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Economic Valuation of Rice Crop Damage by Red-billed Quelea and Other Granivorous Birds on a Rural Irrigation Scheme in Western Kenya

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Authors' contributions

This work was carried out in collaboration and cooperation amongst all authors. Author NEO conceived and conceptualised the study, participated in its design and coordination, data analysis and manuscript drafting; author DOO participated in data collection, field logistics and obtaining information on rice paddy dimensions; authors ASM, CA, DC, POA and TM all participated in data collection and initial data organization; author POA further helped in field logistics planning and rice yield data verification. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study aimed at estimating economic losses incurred by farmers from damage of rice crop by graniviorous pest birds and assessing the implication of this for sustainable food security.
Study Design: Line transect bird sampling with spatial and temporal replications; bird feeding rate determination; per-season and per annum economic valuation of rice damage
Place and Duration of Study: Ahero Rice Irrigation Scheme in western Kenya from November 2011 to February 2012.
Methodology: To estimate economic losses of rice we first estimated graniviorous bird density from two census periods from whence we estimated seasonal and annual quantities of rice loss calculated from the birds' feeding rates. We then valued economic damage as a factor of the crop

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loss and prevailing rice producer market price and finally estimated net economic loss by subtracting the cost of hiring labour to scare birds from damaging mature crop. Period of bird damage was restricted to the period between crop-maturity to harvest.

Results: Estimated annual loss was 407 tonnes or 7.7% of potential yield for the whole irrigation scheme excluding bird scaring costs. This was equivalent to Ksh. 40.7 million annually at 1 USD=87 Ksh. representing a 31.1% loss of net income. Inclusive of bird scaring costs, annual losses were Ksh. 20,763/ha equivalent to 39.5% of net income. Estimated annual rice damage due to *Q. quelea* was more than that due to the other granivorous birds combined (215 compared to 192 tonnes).

Conclusion: This loss magnitude considerably undermines efforts to reduce rural poverty and attain sustainable food security. In addition to the crop-guarding method, reducing losses from damage by the pest birds requires integration of several measures that have proved successful elsewhere, adoption of improved farming technologies and planting recently developed higher-yielding rice varieties.

Keywords: Economic valuation; rice damage; pest birds; quelea quelea; ahero; Kenya irrigation; Kenya.

1. INTRODUCTION

Irrigation fields where rice (*Oryza sativa*, L.) is grown are becoming increasingly significant as habitat for birds worldwide [1-4]. This is mainly associable to loss of an estimated 50% of global natural wetland cover in the last century, [5] when compared to a corresponding increase in global rice field cover currently covering about 164 million hectares as of 2012 [5-7]. In Brazil alone, the 9th highest rice producer in the world, increasing rice field cover of paddy-rice corresponded to a 90% loss of natural wetlands between 1970 and 2012 [8] in spite of resultant agrochemical pollution or human disturbance to birds [5, 9-11]. While a few bird species use the rice fields for breeding or dispersal areas, [6], majority utilize them as feeding grounds that compensate for lost natural wetlands [2,5,12,13]. The birds' feeding habits may pose both positive and negative effects on rice farming. For instance, while most insectivores and raptors provision pest control services for rice crop, other ground invertebrate-feeders may contribute to suppression of some disease vectors on the rice fields and many granivores often consume and damage the rice crop itself [7,14-17].

Such perennial loss of stable crops to vertebrate pests constitutes one of the greatest challenges to food security in many Sub-Saharan countries, as it undermines production targets, aggravates food deficits, contributes to undernourishment and accelerates poverty levels among rural populations [18,19]. Large flocks of granivorous birds in general and Red-billed *Quelea Quelea quelea* (hereafter R. Quelea) in particular are responsible for considerable losses of rice and other small grained staples across its range that covers some 20% of Africa's continental land and extends across 25 countries [7,20-22]. The impact of R. Quelea is mainly attributable to their flocking and invasive characteristics that causes large crop losses within very short durations, often overwhelming rice farmers most of whom operate at small subsistence scales, with limited capacity to invest in sustainable control measures [19,23]. The gregarious characteristic of R. Quelea, its adaptability to changing food supplies, constant mobility and habituation against human disturbance [21,22], all provide it with significant foraging advantage over other granivorous birds across the rice fields. According to the Food and Agriculture Organization, R. Quelea alone is considered responsible for the annual loss of an estimated total USD 54 million in value of rice and other small grains across sub-Saharan Africa [7] or USD 70 million worldwide.

Although rice is not the leading staple grain crop in Kenya, it is one of the most significant cereals in the country in such high demand that the volume produced is insufficient to meet local needs, necessitating importation to bridge the deficit [19,24,25]. The crop is typically grown under irrigation in 5 main agricultural development schemes in the country [24,26] and damage of rice by granivorous bird pests in these irrigation schemes is observed during the period from crop maturity to harvesting [23,27].

Many studies have been conducted on the suitability of rice fields as bird habitats in Europe and in the Mediterranean region [28-31] and in Africa, including pest species such as R. Quelea

[21,23,32,33]. However, none of these studies have been conducted in Kenya, especially with a view to making economic valuation of the damage by the granivorous birds despite rising anecdotal and media reports as well as farmer complaints [34-36].

In this study, we aimed to estimate economic losses incurred by farmers from damage of rice crop by R. Quelea and other granivorous pest birds at Ahero Rice Irrigation Scheme in western Kenya with a view to evaluating the impact of the losses to attainment of sustainable food security, and exploring options for reducing such losses through bird control measures. We also aimed to compare contribution of R. Quelea to rice crop damage relative to that of the other graniviorous pest birds in the irrigation scheme. The study is significant and unique as it is the first attempt to quantify losses of rice from bird damage in Kenya in monetary terms. Therefore the results are an important contribution to filling this information gap and providing an evidence-based case for formulating policies to minimize bird damage that may also be scalable to the national and regional levels.

2. METHODOLOGY

2.1 Study Area

Ahero Rice Irrigation Scheme is part of the Kenya National Irrigation Board's Western Regional project which also includes West Kano and Bunyala schemes and is situated on the eastern margin of the Winam Gulf of Lake Victoria, 20 km east of Kisumu City between 0º07'S-09'S and between 34º54' 34º58'E, covering 878 hectares (Fig. 1) [26,37]. Annual rainfall is 1082 mm and is bimodal with a high peak between March and May and a smaller peak between October and December. Mean temperature ranges from 17 to 32ºC and average humidity is 65% [37]. The irrigated area is supplied with water from River Nyando [37, Njoka pers.com] see Fig. 1 and is divided into 12 irrigation blocks ranging from 31-115 ha and which had a total of 533 farming household units, allocated a 1.6 ha paddy-field [37, Otieno pers. obs]. Rice is planted in two seasons each year which often coincides with local rainfall patterns and harvesting takes place in July and January.

The study area forms one of the most significant feeding and dispersal sites for both resident (Kenyan) as well as migratory (Palearctic) birds [38,39], the latter starting to arrive from around October and departing back to their breeding grounds the following February and March [38].

2.2 Sampling

The study was carried out between November 2011 and February 2012 to span two full rice cropping seasons (November 2011-February 2012 and again from April-July 2012). Sampling was conducted across all 12 field blocks and birds were surveyed in 52 total counts, twice in each of the two field seasons. A period of 6-8 days was allowed between the first and second bird survey for each field block during each field season to reduce temporal bias and the two field seasons were chosen deliberately so as to also capture presence of wintering Palearctic bird species [38,39]. Birds were surveyed from 0630-0930 hrs. capturing the peak feeding activity [40] with surveyors worked in pairs such that an experienced Ornithologist made the observations while a partner recorded the data. Information on the seasonal rice production cycle, yield rates, costs of farm inputs and other expenses involved in rice production was obtained from direct interviews with personnel at the Ahero Rice Research Centre and individual farmers.

2.3 Data Analyses and Calculations

Analyses were performed in SPSS version 16 and R program [41,42]. Bird abundance was determined as the average from all counts across both field seasons; species richness was the cumulative total from all observation from all counts for each site while species diversity was determined using the Shannon Diversity index $H' = - \Sigma$ pi In pi where pi is the proportion of the total number of individuals of the ith species of all individuals of all species; In is the natural logarithm [43]. Diversity indices were compared between the two rice growth stages: Before crop maturity and from maturity to harvest. This was because many of the graniviorous pest birds also occur on rice fields in earlier stage of rice growth during which they feed on seeds of other plants before the rice matures [22]. Some of them also consume arthropods in the rice fields during these early flooding stages especially weavers (*Ploceidae*) and widowbirds Euplectes sp that are mixed or opportunistic feeders [38,44]. Abundances were derived from the means of the hierarchically partitioned values of individual observation clusters, multiplied by number of encounters and divided by total sampling area [40,45]. The significance of all statistical tests were set within the 95% confidence interval (P=0.05).

The granivorous pest birds were subdivided into three main groups: Red-billed Quelea (*Ploceidae*) that was the predominant group; other weavers and allies (*Ploceidae*); doves and pigeons (*Columbidae*) and other granivores (*Estrildidae, Fringillidae* and *Viduidae*).

In estimating rice crop damage by the granivorous birds, we adopted a slightly modified form of the model by Tracey et al. [46,47] which is a function of mean daily food intake by birds, estimated bird population and unit price of harvested rice crop. Thus the estimated rice damage by each bird type in each season was calculated as ELB = FR*D*dA where ELB = loss due to bird damage; FR = daily food intake per bird; D = total number of days over which crop damage occurred; dA= estimated bird population from density per hectare (d) and area sampled (A). To minimize over-estimation, the period for which crop damage was estimated included only that of the final 42-45 days from crop maturity to end of harvesting. Thus the assumption was that the birds exclusively or predominantly feed on rice during this period.

We estimated the quantity of rice damage per paddy-field averaging 4 acres (1.6 ha) in kg and for the entire scheme of 1,556 paddies (878 ha) both seasonally and annually (two seasons of 3-4 months each). Estimation of economic loss was conducted by presuming a rice producer market price of Ksh.100 (USD 1.15) per kg. This prices was assumed to apply to all farmers. Cost of crop guarding was a flat value of Ksh. 9,000 per season. We further incorporated the fact that crop-guarding has an average of only 60% success rate as a pest bird control measure, from studies conducted in many parts of West and North Africa [29], meaning there is a 40% chance of bird damage despite crop-guarding. Thus the total economic crop loss due to birds was determined as ELBt = {[(100-60)/100* ELBd] + ELBg} where ELBt = total economic loss due to bird damage plus cost of crop guarding; ELBd= economic loss due to bird damage alone; ELBg= economic loss due to cost of crop guarding.

Percent economic loss from bird damage was calculated from the relationship:

ELBp = [((ST – PCT) – BLT)/ SN]*100 where ELBp = percent economic loss due to bird damage; ST = total sales, equivalent to production (kg*unit cost) minus cost of farm production; PCT = total cost of production; EL Bt = total loss due to bird damage and SN = net sales, as derived from economic theory. The models and estimates above assume that in the rice production cycle, birds are the principal drivers of rice damage and loss during the period from crop maturity to harvesting.

3. RESULTS AND DISCUSSION

3.1 Results

A total of 17 species of granivorous birds from 4 families were encountered (Table 1) with R. Quelea the most abundant and most frequently encountered. Overall abundance of all graniviorous birds was higher during the maturity and harvest of the rice crop than before maturity ($t(74) = 2.275$, $p = 0.026$). On the other hand, diversity of the graniviorous birds was higher in the period before rice maturity (H' = 0.4886) than in the period from crop maturity to harvesting (H' = 0.2530) during which time R. Quelea were predominant.

It was estimated that in the absence of crop-guarding, overall loss of rice crop would be 215.1 tonnes per year due to R. Quelea alone, equivalent to economic loss of Ksh. 21.2 million per year. For each paddy field, this loss totaled 138 kg annually equivalent to Ksh. 13,624 per paddy field, Ksh. 8,515 per ha or 16.2% of realized net income. The overall damage caused by all granivorous birds combined, in absence of crop-guarding, would amount to 407 tonnes annually, equivalent to 7.7% of expected yield. This translates to Ksh. 40.7 million (USD 467,816) annually or 164 kg per ha valued at Ksh 16,375/ha or 31.1% of net income. When cost of crop-guarding are included, the 60% reduction in bird damage (representing guarding effectiveness rate) is undermined by the unit cost of hiring personnel for crop-guarding work. Each paddy-field then losses Ksh. 20, 763/ha and the whole scheme Ksh. 59.5 million per year which erodes 3.7% of total sales or 39.5% of realized net income. This is because from the Fig. supplied by farmers, of Ksh. 9,000 per paddy field per season, the cost of crop-guarding alone is at least Ksh. 28 million per year.

The most destructive birds to the rice crop were R. Quelea (53%) [48] and other weavers (*Ploceidae* = 36%) while the least destructive were doves/pigeons (*Columbidae* = 9%) and smaller granivores (*Fringillidae* and other *Estrildidae* = 2 %) see Fig. 2.

Thus the loss due to R. Quelea was more than that due to the other graniviorous birds combined (Fig. 3). It is however important to note from these results that economic loss of rice to bird damage per se is only a fraction (68%) of the total estimated economic losses reported. The cost of crop-guarding adds to the remaining 32%. Unfortunately, failing to scare away the birds through crop-guarding might result in total crop loss and as such crop-guarding is currently unavoidable.

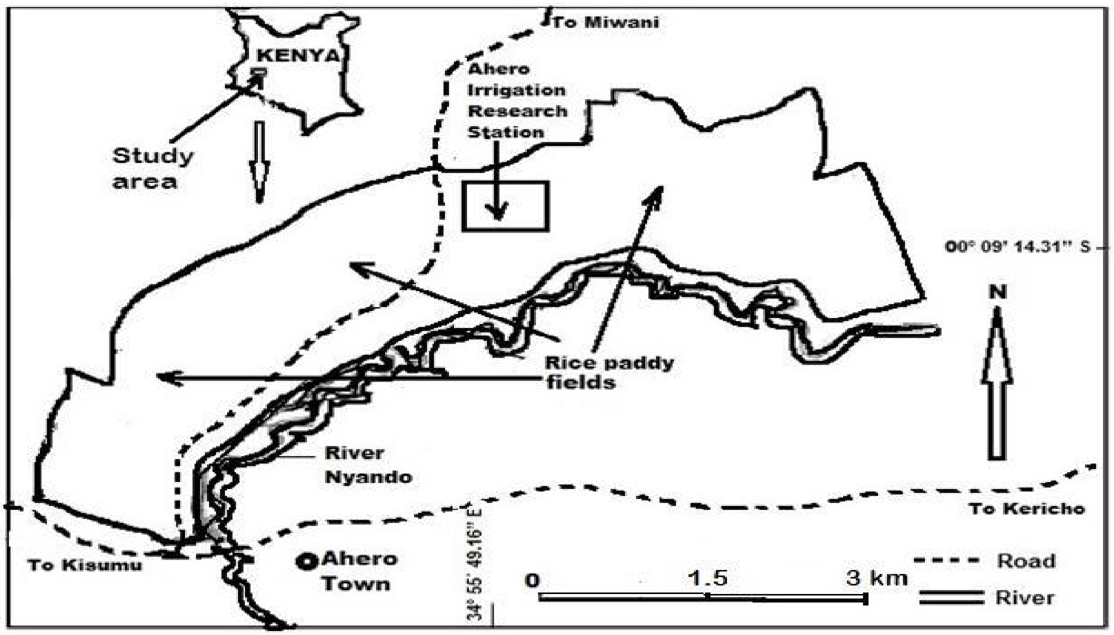

Fig. 1. Map of study area in ahero rice irrigation scheme in western kenya, showing various paddy-fields where sampling was conducted. (Adapted from Bukhari et al. 2011 [37])

Table 1. Checklist of all granivorous pest birds encountered in the Ahero Irrigation scheme Study area during the study from november 2011 to July2012. listis in phylogenetic order

Family	Common name	Scientific name
Columbidae	Emerald-spotted Wood Dove	*Turtur chalcospilos*
	Red-eyed Dove	*Streptopelia semitorquata*
	Ring-necked Dove	*Streptopelia capicola*
	Speckled Pigeon	*Columba guinea*
Estrildidae	African Fire-finch	*Lagonosticta rubricata*
	Red-billed Firefinch	*Lagonosticta senegala*
	Red-cheeked Cordon-bleu	*Uraeginthus bengalus*
Fringillidae	Streaky Seedeater	*Serinus striolatus*
	Yellow-rumped Seedeater	*SerinusXanthopygius*
Viduidae	Pin-tailed Whydah	*Vidua macroura*
Ploceidae	Grosbeak Weaver	*Amblyospizaalbifrons*
	Jackson's Golden-backed Weaver	*Ploceus jacksoni*
	Red-billed Buffalo Weaver	*Bubalornis niger*
	Speke's Weaver	*Ploceus spekei*
	Village Weaver	*Ploceus cucullatus*
	Red-billed Quelea	*Quelea quelea*
	Black Bishop*	*Euplectes gierowii*
	Southern Red Bishop*	*Euplectes orix*

**Consumers both plant material and arthropods*

3.2 Discussion

3.2.1 Economic valuation of rice damage

The steady decline in diversity of granivorous bird species from the early field flooding stages towards rice crop maturity and harvesting depicts a correspondingly steady increase in their dependence on rice as a source of energy. This is because discontinuation of flooding as rice crop matures, leads to loss of weeds and other plants that provide alternative sources of seed food for the birds [15,49]. Many weeds and grasses on rice fields mature earlier than rice and complete their life cycle long before rice is harvested, leaving rice as the only source of food for seed eating birds later in its growth stage [22]. Thus many bird species for which mature rice crop is not the main source of food may at this stage seek foraging opportunities elsewhere, leaving only those that specialize in consuming rice at that stage such as the numerically dominant R. Quelea [38,44].

The per unit area loss or rice crop to graniviorous birds in Ahero, which is slightly higher than that in the Senegal River valley, one of Africa's main rice belts [21,50], is a substantial burden to the local farming community, especially considering that western Kenya is listed among the most economically challenged regions of the country with poverty rates estimated at 48% [51].

Even before including the costs incurred in crop-guarding, the rice lost, at 407 tonnes per year, is enough rice to feed 783 households of 5 members in Kisumu County for one year consuming 2 kg of rice per week interspersed with other food items [19,20]. It is also sufficient to supply 12 boarding high schools with rice meal for one year, each with 550 pupils of 35-50 class sizes [52]. This is an opportunity lost for improving rural nutrition while the revenue lost could go towards significantly combating local poverty rates.

The conditions under which rice is grown in Ahero is nearly similar to those in other rice schemes in Kenya because they are all managed by National Irrigation using integrated irrigation systems [26]. This allows the losses to the bird pests observed at Ahero to the national level. In this regard, the damage to rice caused by R. Quelea alone would amount to about Ksh 410.5 million (USD 4.7 million) based on the total acreage of 17,000 ha under [19,24]. Considering losses to all graniviorous pest birds combined, projected national loss would be valued at 11,000 tonnes equivalent to Ksh. 1.1 billion (USD 13.2 million). This is enough to reduce the country's rice imports by about 7% based on 2012 Fig. [28] thus narrowing the national deficit to some degree and contributing towards overall national rice sufficiency [25].

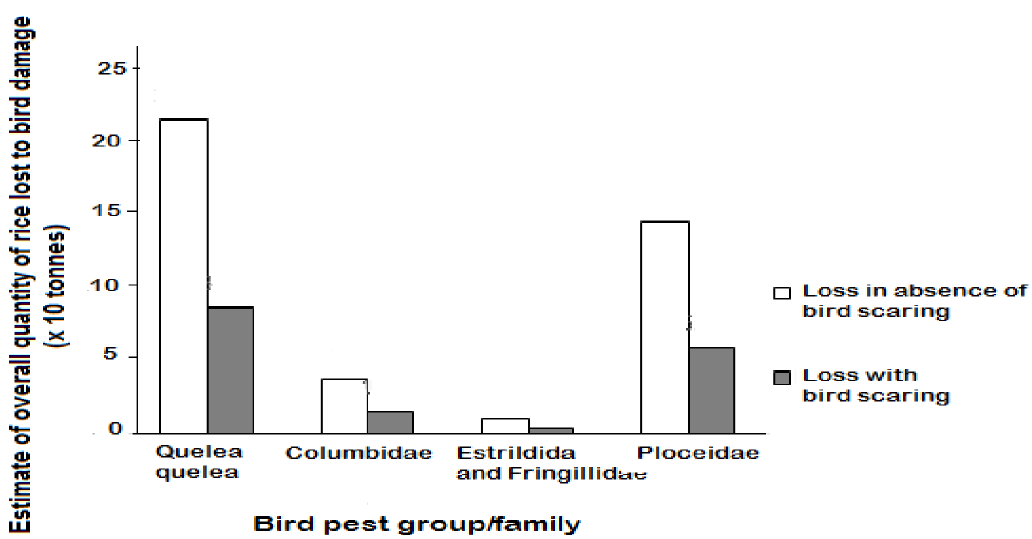

Fig. 2. Estimates of total annual quantity of rice crop loss to damage by various graniviorous pest bird groups at Ahero irrigation scheme. Estimates are for the total irrigated area covering 878 ha

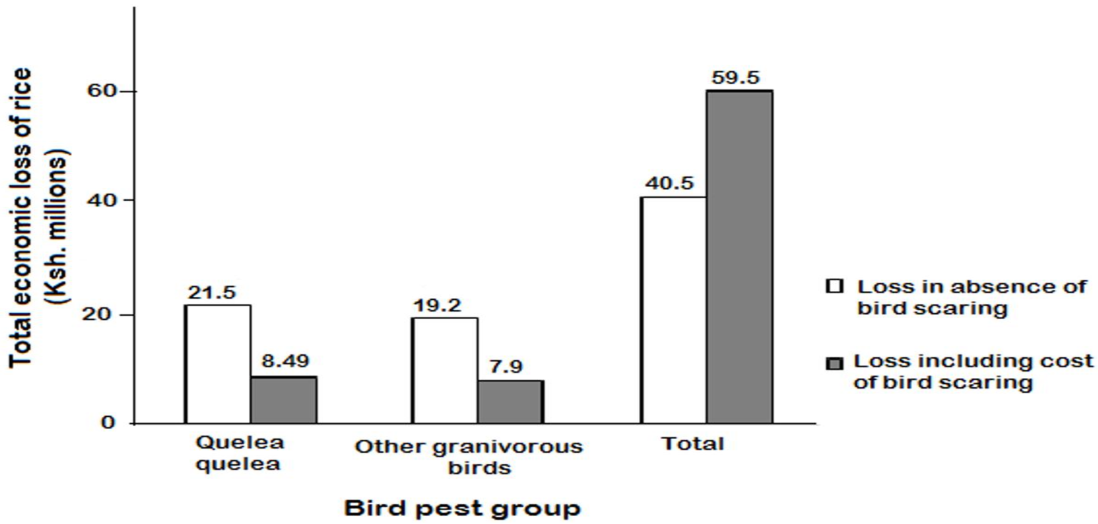

Fig. 3. Estimated economic loss of rice crop to various graniviorous birds at Ahero rice scheme. Estimates are for the total irrigated area covering 878 ha and based on a standard paddy price of Ksh. 100 per kg

Despite the considerable acreage under rice production in Kenya the annual demand for rice in the country still stands at 280,000 tonnes which still far exceeds the local production supply of 122,465 tonnes causing a rice deficit of 157,535 tonnes [25]. For instance in 2012, the country exported only USD 2.5 million worth of rice, which was 1.3% of the USD 191 million imported [28], making Kenya virtually a 100% net importer of the crop. Therefore, for self-sufficiency to be attained, the country needs, in addition to controlling pest birds, to increase production through greater intensification [20], increased irrigation acreage [19], local marketing efficiency or reduction of post-harvest losses [20,22,53]. Rice importation creates a dis-incentive for farmers because it creates unfair international competition, depresses local producer market prices, raises retail prices due to import levies, erodes foreign exchange reserves and provides depresses increased production efforts by farmers [19].

Technical support for wider adoption of new farming technologies and higher yielding varieties has also been proposed as an option for increasing rice production, which may offset losses to pest birds. For instance, planting seeds of the New Rice For Africa (NERICA) varieties [54,55] has been observed to considerably increase production in West Africa [54,56,57]. According to the Africa Rice Centre, NERICA is a fast-growing variety that can increase per hectare yields by up to 25-30% more than Basmati variety, which is currently the most widely grown by Kenyan farmers [26,55,57]

3.2.2 Control of pest birds

The challenge in controlling R. Quelea as rice pests lies in their characteristic large sporadically moving flocks, their high reproduction and feeding rates that frequently causes heavy crop damage in short time periods [7,32,44]. Furthermore, like other crop pests, R. Quelea are expected to increase in numbers and cause more serious crop damage across its range in coming years as expected rainfall becomes increasingly unpredictable or deficient due to climate change [7,33]. This calls for control measure that are both effective and sustainable in the long term.

However, no single control measure has been proved completely effective in eliminating damage of rice and other grain crops by R. Quelea or other colonial graniviorous birds in any parts of Africa despite application of many different methods. These include crop-guarding, poisoning repulsion by explosive sounds, destruction of nesting and roosting sites, mass capture, planting buffer grain crops and use of decoys [21,23,29]. Reidinger and Libay [58] even reported success in controlling weaver pests on corn by covering parts of the crops with very sticky glue to trap some of the birds whose distress calls effectively discouraged other birds from feeding on the crop fields in Nebraska.

However, many of these strategies have various environmental, policy and economic shortcomings. For instance, crop-guarding, which is the most widely used, is not fully effective because firstly, while R. Quelea forage on the fields from as early as 0500 hrs. to as late as 1830 hrs. each day [38,44,48], crop guards are rarely able to commence guarding duty before 0700 hrs. and rarely continue beyond 1730 hrs. Secondly, it is practically non-feasible for one guard that is usually engaged, to diligently protect a 4-acre mature crop from all flocks of granivorous birds for 13 continuous hours of daylight. Finally, efficiency of crop guarding duty is often contingent upon favourable weather and logistical conditions including daily commuting distance from the guard’s homestead to the field site [29]. In addition, crop-guarding ultimately increases production costs.

Other control measures also have drawbacks. For instance, birds quickly habituate against decoys; use of pesticides can result in environmental pollution or death of non-target species [10] while capturing or other contact measures like sticky glueconflicts with wildlife protection laws of many countries including Kenya [58,59]. Similarly, while planting buffer crops to cushion the main crop requires extra acreage. Crop-guarding increases production costs moved to end pf previous paragraph.

Therefore successful control of rice pest birds must entail an integration of several control measures. Typically, granivorous bird pests are initially attracted to paddy-fields by many weeds whose seeds form important food sources at this stage while rice is still immature but because weeds mature and die off earlier than rice, the birds later turn on to rice as the sole source of food [22]. Therefore, controlling weeds on rice fields and planting early-maturing varieties may help to minimize rice loss by ensuring that firstly, the weeds do not attract the birds in the first place and, secondly, the mature crop is exposed to pest birds for a shorter period. In addition, planting at different times around the year may also help to distribute the damage pressure, while growing quick maturing varieties may reduce exposure time to bird damage.

Another effective but costly measure is the use of specially designed barrier netting to block pest bird access to the crop during the final period of maturity and harvesting [29]. The method has been used effectively in many developed counties including in North America and Europe [17]. They were also observed to be effective in a number of rice fields in Senegal, Mali and Nigeria [29] and in controlling House Sparrow Passer domesticus access to vineyards in Israel [60]. Despite high initial cost outlays, maintenance requirements and the fact that it also bars other bird species that are beneficial in controlling arthropod pests, use of barrier netting is a potentially sustainable solution to rice damage as it effectively excludes all pest birds [29,32,58,61] while also eliminating the need for crop-guarding labour, thus reducing overall production costs.

Another option is to attract predatory birds such as raptors to the rice fields. Such birds can effectively control crop pest birds [44,62] but they rarely occur on the rice fields due to either lack of perching surfaces like trees, or due to human disturbance. Perching surfaces may be constructed and erected across the paddy-fields from where the birds of prey would predate upon the flocks of pest birds or discourage them from landing upon the crop [44,62]. The method was used to attract the Australian Harrier *Circus approximans* to control frugivorous birds in a New Zealand vineyard with great success [63]. Two groups or researchers [64,65] also attributed declines in many European farmland birds to predation pressure by carnivorous birds. Attracting predatory birds on the rice fields would have the additional benefit of controlling populations of other rice pests such as rodents and squirrels (64,66]. Finally, as part of an integrated scheme to control pest birds, more recent research has begun to focus on modeling regional climate data, rainfall patterns and crop seasonality which, together with satellite technology, may be used to generate early warning systems for anticipated invasions by Quelea and other pest species across their ranges [33,44] and mobilize resources and strategies for effective control of damage.

4. CONCLUSIONS

Rice damage by pest birds represents a significant economic loss to farmers in at Ahero Rice Scheme and undermines efforts to reduce poverty and improve rural population nutrition and welfare. The greatest loss is attributable to R. Quelea flocks which attack the crop in the final crucial months. The loss to R. Quelea is more than that due to all the other graniviorous pest birds combined, mainly due to occurrence of R.

Quelea in larger flocks than all the others. These losses are incurred in spite of investment by farmers in labour to protect the crop through crop-guarding. When projected to the national scale for all rice schemes in Kenya, loss to pest represents such a significant drawback to national rice sufficiency that is the birds were to be totally controlled, the country could potentially reduce its annual rice import volumes by 7% and thus boost domestic demand. To minimize economic losses to bird damage, there is need for an integrated system of bird control that includes a combination of many different measure that are both cost effective and sustainable to the farmers, in addition to crop-guarding. Such a scheme would best be applicable at the scale of the whole irrigation scheme with good coordination supported by a rice farmers' corporative organization or a local agricultural authority. Adoption of other farming systems that help to minimize impact of bird damage would also reduce economic losses. These include planting of fast-maturing and high-yielding rice varieties, more effective control of weeds that attract granivorous birds, and planting at different times across the year.

CONSENT

Not applicable.

ETHICAL APPROVAL

Not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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