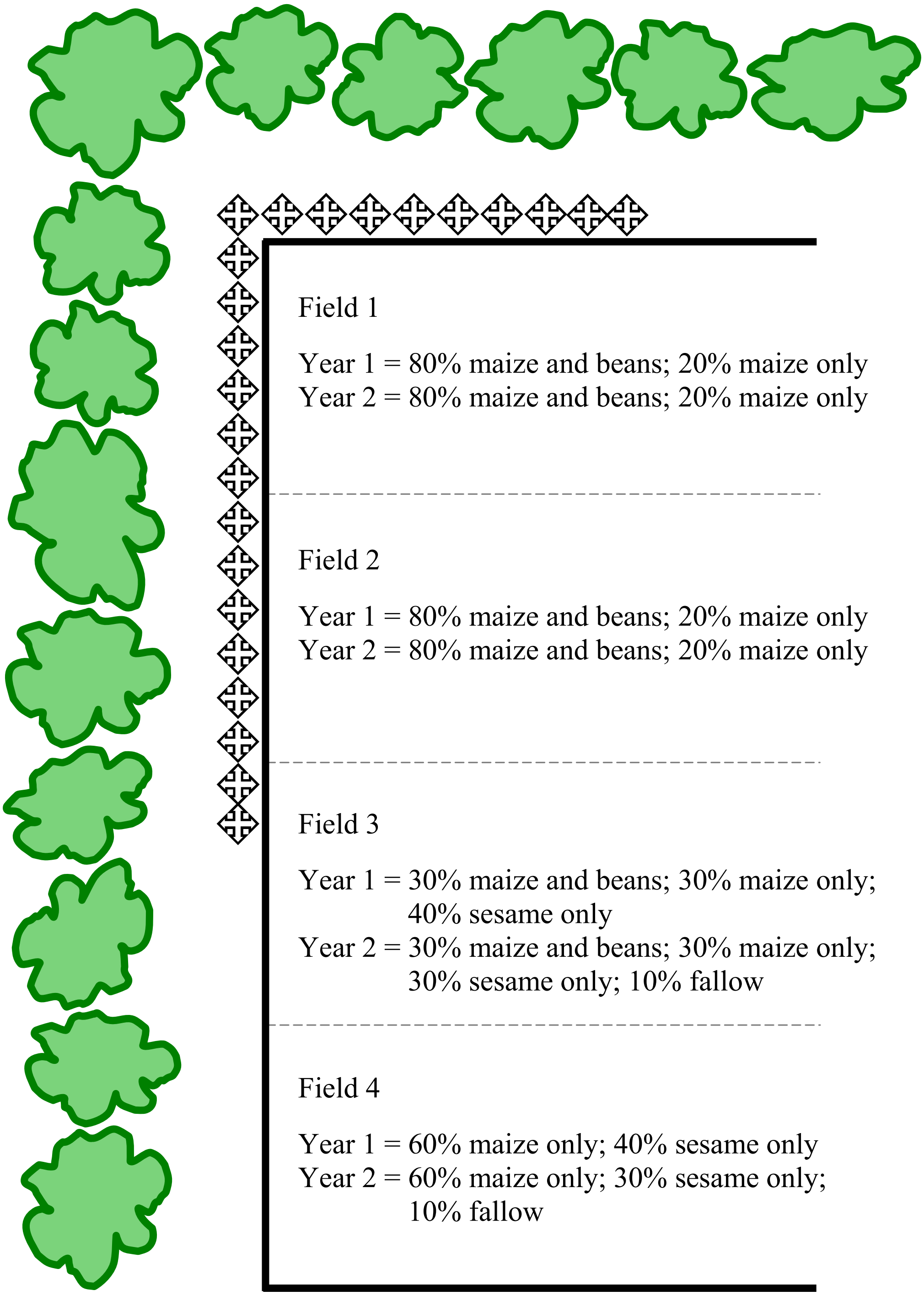

Figure 24 Schematic diagram showing the four crop fields at the farm, types of crop grown within each field in Year 1 and Year 2, and the location of the jatropha fence for Year 2.

= jatropha = farm edge = forest

Table 5 Frequency of crop-foraging events at the farm in Year 2 compared to Year 1. The jatropha fence extended along Fields 1 and 2 in Year 2, but not Fields 3 and 4.

Foraging species	Frequency of CFEs: Year 2	Frequency of CFEs: Year 1	Difference in frequency of CFEs: Year 2 minus Year 1
Field 1			
Baboon	0	12	– 12
Bush pig	0	3	– 3
Red-tailed monkey	0	5	– 5
Vervet monkey	0	1	– 1
All	0	21	– 21
Field 2			
Baboon	3	1	+ 2
Bush pig	0	2	– 2
Ground squirrel	0	2	– 2
Porcupine	0	1	– 1
Red-tailed monkey	0	1	– 1
All	3	7	– 4
Field 3			
Baboon	6	0	+ 6
Blue monkey	2	0	+ 2
Bush pig	2	0	+ 2
Porcupine	2	0	+ 2
Red-tailed monkey	5	0	+ 5
All	17	0	+ 17
Field 4			
Baboon	5	1	+ 4
Bush pig	5	1	+ 4
Porcupine	2	0	+ 2
Red-tailed monkey	2	0	+ 2
All	14	2	+ 12

Although frequency of crop foraging at the farm was similar in Year 1 (30 CFEs) and Year 2 (34 CFEs), there was a major shift in where crops were damaged during each season, which aligned directly with location of jatropha fence. There was an 90% decrease in crop foraging in fields bordered by the fence and a fifteen-fold increase in adjacent fields not bordered by the fence. Because results were not due to differences in crop availability or foraging activity across seasons, it was concluded the jatropha deterred foraging very effectively, particularly by baboons. As was the case for barbed-wire fences, the primary effect of the barrier was to shift crop foraging away from protected fields. As a behavioural indicator of deterrent effect, primates were observed to almost always travel the entire length of the fence before entering where the fence ended. Primates were especially vigilant while travelling along the fence and appeared to inspect the jatropha without touching it; this may have been partly because the barrier was a reasonably novel structure and also because it obscured their view of the farm. Primates were not observed attempting to climb over or through the jatropha, using stems as vantage points, or touching or interacting with the fence, suggesting the jatropha was also a repellent. Other crop-foraging events involved animals entering Fields 3 or 4 directly from a forest edge not adjacent to the fence, without travelling near the jatropha.

Ocimum Planted as a Hedge

Ocimum (*Ocimum kilimandscharicum*) or camphor basil is a perennial, bushy shrub growing to almost two metres in height unless trimmed; corolla are pink, mauve or white, leaves are serrated, from 30mm to 60mm long and 15mm to 30mm wide, and branches are woody and numerous (Paton, 1992; Makri and Kintzios, 2007). Figure 25 shows plants that are partially and fully mature. Ocimum plants are aromatic and secrete nectar with high sugar content at high frequency, attracting large numbers of bees for pollination (Sajjanar et al., 2003; Sajjanar et al., 2004). The strong odour of the plants and frequent presence of bees provide ocimum with repellent properties and render it noxious and aversive for many animals.

Figure 25 Partially mature ocimum plant (left) and fully mature ocimum plant (right). Branches become markedly more woody as the plant matures and flowers increase in colour from white-pink to pink-mauve-purple.

Ocimum is self-propagating: seeds from mature plants fall near edges of the plants annually for three to four years and those germinating develop into mature plants over seven to eight months. This process usually increases the density and space occupied by ocimum each year. Although seedlings can be transferred, plants beyond seedling stage usually die if relocated. When ocimum is grown in alternating rows as a hedge, the many branches and leaves form a dense, interwoven barrier from ground level to hedge top. Because of this, self- propagation, and the repellent properties of the plants from their odour and the presence of bees, ocimum was likely to be useful as a barrier to crop foraging.

Four months in advance of the Year 2 crop-growing season, more than 2,000 ocimum seeds were broadcast over planting beds to grow seedlings, and watered by hand. Each bed had a thatch cover to protect seedlings from birds and shade them from excessive heat from the sun (Figure 26). Covers were raised as seedlings grew, until they were sufficiently established to be transferred and replanted at farms (Figure 27).

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Figure 26 Thatch covers over planting beds used to grow ocimum seedlings.

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Figure 27 Collecting ocimum seedlings from a planting bed for transfer to farms.

Full-length or partial-length wire mesh fences were used in conjunction with ocimum hedges at farms to act as a support for growing plants and increase the potential deterrent impact of each barrier (Figure 28). Posts for wire mesh fences were plantation pine, chemically treated to resist borers and weather, averaging 1.5m in length and 100mm diameter. Holes for posts were dug at 2m intervals along the hedge line and 400mm to 500mm deep to ensure a solid foundation. Mesh was 12mm chicken wire and attached to the posts using galvanised 25mm U-nails. Nails were on the side of the post closest to the hedge and where animals approach from to increase strength if pushed by animals.

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Figure 28 Extent of a wire-mesh fence to support and complement ocimum at a farm.

Ocimum planted as a three-row hedge

Ocimum was introduced at one farm as a 103m, three-row hedge extending along the entire 57m farm-forest boundary as well as 23m along each side boundary. A mesh fence was built along half of the hedge. Plants were 300mm to 400mm apart and offset in rows to maximise hedge density, especially at ground level (Figure 29). The hedge comprised more than 1,000 ocimum plants on completion, enclosing 1,311m^2 of fields on three sides. Hedge height was 800mm to 1,100mm and width was 900mm to 1,200mm, growing as the ocimum propagated.

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Figure 29 Corner section of the three-row hedge of ocimum at a farm in Year 2.

The ocimum hedge paired with the mesh fence was a very effective deterrent; only one CFE (by red-tailed monkeys) occurred within fields bordered by the hedge and fence in Year 2, compared to twelve CFEs within these fields for Year 1. The hedge with fence had greatest impact on foraging by baboons and blue monkeys, suggesting links to primate body size. A wide hedge with bees and a mesh fence too high for most primates to leap over would have been more difficult for larger-bodied primates to traverse. Hedge density would be a barrier for baboons or blue monkeys before it was barrier to red-tailed monkeys. Ocimum without a mesh fence was less effective for deterring crop foraging, appearing to shift activity to other fields. As expected, bees were present around the ocimum plants throughout Year 2 and did not concentrate to a greater or lesser extent near the wire mesh fence. Presence of bees was probably aversive for most wildlife, but not central to deterrent effectiveness; wildlife were not observed fleeing from bees at the farm. However, it is unlikely a mesh fence could have deterred farm entry to the extent it did if the ocimum had not been present, because it would have been much easier for wildlife to approach fields without an obscured view between the forest and the farm. The hedge's deterrent properties would increase over time with greater height, width, or density. When interviewed at the end of Year 2, the farmer identified two potential shortcomings of using ocimum as a deterrent. Firstly, because ocimum plants have a short lifespan of three to four years, it is necessary to supplement or replace sections of a hedge every few years, for which the farmer must set aside land for seed beds and allocate time to monitor and plant seedlings. Secondly, over time a multiple-row ocimum hedge can occupy two or more metres of land at a farm edge, rendering it unavailable to grow primary crops. The farmer also noted that ocimum could be a viable cash crop if local markets were created and used.

Ocimum planted as a single-row hedge along a mesh fence

At another farm is was expected that planting ocimum along the full length of a mesh fence would (i) make the fence less traversable for primates because the plants increased density, (ii) make the fence aversive for primates due to the odour of the plants and presence of bees, and (iii) increase risks of crop foraging by increasing the size of the barrier to be negotiated when fleeing from farm and reducing primates' view between the forest and farm. Because the ocimum was planted outside the fence and facing the forest edge, to maximise contact with potential foragers, it was intended to modify primate farm-entry behaviour more than farm-exit behaviour. While the fence was the primary impediment for primates fleeing from farm to forest, it was unlikely to deter farm entry without ocimum or a similar supplement. The hedge and fence was 122m in length, extending for 64m along more than two-thirds of the farm-forest edge and 58m along one side boundary of the farm to partly enclose almost 4,000m^2 of crop fields.

Ocimum seedlings were placed 250mm to 350mm apart in a single row along the fence; the spacing was closer than used for the hedge at the other farm (above) because hedge density was not being enhanced with multiple rows. The hedge included almost 550 ocimum plants on completion. Hedge width was 350mm to 450mm and height was 900mm to 1,200mm; the hedge grew in width and height as the plants propagated. The hedge and fence are shown in Figure 30, while Figure 31 is a schematic diagram showing the four crops fields at the farm and location of the hedge and fence. Frequency of crop-foraging events during Year 1 and Year 2 is summarised in Table 6.

Figure 30 Ocimum plants along a wire mesh fence at a farm in early May of Year 2 (top) and early July of Year 2 (bottom).

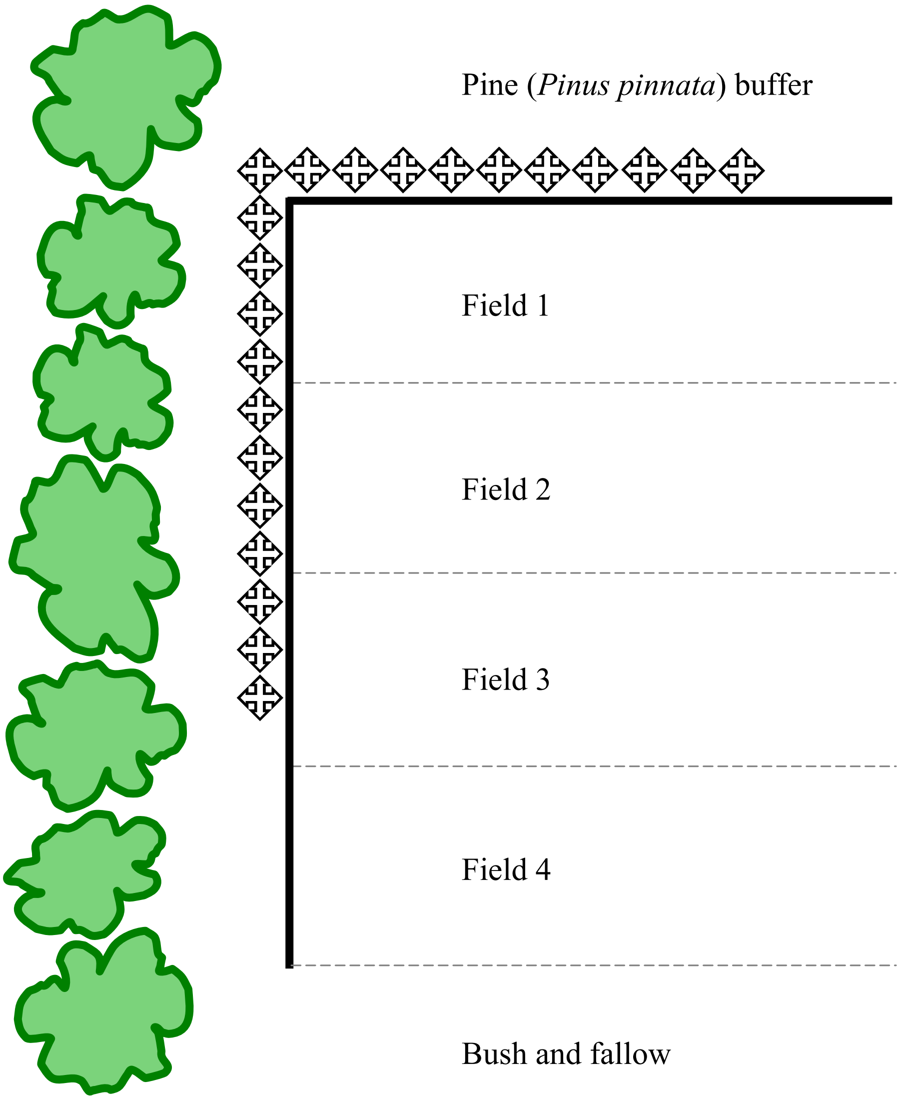


Figure 31 Schematic diagram showing the four crops fields at the farm and the location of the wire-mesh fence with ocimum hedge in Year 2. Maize was present across at least 80% of each field in Year 1 and 90% of each field in Year 2.

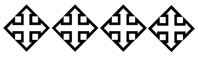
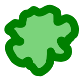
 = fence and ocimum hedge = farm edge  = forest

Table 6 Frequency of crop-foraging events at the farm in Year 2 compared to Year 1. Frequency is summarised for each of the crop fields shown in Figure 31.

Foraging species	Frequency of CFEs[1] Year 2	Year 1	Difference in frequency of CFEs: Year 2 minus Year 1
Field 1			
Baboon	0	19	– 19
Blue monkey	0	2	– 2
Red-tailed monkey	0	2	– 2
All	0	23	– 23
Field 2			
Baboon	3	11	– 8
Blue monkey	0	1	– 1
Red-tailed monkey	0	2	– 2
All	3	14	– 11
Field 3			
Baboon	3	5	– 2
Blue monkey	8	0	+ 8
Red-tailed monkey	0	1	– 1
All	11	6	+ 5
Field 4			
Baboon	10	3	+ 7
Blue monkey	7	0	+ 7
Bush pig	1	0	+ 1
Chimpanzee	2	0	+ 2
All	20	3	+ 17

The results in Table 6 confirm the mesh fence and ocimum hedge were an effective deterrent to foraging. As for many fences implemented during Year 2, the barrier shifted crop foraging away from the fields it bordered. Foraging patterns were very similar to those in response to the jatropha fence at another farm (see above). CFE frequency decreased markedly in fields most enclosed by the barrier but increased considerably in fields not or only partly bordered by the barrier. Primates were not observed attempting to climb over the barrier, using it as a vantage point, touching it, or otherwise interacting with it, which suggests the ocimum had repellent effects. Bees were around the ocimum plants throughout Year 2 and were probably aversive for most primates. Primates were observed to only flee or exit the farm away from the fence and ocimum, often using a longer indirect route to the forest, avoiding the barrier. During most CFEs in Year 2 primates did not forage where the barrier was directly between them and the forest, even when they were close to the farm edge. The barrier therefore not only addressed primate farm-entry behaviour effectively, but also deterred foraging in fields where it could impede an escape from the farm. This not only provides further evidence that primates will usually elect to not crop forage in a fenced area if crops are more accessible in other fields, but also that a barrier does not need to fully enclose a field to be effective as a deterrent to crop foraging.

ALARM SYSTEMS AND GUARDING

Alarms assessed as deterrents in Year 2 linked bells (as the signalling apparatus) to a net or rope barrier; bells were activated when wildlife interacted with the barrier, alerting a farmer to animal presence. Guarding was systematic (rather than sporadic) and evaluated for both a full-time (i.e. every day) and part-time (i.e. most days) schedule. Each of the methods called for active human input and responses to crop-foraging animals. Dogs were purchased at two farms to assist farmers with guarding as well as detecting and responding to wildlife.

Net Fence with Bells

A net fence 110m in length was constructed at one farm to enclose a large field of beans on three sides. Fence height was 1.4m to 1.5m. Both the upper and lower edges of netting were secured to a strand of barbed wire to keep the netting rigid and deter animals from digging under it (Figure 32). A bell was attached to each section of net (Figure 33) to sound when a potential crop forager pushed, attempted to climb, or otherwise interacted with the netting, allowing the farmer to respond. The mesh-size of the netting was sufficiently small to make the net difficult for primates to climb, especially with movement of the net; the barbed wire was also a deterrent to climbing. The bells were audible over about 120m in light wind.

Figure 32 Netting attached to strands of barbed wire at the farm.

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Figure 33 Bells used with the net fence (top) and attaching a bell to the fence (bottom).

Fence posts were pine off-cuts purchased locally; these were approximately 1.8m in length, placed 300mm to 400mm into the ground, and spaced at 2m intervals along the perimeter of the crop field. Sections of netting were attached to the posts with galvanised 25mm U-nails. The netting was designed for commercial use to prevent birds accessing fruit trees; nets that local people used for hunting (or mosquito nets) would have been equally effective and less expensive. Bells were purchased via Canada and designed to alert bears to human presence within wilderness areas; bells used locally when hunting with nets would have been equally effective and less expensive. Bells were attached to the fence using a built-in Velcro® strap; they were sufficiently heavy to not sound in light wind, but sufficiently sensitive to sound if an animal came into contact with the netting. Four members of the project team constructed the fence in six hours. Two views of the completed net fence with bells are shown in Figure 34.

Figure 34 Side section (top) and corner section (bottom) of the net fence with bells constructed at a farm to protect a large crop field of beans.

Crop availability within the fenced field was equivalent over Year 1 and Year 2, and farmer presence was also equivalent in each growing season. The fence and bells were implemented in early May of Year 2 and the beans were harvested in late July. Table 7 lists the frequency of crop-foraging events in the fenced field, confirming a marked reduction (almost cessation) in foraging with use of the system.

Table 7 Frequency of crop-foraging events in the field with the net fence and bells.

	Frequency of crop-foraging events				
Period	**Baboon**	**Blue monkey**	**Red-tailed monkey**	**Vervet monkey**	**All**
Year 1	5	0	0	9	14
Year 2 prior to fence	3	2	4	10	19
Year 2 after fence	1	0	0	1	2

While the fence with bells operated effectively as an alarm system, it appeared to also have deterrent properties as a barrier irrespective of the bells. The fence was a novel structure and primates appeared to avoid it despite frequent presence prior to construction. On at least six occasions primates were observed travelling along the fence and visually inspecting the nets without interacting with them. The farmer suggested primates may have feared nets because some local people use nets when hunting. The farmer also stated a main benefit of the alarm system, in addition to reduced bean loss, was he could work and rest further than usual from the farm edge because the bells would alert him if animals attempted to enter the farm, and this also meant he did not need to guard frequently.

Rope Fence with Bells

A rope fence was built along a section of farm-forest boundary at a farm during Year 2. The fence was 22m in length, averaged 750 to 850mm in height, and comprised four strands of sisal attached to a series of pine posts. A bell was fixed to the upper rope in each section of the fence (Figure 35). The ropes were interlinked with twine to ensure that they all moved if any one of them was moved, thereby sounding the bell. The fence's location was relatively out of view for the guard at the farm (see below); it was therefore anticipated that the alarm would complement guarding activity. The bells were audible over almost 150m in light wind and similar alarms have been reported as early-warning systems for crop-foraging elephants (Osborn and Parker, 2002; Graham and Ochieng, 2008). Pine posts were used for the fence, averaging 1.5m in length and 100mm diameter. Post holes were dug at 3.8m intervals along the farm edge and 400mm to 500mm deep. Brass bells were purchased outside Uganda, but those used by local people when hunting with nets may have been equally effective and less expensive. Three members of the project team constructed the fence within three hours.

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Figure 35 Section of the rope fence with bells constructed at a farm in Year 2.

The rope fence with bells operated effectively as an alarm; in four instances chimpanzees or baboons sounded one of the bells on entering the crop field via the fence, allowing the farm guard to respond. However, chimpanzees and bush pigs avoided the fence when entering the field on seven occasions. This suggests that while the system had some deterrent properties it was not effective for reducing overall frequency of crop foraging, probably because it was of insufficient length to be unavoidable when entering the field. Based on observations and the farm guard's reports, primate activity near the farm-forest edge closest to the fence was only reduced slightly after constructing the fence. The results indicate such an alarm system could be a useful adjunct to guarding, although probably only if it covers a large proportion of a crop field and requires a potential forager to interact with it to enter the field. This was reported by Osborn and Parker (2002) and Graham and Ochieng (2008) regarding elephants, and was also the case for the net fence and bells discussed above.

Using Dogs

Dogs were purchased locally to assist two farmers with guarding their crop fields as well as detecting and/or responding to wildlife. The dogs were pups of the most common and hardy breed in the area. It was preferable to obtain them at young age and train them to work with a farmer, which also ensured the dogs would consider the farm as their territory. It was also prudent to obtain three dogs because one or two might not survive to adulthood. Although twelve dogs in total (two sets per farm) were purchased over Year 2 none survived for more than a few weeks. This was primarily due to poor nutrition. Farmers were often only able to feed the dogs rice or vegetables, usually in small quantities, which confirmed keeping dogs can involve considerable cost for farming families.

Systematic Guarding

Farmer guarding activity in Year 1 was usually sporadic, occurred markedly less often than farmers stated or preferred, and comprised a relatively small proportion of a farmer activity budget. In most cases guards were regularly distracted or preoccupied with other tasks when at guarding sites, and only intermittently vigilant. Guards typically remained at one location on the farm and were rarely observed patrolling fields or farm edges. Guarding also usually occurred in short bouts rarely exceeding two to three hours. Although there may have been numerous reasons for this, farmers associated level of crop loss with the amount and quality of guarding over a season, and were reliant on guarding as a core crop-protection technique. Accordingly, it was agreed with farmers to trial systematic guarding at two farms in Year 2.

Guarding systematically required a farmer to (a) only guard and not engage in other activity from just after sunrise through to just prior to sunset, (b) be as vigilant as possible over this period, (c) patrol fields and farm edges frequently but not at regular intervals or in patterns animals could discern, and (d) actively respond to any animals observed on the farm or at a farm-forest edge. While systematic guarding could be conducted using a guard hut as a base and shelter (Figure 36) it was considerably more active than guarding observed over Year 1. Because farmers were unable to allocate sufficient time and resources to conduct extensive guarding, men with experience of farming and wildlife crop-foraging activity were hired as guards. Men were recruited to avoid potential confounding effect of guard gender. Guarding was trialled at two farms that did not have other deterrents focusing on diurnal wildlife, had crops foraged sufficiently over Year 1 to discern changes over Year 2, and would benefit by having a guard.

Figure 36 Guard hut at the edge of a farm in Year 2.

To gauge the impact of systematic guarding, each guard was required to maintain records of animals they observed on-farm or at the farm-forest edge, and hence responded to; this was also intended to keep guards focused. Details included when, where, which species, and how many individuals were encountered, with notes regarding the guard's actions and responses by animals. Guards were permitted to carry weapons, chase animals, and/or throw objects at them but were not to use weapons, traps, or snares, or to kill or injure any animals.

Systematic guarding was conducted on two schedules. At Farm 1 guarding occurred all days of each week; one guard worked Monday to Friday while another guarded on Saturday and Sunday. This full-time schedule reflected maximum effort a farmer could invest in guarding over daylight hours; from the perspective of crop foragers the schedule was continuous and entirely predictable. For comparison, guarding occurred on a part-time basis at Farm 2, and although the guard was present throughout 50% of days for the trial period, the days varied each week and were assigned randomly. This schedule reflected feasible guarding effort if a farmer needed to undertake other tasks regularly and/or could share guarding activity. From the perspective of crop foragers, guarding on this schedule was not predictable.

As summarised in Table 8, there was a large reduction in CFE frequency at both farms from Year 1 to Year 2. This was probably almost entirely due to increased guarding effort as well as better quality guarding, demonstrating systematic guarding can mitigate crop foraging by wildlife markedly. The decrease was evident for each crop-foraging species, except baboons at Farm 2.

Table 8 Frequency of crop-foraging events between sunrise and sunset at Farm 1 and Farm 2 during Year 2 compared to Year 1.

Species	Frequency of CFEs: Year 2	Frequency of CFEs: Year 1	Difference in frequency of CFEs: Year 2 minus Year 1
Farm 1: full-time guarding			
Baboon	3	11	– 8
Vervet monkey	0	14	– 14
All	3	25	– 22
Farm 2: part-time guarding			
Baboon	10	10	0
Blue monkey	1	4	– 3
Chimpanzee	1	9	– 8
Red-tailed monkey	7	10	– 3
Other wildlife	0	3	– 3
All	19	36	– 17

As expected, the extent of CFE reduction was aligned with effort and greater at Farm 1. The frequency of guards' encounters with primates on the farm or near the farm-forest edge also differed between Farm 1 and Farm 2. Number of encounters each month broadly decreased as the trial progressed. Because farm-edge primate encounters can be a measure of potential crop-foraging activity (Warren, 2003) they can be used as indices of guarding efficacy and reflect effort as well as quality. There were considerably fewer encounters with primates at or near Farm 1, indicating guarding full-time had much greater impact on primate behaviour than guarding part-time. The constant and predictable presence and patrolling of a guard at Farm 1 could have conditioned primates to shift crop-foraging activity to other farms. This would have been reinforced whenever primates checked foraging opportunities at the farm, because the guard would have been present and probably responded to them.

In contrast, the unpredictable presence of a guard at Farm 2 may have led primates to check foraging opportunities more often; in many instances the guard would have been present and chased them, and on other occasions the guard would have been absent, and primates near Farm 2 probably did not shift their foraging locations to the same degree as those at Farm 1. However, it is likely that even part-time guarding at Farm 2 had greater deterrent impact on primate crop-foraging behaviour than the sporadic guarding observed during Year 1 because it occurred more often and was systematic. It is also possible the deterrent effects of guard presence continued when the guard was absent; only 40% of CFEs that occurred at Farm 2 when the guard was not working were on the first day of a period of absence.

The findings confirm guarding can deter crop-foraging wildlife effectively when a farmer is able to invest sufficient time or share effort. While impacts directly reflect amount of effort invested, guarding on a 50% of time basis is still worthwhile. However, in all cases, quality of guarding behaviour is critical; irrespective of effort guarding is probably only effective in the longer term when systematic. This confirms guarding should be approached as an active rather than sedentary behaviour, and comprises more than simply human presence on a farm.

INDIRECT DETERRENTS

Indirect methods of crop protection involve adjusting normal farming practices in ways that minimise vulnerability to crop foraging (and therefore probability of crop loss), rather than introducing tools to repel, impede, or exclude wildlife. Methods observed during the project were (i) planting primary crops in locations less accessible to wildlife, (ii) changing type of crop planted in an area, and (iii) synchronising the planting and maturation of crops across neighbouring farms to promote equivalent crop availability. These techniques require longer term monitoring to assess their effects because it is often difficult to manipulate broad-scale farming practices experimentally; a farm-wide mistake may compromise farmer subsistence.

The impact of crop location on crop-foraging patterns was assessed at one farm. The farmer usually planted her primary crops (maize, beans, and cassava) in fields along the farm-forest edge. However, in Year 1 it was necessary to leave these fields fallow to improve fertility of the soil; therefore primary crops were planted in fields beyond houses on the farm between 110m and 170m from the forest edge. Although there were 14 CFEs in Year 1, only two (by bush pigs) were of primary crops; all others were primate CFEs of bananas and greens near the forest edge. The farmer reverted to traditional fields for Year 2, planting primary crops from the forest edge up to 70m onto the farm. The greater accessibility of primary crops for wildlife during Year 2 was reflected in CFE frequency: 81% of CFEs were of primary crops and only five were primate CFEs of bananas and other fruits. Because on-farm activity and availability of each primary crop was equivalent across years, the foraging patterns confirm that planting crops in locations less accessible for wildlife deters crop foraging effectively. This is probably because wildlife are required to travel greater distances onto a farm, which usually increases the probability of detection by a farmer and therefore the risks of foraging. Although farm size and rotation of fields may make it difficult for a farmer to optimise crop locations to minimise damage by wildlife, the strategy seems worthwhile when possible.

The effect of crops maturing earlier than on neighbouring farms was noted at two farms. The farmers each planted fields of maize early in the season during Year 1, which matured earlier than other maize in the area. As a result the ripe maize was highly conspicuous (especially to crop foragers) and was damaged frequently, providing low yields. The farmers synchronised planting with other farmers for Year 2 to ensure their maize was not the only ripe maize available at any stage of the season. Foraging on maize by wildlife decreased considerably at both farms in Year 2 (six CFEs over both farms) compared to Year 1 (24 CFEs over both farms). Although crop synchronisation and/or planting alternative crops appeared to be effective to reduce damage, farmers' options for changing crops are frequently limited by suitability of land, seed prices, or the need for food and cash income; adjusting the timing of crop planting may be much more feasible.

CONCLUSIONS

Results from the project confirm it is possible to develop, implement, monitor, and evaluate a series of effective deterrents to crop foraging by wildlife in partnership with farmers. Many trials were under almost experimental conditions and utilised time-series data to evaluate effectiveness. The deterrents were largely unsophisticated, rated favourably by farmers, easy for them to use, and locally appropriate. The techniques mainly addressed crop foraging by primates or bush pigs but may be applicable for similar animals.

Barbed-wire fences, jatropha and ocimum hedges, and the net fence with bells shifted crop foraging to other fields of farms, or to other farms; this was probably also the outcome for solar lights and systematic guarding. These deterrents usually shifted farm entry and exit points in addition to CFE locations. Accordingly, the effectiveness of the deterrents could have been partly contingent on whether the same or similar crops were available and accessible within fields not protected by deterrents. Wildlife in Year 2 were usually able to access crops away from protected fields and therefore had alternative foraging opportunities; hence they were likely to travel elsewhere to consume crops if they perceived this involved less risk or was energetically less costly than interacting with a deterrent. This does not imply the deterrents were less effective; however, it may be informative to assess wildlife behaviour when there are fewer alternate crop-foraging options. Results for shifting crop foraging demonstrate the importance of considering the impacts of deterrents for neighbouring farmers. If savings in crop loss for some farmers are offset by increased stem damage for others there will be little net improvement in community food security or tolerance of wildlife, which compromises any mitigation deterrents were intended to achieve.

It is possible that many deterrents implemented at farms are effective partly due to novelty. The presence of construction activity, structures, alarms, other apparatus, and guards could encourage wildlife to be more cautious and avoid farms or fields, at least initially. However, the learning abilities of wildlife (especially primates) often allow them to adapt or habituate to crop-protection methods over time, and develop ways to bypass or overcome deterrents. As a result it will usually be necessary to adjust or modify deterrents over time to maintain their efficacy. A key aspect of this involves renewing a deterrent's novelty, confirming that developing deterrents is largely a matter of managing animals' perceptions of foraging risks and costs. Long-term monitoring would be required to assess whether or how wildlife adapt to crop-protection methods, and which methods provide best protection over time. Deterrent efficacy was also typically greater when methods were used in combination. Most deterrents need to be associated with effective guarding and farmer responses in order to remain effective, or wildlife will perceive interacting with deterrents rarely carries aversive consequences.

Almost all barriers evaluated by the project (notably the barbed-wire fences, jatropha fence, and ocimum hedges) demonstrated that barriers do not need to enclose an area entirely to be effective as a deterrent to crop foraging. This was evident for foraging by primates and by bush pigs, and especially the case for barriers that were (i) built along a major proportion of farm-forest edge, (ii) relatively long, and (iii) relatively straight. Degree of effectiveness for a partial barrier may depend on scale. Results also confirmed primates were uncomfortable within fenced areas.

There is no reason to suppose that variables influencing crop foraging by a species at a farm today will always do so, or will to the same extent. Techniques for protecting crops should be modifiable for changes in conditions, or adaptation by wildlife or farmers. Although it is critical to incorporate and address farmers' perceptions in strategies to mitigate conflict due to crop foraging, the strategies must also deliver real reductions in crop loss. To understand and mitigate conflict it is imperative to have comprehensive and accurate accounts of local crop-foraging activity, including related wildlife and farmer behaviour (which can interlink). Throughout the project it was apparent that protecting crops involves compromises between techniques that are desirable and those that are feasible and affordable. Such limitations can generate frustrations for farmers that fuel problem interactions with wildlife, particularly where foraging is persistent and involves considerable costs. Because crop loss is a major driver of disputes with wildlife for farmers, any tools or techniques to reduce losses will contribute to conflict mitigation.

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