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AN ECOLOGICAL STUDY OF AND DEVELOPMENT OF A MONITORING TECHNIQUE FOR THE DAMAGE DONE TO AVOCADO FRUITS BY HEMIPTERA IN THE HAZYVIEW REGION OF SOUTH AFRICA

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SUMMARY

Hemiptera on avocado fruit in South Africa causes two kinds of symptoms: protrusions (attributed to stinkbugs, including Nezara viridula *(L) (Pentatomidae) and/or* Penthimiola bella *(Cicadellidae)) and indentations (caused by coconut bug* Pseudotheraptus wayi *(Brown) (Coreidae)). In the present study it was found that:*

1. *the incidence of protrusions on Hass avocados (10%) was five times greater than on Fuerte (2%),*
2. *this damage is inflicted during early fruit development and did not increase above 11% (average 9%) during the study period,*
3. *damage was distributed throughout the study site with no edge effect,*
4. *feeding was density independent and random regarding height and aspect of avocado trees,*
5. *fruits with protrusions were not aborted, and*
6. *the high percentage of fruits on which the leafhopper* P. bella *was trapped indicated that this may not be the causal agent of the protrusions.*

A technique for monitoring the incidence of fruit bearing protrusions is described. Feeding by coconut bug was also density independent and random, but did enhance fruit drop and the mass of indented fruit was 28% lower than that of healthy fruit and those bearing protrusions indicating that these fruits are less energy expensive than those bearing protrusions whose Mass did not differ from that of healthy fruits. There was no relationship between the incidence of fruit displaying protrusions and indentations, indicating that even though there are similarities in the internal damage to the fruit and patterns of feeding, the protrusions are not caused by the coconut bug.

INTRODUCTION

Until recently, there have been few and relatively unimportant avocado pests (Annecke & Moran, 1982). However, during the last decade there has been a threefold increase in the number of insect pest tax a damaging avocado fruits and this has been attributed to the recent expansion in the avocado industry (Dennill & Erasmus, 1992).

During the last three years, avocado fruits have been increasingly attacked by Hemiptera that induce protrusions on the fruit surface. The damage, described and illustrated by Dennill & Erasmus (1991), has been attributed to stinkbugs, including *Nezara viridula* (L) (Pentatomidae), by various researchers and consultants (see Dennill & Erasmus, 1991). In packhouse surveys of insect damage to avocado fruits in the Nelspruit Hazyview district during 1990 and 1991, this damage was fourth and most important, causing losses of 1.8% and 3.1% of the fruits, respectively (Dennill & Erasmus, 1991, Erichsen, 1992). During the 1991 and 1992 seasons, there has been a sudden increase in the incidence of this damage in the Hazyview area (25° S; 31° E), where some farmers claim to have lost up to 30% of their crop (W Vos, personal communication). The damage is also becoming more widespread, as reported from the Tzaneen and Natal avocado growing regions during 1991 and 1992 (C.J. Partridge, personal communication). Although researchers were previously unanimous that this damage was caused by stinkbugs (Dennill & Erasmus, 1991), W.J. du Toit & C. Erichsen (personal communication) claim that the citrus leafhopper (*Penthimiola bella* (Stal) (Cicadellidae) is responsible.

The present study concerns two symptoms caused by hemipteran feeding on avocado fruit: protrusions and indentations. In the center of the protrusions just below the fruit surface, the feeding hole where the insect inserted its piercing sucking mouthparts is clearly demarcated by an elongated (1-3 mm) rod-like scar of dead, black tissue. This scar is surrounded by corky, orange coloured tissue. Indentations in the fruit surface are attributed to coconut bug, *Pseudotheraptus wayi* (Brown) (Coreidae), feeding on young fruits (De Villiers, 1990, Du Toit & De Villiers, 1990, Van der Meulen, personal communication, Viljoen, 1986). Within the flesh of the fruit below these indentations are feeding marks and scar tissue identical to those occurring immediately below the protrusions.

The aims of the present study were to determine:

1. Levels of damage on the two main cultivars (Hass and Fuerte),
2. Whether there is an increase in the incidence of damage over time (to determine whether the damage was inflicted only during the early stages of fruit development between September and December),
3. The distribution of the damage within trees regarding height and aspect (some insects, e.g. citrus thrips *Scirtothrips aurantii* Faure (Thripidae)), are more damaging on the warmer northern aspects of their host plants at higher southern African latitudes (Grout & Richards, 1990),
4. The distribution of the damage within an orchard (some insects are more damaging on the periphery),
5. Whether feeding is density dependent,
6. Whether there is any relationship between the incidence of the two kinds of damage (since the internal scars are similar in both cases and since some researchers are currently doubting the identity of the insect(s) causing the protrusions),
7. The percentage of fruits on which the leafhopper *P. bella* could be trapped (using

Flytac) and to relate this to the incidence of fruits bearing protrusions,

8. Whether the two kinds of feeding enhance fruit drop, and
9. A practical technique for monitoring this damage.

MATERIALS AND METHODS

The study was undertaken on the farm of Mr W. Vos (25° 5'S; 30° 59'E), which appeared to be most severely affected in the Hazyview area. The orchard selected consists of 2374 trees of cultivars Hass and Fuerte planted in alternating sets of three rows of each. The study site within this orchard is narrow (41 rows, maximum 26 trees/row), being bordered on the eastern side by a riverine habitat containing indigenous vegetation invaded by weeds e.g. bugweed (*Solarium mauritianum* Scop.) and on the western side by a dust road beyond which the orchard continues (see Fig. 1). The study began on 9 December 1991 after the farmers in the Hazyview area had alerted the South African Avocado Growers' Association to the problem. At this stage the width of the healthy developing fruits was that of a golf ball (mean mass = 46 g). Examination of the study orchard revealed that there were also many fruits displaying indentations associated with coconut bug. The only other insect damage observed could be ascribed to loopers (Geometridae) (De Villiers & Van den Berg, 1987), and was minimal (3 fruits damaged). Since the identity of the insect causing the protrusions was in question, and since the only other insect-induced damage in the orchard was due to coconut bug, the fruits displaying indentations caused by the latter were examined in a similar way to those bearing protrusions.

Levels of damage (protrusions) on different cultivars

Between 9 and 13 December 1991, eleven pairs of contiguous rows of Hass and Fuerte trees (rows three and four and thereafter every second and third row) were selected. In each set of rows every fifth pair of trees (one of each cultivar) was selected, and the damaged and undamaged fruits at head height were counted on each tree. Since the rows in the study area consist of about 30 trees each, six pairs of trees should have been sampled per row, yielding a total of 66 trees of each cultivar. However, since some trees had died or been removed, a total of 65 Hass and 59 Fuerte trees were sampled in order to determine whether there was a difference in the incidence of damage between these cultivars.

Incidence of damage (protrusions) over time

In order to determine whether there was an increase in the incidence of damage overtime, a random sample of Hass trees in the same orchard was selected monthly from December 1991 to June 1992. On each tree, the fruit at head height were examined for damage as described above. Only Hass trees were used since the results indicated that Fuerte trees suffered only mild damage (2%) compared with Hass trees which were 5 times more severely affected (10%).

Distribution of damage (protrusions) within the orchard

The 65 Hass trees sampled according to the method described above were scored from 1 to 5 according to the percentage of fruits that were damaged (0%, 1-25%, 2650%, 51-75% and 76-100%, respectively). In this way the distribution of the damage in the orchard could be mapped.

Distribution of damage (protrusions and indentations) within trees

Eleven Hass trees were randomly selected within the study area. Each tree was divided into horizontal 1-m strata and each stratum into four aspects (north, east, south & west). The fruits in each 1-m segment were picked and the damaged fruit (bearing protrusions or indentations) and undamaged fruit were counted.

In this manner, the proportion of damaged fruits in each height class and aspect could be determined. Only Hass trees were used since the results indicated that Fuerte trees suffered only mild damage (2%) whereas Hass trees were 5 times more severely affected (10%).

Density dependence (protrusions and indentations)

Using the methods described in the preceding section, each tree was divided into a number of segments (each aspect of each 1-m height class). For each segment, the total number of fruit could be used as an index of fruit density while the percentage of damaged fruit could be used to determine the incidence of damage for the density of fruits in that segment. These data could be used to determine the relationship between fruit density and incidence of damage for both kinds of damage.

Relationship between the incidence of protrusions and indentations

Because the results indicated similarities in the pattern of distribution of both kinds of damage, it was thought that both symptoms may be caused by the same insect, namely coconut bug. The symptoms could thus be different either because the fruit were attacked at different stages of development, or because the fruit were attacked by different life stages of the insect. The relationship between the proportion of fruits bearing each symptom was therefore examined for the eleven trees and for the segments (1-m strata divided into aspects) into which the 11 trees had been divided. In addition, the mass of healthy fruit, fruit bearing protrusions and indented fruit, was determined for 100 randomly selected fruit of each kind.

Trapping *P. bella* on sticky fruits

Every month from December 1991 until June 1992, 20 Hass trees were randomly selected throughout the study site. On each tree, a minimum of 20 fruits (5 on each aspect of each tree) were painted with Flytac in order to trap insects feeding on the fruit surfaces. These fruits were left to hang unhindered for 5 days and then examined for the presence of *P. bella.*

Enhancement of fruit drop (protrusions and indentations)

Damaged and undamaged fruits lying on the ground underneath each of the eleven Hass trees described above were counted. The relationship between the percentage of fruits dropped and percentage of damaged fruits among the dropped fruits could thus be investigated to determine whether damaged fruits were shed.

Development of a sampling technique

In order to devise a practical method for assessing losses due to fruits bearing protrusions, quick counts of damaged and undamaged fruits at head height were compared with the actual incidence of damage for 20 Hass trees. In addition, the percentage of damaged fruit in the 1-2 m stratum, which is easily accessible, was compared with the actual incidence of damage on the eleven Hass trees described above.

RESULTS

Levels of damage (protrusions) on different cultivars

The percentage of Hass avocados displaying protrusions (9.8%) was five times that of Fuerte avocados (2.1 %) (Table 1).

TABLE 1 A comparison of the incidence (%) of damage (protrusions) on Hass and Fuerte avocados.

Cultivar	% fruit damaged	Sample size	
		No. fruit	No. trees
Hass	9.8	3526	65
Fuerte	2.1	2566	59

Incidence of damage (protrusions) over time

There was no increase in the incidence of damage to Hass fruits during the study period (Table 2). Data collection was terminated at the end of June just prior to harvest.

TABLE 2 The incidence (%) of damage (protrusions) on Hass avocados from December 1991 until June 1992.

Date	% fruit damaged	Sample size	
		No. fruit	No. trees
09-13.12.91	9.8	3526	65
16-20.12.91	11.1	1000	20
27-31.01.92	8.6	1000	20
17-21.02.92	8.0	1000	20
23-27.03.92	9.6	2400	50
20-24.04.92	9.0	2285	50
18-22.05.92	8.1	2371	50
22-26.06.92	8.0	2337	50

Distribution of damage (protrusions) within the orchard

The damage was evenly distributed throughout the study area; fruit on 75% of the trees were damaged and the median score for damage was 2 (i.e. 1-25%) (Fig. 1). Trees displaying highest levels of damage (25-75%) were scattered and did not occur on the borders of the study area (Fig. 1).

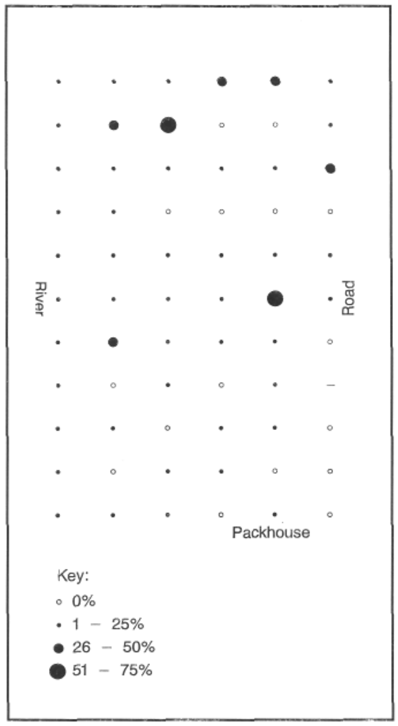

FIG. 1 The pattern of distribution of damage (protrusions) within the study orchard.

Distribution of damage (protrusions and indentations) within trees

The vertical distribution of fruit bearing protrusions was similar to that of the distribution of fruits on the trees (Fig. 2). The vertical distribution of fruits with indentations followed a similar trend except in the higher 3 4 m stratum where there was a relatively greater incidence of damage (Fig. 3).

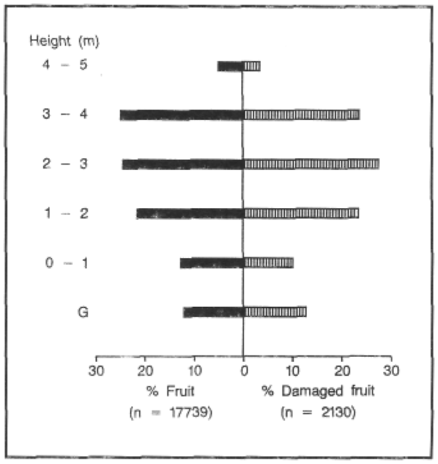

FIG. 2 Diagrammatic comparison of the vertical distribution of damaged fruit (protrusions) with the general vertical distribution of fruit on Hass avocado trees.

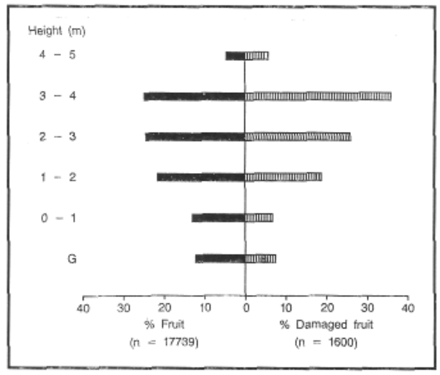

FIG. 3 Diagrammatic comparison of the vertical distribution of damaged fruit (indentations) with the general vertical distribution of fruit on Hass avocado trees.

Regarding both protrusions and indentations, there was no difference in incidence of damage (= proportion of damaged fruit out of the total number of fruit) within each aspect of the 11 trees (Tables 3 & 4). However, a comparison of the distribution of damaged fruits within the trees showed that there were significantly lower proportions of damaged fruit on the southern aspects of the trees (Table 3). The distribution of fruits (both damaged and undamaged) on the trees followed the same trend, with significantly lower proportions of fruit on the southern aspects of the trees (Table 3).

TABLE 3 A comparison of the distribution (xa) and incidence (xb) of damaged fruits (protrusions only), and the distribution of fruits (damaged and undamaged) (xc) in each of the four aspects of 11 Hass avocado trees. Weighted analyses of variance were performed on the data that were tested for normality (transformations were not required).

Aspect	% damaged fruit				% fruit in each aspect	
	xa	(s.e)	xb	(s.e.)	xc	(s.e)
W	28.17	(2.761)	11.86	(1.911)	28.50	(1.755)
N	27.47	(2.761)	13.36	(2.058)	24.64	(1.755)
E	26.88	(2.761)	12.09	(1.979)	26.59	(1.755)
S	17.38	(2.761)	10.26	(2.267)	20.26	(1.755)
LSD*	10.46		-		6.650	
P	0.027		0.794		0.013	

* Tukey's multiple comparison LSD at P = 0.05; s.e., standard error of the mean.

TABLE 4 A comparison of the incidence (xa) and distribution (xb) of damaged fruits (indentations only) in each of the four aspects of 11 Hass avocado trees. Weighted analyses of variance were performed on the data that were tested for normality (transformations were not required).

Aspect	% damaged fruit			
	xa	(s.e)	xb	(s.e.)
W	10.29	(1.588)	30.86	(3.294)
N	7.37	(1.708)	19.11	(3.294)
E	9.10	(1.644)	25.46	(3.294)
S	11.78	(1.884)	24.58	(3.294)
P	0.357		0.111	

s.e. Standard error of mean.

Density dependence (protrusions and indentations)

The relationship between the percentage of the total number of fruit and the percentage of fruit bearing protrusions in each stratum was strongly linear with a positive slope of approximately 1 (Fig. 4). The implied lack of density dependence was confirmed by the absence of a relationship between the number and percentage of damaged fruit in each segment (R^2 = 0.01; n = 185) In contrast, the relationship between the total number of fruit and the percentage of fruit with indentations in each stratum was exponential (Fig. 5) although a straight line also fitted the data (y = 6.02 + 1.36x; R^2 = 80%; n = 6). The suggested density dependence was, however, not confirmed by testing the relationship between the number and percentage of damaged fruit for each segment (R^2 = 0.80%; n = 185).

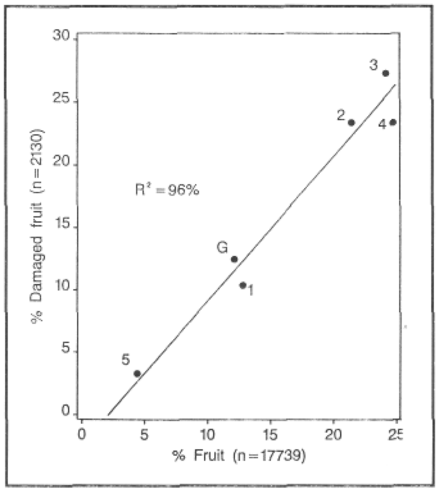

FIG. 4 The relationship between the total number of fruit and the percentage of damaged fruit bearing protrusions on the ground and in vertical 1-m strata into which 11 Hass trees were divided (y. = 2,23 + 1.13x). (G. fruit lying on ground; 1. fruit in 0-1m stratum; 2. fruit in 1-2m stratum, etc.).

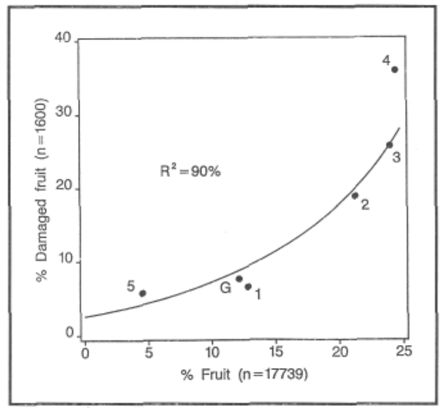

FIG. 5 The relationship between the total number of fruit and the percentage of damaged fruit with indentations on the ground and in vertical 1-m strata into which 11 Hass trees were divided (y = e (1.0 3+0.092x)). (G. fruit lying on ground; 1. fruit in 0-1m stratum; 2. fruit in 1-2m stratum, etc.).

Relationship between the incidence of protrusions and indentations

There was a positive linear relationship between the proportions of fruit bearing protrusions and indentations on the 11 Hass trees (y = 0.79 + 1.322x; R^2 = 66%; P = 0.002). However, the more detailed regression of the percentage of fruits bearing protrusions versus those with indentations in each of the segments into , which the trees has been divided indicated that there was no relationship (R^2 = 4%; n = 185). The Hass of healthy fruit (mean = 46.3 g; s.e. = 1.61) and fruit bearing protrusions (mean = 46.5 g; s.e. = 1.34) was similar whereas indented fruit were 23% lighter (mean = 33.6 g; s.e. = 0.92) (Student'st = 6,855; P < 0.0001).

Trapping *P. bella* on sticky fruits

Although the number of leafhoppers trapped per fruit was generally low throughout the study period (maximum 1.65), the percentage of fruits visited by *P. bella* reached up to 65% (Table 5).

TABLE 5 The incidence of sticky fruit visited by *P. bella* and the number of leafhoppers trapped per fruit for each month from December 1991 to June 1992.

Month	Total no. of leafhoppers	Total no. fruits	No. leafhoppers per fruit	% fruits visited
Dec	378	1596	0.24	19.42
Jan	971	590	1.65	64.58
Feb	405	500	0.81	43.00
Mar	19	400	0.05*	4.75*
Apr	277	400	0.69	34.00
May	188	400	0.47	14.25
Jun	68	400	0.17	11.75

* The low number of leafhoppers trapped and percentage of fruits visited was attributed to heavy rain during this field trip.

Enhancement of fruit drop (protrusions and indentations)

There was no relationship between the percentage of fruit dropped and the percentage of fruit bearing protrusions among those that had dropped (R^2 = 17.15%; n = 11). However, there was a strong rectangular hyperbolic relationship (R^2 = 99%) between the percentage of fruit dropped and the percentage of fruit with indentations among those that had been dropped (Fig. 6). This indicates that trees with a higher percentage fruit drop shed a higher proportion of damaged fruits, the proportion of damaged fruit dropped increasing dramatically when the percentage fruit drop exceeds about 24%.

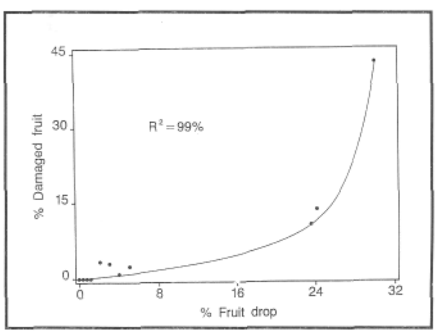

FIG. 6 The relationship between the percentage of fruit dropped and the percentage of fruit with indentations among the dropped fruit (Y = 2.76 + 3. 73/ 1-0.0319X).

Development of a sampling technique

Head-height counts of damaged fruits were an unreliable index of the actual levels of damage on the trees (y = 6.808 + 0.730x; R^2 = 24%; P = 0.029; n = 20). However, the percentage of damaged fruit in the 1-2 m stratum is a reliable index of the actual fruit loss (y = 3.255 + 0.791x; R^2 = 88%; P = 0.00002; n = 11).

DISCUSSION

Although sampling the incidence of protrusions at head height was not an accurate assessment of actual fruit loss, the large number of fruit sampled in this manner to compare damage on Hass and Fuerte cultivars clearly indicated that losses were significantly greater (five times) on Hass. The low variation (8-11%) in the percentage of Hass fruit with protrusions over eight sampling dates (from December 1991 to June 1992) since the initiation of the study indicates that (a) the incidence of damage remained fairly constant, and that 10% is probably a reliable estimate of fruit loss, and (b) that this damage was done during the earlier stages of fruit development (September to November).

The incidence of fruit with protrusions was not greater along the borders of the orchard, but was distributed throughout the study site. Trees with the highest levels of damage occurred in the centre of the study site, indicating that the insect is highly mobile. A less mobile, slower disperser would produce a typical edge effect, or a wave of damage advancing from a particular point of infestation within the orchard. The pests currently causing lesions on avocado fruit in South Africa are all sporadic because they are polyphagous whose mobility enables them to exploit a range of crops (Dennill & Erasmus, 1992). The pentatomids (and possibly cicadellids) causing the protrusions conform to this suite.

The distribution of fruit bearing protrusions within the trees indicates clearly that feeding by the pest is not density dependent; irrespective of height or aspect, a constant percentage of fruits was damaged. The proportion of damaged fruits was significantly lower on the southern sides of the trees, but this occurred only because there were less fruit on the southern aspects (it is commonly known that the shadier sides of trees bear less fruit Hartmann *et al.,* 1988, Jackson, 1986). Comparison of the incidence of damage in the four aspects of the trees, however, confirmed random feeding.

There was no enhancement of fruit drop by the feeding of the insects causing protrusions. This is unfortunate since it means that the trees expend energy, maturing fruit that are useless to the grower. In contrast, feeding by coconut bug does enhance fruit drop. The indentations are attributed to feeding by coconut bug at an early stage of fruit development (De Villiers, 1990, Du Toit & De Villiers, 1990, Van der Meulen, personal communication, Viljoen, 1986). The damaged part of the developing fruit does not grow normally while the healthy surrounding tissue does, resulting in an indentation where the damage was done. The first phase of fruit abortion occurs during the early stages of fruit development (September-October), and this explains why the trees can shed a high proportion of developing fruits with this kind of damage.

It is equally unfortunate that the mass of fruit with protrusions is similar to that of healthy fruit, since this implies that the damaged fruit are as energy expensive to the plant as healthy fruit. In contrast, the indented fruit were 28% lighter in mass and are therefore about 28% less energy consuming.

Although the feeding by coconut bug causes internal scars similar to those underneath the protrusions and is similarly density independent, showing no preference for a particular aspect and only a possible tendency for the upper reaches of the trees, there was no correlation between the two kinds of damage. This, and the difference in fruit drop and mass between the two kinds of damaged fruit, suggests that the two symptoms are caused by different species (and specifically that it is probably not coconut bug at a younger stage of nymphal development or different stage of fruit development). The high incidence of sticky fruit visited by *P. bella* (<65%) indicates that *P. bella* may in fact not be responsible for the protrusions which occurred on a constant c. 9% of the fruits throughout the study period.

Sampling fruit with protrusions at head height yielded samples that were too small to accurately estimate crop loss. Counts of the fruit in the 1-2 m stratum were, in contrast, accurate. This is to be expected since feeding by the insect is random and the proportion of fruit in the 1-2 m stratum is high (21%). These results indicate that only the 1-2 m stratum need be counted in order to monitor the damage caused by this pest, and that further time saving could be achieved by sampling a proportion of fruit (within the accessible 1-2 m stratum) of magnitude between the total number of fruit in this stratum and that at head height.

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