# Assessment of avoidable losses and economic injury levels for the sorghum head bug, *Calocoris angustatus* Leth. (Hemiptera:Miridae) in India

H. C. Sharma and V. F. Lopez

*International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru P.O., A.P. 502 324, India*

Abstract. Avoidable losses and economic injury levels (EILs) were computed for the sorghum head bug, *Calocoris angustatus* Leth., on three cultivars during three rainy seasons (1985–1987) at ICRISAT. Grain yield in plots protected with 2–5 insecticide sprays (carbaryl at 500 g a.i./ha) between the half-anthesis and the dough stage was significantly higher than in untreated plots, with cost–benefit ratios > 1. Plots that were not protected at half-anthesis and/or complete-anthesis, and at milk and dough stages, suffered a significant loss in yield. Bug damage spoiled the grain quality in terms of germination, 1000-grain mass, grain hardness and percentage floaters. Three to four sprays between complete-anthesis and the dough stage prevented a significant reduction in grain quality. Head bug density at half-anthesis, complete-anthesis, milk and dough stages was significantly and negatively associated with grain yield. Bug density at different stages explained 43–94% of the variance in yield. Direct effects of bug numbers at the milk stage and the indirect effects of head bug density at other stages through the milk stage contributed towards maximum reduction in yield. Maximum avoidable losses were recorded in cultivar ICSV 1 (88·6%), followed by CSH 1 (69·9%), and CSH 5 (53·9% in 1986 and 55·0% in 1987). Loss in grain yield/ha due to one insect/panicle at half-anthesis and that based on natural increase, were 548 and 232 kg in CSH 5 during 1986 and 1987, respectively, 251 kg in ICSV 1, and 77 kg in CSH 1. EILs based on a cost–benefit ratio of 1:1 ranged from 1·3–1·4 insects/panicle for CSH 1, 0·4 for ICSV 1, and 0·4–0·6 and 0·2–0·4 for CSH 5 during 1986 and 1987, respectively. Simple cost estimates for insecticide sprays and the resultant saving in grain yield are a useful tool for decision-making in pest management.

Keywords: Sorghum; head bug; *Calocoris angustatus*; avoidable losses; economic injury level; India

## Introduction

Sorghum (*Sorghum bicolor* (L.) Moench.) is one of the most important cereal crops in Asia, Africa, and Latin America. Grain yields on peasant farms are generally low, partly because of insect pests (Sharma, 1985a). Nearly 32·1% of the production is lost because of insect pests (Borad and Mittal, 1983). Panicle-feeding insects alone result in an annual loss of nearly US $100 million in India (Leuschner and Sharma, 1983).

*Calocoris angustatus* is one of the most important pests of grain sorghum in India. Adults and nymphs feed on the endosperm of the developing grain from anthesis to the hard-dough stage, and this results in severe loss in grain yield and quality (Sharma, 1985b).

Avoidable losses and economic injury levels (EILs) have been determined for relatively few pests, although these are central issues in decision-making in pest management. The problem lies in adopting an appropriate methodology to compute losses, and the variation in the cost of inputs and the associated savings in yield (Pedigo, Hutchins and Higley, 1986). In sorghum, EILs have been reported for shoot fly, midge, armyworm, and some coreid and pentatomid bugs (Hall and Teetes, 1982), but not for mirid head bugs. This paper reports the results of studies on the losses and EILs for *C. angustatus* on three sorghum cultivars. An attempt has also been made to compute EILs from a cost–benefit ratio of 1:1, based on one insect across all panicle developmental stages or by following the natural increase of bugs. EILs were also computed by the formula of Norton (1976) and compared with those calculated from cost–benefit ratios.

The loss of grain quality due to damage by head bugs is important. Endosperm texture is an important characteristic in food preparation. Vitreous and hard endosperm is preferred for several porridges (Rooney and Murty, 1982). Bug feeding increases amylase activity, and severely affects the grain quality, both physically and biochemically. During the rainy season, bug feeding renders the grain susceptible to mould infection, causing further deterioration in grain quality. Bug damage changes the endosperm texture and spoils the grain quality. Data were recorded on 1000-grain mass, grain hardness, percentage floaters and percentage germination, to evaluate the effect of bug damage on grain quality during the 1987 rainy season.

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## Materials and methods

*Effect of different spray schedules on head bug numbers and grain yield*

Studies were carried out at ICRISAT during three rainy seasons (1985–1987), with sorghum cultivars ICSV 1 and CSH 1 studied in 1985, and CSH 5 in 1986 and 1987. The crop was planted on ridges 75 cm apart, and the seedlings were thinned to a 10 cm spacing within the row 15 days after emergence. Carbofuran 3G at 40 kg/ha, i.e. 1·2 kg a.i./ha, was applied at the time of planting to protect the crop from shoot fly and stem borer damage. Two infester rows of hybrids CSH 1 and CSH 5 were planted every eight test rows 20 days before the experimental plots. Each plot measured 6 × 9 m. The experiments were laid out in a randomized block design and there were four replications. Head bugs collected from other fields were uniformly spread in the infester rows at panicle emergence. The bugs multiplied for one generation and then moved to the test plots. This provided uniform infestation and increased the head bug population in the experimental plots.

Carbaryl (1-naphthyl methylcarbamate) at 500 g a.i./ha was sprayed at 500 l/ha with a knapsack sprayer, with a hollow cone nozzle, and a pump pressure of 2·5–3·0 kg/cm$^2$. A polyethylene screen (2 × 2 m) was held downwind to minimize drift to adjacent plots. The spray schedules are given in *Tables 1–4*.

Head bugs were counted in 10 randomly selected panicles in each plot 24 h after each spraying during 1985, and 24 h before and after each spraying during 1986 and 1987, at different stages of panicle development. At maturity, sorghum panicles from the central four rows of each plot were harvested for grain yield.

Data on bug numbers and grain yield were subjected to analysis of variance, and the treatment means were compared using the least significant difference (LSD). Correlation and regression coefficients of bug numbers and grain yield at different stages of panicle development were computed. The data were also subjected to path coefficient analysis to determine the direct and indirect effects of bug numbers at different stages of panicle development on grain yield.

TABLE 1. Effect of carbaryl sprays on head bug numbers and grain yield at different stages of panicle development in CSH 1 (1985 rainy season)

| Treatment | No. of head bugs / panicle after spray | | | | | Grain yield (kg/ha) | Cost–benefit ratio |
|---|---|---|---|---|---|---|---|
| | HA | CA | M | D | HD | | |
| T1 HA[a] | 0·3(0·4)[b] | 3·6(1·8) | 21·7(4·6) | 81·6(8·7) | 4·7(2·1) | 1409 | 1: 9·0 |
| T2 HA + CA | 0·1(0·2) | 0·1(0·3) | 2·0(1·4) | 16·3(3·9) | 5·0(2·2) | 1605 | 1: 5·5 |
| T3 HA + CA + M | 0·4(0·6) | 0·4(0·6) | 0·4(0·5) | 18·7(4·0) | 4·0(2·0) | 1496 | 1: 3·3 |
| T4 HA + CA + M + D | 0·0(0·0) | 0·3(0·5) | 0·5(0·7) | 1·5(1·1) | 1·3(0·9) | 1159 | 1: 1·6 |
| T5 HA + CA + M + D + HD | 0·2(0·3) | 0·4(0·6) | 0·4(0·5) | 2·7(1·6) | 0·0(0·0) | 1678 | 1: 2·4 |
| T6 CA + M + D + HD | 7·0(2·6) | 0·2(0·4) | 0·5(0·6) | 2·5(1·4) | 0·3(0·5) | 1383 | 1: 2·2 |
| T7 M + D + HD | 4·7(2·4) | 15·3(3·8) | 0·3(0·5) | 1·1(1·0) | 0·2(0·3) | 1575 | 1: 3·6 |
| T8 D + HD | 5·6(2·3) | 18·3(4·1) | 56·3(7·3) | 1·0(0·9) | 0·3(0·4) | 655 | 1: 0·8 |
| T9 HD | 11·7(3·0) | 22·0(4·4) | 64·0(7·9) | 65·0(8·0) | 0·3(0·4) | 455 | 1: −0·5 |
| T10 Untreated–check | 13·7(3·7) | 10·3(3·1) | 51·3(7·1) | 61·0(7·7) | 6·0(2·2) | 505 | — — |
| SE | ±(0·36) | ±(0·47) | ±(0·51) | ±(0·76) | ±(0·31) | ±106·8 | |

[a]HA, Half anthesis; CA, complete anthesis; M, milk stage; D, dough stage; HD, hard dough stage; [b]figures in parentheses are $\sqrt{n}$ transformations

TABLE 2. Effect of carbaryl sprays on head bug numbers and grain yield at different stages of panicle development in ICSV 1 (1985 rainy season)

| Treatment | No. of head bugs / panicle after spray | | | | | Grain yield (kg/ha) | Cost–benefit ratio |
|---|---|---|---|---|---|---|---|
| | HA | CA | M | D | HD | | |
| T1 HA[a] | 1·9(1·3)[b] | 0·8(0·9) | 12·7 (3·1) | 6·7(2·4) | 0·1(0·2) | 2366 | 1:20·4 |
| T2 HA + CA | 1·7(1·1) | 0·3(0·4) | 0·8 (0·9) | 2·5(1·5) | 1·1(0·6) | 2451 | 1:10·8 |
| T3 HA + CA + M | 0·5(0·6) | 0·4(0·6) | 0·3 (0·3) | 5·0(1·5) | 0·5(0·3) | 2253 | 1: 6·5 |
| T4 HA + CA + M + D | 1·3(0·8) | 0·4(0·6) | 0·0 (0·0) | 0·1(0·1) | 0·1(0·2) | 2599 | 1: 5·8 |
| T5 HA + CA + M + D + HD | 3·6(1·7) | 5·2(1·6) | 0·1 (0·1) | 0·1(0·1) | 0·1(0·2) | 2161 | 1: 3·7 |
| T6 CA + M + D + HD | 17·5(4·1) | 0·7(0·8) | 0·3 (0·5) | 0·2(0·3) | 0·1(0·2) | 1895 | 1: 4·0 |
| T7 M + D + HD | 12·5(3·4) | 38·7(6·1) | 0·7 (0·7) | 0·0(0·0) | 0·0(0·0) | 469 | 1: 0·6 |
| T8 D + HD | 11·0(3·2) | 22·7(4·8) | 87·2 (9·3) | 0·1(0·3) | 0·0(0·0) | 296 | 1: 0·0 |
| T9 HD | 11·0(3·2) | 19·1(3·3) | 89·5 (9·1) | 10·5(2·8) | 0·0(0·0) | 587 | 1: 2·9 |
| T10 Untreated–check | 9·7(2·9) | 34·2(5·3) | 159·2(12·4) | 4·2(2·0) | 0·0(0·0) | 296 | — — |
| SE | ±(0·40) | ±(0·75) | ±(0·70) | ±(0·44) | ±(0·21) | ±199·1 | |

[a,b]As in *Table 1*

TABLE 3. Effect of carbaryl sprays on head bug numbers and grain yield at different stages of panicle development in CSH 5 (1986 rainy season)

| Treatment | No. of head bugs / panicle | | | | | | Grain yield (kg/ha) | Cost–benefit ratio |
|---|---|---|---|---|---|---|---|---|
| | CA | | M | | D | | | |
| | Before spray | After spray | Before spray | After spray | Before spray | After spray | | |
| T1 CA[a] | 7·7(2·7)[b] | 1·4(1·1) | 4·0(1·9) | 11·0(3·2) | 11·2(3·3) | 5·5(2·3) | 2770 | 1:14·14 |
| T2 CA + M | 8·5(2·9) | 0·8(0·9) | 8·0(2·7) | 0·5(0·6) | 2·5(1·5) | 1·5(1·2) | 2766 | 1: 7·14 |
| T3 CA + M + D | 9·2(3·0) | 0·4(0·4) | 3·2(1·8) | 1·4(1·0) | 8·2(2·4) | 0·6(0·8) | 2903 | 1: 5·15 |
| T4 M + D | 8·2(2·8) | 7·5(2·7) | 52·2(6·9) | 1·1(1·0) | 4·0(1·8) | 0·0(0·0) | 2426 | 1: 5·94 |
| T5 D | 7·2(2·6) | 5·2(2·2) | 56·0(7·4) | 92·7(8·9) | 51·7(6·6) | 0·6(0·6) | 1531 | 1: 1·92 |
| T6 Untreated–check | 11·0(3·2) | 4·5(2·1) | 60·7(7·6) | 70·5(8·3) | 57·0(7·4) | 31·5(5·4) | 1339 | 1: 1·00 |
| SE | ±(0·19) | ±(0·19) | ±(0·59) | ±(0·96) | ±(0·76) | ±(0·53) | ±172·8 | |

[a,b]As in *Table* 1

TABLE 4. Effect of carbaryl sprays on head bug numbers and grain yield in sorghum hybrid CSH 5 (1987 rainy season)

| Treatment | No. of head bugs / panicle | | | | | | | | Grain yield (kg/ha) | Cost–benefit ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | HA | | CA | | M | | D | | | |
| | Before spray | After spray | Before spray | After spray | Before spray | After spray | Before spray | After spray | | |
| T1 HA[a] | 4·0(2·1)[b] | 0·0(0·0) | 11·0(3·2) | 3·0(1·6) | 158·0(12·2) | 96·0 (9·7) | 54·0(7·3) | 12·5(3·3) | 2170 | 1:10·95 |
| T2 HA + CA | 5·0(2·2) | 0·0(0·0) | 7·0(2·6) | 0·0(0·0) | 22·0 (4·5) | 8·0 (2·8) | 16·0(4·0) | 9·0(2·9) | 2388 | 1: 6·57 |
| T3 HA + CA + M | 6·0(2·3) | 0·0(0·0) | 12·0(3·2) | 0·0(0·0) | 15·0 (3·8) | 2·0 (1·5) | 17·0(4·1) | 8·0(2·8) | 2128 | 1: 3·51 |
| T4 HA + CA + M + D | 3·0(1·8) | 0·0(0·0) | 11·0(3·2) | 0·0(0·0) | 9·0 (2·9) | 3·0 (1·5) | 8·0(2·8) | 2·2(1·5) | 2633 | 1: 3·90 |
| T5 CA + M + D | 5·0(2·2) | 5·0(2·2) | 10·0(3·1) | 0·0(0·0) | 15·0 (3·8) | 3·0 (1·6) | 5·0(2·2) | 2·0(1·3) | 2351 | 1: 4·25 |
| T6 M + D | 5·0(2·2) | 4·0(2·1) | 17·0(2·6) | 30·0(5·7) | 182·0(12·5) | 4·0 (2·0) | 7·0(2·6) | 1·2(1·4) | 1770 | 1: 3·48 |
| T7 D | 5·0(2·2) | 5·0(2·1) | 7·0(2·6) | 37·0(5·7) | 161·0(12·5) | 65·0 (8·0) | 32·0(6·0) | 2·2(1·4) | 1150 | 1: 0·75 |
| T8 Untreated–check | 5·0(2·2) | 5·0(2·1) | 10·0(3·1) | 35·0(5·6) | 165·0(12·5) | 111 (10·4) | 30·0(5·3) | 8·0(2·7) | 1075 | |
| SE | ±(0·20) | ±(0·20) | ±(0·57) | ±(0·72) | ±(0·98) | ±(0·59) | ±(0·42) | ±(0·32) | ±170·1 | |

[a,b]As in *Table* 1

*Effect of head bug damage on grain quality*

During the 1987 rainy season, grain from different treatments was given various quality tests. One hundred grains were taken at random from each replication and placed in the folds of moist filter paper in a Petri dish at 25 ± 2°C for a germination test. The paper was moistened every 24 h and the number of grains that germinated counted after 72 h.

Thousand-grain samples were taken at random with an automatic grain counter and equilibrated overnight for moisture content in an oven at 37°C. Grain mass was recorded the following day, and the samples were subjected to a grain-floater test to evaluate the effect of bug damage on grain density. We followed the procedure of Hallgren and Murty (1983) and conducted the test using a sodium nitrate solution of specific density 1·31. Very few grains of the test cultivar, CSH 5, settled at the bottom in sodium nitrate solution, so we compared the percentage floaters in plain water, which has a specific density of 1·0. The heavy grains settling at the bottom were removed and dried overnight at 40°C. The mass of the heavy grains was recorded and expressed as a percentage of the total grain mass.

Grain hardness was recorded on the Kiya® rice hardness tester. Twenty-five grains selected at random were tested for hardness in each replication. Moisture content was equilibrated in an oven at 37°C for 24 h before the test. The maximum force required to break an individual grain was recorded as the hardness score. Data were analysed statistically to compute the least significant difference between treatments. Correlation coefficients between grain quality parameters were also computed.

*Avoidable losses*

Avoidable losses were computed from the grain yield recorded in untreated check plots and those receiving maximum protection against bugs. Avoidable losses ($C$) were computed by:

$$C = \frac{(a - b)}{a} \times 100$$

where $C$ = avoidable loss (%); $a$ = grain yield in protected plots, and $b$ = grain yield in unprotected plots.

*Economic injury level (EIL)*

Economic injury levels were computed from a cost–benefit ratio of 1:1, that is when the cost of control was equal to the value of the grain saved. EILs were based on one insect per panicle across all stages of panicle development, and on the rate of natural increase in the untreated check plots. For example, in CSH 1 the rate of natural increase of head bugs in the untreated control plots was 1, 0.8, 3·7, 4·5 and 0·4 insects/panicle at the half-anthesis, complete-anthesis, milk, dough and hard-dough stages, respectively. The loss in grain yield from one insect per panicle at half-anthesis was computed by using the rate of natural increase of bugs at different stages in the regression equation (*Tables 7* and *9*).

EILs were also computed by the formula of Norton (1976), as discussed by Pedigo *et al.* (1986):

$$\mathrm{EIL(Q)} = \frac{C}{P \times D \times K}$$

where $C$ = cost of insecticide use per hectare,
$P$ = price of produce/quintal (one quintal (q) = 100 kg)
$D$ = loss in grain yield (q/ha) associated with one insect/panicle, and
$K$ = reduction in pest attack (0·80).

## Results

*Effect of different spray schedules on head bug numbers and grain yield*

During the 1985 rainy season, bugs remained under check in plots sprayed at half-anthesis and/or complete-anthesis to hard-dough stage (treatments T2 to T6) (*Table 1*). However, there was some increase in bug numbers in plots sprayed at half-anthesis and complete-anthesis only. Grain yield did not differ significantly among plots treated at half-anthesis + complete-anthesis and those treated up to hard-dough stage with 3–5 sprays (T3 to T5). In ICSV 1, plots not protected at half-anthesis + complete-anthesis suffered a significant loss in grain yield (*Table 2*). This suggests that protection during the initial stages of grain development (half-anthesis to complete-anthesis stages) is most critical for head bug control. However, cultivar susceptibility to bugs at a particular stage of development also seems to affect the extent of grain damage: e.g. ICSV 1 appears to be more susceptible to head bugs during the initial stages of grain development compared with CSH 1. ICSV 1 has a small grain and compact panicle, compared with the bold grain and semi-compact panicle of CSH 1. These characteristics may also account for the differences in susceptibility of these cultivars to bugs.

Cost–benefit ratios were >1 in plots protected with 1–5 sprays from the half-anthesis and hard-dough stages in CSH 1, and between the complete-anthesis and hard-dough stages in ICSV 1.

A three-spray schedule was followed during the 1986 rainy season on CSH 5 (*Table 3*). Plots protected at the complete-anthesis, milk and dough stages gave the maximum grain yield, followed by those treated at the complete-anthesis and milk stages. These treatments also gave good control of bugs. Plots not treated at complete anthesis suffered a significant reduction in grain yield. Plots protected at the dough stage only, suffered as much bug damage as the untreated check plots. Cost–benefit ratios ranged from 5·15 to 14·14 in plots treated with 1–3 sprays between the complete-anthesis and dough stages.

During the 1987 rainy season, four sprays were applied in different combinations on CSH 5 (*Table 4*). Plots protected at all four stages of panicle development yielded 2630 kg/ha compared with 1075 kg/ha in the unprotected plots. Plots protected at the half-anthesis and/or complete-anthesis and milk stages did not differ significantly from those receiving complete protection. However, plots that were not protected at these stages suffered heavy losses in grain yield. Plots protected with 3–4 sprays of insecticide gave cost–benefit ratios of 3·5–4·3.

*Effect of head bug damage on grain quality*

Grain germination (%), thousand-grain mass, heavy grain (%), and grain hardness were significantly higher when the panicles were protected between the half-anthesis and dough stages, and between the complete-anthesis and dough stages (*Table 5*). Plots not protected either at the complete-anthesis and/or milk and dough stages, suffered a significant reduction in grain quality. Similarly, plots not protected either at the complete-anthesis and/or the milk stage showed a greater reduction in grain quality.

Correlation coefficients between grain hardness, 1000-grain mass, percentage floaters and grain germination were positive and significant, indicating that damage by head bugs affects all the grain quality parameters (*Table 6*).

TABLE 5. Germination (%), 1000-grain mass, heavy grain (%), and grain hardness of CSH 5 grain from plots protected at different stages of panicle development (1987 rainy season)

| Treatment | Germination (%) | 1000-grain mass (g) | Heavy grain (%) | Grain hardness |
|---|---|---|---|---|
| T1 HA[a] | 11·5 | 16·81 | 59·6 | 0·19 |
| T2 HA + CA | 10·0 | 17·96 | 59·4 | 0·34 |
| T3 HA + CA + M | 10·3 | 17·95 | 74·0 | 0·55 |
| T4 HA + CA + M + D | 26·0 | 20·15 | 92·5 | 0·55 |
| T5 CA + M + D | 21·3 | 20·02 | 82·8 | 0·84 |
| T6 M + D | 15·3 | 16·17 | 45·1 | 0·73 |
| T7 D | 5·5 | 13·71 | 20·7 | 0·25 |
| T8 Untreated-check | 3·3 | 12·87 | 10·0 | 0·24 |
| SE | ±3·01 | ±0·87 | ±9·35 | ±0·0495 |

[a]As in *Table 1*

*Direct and indirect effect of head bug density at different stages of panicle development on grain yield*

The direct and indirect effects of bug density at different stages of panicle development on grain yield are given in *Table 7*. Head bug numbers at the half-anthesis to dough stages were significantly and negatively associated with loss in grain yield, except in bug numbers at the dough stage in ICSV 1 and CSH 5 during 1987. Correlation coefficients indicated that head bug numbers at the complete-anthesis and milk stages had maximum effect on grain yield, and their regression coefficients were also significant (except CSH 1 and CSH 5 during 1986). Head bug density after spraying at different stages of panicle development explained 42·6% of the variance in grain yield for CSH 1; this percentage was 72·6% for ICSV 1, and 82·0% for CSH 5. During 1987, the mean numbers of bugs before and after spraying at each stage of panicle development were considered for regression analysis. All the regression coefficients were significant, and they explained 93·7% of the variance in grain yield. Thus, bug density before and after spraying during the various developmental stages is important in determining the loss in grain yield.

The direct effects of bug numbers at the milk stage were maximum in both CSH 1 and ICSV 1. Bug numbers at the half- and complete-anthesis stages also showed negative direct effects and on the correlation and regression coefficients. The indirect effects of head bug numbers at these stages through head bug density at the milk stage were also negative. In CSH 1, bug density at the dough stage also showed considerable negative direct effects.

Direct effects of bug density at the complete-anthesis, milk, and dough stages were negative in CSH 5 in 1986. The bug numbers at the complete-

Table 6. Correlation coefficients between grain germination (%), 1000-grain mass, heavy grain (%), and grain hardness in CSH 5 (1987 rainy season)

| | Germination (%) | 1000-grain mass | Grain hardness | Heavy grain (%) |
|---|---|---|---|---|
| Germination (%) | | | | |
| 1000-grain mass | 0·71* | | | |
| Grain hardness | 0·57* | 0·59* | | |
| Heavy grain (%) | 0·67* | 0·83** | 0·56* | 1·00 |

*, **Significant at $P = 0·05$ and $P = 0·01$, respectively

Table 7. Direct and indirect effects of head bug density at different stages of panicle development on grain yield (1985–1987 rainy seasons)

| | Half anthesis (HA) | Complete anthesis (CA) | Milk (M) | Dough (D) | Hard dough (HD) | Correlation coefficient ($r$) | Regression coefficient ($b$) |
|---|---|---|---|---|---|---|---|
| CSH 1, 1985 rainy season[a] | | | | | | | |
| HA | −0·13 | −0·02 | −0·25 | −0·06 | −0·0002 | −0·46* | −11·0 |
| CA | −0·09 | −0·03 | −0·30 | −0·02 | −0·003 | −0·46* | −1·7 |
| M | −0·06 | −0·02 | −0·50 | −0·08 | 0·008 | −0·67** | −9·4* |
| D | −0·03 | −0·01 | −0·17 | −0·25 | 0·007 | −0·45* | −3·4 |
| HD | −0·001 | 0·01 | −0·02 | −0·09 | 0·02 | −0·10 | 3·5 |
| $X$ = 0·47 | | | | | Intercept = 1423*; $R^2$ = 42·6 | | |
| ICSV 1, 1985 rainy season[a] | | | | | | | |
| HA | −0·36 | −0·12 | −0·12 | 0·01 | 0·02 | −0·58** | −52·0* |
| CA | −0·10 | −0·43 | −0·15 | 0·01 | 0·01 | −0·67** | −22·6* |
| M | −0·10 | −0·16 | −0·41 | −0·01 | 0·01 | −0·67** | −7·1* |
| D | 0·05 | 0·06 | −0·05 | −0·04 | −0·01 | 0·01 | −7·7 |
| HD | 0·09 | 0·08 | 0·07 | −0·01 | −0·08 | 0·14 | −120·0 |
| $X$ = 0·24 | | | | | Intercept = 2480*; $R^2$ = 72·6 | | |
| CSH 5, 1986[a] | | | | | | | |
| CA | | −0·20 | −0·34 | −0·10 | ... | −0·64** | −79·3 |
| M | | −0·11 | −0·60 | −0·17 | ... | −0·89** | −13·4* |
| D | | −0·08 | −0·44 | −0·24 | ... | −0·76** | −8·9 |
| $X$ = 0·16 | | | | | Intercept = 3296*; $R^2$ = 93·7 | | |
| CSH 5, 1987[b] | | | | | | | |
| HA | −0·40 | −0·89 | 0·36 | 0·21 | ... | −0·72** | −156·5* |
| CA | −0·27 | −1·30 | 0·72 | −0·04 | ... | −0·89** | −83·4* |
| M | −0·15 | −0·97 | 0·97 | −0·63 | ... | −0·79** | 9·4* |
| D | 0·10 | −0·05 | 0·63 | −0·96 | | −0·30 | −55·7* |
| $X$ = 0·06 | | | | | Intercept = 3652; $R^2$ = 93·7 | | |

[a]Number of head bugs after spraying; [b]mean number of head bugs before and after spraying; *, **significant at $P = 0·05$ and $P = 0·01$, respectively; $R^2$, coefficient of determination (%); $X$, effect of residual factors

anthesis and dough stages also showed negative indirect effects through head bug density at the milk stage.

On the basis of mean bug numbers before and after spraying during 1987, the direct effects were negative and greater for head bug density at the half-anthesis, complete-anthesis, and milk stages. However, both the direct and indirect effects of head bug density at the milk stage were positive, indicating that much of the loss in grain yield is inflicted by bugs before or even after the milk stage.

Head bug density after spraying explained 52·5% of the variation in direct and indirect effects for CSH 1, 76·1% for ICSV 1, and 84.3% for CSH 5 (during 1986). The mean bug numbers considered during 1987 explained 97·3% of the variance.

### *Avoidable losses*

Maximum avoidable losses were recorded in ICSV 1 (88·6%), followed by CSH 1 (69·9%) and CSH 5 (53·9% in 1986, and 55·0% in 1987) (*Table 8*). Loss in grain yield/ha due to one insect/panicle across all stages was 286 kg in CSH 5 in 1987, 209 kg in ICSV 1 in 1985, 154 kg in CSH 5 in 1986 and 22 kg in CSH 1 in 1985. However, when we consider the natural rate of increase in head bug numbers in the unprotected plots and use it in the regression equation, the loss in grain yield/ha was 548 kg in CSH 5 in 1987, 251 kg in ICSV 1 in 1985, 232 kg in CSH 5 in 1986 and 77 kg in CSH 1 in 1985 (*Table 9*).

### *Economic injury level (EIL)*

Economic injury level (EIL), based on a cost–benefit ratio of 1:1 and Norton's procedure (Norton, 1976)

TABLE 8. Extent of avoidable losses due to head bugs in three cultivars (1985–1987 rainy seasons)

| Cultivar | Grain yield (kg/ha) Protected | Grain yield (kg/ha) Unprotected | Avoidable losses (%) |
|---|---|---|---|
| CSH 1 (1985) | 1677 | 505 | 69·89 |
| ICSV 1 (1985) | 2599 | 296 | 88·61 |
| CSH 5 (1986) | 2903 | 1339 | 53·88 |
| CSH 5 (1987) | 2388 | 1075 | 54·98 |

was 1·3–1·4 insects/panicle for CSH 1 (4·5 insects/panicle based on one insect/panicle across all stages) and 0·4–0·6 insects/panicle for ICSV 1 and CSH 5 (EIL for CSH 5 in 1987 was 0·2 insects/panicle). EILs calculated by the Norton (1976) formula were close to those calculated on the basis of a cost–benefit ratio of 1:1 (*Table 9*).

## Discussion

Grain yield did not differ significantly between plots treated at the half-anthesis to dough stages with 2–4 sprays. However, plots that were not protected at half anthesis and complete anthesis suffered a significant loss in grain yield, indicating that bug damage during the initial stages of panicle development results in severe losses in grain yield. This observation supports earlier findings (Sharma and Leuschner, 1987) that protection around complete anthesis is most critical in preventing head bug damage. Cost–benefit ratios were > 1 for plots protected with 2–4 sprays between the half-anthesis and dough stages, and thus control of head bugs on high-yielding cultivars is economically feasible, to minimize the losses in grain yield and quality.

Head bug damage caused a severe loss in grain quality. The quality of grain from plots protected with 3–4 sprays at the half-anthesis to dough stages differed substantially from those treated with 1–2 sprays and half anthesis and complete anthesis. However, grain yield from plots protected with 1–2 sprays at the half-anthesis and/or complete-anthesis stages did not differ significantly from those protected with 3–4 sprays. Therefore, it seems that even though the quantitative reduction in yield may not be great, the quality can be severely affected with partial protection or by low levels of head bug infestation.

Avoidable losses due to head bugs ranged from 53·9% on CSH 5 to 88·6% in ICSV 1. Loss of grain yield was generally much greater in ICSV 1 and CSH 5 than in CSH 1. The former has a compact panicle, which is suitable for the growth and survival of bugs, whereas the rate of population build-up on CSH 1 may be slower because of its semi-loose panicle. Therefore, sorghum cultivars should mainly

TABLE 9. Economic injury levels (EILs) for *C. angustatus* (1985–1987 rainy seasons)

| Cultivar | Year | Loss in grain yield (kg/ha) One insect per panicle[a] | Loss in grain yield (kg/ha) Following natural increase[b] | EIL (one insect across stages)[c] | EIL (based on natural increase)[c] | EIL (Norton, 1976) |
|---|---|---|---|---|---|---|
| CSH 1 | 1985 | 22 | 77 | 4·5 | 1·3 | 1·4 |
| ICSV 1 | 1985 | 209 | 251 | 0·5 | 0·4 | 0·4 |
| CSH 5 | 1986 | 154 | 548 | 0·6 | 0·4 | 0·5 |
| CSH 5 | 1987 | 286 | 232 | 0·4 | 0·2 | 0·2 |

[a]Based on one insect/panicle across all stages, i.e. $X_1$, $X_2$, $X_3$, and $X_4 = 1$ in regression equations (*Table 7*); [b]based on natural increase of the insect in unprotected plots, i.e. 1, 0·9, 3·4, 4·5 and 0·5 bugs/panicle in unprotected plots at half-anthesis ($X_1$), complete anthesis ($X_2$), milk ($X_3$), dough ($X_4$) and hard-dough ($X_5$) stages respectively, in CSH 1 or $Y = 1423 - 11{\cdot}0X_{1{\cdot}0} - 1{\cdot}7X_{0{\cdot}9} - 9{\cdot}4X_{3{\cdot}4} - 3{\cdot}4X_{4{\cdot}5} + 3{\cdot}5X_{0{\cdot}5}$ (*see* regression coefficients in *Table 7*); [c]cost benefit ratio, 1:1

be bred for a loose to semicompact panicle, to minimize losses due to head bugs.

Economic injury levels ranged from 1·3 to 1·4 for CSH 1, from 0·4 to 0·6 for ICSV 1, and from 0·2 to 0·4 for CSH 5. EILs based on a cost–benefit ratio of 1:1 and those calculated by Norton's formula (Norton, 1976) were closely comparable.

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