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Maize Yield Losses From Stemborers in Kenya

Hugo De Groote
International Maize and Wheat Improvement Center (CIMMYT), P. O. Box 25171, Nairobi, Kenya
E-mail: h.degroote@cgiar.org

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Abstract—Maize is the major food crop in Kenya, where 2.3 million tonnes are produced annually to feed an estimated 28.6 million people (79 kg/person p.a.). Population growth in the country is high (2.9 % p.a.), resulting in increased pressure on arable land and, consequently, increased pest pressure on crops. Stemborers are one of the most important pests of maize. Previous research with artificial infestation established clear links between damage factors and yield losses. These results, however, cannot be extrapolated to estimate crop losses in farmers' fields under natural infestation. Due to lack of field data, farmers' (often subjective) estimates of losses under natural infestation and the incidence of infestation were used to estimate maize yield losses for each of Kenya's major agroecological zones. The yield loss was estimated to be 12.9 %, amounting to 0.39 million tonnes of maize, with an estimated value of US$ 76 million. High-potential areas have relatively low crop loss levels (10–12 %), while the low-potential areas have higher losses (15–21 %). Taking into account the higher yield of the former areas (more than 2.5 t/ha), the loss per hectare is remarkably constant, between 315 and 374 kg/ha, except for the dry mid-altitude zones, where losses total approximately 175 kg/ha. The value of these losses is estimated at US$ 61–75/ha and US$ 34/ha, respectively. Such estimates are useful for setting research and extension priorities.

Key Words: stemborer, crop loss, maize, Kenya

Résumé—Le maïs est la principale culture au Kenya, avec 2,3 million de tonnes produites annuellement pour nourrir une population estimée à 28,6 million (79 kg/personne et par an). La croissance de la population dans le pays est élevée (2,9 % par an), avec pour conséquence une pression croissante sur les terres arables, et une augmentation des problèmes dues aux ravageurs. Les foreurs sont un des ravageurs les plus importants du maïs. Des études antérieures, effectuées à partir d'infestations artificielles ont établi une relation étroite entre les pertes des récoltes et les dégâts lies aux foreurs. Toutefois, ces résultats ne peuvent pas être utilisés pour estimer les pertes dans les champs des paysans sous infestation naturelle. Pour palier à l'absence des données de terrains, les estimations des pertes sous infestation naturelle (souvent subjectives) et l'incidence de l'infestation telles que founis par les paysans, ont été utilisés pour estimer les pertes en recolte de maïs dans chaque zone agroecologique importante du Kenya. Les pertes moyennes ont été estimées à 12.9 %, équivalent à 0.39 million de tonnes de maïs d'une valeur approximative de 76 million de dollars. Les régions à haut potentiel ont généralement un taux de pertes plus faible (10–12 %) que les régions à faible potentiels (15–21 %). En valeur absolue, et du fait de rendements plus élevés dans les regions a haut potentiel, les pertes par ha sont relativement constante entre 315 et 374 kg/ha, excepté dans la zone sèche d'altitude moyenne où les pertes totales sont de 175 kg/ha. La valeur de ces pertes est estimée à respectivement 61–75 dollars par hectare et 34 $/ha. Ce genre d'estimations est utiles à la détermination des priorités de recherche et de la vulgarisation agricole.

Mots Clés: foreur, perte de recolte, maïs, Kenya

Introduction

Maize is a major food crop in Africa, especially in the eastern and southern regions of the continent. For many people, it is the main staple, as evidenced by annual consumption levels of 81 kg/per capita in the region and 103 kg/per capita in Kenya (Pingali, 2001). Food production has not kept pace with population growth, and most of the arable land is now being cultivated, leading to serious problems in food security. Agricultural intensification often leads to higher pest pressure, and stemborers are considered to be one of the most important pests in cereal production in East Africa. The importance of a pest is determined by the extent of the losses it causes.

Agricultural research and extension institutes are seeking to develop and disseminate technologies that will improve agricultural production and thus the livelihoods of farmers and their families. Funds are limited and to ensure proper management, different proposed technologies need to be assessed and compared. To compare the potential of new technologies, the cost of developing each technology is compared with the value of the expected benefits. In crop production, this would be the value of the expected yield increase, multiplied by the area affected. For pest control, the expected yield increase would be the yield loss due to the particular pest, multiplied by the efficiency of the proposed technology in abating those losses. Comparing total benefits with the total costs of research in the development of a specific technology will indicate its economic merit, and comparing these calculations across a number of proposed interventions will allow for priority setting. In setting priorities, proposals can be ranked based on their economic merits (comparing their cost/benefit ratios), while taking into account their impact on other objectives of public policy such as food security, poverty alleviation, and reducing inequalities between different groups based on characteristics such as gender or available resources.

This paper presents an example of such a calculation, specifically for stemborers in Kenya. After a brief review of the concepts, the importance of stemborers is discussed and past studies dealing with the losses caused are reviewed. The crop losses due to stemborers are then calculated based on farmers' estimates. An ongoing collaborative study between CIMMYT (the International Maize and Wheat Improvement Center) and the Kenya Agricultural Research Institute (KARI), on the assessment of crop loss due to stemborers in maize in Kenya, is described.

Conceptual Framework

To estimate the economic value of losses due to stemborers, the actual losses need to be measured. Crop loss can be defined as the difference between the actual yield and the potential yield, more precisely, the yield that would have been obtained in the absence of the pest under study. Multiplied by the area of the region and the price of maize, an economic evaluation can be made of the pest's importance.

Crop loss can be defined as the difference between potential yield Y_p and actual yield Y_r. It is convenient to express this difference as a proportion of the potential yield, to obtain a proportional crop loss r:

$$r = \frac{Y_p - Y_r}{Y_p}$$

If this ratio r is known, loss can then be derived from actual yield with following formula:

$$Y_p - Y_r = Y_r \frac{r}{1 - r}$$

The ratio r can be obtained from different sources: farmers' estimates, experts' estimates, or crop loss estimates from the field.

Similarly, crop loss for an area or for a country can be defined as the difference between potential production X_p and actual production X_r (expressed in kg or tonnes). When r is known, we can use a similar formula to estimate absolute crop losses:

$$X_p - X_r = X_r \frac{r}{1 - r}$$

A third method is to derive the crop loss, ratio or absolute value, indirectly from occurrence, incidence, or damage indicators. Occurrence is usually expressed as a binary variable (pest is present). Incidence means the extent of occurrence, or the number of stemborers per plant or per m^2. To avoid destruction of the plant, it can also be approximated by counting the number of infested plants. Other indicators of incidence are damage indicators, such as the number of moth exit holes or foliar damage score. In general, the number of insects n can be estimated through a damage score or rating x:

$$n = f(x)$$

This function can be estimated through regression, and several functional forms are available (Walker, 1991b). Similarly, functions exist that relate the incidence of insects to yield reduction (Walker, 1991c), and some have been developed for stemborers (Walker, 1991a). Alternatively, yield Y can be directly related to a set of damage indicators such as tunnel length for stemborers d, with a set of other relevant variables z such as management practices or variety.

$$Y = f(d, z)$$

Once this relationship and its precision are established, it permits a more economical way of estimating yield loss than direct estimation in trials. Therefore, damage estimators such as moth exit holes should also be measured during crop loss trials to estimate the functional relationship with yield. The accuracy (deviation from the population mean), as well as the precision (size of deviations from the mean by repeated sampling) of indirect yield loss measurement, can then be compared to the direct measurement method by calculating the mean square error (Cochran, 1977), which combines bias and standard error in a measure of total survey error. It is possible to develop cost functions to calculate the cost of obtaining a crop loss estimate within a given error margin (De Groote, 1996). By developing these cost functions for the different estimation methods, the least expensive way to obtain estimates within a given error margin can be calculated.

Finally, to obtain an economic evaluation, losses need to be multiplied by prices. Secondary data will be used here for this purpose.

Maize and Stemborers in Kenya

Maize production in Kenya

A study by CIMMYT and KARI (Kenya Agricultural Research Institute) defined six major agroecological zones for maize production in Kenya (Hassan, 1998), represented in Fig. 1. Moving from east to west, these are the Lowland Tropics (LT) at the coast, followed by the Dry Mid-altitudes and Dry Transitional zones around Machakos. These three zones are characterised by low yields (less than 1.5 t/ha); although they cover 29 % of maize area in Kenya, they only produce 11 % of the country's maize (Table 1). In Central and Western Kenya, we find the Highland Tropics (HT), bordered on the west and east by the Moist Transitional (MT) zone (transitional between mid-altitudes and highlands). These zones have high yields (more than 2.5 t/ha) and produce 80 % of the maize in Kenya on 30 % of the area (see Table 1). Finally, around Lake Victoria, is the Moist Mid-altitude (MM) zone, which produces moderate yields (1.44 t/ha), covers 22 % of the area and produces 9 % of the country's maize.

By using production data from 1998 from the Ministry of Agriculture, and combining these with the population census of 1999, the food security situation in each zone can be assessed (Table 2).

Table 1. Agroecological zones for maize production in Kenya

		Major season			Second season			Total		
Agroecological zone	Elevation (metres)	Area '000 ha	Yield t/ha	Prodn. '000 ton	Area '000 ha	Yield t/ha	Prodn. '000 ton	Yield t/ha	Prodn. '000 ton	Prodn. %
Lowland Tropics	0–700	33	1.36	45	8	0.99	8	1.29	53	2
Dry Mid-altitude	700–1400	118	1.03	122	48	0.83	40	0.98	162	6
Dry-Transitional	1100–1700	37	1.21	45	29	1.08	32	1.15	76	3
Moist-Transitional	1200–2000	424	2.76	1170	42	1.50	64	2.65	1234	46
Highlands	1600–2900	307	2.91	893	9	1.73	16	2.88	909	34
Moist Mid-altitude	1110–1500	118	1.44	170	55	1.11	62	1.34	231	9
Total		1037	2.31	2395	207	1.33	276	2.15	2671	100

Source: Survey data from 1992 (Hassan, 1998).

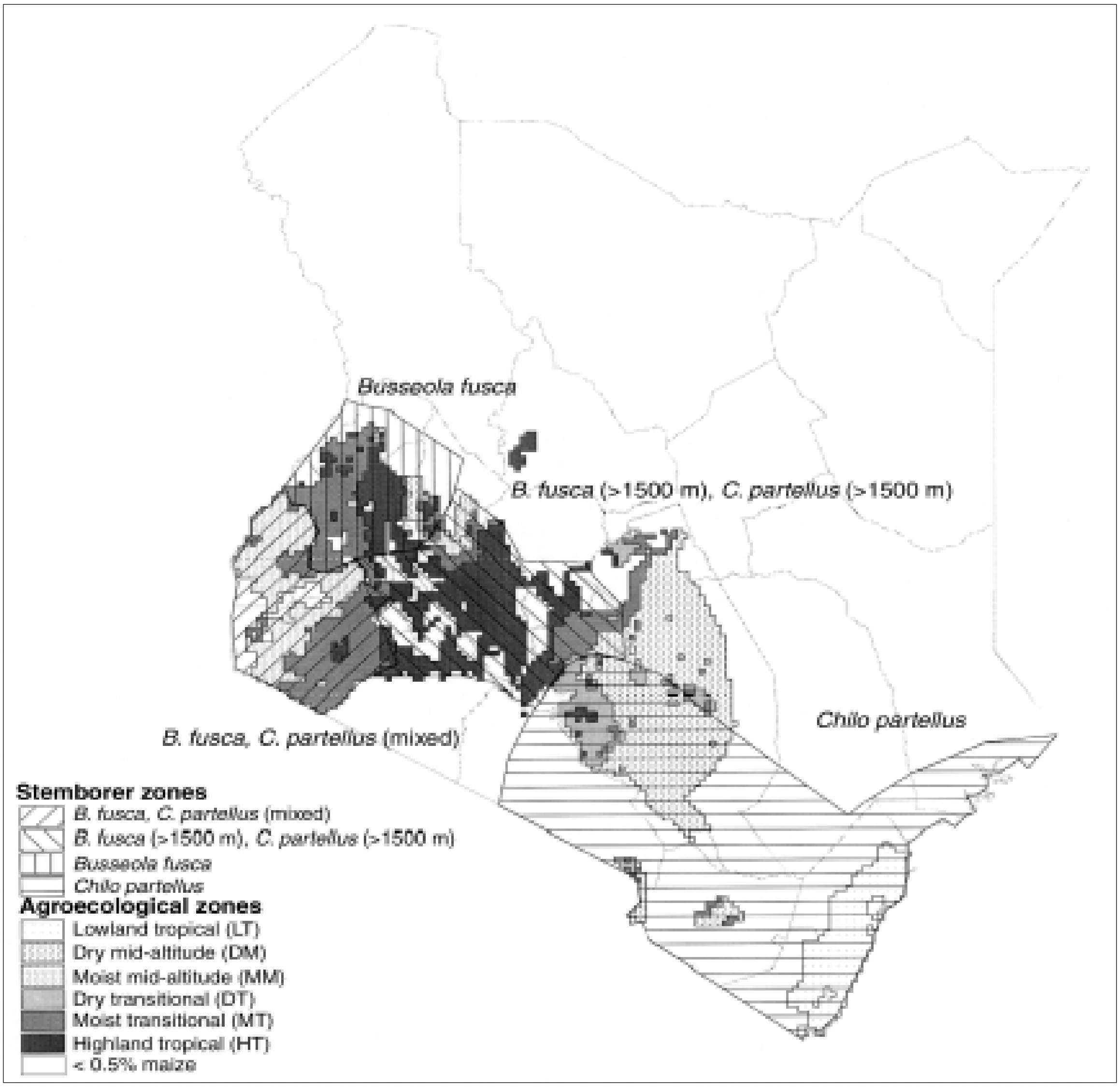

Fig. 1. Major stemborers in Kenya's agroecological zones. Agroecological zones after Hassan (1998); stemborers after W. Overholt (pers. commun.)

Table 2. Agroecological zones and food security in Kenya

Agroecological zone	Area (1992) '000 ha	Area (1992) %	Prodn (1992) '000 ton	Prodn (1992) %	Population (1999) '000	Population (1999) %	Maize prodn (1998) '000 ton	Maize prodn (1998) kg/person
Lowland Tropics	41	3	53	2	1987	7	28	14
Dry Mid-altitude	166	15	162	6	2342	8	87	37
Dry-Transitional	66	11	76	3	1304	5	38	29
Moist-Transitional	466	23	1234	46	7537	26	1024	136
Highlands	316	6	909	34	3812	13	403	106
Moist Mid-altitude	173	22	231	9	3018	11	210	70
< 0.5% maize					5942	21	210	35
Other					2637	9	423	160
Total	1244	100	2671	100	28,579	100	2424	85

Average maize production per person is calculated at 80 kg/per capita for the whole of Kenya. Only the high potential zones (MT and HL) have a higher per capita production. Together the two zones have a population of about 11 million people, 40 % of the Kenyan population, but they produce 80 % of the maize (Table 2).

Stemborers in Kenya

In Kenya, the most important species of stemborers are the spotted stemborer *Chilo partellus* (Swinhoe), found in the warmer and lower areas, and *Busseola fusca* Fuller, found in the cooler and higher altitudes (Mulaa, 1995). A third, less important species is *Sesamia calamistis* Hampson, found at elevations of up to 2600 m. For the first two species, four major areas of distribution can be distinguished, as illustrated in Fig.1 (W. Overholt, pers. commun.). The first area is situated in the southeast , where *C. partellus* is important, and it covers the lowland tropics and most of the dry areas. The second area covers the highlands and the eastern moist transitional zone and is distinguished by *C. partellus* below an altitude of 1500 m, and *B. fusca* above that. The third area, around Lake Victoria, has a mixture of the two species, and covers the moist mid-altitudes and the southwest of the moist transitional zone. The fourth area covers the northwest corner of the highlands and moist transitional zones and is dominated by *B. fusca*.

Damage and Losses by Stemborers—Direct Measurement

Stemborers' initial damage is caused by feeding on the leaf tissues, followed by tunnelling and feeding within the stem, and sometimes the maize cobs (Swaine, 1957). Infestation by *C. partellus* on maize starts with oviposition on the leaves (Ajala and Saxena, 1994). After hatching, the first instars move into the leaf whorls where they feed and develop on the bases of the leaves, causing lesions. The late third or early-fourth instars bore into the stem, feeding on tissues and making tunnels. When the infestation is severe, the larvae, either in the leaf whorl or in the stem, can cut through the meristematic tissues; the central leaves dry up to produce the 'deadheart' symptom, resulting in the death of the plant.

A number of studies in eastern Africa have demonstrated a strong relationship between maize yield and damage caused by artificial infestation of stemborers. Ajala and Saxena (1994) studied the relationship among damage parameters such as foliar damage, deadhearts (%), stem tunnelling, morphological parameters such as plant height and number of ears per plant, and their influence on grain, after artificial infestation of three-week-old maize plants, with 30 first-instars. Reduction in the number of ears harvested due to larval infestation was found to be the primary cause of grain yield loss, mainly due to stem tunnelling of the plants. Yield losses were estimated to fall between 34 and 43 %. Alghali (1992) showed that yield loss due to stemborer damage is influenced by the cultivar, and by the time and number of larvae involved in infestation. Seshu Reddy and Sum (1991) found a linear relationship between infestation and yield loss, and that the extent of loss increased with earlier infestations. This permitted the calculation of an economic injury level (EIL). The Katumani variety, for example, had an EIL of 3.2 and 3.9 larvae/ plant for 20- and 40-day-old plants, respectively. Studies with other varieties showed that the EIL varies with the crop variety (Seshu Reddy and Sum, 1992).

It would be ill-advised, however, to extrapolate the results of artificial infestation trials to estimate crop losses over geographic areas. The grain yield of Katumani Composite B (KCB), for example, is significantly reduced under artificial infestation, but under natural infestation it escapes due to its early maturity (Kumar and Saxena, 1994). Similarly, planting time can have a significant effect on the extent of yield loss. Studies in Ethiopia, using different planting times under natural infestation, indicate a positive correlation between crop loss and late planting (Gebre-Amlak et al., 1989). Second-generation larvae caused crop losses ranging from 22.5 to 100 %, while losses attributed to the first generation were only 0 to 22.6 %.

A study under natural infestation in three sites in Trans Nzoia district (Kenya) estimated the crop losses at 36.9 %; this under recommended farm practices (Mulaa, 1995). Extrapolation of these data may again be dangerous, since crop losses measured under these conditions might not be representative of actual farmers' conditions. Therefore, only systematic surveys under natural infestations and under farmers' conditions can produce more reliable crop loss estimates for a given area.

Two national crop loss assessments from natural infestation in Africa are available. In Cameroon, Cardwell et al. (1997), observed that *B. fusca* accounted for 95 % of all the species found on maize, followed by *Eldana saccharina* (Walker). In the first cropping season, the percentage of stemborer infestation was similar in the lowlands and highlands with a mean of 43 %. Stemborer incidence was higher during the second cropping season: in both low- and mid-altitude fields, 52–56 % of the plants were infested. Using the production function method, the cob weight loss was calculated at 9 g per plant. At that time, the average plant loss from deadheart across the zones was 11 %. The authors, however, did not translate these figures into crop losses for different areas; neither did they estimate the economic value of those losses. We can, however, assume a plant density of 40,000 plants per hectare, which brings the losses to 360 kg/ha, and compare this to the average maize yield in Cameroon of 2.1 t/ha (Aquino et al., 1999), to obtain a crop loss estimate of 14 %. In Ghana, using the production function, crop loss was estimated at 14–17 % in the savanna zones and 27 % in the rainforest zone (Gounou et al., 1994).

Farmers' Estimates of Crop Loss

Although no systematic physical measurement of stemborer losses have been undertaken in Kenya, estimates from a national farmer survey from 1992 are available (Hassan, 1998). Farmers were asked to estimate the percentage of their maize that was lost or affected by stemborer attack (discrete: 10, 25, 50, 75 or 100%); the season(s) that the attack occurs (major, minor or both); and the frequency of the attack, expressed as the number of years between two attacks. Multiplying the proportion of crop loss by the potential production of the respective season and dividing by the frequency of stemborer attacks, the farmers' estimates of crop losses per zone can be obtained (Table 3).

During the survey, total maize production was estimated at 2.6 million tonnes (calculated as the average of production for the survey year 1992, the production from the previous year, and the farmers' estimates of production in a normal year). The farmers estimated crop loss from stemborer attack at 30 %. Adjusting for frequency, by season, the total loss due to stemborers is estimated at 0.4 million tonnes, or 12.9 % of the estimated harvest. The average maize price in Kenya from 1997 to 2000 is estimated at 1300 Ksh/bag of 90 kg, or US$ 193/tonne (based on monthly maize wholesale prices for 24 markets in different parts of Kenya, Ministry of Agriculture, unpublished data). Multiplying total losses by this price results in an estimated loss of US$ 59 million. In absolute terms, most of this loss is situated in the moist transitional zone (40 % of the total value) and the highlands (23 %). Only a small fraction of this loss is situated in the dry lands (4.5 %) and the lowlands (3 %).

It should be noted, however, that the two zones with high absolute losses have low relative losses (11 and 15 %, respectively), but these zones have also much higher yields, 2.8 and 2.9 t/ha, respectively (Table 2). An alternative way to express the importance of losses due to stemborers is to express its value per hectare. The average loss per hectare is remarkably constant: 315 to 374 kg/ha, except for the dry mid-altitudes where losses amount to only 175 kg/ha. The value of that loss can be estimated at US$ 61 to 74/ha, with the dry mid-altitudes only at US$ 34/ha.

Table 3. Value of loss per hectare, by agroecological zone (farmers' estimates)

Agroecological zone	Yield t/ha	Prodn '000 t	Loss+ '000 t	Loss % of potential	Value of loss++ US$ million	Adoption rate % farmers	Loss t/ha	Value of loss $/ha
Lowland Tropics	1.29	53	14	20.3	3	40	0.346	67
Dry Mid-altitudes	0.98	162	28	14.6	5	65	0.175	34
Dry Transitional	1.15	76	20	20.7	4	90	0.315	61
Moist Transitional	2.65	1234	173	12.3	33	95	0.386	75
Highlands	2.88	909	100	9.9	19	95	0.320	62
Moist Mid-altitude	1.34	231	60	20.7	12	75	0.374	72
Total	2.15	2666	394	12.9	76		0.341	66

+Farmers' loss estimates/ha x area affected (Hassan, 1998).
++Estimated at US $ 193/t.

If we extrapolate from these data the potential impact of a new technology, we have to take into account other factors, such as the technical efficiency of that technology, the likely adoption rate, and the cost. Farmers in the dry mid-altitudes, for instance, are historically less likely to adopt modern varieties (65 %) and the value of crop loss per hectare in the area is low. Biological control methods could be a less costly solution there. The lowlands equation is different again. The zone shows an average loss of US$ 67/ha, but has only 33,000 ha of maize, with a narrow range of varieties, and only 40% of its farmers adopting modern varieties. As a result, the cost of developing varieties for this area might be high compared to the low potential benefits.

The moist transitional and highland tropics exhibit losses of US$ 74 and 61/ha, respectively, and very high adoption rates of modern varieties, especially hybrids. Chances of adoption of new resistant varieties are high and so are potential benefits, although the low frequency of stemborer attack in this area might be a negative factor. The moist mid-altitude and dry transitional zones are areas of medium potential. They both have high losses per hectare (US$ 97 and 82/ha, respectively), but the adoption rate is low for the moist mid-altitudes (75 %), while the maize area of the dry transitional is small (37,000 ha) and comparable to the lowlands.

Further Research

To date, the estimates of crop losses attributable to stemborers for East Africa are not very reliable. Most of the direct estimates were obtained from on-station research involving artificial infestation, or covered only small areas. The farmers' estimates from the survey by Hassan (1998), on the other hand, were obtained from a nationwide representative sample, but the accuracy of their estimates has not been tested. This paper shows how they present a very interesting first estimate of losses by region. To better focus breeding efforts towards insect resistant varieties, the Insect Resistant Maize for Africa (IRMA) project has initiated studies using both farmers' estimates and on-farm direct assessment of crop losses.

Farmers' estimates were obtained using Rapid Rural Appraisals during the first half of 2000, in villages that were representative of all agroecological zones. The major tool used was group interviews, conducted with male and female farmers. Information was collected on farmer preferences of crop varieties and the criteria used to select them. The relative importance of stemborers was obtained from ranking of the important constraints to maize production, as well as the important pests. Farmers were then asked to quantify the losses they suffered due to stemborer damage, and whether they would be interested in buying resistant varieties.

On-farm loss assessments are being conducted to evaluate potential yield benefits from using resistant maize varieties. In addition, the potential impact of the new insect resistant varieties is being assessed using on-farm evaluations in the different zones and being compared with crop losses in local varieties. The first results of these studies are currently being analysed.

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References

Ajala S. O. and Saxena K. N. (1994) Interrelationship among *Chilo partellus* (Swinhoe) damage parameters and their contribution to grain yield reduction in maize (*Zea mays* L.). *Appl. Entomol. Zool.* 29, 469–476.

Alghali A. M. (1992) Effects of cultivar, time and amount of *Chilo partellus* Swinhoe (Lepidoptera : Pyralidae) infestation on sorghum yield components in Kenya. *Maydica* 37, 371–376.

Aquino P., Carrión F. and Calvo R. (1999) *Selected Maize Statistics. Part 3 of CIMMYT 1997/98 World Maize Facts and Trends; Maize Production in Drought-stressed Environments: Technical Options and Research Resource Allocation.* CIMMYT, Mexico, D.F.

Cardwell K.F., Schulthess F., Ndemah R. and Ngoko Z. (1997) A systems approach to assess crop health and maize yield losses due to pests and diseases in Cameroon. *Agric. Ecosyst. Environ.* 65, 33–47.

Cochran W. G. (1977) *Sampling Techniques.* John Wiley and Sons, New York. 428 pp.

De Groote H. (1996) Optimal survey design for rural data collection in developing countries. *Q. J. Int. Agric.* 35, 163–175.

Gounou S., Schulthess F., Shanower T., Hammond W.N.O., Braima H., Cudjoe A.R. and Antwi K.K. with I. Olaleye (1994) Stem and ear borers of maize in Ghana. *Plant Health Management Research Monograph No. 4.* International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Gebre-Amlak A., Sigvald R. and Petersson J. (1989) The relationship between sowing date, infestation and damage by the maize stalk borer, *Busseola fusca* (Noctuidae), on maize in Awassa, Ethiopia. *Trop. Pest Manage.* 35, 143–145.

Hassan R. M. (Ed.) (1998) *Maize Technology Development and Transfer: A GIS Application for Research Planning in Kenya.* CAB International, Wallingford, UK/ CIMMYT/KARI. 230 pp.

Kumar H. and Saxena K. N. (1994) Infestation and damage on three maize cultivars by the stalk-borer *Chilo partellus* (Swinhoe) in relation to their yield in western Kenya. *Insect Sci. Applic.* 15, 331–335.

LeClerg E. L. (1971) Field experiments for assessment of crop losses. In *Crop Loss Assessment Methods. FAO Manual on the Evaluation and Prevention of Losses by Pests, Diseases and Weeds* (Edited by L. Chiarappa). FAO, Rome.

Mulaa M. A. (1995) Evaluation of factors leading to rational pesticide use for the control of the maize stalk borer *Busseola fusca* in Trans Nzoia district, Kenya. PhD thesis, University of Wales, Cardiff.

Pingali P.L. (ed.) (2001) *CIMMYT 1999–2000 World Maize Facts and Trends. Meeting World Maize Needs: Technological Opportunities and Priorities for the Public Sector.* CIMMYT, Mexico, D.F. 60 pp.

Seshu Reddy K. V. and Sum K. O. S. (1991) Determination of economic injury of the stemborer, *Chilo partellus* (Swinhoe) in maize, *Zea mays* L. *Insect Sci. Applic.* 12, 269–274.

Seshu Reddy K. V. and Sum K. O. S. (1992) Yield–infestation relationship and determination of economic injury level of the stem-borer, *Chilo partellus* (Swinhoe) in three varieties of maize, *Zea mays* L. *Maydica* 37, 371–376.

Swaine G. (1957) The maize and sorghum stalkborer *Busseola fusca* in peasant agriculture in Tanganyika territory. *Bull. Entomol. Res*. 48, 711–722.

Walker P. T. (1991a) Empirical models for predicting yield loss caused by one type of insect: The stemborers, pp. 133–137. In *Crop Loss Assessment and Pest Management* (Edited by P. S. Teng). APS Press, The American Phytopathological Society, St Paul, Minnesota.

Walker P. T. (1991b) Measurement of insect pest populations and injury, pp. 19–29. In *Crop Loss Assessment and Pest Management* (Edited by P. S. Teng). APS Press, The American Phytopathological Society, St Paul, Minnesota.

Walker P. T. (1991c) Quantifying the relationship between insect populations, damage, yield and economic thresholds, pp. 114–125. In *Crop Loss Assessment and Pest Management* (Edited by P. S. Teng). APS Press, The American Phytopathological Society, St Paul, Minnesota.