# Chapter 9

# Injury and Yield Losses Due to the Maize Stem Borer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) on Smallholder Farms

**Frank T. Ndjomatchoua, Henri E. Z. Tonnang, Clément Tchawoua, and Bruno P. LeRu**

**Abstract** The present study aims at investigating damage and yield losses due to *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), which is one of the most important insect pests of maize in Kenya. A precise sampling scheme was applied to study the incidence of damage in maize caused by this insect pest on selected small-scale farms, on which pest control measures and fertilisers had not been applied. During the crop-growth stages and harvesting, plant and cob geometrical features were recorded, together with the length of tunnels bored by the insect. It is demonstrated that cob mass is an adequate variable for understanding yield losses caused by this pest. Although the number of plants damaged characterised by stem tunnels was greater than those with cob tunnels, the damages inflicted in the ears have the most considerable impact for yield losses. The recorded yield losses ranged from 35.96% to 48.19%, corresponding to 56.85 to 133.48 Kg/ha in terms of average cob-mass reduction. In general, the cob tunnel and the time of infestation were linearly correlated, while cob tunnel length and cob biomass were linked by a cubic nonlinear function. The observed yield losses at harvest of the maize crop suggest that control measures should be applied continuously, throughout the whole growing season.

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## 9.1 Introduction

Kenya is among the Sub-Saharan countries of Africa with a higher consumption rate of maize per person (Ranum et al. 2014). The cropping of this staple food in Kenya is significantly constrained by insect pests such as lepidopteran stem borers (De Groote 2002; Kfir et al. 2002). Reported maize yield losses are attributed to infestations by stem borers, which can damage more than half of the total production as a result of leaf feeding, stem tunnelling and grain damage (Kfir et al. 2002; Polaszek 1998).

The assessment of yield losses in maize caused by stem borers is usually done by collecting data such as the mass of plant stem, cob or grains (Herbert 2000; Walker 1981). The relevance of the knowledge gained from the data depends on the resources available for sampling and the accuracy needed for the purposes of assessment (Herbert 2000; Walker 1983b). After obtaining data on the different degrees of reduction in masses of maize grain, the yield losses can be assessed by comparing the features of un-attacked and attacked plants (Herbert 2000; Walker 1983b).

The stem borer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) is one of the most important stem borer species that attacks maize in Sub-Saharan Africa, and Kenya in particular (Harris and Nwanze 1992; Kfir et al. 2002; Ong'amo et al. 2006). The injuriousness of *B. fusca* has been assessed by various authors over the decades (Ingram 1958; Walker 1960; Harris 1962; Usua 1968; van Rensburg et al. 1988b; Macfarlane 1990; van den Berg et al. 1991; Cardwell et al. 1997; Ebenebe et al. 1999; Ndemah et al. 2001; Ndemah and Schulthess 2002; Chabi-Olaye et al. 2005). These studies emphasised that the major factors affecting yield losses are: the destruction of the growing part of the plant (dead heart), the number of larvae per plant, stem tunnelling, ear damage, and positions of the attacks on the stem.

Estimating the link between pest damages and yields losses at the field scale by empirical models can be useful for predicting and managing the pest (Bardner et al. 1974; Herbert 2000; Madden et al. 1995; Walker 1983a). Most of the relationships between the level of damage caused by *B. fusca* and yield are decreasing functions (Cardwell et al. 1997; Ndemah et al. 2001; Ndemah et al. 2003a; Walker 1960). In addition to regression analysis, the estimate of the overall percentage of yield losses can be useful to policymakers and farmers for gaining a better perception of the incidence of pest damages (Ajala and Saxena 1994; Ampofo 1988; Chabi-Olaye et al. 2005; Chabi-Olaye et al. 2006; Chabi-Olaye et al. 2008; Cugala et al. 2006; De Groote 2002; Walker 1983a, b; Zadoks 1985).

While yield-loss estimates comprise key information for use in managing stem borers, the estimates of yield losses in existing studies are ambiguous. On one hand, it seems to be overestimated, while on the other hand, the methods and techniques for estimations are either not clear or unknown (Calatayud et al. 2014; Harris and Nwanze 1992; Kfir et al. 2002; Walker 1987). Links between pest damages and yields have been established, but their extrapolation is difficult because the studies have been carried out using artificial infestations, on insecticide-protected fields, or the data collected focused on a few samples, randomly selected in the field (Ingram 1958; Walker 1960; Harris 1962; Usua 1968; van Rensburg et al. 1988b; Macfarlane 1990; van den Berg et al. 1991; Cardwell et al. 1997; Ebenebe et al. 1999; Ndemah et al. 2001; Ndemah and Schulthess 2002; Chabi-Olaye et al. 2005). Additionally, rigorous selections of plant physical traits used to study damage incidence and associations of ear mass to different damage types have not been made.

Although the perceptions of African farmers of the impact of lepidopteran stem borers are still high (Bonhof et al. 2001; Ebenebe et al. 2001; Oben et al. 2015), it is noticed that the values of yield losses due to *B. fusca* currently reported in literature have not been updated (Calatayud et al. 2014; Harris and Nwanze 1992; Kfir et al. 2002; Walker 1987).

The purposes of this study are: (i) to gain an understanding of the current trends in damage incidences attributable to lepidopteran stem borers on small-scale maize farms; (ii) to link these to yield losses, (iii) to describe the incidence of infestation dynamics on the yield, and (iv) to establish empirical relationships between damage types and yield losses.

## 9.2 Materials and Methods

### *9.2.1 Study Site and Data Collection Protocol*

The trial was conducted at Murang’a located between Nyeri and Thika (00° 43′ 00″ S, 37° 09′ 00″ E, 1255 m above sea level) in Kenya. As a result of the varying altitudes, Murang'a can get quite cold from May to Mid-August and can experience hail.

Murang’a has a tropical climate classified as Equatorial savannah with dry winter (Aw) (Kottek et al. 2006). In contrast with winters, the summers have considerable rainfall. The average annual temperature and precipitation are 20.0 °C and 1195 mm, respectively. The driest month is September, with 19 mm of rainfall. Most precipitations here fall in April, averaging 310 mm. The warmest month of the year is November, with an average temperature of 22.5 °C. August is the coldest month, with temperatures averaging 18.1 °C. The difference in precipitation between the driest and the wettest month is 291 mm. Temperatures vary by 4.4 °C, throughout the year.

**Table 9.1** Description of plots

| Plots | Row length | Row spacing | Dimensions (length × width)[a] | GPS coordinates | |
|---|---|---|---|---|---|
| | | | | Latitude | Longitude |
| 1 | 21.00 | 0.60 | 21.00 × 17.17 | −0.922244964 | 37.15198829 |
| 2 | 21.00 | 0.60 | 21.00 × 17.17 | −0.922477751 | 37.15234651 |
| 3 | 18.60 | 0.60 | 23.40 × 20.70 | −0.923219997 | 37.14361341 |
| 4 | 18.60 | 0.60 | 18.60 × 10.80 | −0.919620737 | 37.13853050 |
| Plots | Total number of rows | Total number of plants per row | Space between plants in row | Total number of quadrants during sampling at harvest | Total number of maize plants |
| 1 | 36 | 60 | 0.30 | 4 | 2160 |
| 2 | 36 | 60 | 0.30 | 4 | 2160 |
| 3 | 40 | 70 | 0.30 | 4 | 2800 |
| 4 | 32 | 37 | 0.30 | 4 | 1184 |

[a] Dimensions given in m. The plots were located within a radius of 0.7 Km

A total of four sites were selected from the farmer's field. Then, each plot was divided into four quadrants of equal size. Land preparation was done one month before the onset of rains. Plant residues from the previous season were removed from the experimental plot. Oxen ploughing was carried out on the plots. A commercial maize variety, DUMA-4, commonly grown by Kenyan farmers in mid-altitude areas, was used throughout this study. Planting activities were done by manual labour, at a spacing of 30:70 cm.

The seeds provided to farmers were planted in four plots, as described in Table 9.1. The plots were submitted to identical management and exposed to natural infestation by *B. fusca*. No integrated pest management (IPM) control measure and no fertiliser were applied during the whole of plant growing period. Planting was conducted on 3rd March 2014. After germination, only two healthy plants were left to continue growing in each cluster hole until harvest, which occurred during July 2014. The data collection started on 16th April 2014, approximately three weeks after plant germination, in order to give time for the laid eggs to hatch and the larvae to start feeding on the young plants, and ended on 25th July 2014.

Data collection protocol was identical for all plots. In each plot, all plants were monitored weekly to detect infested maize individuals. The incidence of damage was determined by visual observation of all plants within the plots. Infected plants were tagged with coloured plastic materials having a unique set of numbers and letters which served as an identifier. The types of damages assessed were leaf damage, exit hole, and dead heart. Observations were done in one-week intervals, beginning on 16th April 2014. Plants were examined *in situ* without uprooting. Damage level, taken as the tunnel length bored into the stem and the ear by *B. fusca* individuals that successfully colonised the plants, was assessed at harvest. This was conducted by dissecting (opening by vertical splits) the ears and stems of infested plants.

During harvest, all infested plants were uprooted for proper inspection. An additional 25 non-infested plants were randomly harvested in each quadrant within the experimental plots.

Plants variables, such as stem length and diameters, and plant dry mass (leaves and stem without the cob) were recorded. Physical characteristics of unshelled maize cobs, with corn silk and husk removed were collected. Cob lengths, mass and diameter from both infested and non-infested plants were also recorded. The total number of plants observed in each experimental plot is given in Table 9.1.

### *9.2.2 Data Analyses*

Data were subjected to a one-sample Kolmogorov-Smirnov (K-S) normality test. The mean values of physical features of stems and ears from both non-infested and infested plants were compared, using Welch's two-sample Student t-test for pairs of normally distributed data. Wilcoxon's two-sample test was used for pairs of non-normally distributed data. The Fligner-Killeen (F-K) test was used to assess variance homogeneity between plots (Conover et al. 1981; Fligner and Killeen 1976). All the statistical tests were considered as less significant for $p$-values $\geq 0.05$.

To determine yield loss, only the cob masses were considered (Cardwell et al. 1997; Ebenebe et al. 1999; Ndemah et al. 2001, 2003b). Yield loss is frequently expressed as the fraction (percentage) of the attainable yield lost because of pest injuries (De Groote 2002; Walker 1983a; Zadoks 1985). It is then called relative yield loss (*RYL*), and is computed as: $RYL = 100 \times [(Y - Y_i)/Y]$ (Ajala and Saxena 1994; Ampofo 1988; Chabi-Olaye et al. 2005, 2006, 2008; Cugala et al. 2006; De Groote 2002; Walker 1983a, b; Zadoks 1985). Yield loss was expressed as a difference in mean cob masses between the un-infested ($Y$) and infested plants ($Y_i$). In addition, the total losses per hectare were estimated by summing the difference between the average value cob masses from non-infested plants and individual values of cob masses from infested cobs, after which the result was divided by the plot surface value and expressed in hectares.

The estimate of the parameters of the damage functions that link *B. fusca* tunnel length and corresponding cob masses was conducted through nonlinear least squares, using the Levenberg-Marquardt method (Marquardt, 1963). The goodness of fit and selection of the candidate nonlinear functions was operated with the Akaike Information Criteria (AIC) (Akaike 1974) and the R-squared. The linear link between the evaluation of yield losses and the mean cob tunnelling was calculated by using Person's correlation coefficient (PCC). All analyses were conducted with statistical software R (R Core Development Team 2013).

## 9.3 Results

Data collected at harvest show that plants infested by *B. fusca* outnumbered the proportion containing the crambid *Chilo partellus* (Swinhoe) and the noctuid *Sesamia calamistis* Hampson. The relative percentages of the tunnelled maize

**Table 9.2** Number of larvae found in the plants during field sampling

| | *Busseola fusca* inside tunnels | | | | *Chilo partellus* inside tunnels | | | | *Sesamia calamistis* inside tunnels | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bf/S | Bf Total in Stem | Bf/C | Bf Total in Cob | Cp/S | CP Total in Stem | Cp/C | Cp Total in Cob | Sc/S | Sc Total in Stem | Sc/C | Sc Total in Cob |
| Plot 1 | 1.25 | 45 | 1 | 7 | 1 | 1 | 0 | 0 | 1 | 5 | 1.66 | 5 |
| Plot 2 | 1.15 | 37 | 1 | 1 | 0 | 0 | 0 | 0 | 1.5 | 3 | 1 | 3 |
| Plot 3 | 1.38 | 63 | 1.33 | 8 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Plot 4 | 1.07 | 29 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total of plants tunnelled | | Total of cob tunnelled | | Total of plants tunnelled | | Total of cob tunnelled | | Total of plants tunnelled | | Total of cob tunnelled | |
| Plot 1 | 40 | | 7 | | 1 | | 0 | | 5 | | 3 | |
| Plot 2 | 32 | | 1 | | 0 | | 0 | | 2 | | 3 | |
| Plot 3 | 47 | | 6 | | 0 | | 0 | | 1 | | 0 | |
| Plot 4 | 27 | | 2 | | 0 | | 0 | | 0 | | 0 | |

Bf/S, Cp/S, and Sc/C = mean number of *B. fusca* (Bf)*, C. partellus* (Cp) and *S. calamistis* (Sc) per maize stem (S). Bf/C, Cp/C, and Sc/C = the mean number of *B. fusca, C. partellus* and *S. calamistis* per maize cob (C)

plants were 92.57%, 0.57% and 6.87% for *B. fusca, C. partellus* and *S. calamistis*, respectively (Table 9.2).The majority of larvae were found in stem tunnels and less in cob tunnels (Table 9.2). The ratio (%) of the total number of larvae inside stem tunnels-cob tunnel was 90.63–9.37 for *B. fusca*, 52.94–47.06 for *S. calamistis.* Unique *C. partellus* larvae were found in stem tunnel. The average number of larvae per plant and cob did not exceed 2 (Table 9.2).

The comparison between average physical traits of infested and un-infested maize plants is depicted in Fig. 9.1. Only the cob masses between non-infested and infested plants were differed significantly across all plots. The variance homogeneity among cob masses of infested plants across all plots was less significant (p-val < 0.05) compared with all other factors.

The relative yield losses in term of average cob mass reductions were estimated for each plot as 40.79%, 43.14%, 48.19% and 35.96% for plots 1, 2, 3 and 4, respectively. Given the plant density across plots ranging from 58111 to 58940 plants/ha, with an average of one cob per plant, infestations from *B. fusca* inflicted losses ranging from 56.85 to 133.48 kg/ha. Total yield losses due to stem and cob tunnelling were 42.86% and 62.52%, respectively.

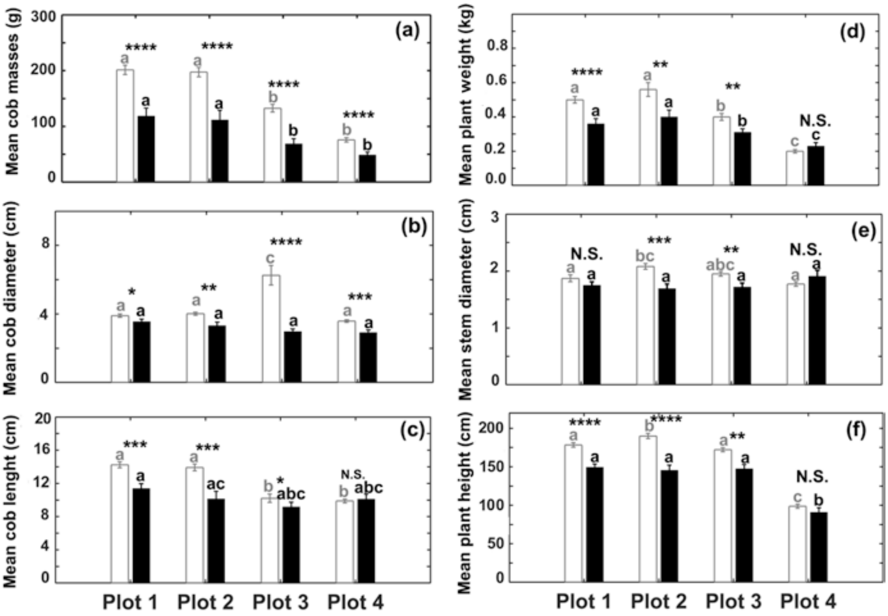

**Fig. 9.1** The black and white bars represent infested and non-infested sets of plants; the star is the significance level between means.
The symbols are: N.S. (Not Significant) for P > 0.05, ∗for P < 0.05, ∗∗for P < 0.01, ∗∗∗for P < 0.001, ∗∗∗∗for P < 0.0001. Bars with the same color letter are not significantly different (P > 0.05)

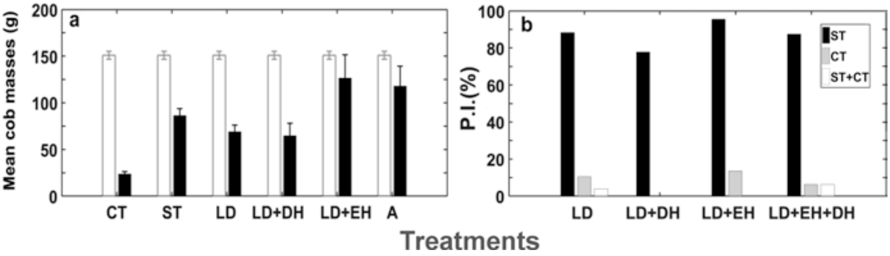

**Fig. 9.2** Effect of the first infestation on the mean cob biomass reduction (**a**, A = LD+DH+EH. The black and white bars represent infested and non-infested sets of plants). Proportion (**b**) of plants infested (P.I.), plant with stem tunnelling (ST) and cob tunnelling (CT) according to the type of infestation such as leaf damage (LD), dead heart (DH), exit hole (EH)

*Busseola fusca* was able to bore, on average, 60.23% and 15.18% of the cob and plant stem lengths, respectively. An investigation of damage severity in cobs, according to the type of infestation such as leaf damages (LD), dead heart (DH), exit hole (EH), was conducted. It was observed that all infested plants have, on average, a lower cob mass compared with the non-infested ones (Fig. 9.2a). The cob tunnelling induced the lowest cob masses, directly followed in terms of incidence by

LD+DH (Fig. 9.2b). It can be noticed that a high proportion (>70%) of infested plants had tunnelled stems. A lower number of infected plants showed cob tunnelling, and it was also noticed that a reduced proportion (<20%) of plants were damaged by stem tunnelling and cob tunnelling, simultaneously. Additionally, 100%, 24.67%, 19.48% and 6.49% of infested plants with LD, LD+EH, LD+EH+DH, and LD+DH, respectively, had a cob at the time of harvest.

Yield-loss patterns attributable to different damages with time are depicted in Fig. 9.3. When the damages are taken separately, a particular trend of variation in yield, according to the week of the first infestation, was not observed. No yield losses for plants with LD at week 11 was noticed while for weeks 4, 7 and 10, no new damages were recorded (Fig. 9.3a). The time of infestation was not related to leaf damage incidence. The EH graph (Fig. 9.3b) did not show any particular trend. For the DH (Fig. 9.3c), the time factor appeared important, and when this damage occurred at the initial stages of maize development, the yield loss is high. However, when DH occurred later in the plant life cycle (after the 7th week of planting), yield losses were lower.

In general, the maize variety selected showed that, after 5 weeks, almost half of the plants in each plot had managed to generate cobs. When the analysis was conducted by pooling data without distinguishing the type of infestations, the losses decreased with the time period of infestation (Fig. 9.3d). The linear regression between the yield losses ($y$) and the time ($t$) of infestation in week ($y = at + b$) had slope $a = -4.28 \pm 0.02$ and intercept $b = 60.48 \pm 0.17$ (P-val > 0.05, $R^2 = 0.31$), with Pearson correlation coefficient $R = -0.56$. This suggests that the linear function was not representative for that data set. However, the linear regression between the average cob tunnel ($y$) and the time of infestation ($t$) in week ($y = at + b$) had slope $a = 0.50 \pm 0.13$ with intercept $b = 3.14 \pm 0.11$ (P-val < 0.05, $R^2 = 0.78$) and Pearson

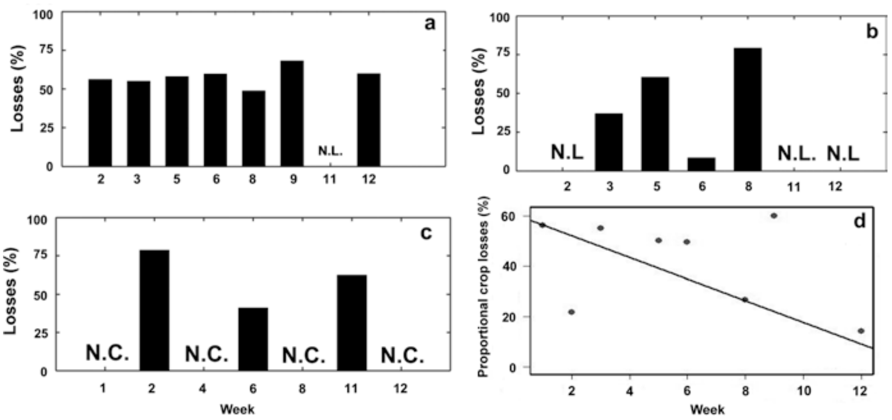

**Fig. 9.3** Temporal patterns of yield losses for plant with leaf damage (**a**), exit hole (**b**), and dead heart (**c**), N.L. and N.C. = no losses and no cob, respectively. Linear regression (**d**) between the week of infestation and the yield losses

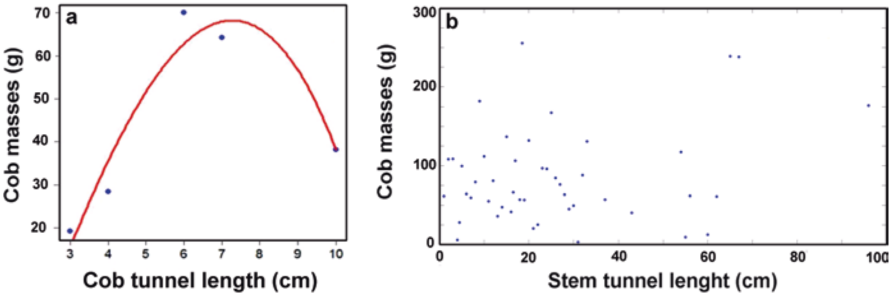

**Fig. 9.4** Relationship (**a**) between length of cob tunnel and cob mass. The the red curve is the estimated function. Cob mass (**b**) as a function of cob tunnel

correlation coefficient $R = 0.88$, showing a linear tendency for mean cob tunnelling increases with time.

Analysis of the link between the cob masses and severity of damages on the stem and cob is shown in Fig. 9.4. After several trials to select a bell-shaped nonlinear function using the AIC, it was observed that the link between cob mass ($y$) and the cob tunnel length ($x$) follows a trend represented by a cubic function (Fig. 9.4a). The analytical expression is: $y = a + bx + cx^3$ and the coefficients are: $a = -54.46 \pm 19.70$, (P-val > 0.05), $b = 26.13 \pm 4.99$ (P-val < 0.05) and $c = -0.16 \pm 0.03$ (P-val < 0.05); $R^2 = 0.92$. We were not able to find any function linking the cob mass and the tunnel length (Fig. 9.4b). This result implies that, while the average value of cob tunnel length increases linearly with time of infestation, the cob masses of infested plants follow a pattern depicted by a cubic functional curve.

## 9.4 Discussion

### *9.4.1 Overview*

In regard to the yield losses and damages attributable to *B. fusca* on maize farms, all recorded studies have been based on different methodological approaches, yielding a high variability in results (Ingram 1958; Walker 1960; Harris 1962; Usua 1968; van Rensburg et al. 1988b; Macfarlane, 1990; van den Berg et al. 1991; Cardwell et al. 1997; Ebenebe et al. 1999; Ndemah et al. 2001; Ndemah and Schulthess 2002; Chabi-Olaye et al. 2005). For comparison purposes, the approach, as well as a synthesis of the methodologies used in literature, applied to study yields losses attributable to *B. fusca* on maize is provided in Table 9.3. Lack of standardisation of experimental methods makes any comparison of results difficult or subjective. This causes a serious problem in the selection of the information concerning the damaging ability of *B. fusca* that may be given to farmers and decision makers. In this work, a simple, realistic and accurate approach has been implemented to study this problem.

**Table 9.3** A summary of methods used in literature to study damage and yield losses due to *Busseola fusca* attacking maize

| Country | Use of insecticide∗ | Use of fertilizer | Artificial infestation | Random harvest of infested plants | References |
|---|---|---|---|---|---|
| Kenya | ✗ | ✗ | ✗ | ✗ | This study |
| South-Africa | ✓ | ✓(c), ✗(a, b), | ✓(a, c), ✗(b) | ✓ | a: van Rensburg et al. (1988a). b: van Rensburg et al. (1988b). c: van Rensburg et al. (1988c). |
| Nigeria | ✗ | ✓ | ✓ | ✗ | Usua (1968) |
| Cameroon | ✓ | ✓(a), ✗(b, c) | ✗ | ✓ | a: Ndemah and Schulthess (2002). b: Chabi-Olaye et al. (2005). c: Chabi-Olaye et al. (2008). |
| Lesotho | ✓ | ✗ | ✗ | ✓ | Ebenebe et al. (1999). |

Damages and yield losses

| Country | Damages considered | | | | Plant parts considered to measure yield losses | | Link between damages level and yield losses | | Yield losses estimates | | References | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LD | EH | DH | ST | CT | Cob mass | Seed mass | L. | N.L. | N.E. | | |
| Kenya | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | 35.96–48.19% | This study |
| South-Africa | ✓ | ✓ | ✓ | | | ✓( b) | ✓(a, c) | | | ✓ | N.E. | a: van Rensburg et al. (1988a). b: van Rensburg et al. (1988b). c: van Rensburg et al. (1988c) |
| Nigeria | ✓ | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | N.E. | Usua, (1968) |
| Cameroon | | | | ✓ | | | ✓ | ✓ (N.S) | | | 0.4–41.00% | Chabi-Olaye et al. (2005); Chabi-Olaye et al. (2008); Ndemah and Schulthess (2002) |
| Lesotho | | | | | | ✓ | ✓ | | | ✓ | 0.4–36.60% | Ebenebe et al. (1999) |

∗Symbols ✓and ✗ refer to 'yes' and 'no', respectively. The abbreviated names of damages are: leaf damage (LD), exit hole (EH), dead heart (DH), plant stem tunnelling (ST) and cob tunnelling (CT). The relationship between the yield losses and the damages are grouped into two categories such as linear (L.), non-linear (N.L.); not estimated (N.E.) means that authors did not estimate a link between damages and yield losses or that the overall yield losses are not estimated. N.S. = not significant. Only studies where a clear establishment of a link between damages intensity and yield losses are reported in this table

### *9.4.2 Methodology of Sampling*

In our work, all plants in the field were considered, in contrast to other studies available in the literature (Cardwell et al. 1997; Chabi-Olaye et al. 2005; Ebenebe et al. 1999; Harris 1962; Ingram, 1958; Macfarlane 1990; Ndemah et al. 2001; Ndemah and Schulthess 2002; Usua 1968; van den Berg et al. 1991; van Rensburg et al. 1988; Walker 1960). Focusing on only a few samples can originate a considerable bias, which reduces the accuracy of results because the selected plants not always provide a valid representation of the whole farm. The majority of methods used in the literature for studying yield losses attributable to lepidopteran stem borers comprise visual-damage rating, by which grain or cob masses are assessed (Ingram 1958; Walker 1960; Harris 1962; Usua 1968; van Rensburg et al. 1988b; Macfarlane 1990; van den Berg et al. 1991; Cardwell et al. 1997; Ebenebe et al. 1999; Ndemah et al. 2001; Ndemah and Schulthess 2002; Chabi-Olaye et al. 2005). In contrast, we appled weekly visual ratings and measurements of cob masses at harvest.

### *9.4.3 Plant Physical Trait to Study* **B. fusca** *Injury*

Although several studies about the link between *B. fusca* damaging factors and yields losses have been conducted over decades (Cardwell et al. 1997; Chabi-Olaye et al. 2005; Ebenebe et al. 1999; Harris, 1962; Ingram, 1958; Macfarlane 1990; Ndemah et al. 2001; Ndemah and Schulthess 2002; Usua 1968; van den Berg et al. 1991; van Rensburg et al. 1988; Walker 1960), it is noticed that a rigorous selection of the plant physical features suitable for studying incidence of the pest has not been done. Comparing features of infested and uninfested plants has been suggested as a systematic method for assessing yield losses in cereals (Walker 1983b). However, studies have considered cob mass (infested versus non-infested) directly as an indicator to assess the pest impact, but without much justification (Cardwell et al. 1997; Ebenebe et al. 1999; Ndemah et al. 2001, 2003b). In this study, a statistical comparison of the plants' physical features has been conducted in order to select cob masses as the key factor.

### *9.4.4 Revisiting Yield Losses in Maize Due to* **B. fusca**

The study of the incidence of pest damage provides crucial data for decision makers that would enable them to allocate meaningful resources for research and management (Reddy and Walker 1990; Savary et al. 2006; Walker 1983a; Zadoks 1985). Therefore, making decisions about controlling lepidopteran stem borers should rely on an accurate estimate of damage incidences and yield losses. However, the values of the overall yield losses in maize attributable to *B. fusca* reported in the literature vary greatly from one country to another, and between different agro-ecological zones (Kfir et al. 2002). Losses reported ranged from 10% to 100% in South Africa (Kfir et al. 2002), 0.4% to 36% in Lesotho (Ebenebe et al. 1999), 0.4% to 41% in Cameroon (Cardwell et al. 1997; Chabi-Olaye et al. 2005; Chabi-Olaye et al. 2008; Ndemah and Schulthess 2002), and 17% in Zimbabwe (Walker 1987). In Kenya and Tanzania, 12% in yield reductions for every 10% of plants attacked have been reported (Walker 1960) and, later on, yield losses of 14% were reported by Walker (1987). All the methods for estimating the yields losses were carried out either by comparing grain or cob masses in a few infested plants, in the field (Cardwell et al. 1997), or by comparing grain masses in a few samples from fields that were protected and unprotected by insecticide (Walker, 1960, 1987; Ebenebe et al. 1999; Ndemah and Schulthess 2002; Chabi-Olaye et al. 2005; Chabi-Olaye et al. 2008). The present research opted to sample all the damaged plants on naturally infested farms. Average yield-loss estimates in this study range between 35.96% and 48.19%.

### *9.4.5 Injuriousness of* **Busseola fusca**

Several studies have been conducted to identify the types of damage that imply higher yield losses due to *B. fusca* (Cardwell et al. 1997; Ebenebe et al. 1999; Ingram 1958; Ndemah et al. 2001; Ndemah et al. 2003b; van Rensburg et al. 1988). Because of the various experimental approaches adopted in these different studies, it was difficult to specify the types of damages (LD, DH, EH, ST or internode attacks) that have the most significant effect in the reduction of maize yields. Concerning tunnelling, *B. fusca* was reported to tunnel from 15% to 30% of the length of the stem (Cugala et al. 2006), a range almost similar to our results. In this study, although the stem tunnelling considerably reduced the cob masses, the results obtained suggest that cob tunnelling by *B. fusca* has a greater effect on yield.

*Busseola fusca* is reported to prefer attacking young plants (Calatayud et al. 2014; Harris and Nwanze 1992; Kfir et al. 2002), and this is a primary reason leading IPM practitioners to apply control measures at the early stage of development of maize crops (Kfir et al. 2002). However, the results obtained in this study suggested that all the plants with leaf damages (primary infestation damage from *B. fusca*) had a cob at the end, in contrast to those having secondary and ternary damages like dead hearts and exit holes, respectively. Therefore, control measures should be applied continuously during the maize life cycle.

### *9.4.6 Temporal Pattern of Infestation*

Much information on the temporal patterns of stem borer infestations has been reported in the literature (Ebenebe et al. 1999; Kfir et al. 2002; Ndjomatchoua et al. 2016; Reddy et al. 1991; van Rensburg 2001; van Rensburg and van den Berg 1992). It is demonstrated that *C. partellus* infestation on younger plants causes a higher incidence of yield losses than infestation on older plants does. Additionally, it is reported that the intensity of leaf damage is significant in younger plants and that stem tunnelling is significantly correlated to yield losses in older plants (Reddy et al. 1991). In the conditions of this study, we did not observe any particular trend in yield losses according to the leaf damage and exit holes made by *B. fusca*. For the dead heart, the time of infestation appears important: when it happens within a two-week interval from planting, yield losses are high. Furthermore, the decrease in yield losses, with the time of infestation observed in this study, is similar to what has been reported in the literature (van Rensburg et al. 1988).

### *9.4.7 Empirical Link Between Infestation and Yield*

Numerous studies have attempted to link the stem tunnelling damages and the cob masses (Cardwell et al. 1997; Ebenebe et al. 1999; Ndemah et al. 2001; Ndemah et al. 2003b). A linear link was presented with little significance in one study (Ndemah et al. 2001). We also failed to establish a link between these two variables in this study. This implies that others factors should be considered while linking yield losses and stem tunnelling, or that no link might exist between these two variables. We went beyond existing studies by estimating the type of link between the cob tunnelling and the cob masses. In general, the yield loss due to a pest on a crop is reported to have a linear or a non-linear function, decreasing with pest-damage intensity (Bardner et al. 1974; Herbert 2000; Madden et al. 1995; Walker 1983a). This trend was observed in maize in the case of *B. fusca* (Cardwell et al. 1997; Chabi-Olaye et al. 2005; Ndemah et al. 2001, 2003a; Walker 1960) and *C. partellus* (Mgoo et al. 2006; Reddy and Walker 1990; Reddy et al. 1991). In this study, a different tendency was observed while analysing cob mass function of the length of the tunnel in a cob, which is a cubic function.

## 9.5 Conclusions

The important role of cob damage caused by *B. fusca* infestation is emphasised. The results confirm that both early and late infestations can be important causes of maize yield losses during the plant life cycle. There is a real need for a standardisation of experimental approaches to be formulated for investigating damages and yield losses attributable to *B. fusca* in order to ensure the replication of studies and facilitate comparisons among results from different authors. The important yield losses recorded in this study on small-scale farms in Central Kenya indicate that *B. fusca* remains a major pest of maize, in spite of the many methods deployed for its control over decades (Bruce et al. 2009; Kfir et al. 2002). Our results suggest that the current control methods, such as male disruption (Critchley et al. 1997), cultural control (Van den Berg et al. 1998), and habitat management (Kfir et al. 2002) should be improved and intensified. Moreover, innovative new control methods, such as dissemination of entomopathogenic fungi (Maniania et al. 2011) and more specific natural enemies (Branca et al. 2011), should be deployed.

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**Conflict of Interest** The authors declare that they have no conflict of interest.

**Research Involving Human Participants and/or Animals and Informed Consent** Not applicable to this study.

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