Crop damage by granivorous birds despite protection efforts by human bird scarers in a sorghum field in western Kenya

Matthew Hiron1*, Diana Rubene1, Collins K Mweresa2, Yvonne UO Ajamma2, Eunice A Owino2 and Matthew Low1

1 Department of Ecology, Swedish University of Agricultural Sciences, Uppsala, Sweden
2 International Centre of Insect Physiology and Ecology, Nairobi, Kenya
* Corresponding author, e-mail: matthew.hiron@slu.se

Cereal crop damage from granivorous birds poses a serious food security problem for subsistence farmers in sub-Saharan Africa. In this region, farmers may rely on human ‘bird scarers’ to limit crop damage. Here we report feeding behaviour and crop damage patterns caused by Village Weavers Ploceus cucullatus and African Mourning Doves Streptopelia decipiens during four days in a 0.12 ha sorghum field protected by two full-time bird scarers in western Kenya. Despite the scarers’ efforts, almost 60% of the seed was lost before harvest. Bird abundance was largely determined by the presence of the bird scarers, with seed loss patterns being a function of distance from these people. Throughout the day, an average of 18 weavers (maximum 120) was present on the crop in any five-minute period. The number of mud projectiles thrown at the birds per 15 min showed only minor diurnal fluctuations, further suggesting that seed eaters attacked the crop throughout the day. Village Weaver individuals took an average 16 seeds per visit, whereas dove individuals took 32 seeds (maximum 105 and 455, respectively). Our study illustrates that avian crop pests can be extremely persistent and, even with consistent diurnal bird scaring activity, severely damage a small crop field. Bird scarers need to be active throughout daylight hours and patrol both the centres and edges of fields to create maximum disturbance to foraging seed eating birds. Further research is needed in order to investigate effects of local- and landscape-level land use patterns on the feeding behaviour of crop pests and the effectiveness of crop protection measures.

Keywords: bird pests, bird scarers, Desmodium, doves, Ploceidae, push-pull, Striga hermonthica

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Introduction

Cereals are important food and cash crops for millions of subsistence farmers in sub-Saharan Africa. Crop yields in this region can be severely affected by granivorous birds (Jackson 1974; Ward et al. 1979), with potentially devastating damage to individual farm production (Elliott 2000), irrespective of protection efforts (Ruelle and Bruggers 1982). Because of these impacts, there has been much research directed towards developing and testing management strategies for avian pests (Elliott 2000), including avian population control (e.g. explosives and poisoning breeding colonies and roosts) and field protection (e.g. nets, chemical repellents and bird scarers; Ward et al. 1979; Ruelle and Bruggers 1982; Mullie 2000). Yet despite some success using these methods, they often have lethal or sublethal non-target impacts (Mullie et al. 1999; McWilliam and Cheke 2004) and are only economical at larger scales. Thus, they primarily benefit large-scale agricultural schemes and commercial farmers, rather than small-scale subsistence farmers (Ruelle and Bruggers 1982).

Research into avian crop pests on subsistence farms and traditional management techniques has been very limited (Ruelle and Bruggers 1982), with crop pest management almost exclusively focusing on one species: the Red-billed Quelea Quelea quelea (e.g. Bruggers and Elliott 1989; Cheke et al. 2007). This is despite other species (e.g. Village Weavers Ploceus cucullatus) being important crop pests for subsistence farmers (Manikowski and Da Camara-Smeets 1979; Ward et al. 1979; Adegoke 1983). As a consequence, there is limited published knowledge about bird behaviour and crop damage patterns in small-scale traditional farming systems in Africa. Traditional farmers still rely heavily on methods such as human bird scaring for crop protection (e.g. Ruelle and Bruggers 1982), which involves family members who patrol the crop fields to physically scare away birds. Although the efficacy of bird scaring is likely to be highly variable and depend on the bird species and abundance, time of year, type of crop, and behaviour of the bird scarers (Ruelle and Bruggers 1982), little is known about the effectiveness of bird scaring as a method for reducing crop loss. Thus, if subsistence farming is to be maintained as a significant part of agricultural production in developing parts of Africa, more research efforts are needed on environmentally sustainable and crop protection methods that are affordable to subsistence farmers (Ward et al. 1979; Ruelle and Bruggers 1982; Elliott 2000).
One reason why very little research has been done on damage in small-scale farming systems may relate to the difficulty in adequately and simultaneously observing human and bird behaviour under controlled field conditions. Thus, in October 2011, we utilised a rare opportunity to study bird scaring at an African crop research station where two local women were employed as bird scarers for an unrelated crop production study on the influence of the parasitic *Striga* weed (purple witchweed; *Striga hermonthica*) on sorghum (*Sorghum bicolor*). We collected data on bird behaviour, crop damage patterns and the activity of the two women during the four days prior to crop harvest to answer the following questions. (1) How much of the crop was lost to birds despite the protective efforts of two full-time employed bird scarers? (2) Was the pattern of crop loss randomly distributed throughout the field or was it influenced by the position of the bird scarers? (3) Was the timing of bird visits to the crop influenced by the time of day and/or the presence of the bird scarers? (4) Did birds show any preference for sorghum that contained the parasitic *Striga* weed in comparison to the crop where the plant parasite was controlled? And (5) How many seeds were removed per bird visit and how did seed intake relate to the amount of time Village Weaver and African Mourning Dove individuals spent in the field?

**Methods**

**Study system**

This study was conducted in October 2011 at the International Centre of Insect Physiology and Ecology, icipe-Thomas Odhiambo Campus (TOC) (00°25′ S, 34°13′ E) at Mbita Point in western Kenya. The icipe-TOC is located along the shore of Lake Victoria at an altitude of 1 240 m above sea level. The study was carried out in an experimental sorghum field subdivided into four plots (c. 0.03 ha each with <2 m bare ground between plots), adjacent to a small observation tower (approximately 10 m outside of the field at the northern edge). The field set-up was designed to demonstrate how a push-pull system (Cook et al. 2007; Khan et al. 2008) of silverleaf desmodium (*Desmodium uncinatum*) intercrop species increases yields by inhibiting the effect of parasitic purple witchweed (*Striga hermonthica*). Thus, half of the field (two diagonal plots) was used as a treatment (*Desmodium*) while the other half served as a control (*no Desmodium*). The experiment was not set up for our project, rather we used the plots for observation without manipulating the system. The field was bordered by a maize field of similar size on one side (along the left outer edge of the plots in Figure 1a) and a hedgerow on the opposite side (along the right edge of the plots in Figure 1a) (see also Supplementary Figure S1). The remaining edges of the field were largely open with only short vegetation for at least 50 m.

Birds often used the maize field for perching before entering the sorghum field. The predominant avian crop pests were Village Weavers and African Mourning Doves *Streptopelia decipiens*. We only observed a small number of Black-headed Weavers *Ploceus melanocephalus*, Baglafecht Weavers *Ploceus baglafecht* and Grey-headed Sparrows *Passer griseus* feeding on the crop, therefore we restricted our study to Village Weavers (hereafter ‘weavers’) and African Mourning Doves (hereafter ‘doves’). We sought and acquired permission to observe and record the bird-scaring activity (i.e. throwing mud projectiles) for the entire four-day study period from the farm manager and the women employed as bird scarers for the push-pull project.

**Bird-scaring methods**

Two women were employed to scare and keep away avian pests from the field from the onset of grain formation until harvesting (harvest was the day after our fieldwork.

![Figure 1](image-url): (a) Schematic diagram of the study plot layout and spatial extent of crop damage. The size of each shaded circle corresponds to the five damage classes (see Methods) from smallest circles (almost all seeds removed) to largest circles (almost all seeds remaining). The box and cross in the centre of the diagram shows where scarers were positioned for the much of the time during the day. (b) Observed (points) and estimated (line with 95% CI) extent of crop damage as a function of the distance from the position of bird scarers in the field (i.e. mostly stationed in the middle of the field)
finished). The women began work at 06:30 (dawn) and worked continuously until 18:30 (dusk) every day during our study (with the exception of short periods when only one scarer remained in the field while the other took a break). These women spent the majority of their time in the middle of the study field (i.e. on a path at the intersection of the four plots; Figure 1a) and primarily used a method of mud throwing to scare away the birds. This was done by attaching a small ball of mud to one end of a stick and then flicking the stick in the direction of the birds. Using this method the women could flick mud balls with high speed and great accuracy into groups of birds on the crop, with the projectile causing the birds to rise up and leave the field. When large groups of birds arrived near the centre of the field, the women would occasionally walk to the location of the birds while waving their arms. To aid observations of bird behaviour and abundance, we used 8 × 42 and 10 × 42 binoculars. During this study, one person counted birds, a second observed bird feeding behaviour, and three other people shared responsibilities for note-taking and observation of mud throwing.

**Crop damage estimation**

In order to estimate the total crop damage caused by birds in the presence of full-time bird scarers, we approximated the number of seeds in the field (maximum crop yield) and the number of seeds removed by birds. Much of the damage had occurred before the start of our project. Maximum crop yield was calculated by estimating stalk density in the field and average number of seeds per stalk on undamaged crop heads. We counted the total number of plant rows in the field and the number of stalks per row in both edge-rows and one row in the middle of each subplot. To estimate the average number of seeds per stalk head we averaged the number of seeds from eight undamaged heads in the field (two heads in each subplot). Bird-mediated crop damage was then assessed from transects placed 6 m apart throughout the field. Along each transect, crop damage was recorded at 3 m intervals by averaging the damage on the four nearest sorghum heads as the approximate proportion of seeds taken (i.e. 100 sampling points in total). We used five classes: no damage, 25% damage, 50% damage, 75% damage and 100% damage (Supplementary Figure S2).

**Bird and scarer activity**

In order to determine whether bird feeding activity on the crop was relatively constant throughout the day or displayed clear temporal patterns, we recorded the number of birds on the crop and the number of mud projectiles thrown. This was conducted during a series of discrete time periods from dawn to dusk. Bird activity was measured by counting the number of individuals in the field during the first 5 min of every observation hour. Observation periods were from 06:15 to 10:00 (morning), 11:00 to 13:00 (midday) and 15:00 to 18:30 (afternoon). In addition, we added extra observations during the morning period (i.e. 5 min counts every half hour) to assess bird activity during the absence or presence of bird scarers (we began observations 15 min prior to the arrival of the women, when the birds first began to arrive at the study field). We recorded the temporal patterns of mud-throwing activity by the women bird scarers by counting the number of mud projectiles thrown that resulted in scaring one or both species (weavers or doves). This was done during each 15 min period for three entire days (06:30 to 18:30).

**Feeding behaviour**

We estimated the average number of seeds that were removed by individuals of the two bird species (weavers and doves). For weavers, we singled out an individual arriving in the field and recorded its arrival time landing on the crop, number of discrete feeding actions (peck at the crop), and time of departure from the crop. These observations were conducted during ten 20-minute periods throughout each day. When a singled-out bird left, a new arriving bird was selected and followed until the end of the 20-minute period. Only adult male weavers were observed for observations of feeding behaviour. For doves, we recorded their visits opportunistically throughout the observation hours because they had a much lower visitation rate than the weavers. The number of feeding actions was the number of times a bird pecked at the crop and, according to our observations, appeared to be a good estimation of number of seeds taken or wasted on the ground.

**Statistical analysis**

For the relationship between crop damage and average distance to a bird scarer, we fitted a linear model with a cubic distance to bird scarer term (with arcsine-transformed proportion damage as the response variable). To visualise temporal patterns in the mud-throwing activity of the bird scarers, we fitted a generalised additive model (GAM) to data describing the number of mud throws resulting in birds being flushed from the crop relative to each 15-minute period throughout the day. We fitted a generalised linear mixed model (GLMM with Poisson distribution and log-link) and used Akaike’s information criterion corrected for small sample size (AICc) to determine relationships between bird abundance in the crop and (1) the presence of human bird scarers and (2) whether the crop contained the parasitic Striga weed. Here, we compared weaver counts before bird scarers arrived and during the first hour after they began working. We included survey day as a random effect to account for the fact that repeated measures from different days were used. Simple linear models were used to describe the relationship between the number of feeding actions and the amount of time spent on the field. In order to estimate if the number of feeding actions (or seeds taken) was a linear effect of time or if feeding rates changed with time on the plant we fitted quadratic time terms that were only retained if they improved models by lowering AICc. All statistical analyses were performed in R (R Development Core Team 2011) using the mgcv package for GAMs and lme4 package (Bates et al. 2011) for GLMMs.

**Results**

**Crop damage**

The crop yield if all seed heads were undamaged was estimated at 22 million seeds (c. 11 000 seed heads containing c. 2 000 seeds per head), which is equivalent
to 183.3 million seeds ha⁻¹. Most of the crop damage was located at the edges of the field; in fact, nearly all seeds on the outer field margins had been consumed by the birds, while many seed heads were untouched nearer the centre of the field where the women were mainly positioned during our observations (Figure 1a). This was supported by an estimate of the proportion of crop damage relative to the distance from the bird scarers, which showed a cubic relationship (ΔAICc with cubic distance term = 0 and without = 4.1) where the degree of damage increased as a function of distance from the field centre and levelled off at maximum damage (100%) furthest away (Figure 1b). Based on our surveys of the crop prior to harvest, 9.24 million seeds remained; thus, 58% of the potential yield had been lost (equivalent of 106 million seeds ha⁻¹).

Activity
Regardless of the time of day or bird-scarer activity, weavers were always present in the field during our five-minute bird counts (Figure 2b). We counted an average of 18 weavers (SE 2.74) per five-minute count (mean of the 75 five-minute survey periods), with the maximum number peaking at 120 individuals. Peaks of weaver abundance corresponded with times when bird scarers were absent, which in this case was before 06:30 each day (Figure 2b). Evidence indicates that this morning peak was largely because of an absence of bird-scarer activity, rather than a natural diurnal feeding pattern, because very high bird abundances were observed on two occasions when heavy tropical rain interrupted the women’s scaring activities. On both occasions when the women left the field and took shelter on the afternoon of the third day, the birds quickly responded despite the time they remained in the field (a quadratic term did not increase in the cumulative number of feeding actions during the time they remained in the field (a quadratic term did not improve model fit more than 2 AICc units; ΔAICc, without quadratic term time = 0 and with = 0.481; r² for best model = 0.53). Weavers showed a quadratic increase in the cumulative number of seeds taken; the number of seeds taken increased with the time spent in the field. Based on our observations of birds from the time of their arrival to departure, both species continued to consume seeds throughout their visit to the crop; the number of seeds taken increased with the time spent in the field (Figure 4). Doves showed a linear increase in the cumulative number of feeding actions during the time they remained in the field (a quadratic term did not improve model fit more than 2 AICc units; ΔAICc, without quadratic term time = 0 and with = 0.481; r² for best model = 0.53). Weavers showed a quadratic increase in the cumulative number of seeds taken; that started to plateau at about 80 seeds (ΔAICc with quadratic time term = 0.0 and without = 63; r² for best model = 0.84). We also observed

Feeding
We observed the feeding behaviour of weavers and doves on 228 and 66 feeding visits to the study field respectively. Weavers took on average 16 seeds (SE 1.47) per visit (assuming each observed peck at the seed head resulted in the removal of one seed) and stayed for 74 s (SE 7.36), whereas doves, on average, took 32 seeds (SE 8.01) and spent 109 s (SE 20.49) in the field. Based on our observations of birds from the time of their arrival to departure, both species continued to consume seeds throughout their visit to the crop; the number of seeds taken increased with the time spent in the field (Figure 4). Doves showed a linear increase in the cumulative number of feeding actions during the time they remained in the field (a quadratic term did not improve model fit more than 2 AICc units; ΔAICc, without quadratic term time = 0 and with = 0.481; r² for best model = 0.53). Weavers showed a quadratic increase in the cumulative number of seeds taken; that started to plateau at about 80 seeds (ΔAICc with quadratic time term = 0.0 and without = 63; r² for best model = 0.84). We also observed
that, unless the birds were scared away, they could remain for very long periods and consume large numbers of seeds; (weaver maximum for a single visit = 625 s and 105 seeds; doves = 625 s and 455 seeds).

**Discussion**

Our study was intensively conducted during four days in one small field. Ideally, many replicates with varied scaring activity and environmental setting (e.g. surrounding vegetation) are needed to make conclusions on field placement and the most effective way to conduct scaring activities. Nonetheless, our results show that birds have a huge potential to deplete seeds from small crop fields. Furthermore, despite 58% of the potential crop being lost, there was strong reason to believe that bird scarers had a substantial impact on the foraging behaviour of the birds based on the following evidence: (1) the distribution of crop damage mainly at the field edges furthest away from the main position of the bird scarers; (2) changes in bird abundance on the crop relative to the presence of bird scarers, with bird numbers peaking in the early morning before scarers arrived and when scarers left the field due to heavy rain; (3) the increase in the amount of seed taken (or ‘pecks’ at the seed head) by birds that escaped detection and fed undisturbed for a longer time; and (4) the difference in bird preference for the non-parasitised crop relative to the presence of the bird scarers where birds utilised two subplots in higher numbers than the other two plots when scarers were absent but used all plots when scarers were present.

Most seed loss occurred towards the edges of the field, at the furthest points from the usual position of the bird scarers, i.e. at the centre of the field (see Figure 1a). This suggested that the birds avoided getting too close to the women, presumably because of a higher chance of being quickly detected and disturbed by a mud projectile. Damage to the crop was almost uniform around all edges (Figure 1b) even though we observed most birds entering the field from, and fleeing after scaring to, an adjoining maize field along one edge of the study field. This suggests that seed loss patterns did not appear to be simply because birds settled at the first part of the crop they encountered after flying in from surrounding vegetation (and hence depleted the edges first). Bird abundance also sharply declined with the arrival of the bird scarers in the morning. We observed that the first mud thrown for the day would result in a large flock of weavers and doves leaving the field, after which only individuals or small groups would have time to enter the field to forage before being detected and scared away. The sudden decline in bird abundance during the morning (Figure 2) could be explained by intrinsic diurnal feeding patterns of the birds (Brandt and Cresswell 2009), rather

![Figure 3](image_url)

**Figure 3:** Boxplot showing the number of weavers in subplots during five-minute bird counts when bird scarers were present or absent. Subplots correspond to two crop treatments: one with a *Desmodium* sp. intercrop, and the other with the *Striga* parasitic weed.

![Figure 4](image_url)

**Figure 4:** Number of feeding actions expressed as a function of time spent in the field for (a) Village Weavers and (b) African Mourning Doves. Lines from a linear regression are added to aid interpretation.
than by the effect of the bird scarers. However, this is unlikely because birds returned in high numbers (almost the same levels of abundance as seen at dawn) for two survey periods during the day when the women were forced to retreat from the field as a result of heavy rain. When the women returned to the fields after the rain, the birds’ abundance again returned to low levels.

Our observations based on pecks per bird — which we assumed were equivalent to the number of seeds taken — show that birds often take a substantial number of seeds prior to detection and removal by the bird scarers. Because both weavers and doves show a largely linear relationship between the time in the field and the number of seeds taken (Figure 4), the quicker the birds are chased the less crop damage will be expected. This is particularly true for the doves that may take up to 30 s before they begin feeding (Figure 4b), which means that birds can be scared off before they have time to inflict damage. Doves, if undisturbed, had the capacity to eat or dislodge more seeds per individual than weavers. However, doves were less frequently observed during the day and at much lower numbers (MH and DR pers. obs.) and therefore probably inflict less damage than weavers.

The 0.12 ha study field was part of an experimental set-up designed to study the effect on sorghum yield of silver leaf Desmodium intercrop, i.e. planted between the rows of sorghum. Desmodium is known to effectively inhibit growth of the parasitic Striga, a weed that attaches to the roots of the host plant and can greatly reduce plant growth and crop productivity (Khan et al. 2008). Interestingly, weavers avoided feeding in the half of the field that contained Striga weed (Figure 1, Supplementary Figure S1) when the bird scarers were absent during the first count period (Figure 3). During this short time window, treatment plots with sorghum/Desmodium had high densities of weavers, whereas no individuals were counted in the sorghum/Striga plots. Once the bird scarers arrived and began working, this preference largely disappeared. This suggests there was some benefit to foraging in the areas of the field with no Striga weed, with this benefit effectively removed by the threat of being hit by a ball of mud. Without additional evidence we cannot say why non-Striga subplots appeared to be preferred but potential explanations include: (1) the subplots with the Desmodium intercrop (no Striga weed) were higher yielding (as is seen with maize/Desmodium fields; Khan et al. 2008) and therefore had higher seed density that made these sites preferable (but see Baker et al. 2011 showing no effect of seed density on granivorous bird feeding rate); (2) the brightly coloured purple Striga flowers influenced the settling patterns of weavers (Supplementary Figure S3); the visual contrast between sorghum seeds and background vegetation might have affected bird feeding preferences if the seeds appeared more conspicuous in Desmodium treatment plots than Striga plots (e.g. Melo et al. 2011); background colour and structure affects feeding rates and seed search times of granivorous birds (Whittingham and Markland 2002); and (3) differences in habitat surrounding the experimental field influenced where weavers land in the field to forage. This seems unlikely, with the diagonal placement of the treatment plots (Supplementary Figure S1) ensuring that either crop treatment type was available regardless of the side of the field being entered from. The plot preference should be further explored to determine if it is consistent in Desmodium-treated crop fields and if it can be incorporated in developing crop protection strategies.

Despite the clear indications that the bird scarers in this study had large effects on the foraging behaviour of Village Weavers and African Mourning Doves, it is not clear how these results translate into effective crop protection. It is possible that the bird scaring effectively protected 40% of the crop. However, it is also possible that bird scaring is less effective than we determined and simply caused the visiting birds to spread their foraging time throughout the day from a few large foraging peaks to many smaller foraging trips (Ward et al. 1979). Thus, without adequate control fields for comparison (with varying levels of bird-scaring activity and different environmental settings such as nearby bushes and human settlement patterns), we can only conclude that scarers altered the foraging patterns of birds. Our results do suggest that scarers should patrol the edges of fields as well as the centres, and more so as fields become larger and the reach of mud projectiles becomes limited.

Conclusions

This study highlights the potential impact of avian crop pests on small-scale subsistence farmers in Africa. In our system the field was an experimental plot with bird scarers employed to protect the crop, but we see our results as being transferable to a family holding reliant on the yield for sustenance. Despite having employed personnel that worked enthusiastically throughout the daylight hours, a large proportion of the crop was still damaged. While this kind of damage at the landscape scale may be reduced by diverse cropping patterns and alternated phenology (Ward et al. 1979), individual farmers with small holdings may still suffer high crop losses with devastating effects on their livelihoods. Considering that world food security and conservation of biodiversity in agro-ecosystems is high on the world political agenda (FAO 1999, Tscharntke et al. 2012), it is imperative that ecologically sound crop protection methods are developed, especially in developing nations. Here we show that bird scaring, although environmentally friendly, is labour intensive (shown by the number of throws each 15 min throughout the day) and that much damage still occurred at the edges of the field furthest away from where the bird scarers were stationed. We also show that weavers and doves are active throughout the day and if undetected can eat (or dislodge) large numbers of seeds in one feeding period. Thus, farmers aiming to reduce crop damage need to patrol fields from just before dawn until dusk while varying their position in and around the field to create maximum disturbance of seed-eating birds.

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