Integrated management of macadamia pests with emphasis on alternative pesticides and more effective monitoring

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ABSTRACT

Typically less than 1% of macadamia trees are surveyed per week with the knockdown technique in order to assess population densities of important stinkbugs. These insects are heterogeneously distributed and distinct hot spots normally occur in most orchards. The selection and number of data trees are very important for the accurate assessment of economically important stinkbugs. Alternative monitoring techniques exist and can be used to confirm results of the knockdown technique. The seasonality as well as the practicality of these techniques are briefly discussed. Approximately 500 stinkbugs were recovered with the branch shaking technique since November 2010. The two spotted bug was the most dominant (79.41%), closely followed by *Nezara pallidoconspersa* (9.24%) and *Nezara prunasis* (8.19%). Eight other stinkbugs (including the coconut bug) contributed only 3.16% of the total amount of stinkbugs recovered during this survey. Although only a proportionally small part of the branches of a tree was surveyed, this technique recovered an estimated 50% of the bugs present in an orchard and as such can be reliably used in combination with the dichlorvos technique to assess the populations of economically important stinkbugs in macadamias. Egg monitoring can be effectively used from January – March, while nut dissection is only effective from flowering until the end of premature nut drop (November). Field weathered residues of two pyrethroid products (suspension concentrate and a capsule suspension) were tested. Both did not have the initial knockdown ability of EC formulations, but had a considerably longer residual action. A formulation of the pathogen, *Beauveria bassiana*, did effectively control stinkbugs but follow up work is required. Commercial control was achieved when the pathogen was mixed with a sub-lethal rate of a synthetic pyrethroid.

INTRODUCTION

Of all the methods listed by Southwood (1978) few offer practical solutions for the monitoring of stinkbugs in tree crops. The dichlorvos technique has been used for a number of years and is currently also the most practical. This technique also has a few problems:

a) Currently decision support is based on less than 1% of the trees in a management block. If the heterogeneous distribution pattern of stinkbugs is taken into account, the opportunities for erroneous interpretations of population surveys are considerable.
b) The dichlorvos method is management intensive. Monitoring sprays have to be applied very early, especially during summertime and it generally requires a significant amount of time and effort to prepare and execute monitoring operations on all farm blocks.
c) Accidental poisoning when dichlorvos is used irresponsibly is a very real possibility.

Fortunately there are alternatives that could be considered, such as the nut dissection, branch shaking and egg scouting techniques. These techniques are highly seasonal and recommendations to use the techniques practically to validate dichlorvos scouting results will enhance spray decision support considerably.

Due to the potential damage these insects could inflict in any macadamia orchard, it is understandable that economic threshold levels are very low. This is especially valid after the end of premature nut drop from November onwards. Essentially all damage from this point forward is additive, which makes the implementation of true integrated pest management (IPM) very difficult.

The potential of using insect pathogens, especially when combined with low rates of insecticides, offer exciting possibilities that should be considered for macadamia crop protection in future.

MATERIALS AND METHODS

Residual action of synthetic pyrethroids

This trial was conducted at the ARC-ITSC in Nelspruit on an unsprayed Nelmak D orchard. Tree branches were sprayed with pyrethroids to the point just before run off. Standard recommended rates were applied as follow:

a) Beta-cyfluthrin SC 125 g/L @ 6 ml/100 L water (pH = 7.6)
b) Beta-cyfluthrin SC 125 g/L @ 6 ml/100 L water (pH = 3.7)
c) Lambda-cyhalothrin CS 50 g/L @ 10 ml/100 L water (pH = 7.64)
d) Lambda-cyhalothrin CS 50 g/L @ 10 ml/100 L water (pH = 3.2)
e) Untreated control.

Each treatment was replicated five times and the chemicals were allowed to dry for ±2 hours. Screen cages containing five yellow edged bugs (*Nezara pallidoconspersa*) were then placed on each treated branch. *N. pallidoconspersa* was selected as an indicator species because unlike *Bathycoelia natalicola* (two spotted bug) and *Pseudotheraptus wayi* (coconut bug) this species can be collected in large numbers from wild castor oil plants (*Ricinus communis*).

Mortality was monitored daily and all dead or moribund insects were replaced at each monitoring interval with field collected insects. Monitoring occurred up to five days post treatment when it became very difficult to collect sufficient quantities of insects from the field. The pH level of treatments b and d was manipulated with the addition of hydrochloric acid.

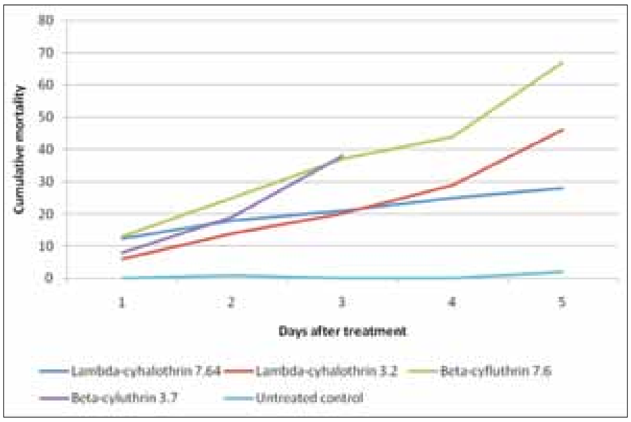

Figure 1. Effect of field weathered residues of Lambda-cyhalothrin CS 50 g/L and Beta-cyfluthrin SC 125 g/L on field collected yellow edged stinkbugs (*Nezara pallidoconspersa*).

Alternative monitoring

Due to the heterogeneous distribution of stinkbugs in a macadamia orchard the expected experimental error made by the current monitoring technique is very large. The following alternative techniques are available to supplement the knockdown technique until pheromone becomes obtainable:

Nut dissection

Ten prematurely aborted nuts were collected underneath ten randomly selected trees at an unsprayed mixed cultivar orchard at the ARC-ITSC in Nelspruit. The nuts were dissected and the presence/absence of feeding puncture marks on the smooth white inner surface of the developing husks was recorded. Nuts were only dissected during the period of premature nut abortion.

Branch shaking

Branches on ten randomly selected trees were shaken every week early in the morning (before 10:00). All the insects were collected and counted. This survey was carried out in an unsprayed orchard at the ARC-ITSC in Nelspruit from flowering until August 2011.

Egg scouting

The bottom 3 m of the main trunks of fifteen mature Nelmak 2 trees was inspected every week for the presence of egg packets. This trial was carried out in an old and very dense unsprayed Nelmak 2 orchard at the ARC-ITSC in Nelspruit. Egg scouting commenced during October (just after flowering) and continued until the end of March 2011.

RESULTS

Residual action of synthetic pyrethroids

According to **Figure 1** the initial pyrethroid induced

Table 1. Optimal pH range and fate of pyrethroids at elevated pH levels for a range of synthetic pyrethroids registered against stinkbugs on macadamias according to http://sitem.herts.ac.uk/aeru/projects/ppdb/index.htm.

Chemical name	Trade names	pH stability	Activity under high pH regimes
Cypermethrin	Avi-Sipermethrin, Cyperin, Cypermethrin 200EC, Cypermethrin, Doodskoot, Kemprin, Knox Worm, Magnum, Makhro Cyper, Novacord, Parashoot, Polythrin, Ripcord, Rockcyper, Sherpa, Sipermethrin & Stalker	3 – 7	30 min. at pH 11
Lambda cyhalothrin	Karate with Zeon Tech, Judo 50 EC, Helerat, Karate, Lamdex 50EC, Lamda-cyhalothrin & Lambda 50 EC	5.2 – 6.9	7 days pH 9
Gamma cyhalothrin	Vantex	5	1.1 days at pH 9
Zeta cypermethrin	Fury 10 EW	4	25 days at pH 7
Alpha cypermethrin	Bestox, Fastac, Sentry, Alpha-thrin, Avalanche, Concord & Magnum Super	4	7.3 days at pH 9
Beta cyfluthrin	Bulldock	4	38 hours at pH 9

mortality was not very high, but at the end of five days both chemicals still inflicted significant levels of control. Compared to EC formulations that were tested during the previous season, it would appear as if the SC and CS formulations gave longer residual control. Both products were also not as pH sensitive as the EC formulations that were tested during the previous season. Even at relative high pH levels both products were still able to induce between ±30 – 70% mortality at the end of the five day period. **Table 1** was included as it gives a summary of the optimal pH range as well as pH induced fate of a number of synthetic pyrethroids that are currently registered against stinkbugs on macadamias.

Alternative monitoring

Individually none of these techniques discussed below are adequately able to monitor the population levels of the two spotted bug accurately for an entire season. Many scouts tend to get disillusioned, especially during the early season when they end up without any insects after shaking numerous branches. This research is therefore designed to give farmers and insect scouts a better insight into the seasonal nature of each individual technique. Finally, all three techniques should be integrated with the current knock-down technique to ensure a more accurate estimation of the population dynamics of the two spotted bug.

Nut dissection

According to **Figure 2** nut dissection rapidly gave an indication of the presence of stinkbugs in an orchard. Small nuts tend to abort very quickly after a feeding event while older nuts remain on the trees for longer. This technique is probably not very accurate after the premature nut drop period came to an end, but large amounts of unseasonal (December – February) aborted nuts is normally a very good indicator of insect activity in an orchard.

Branch shaking

Stinkbugs were sampled in a mixed cultivar orchard during 2010 and 2011 in the Nelspruit region of Mpumalanga. The main species collected with the branch shaking method were two spotted stink bug, *Bathycoelia natalicola* (79.41%), yellow edged stink bug, *Nezara pallidoconspersa* (9.24%) and small green stinkbug, *Nezara prunasis* (8.19%). Seven other stinkbug species comprising only 3.16% of the total were also recovered from the same orchard (**Figure 3**).

Average stinkbug densities were 1.17 adult bugs / tree (range 0.2 – 2.6 bugs/tree). At a plant spacing of 6 m X 6 m (278 trees/ha) the average density of adult

Figure 2. Relative seasonal abundance of individuals of the two spotted bug sampled with the nut dissection and branch shaking methods.

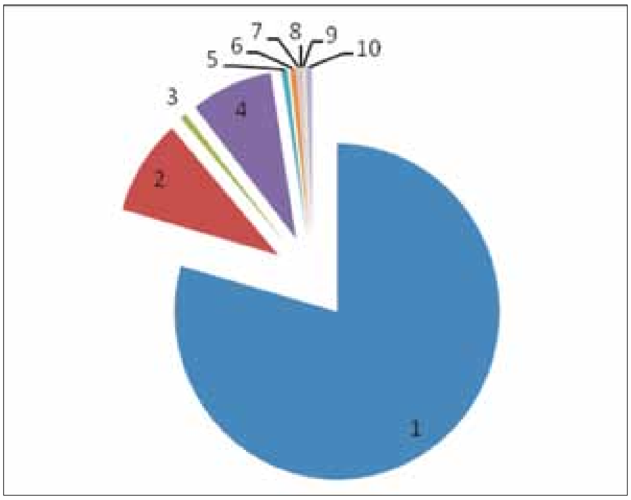

Figure 3. Species composition of stinkbugs that were collected in the unsprayed cultivar orchard at the ARC-ITSC in Nelspruit. 1 - *Bathycoelia natalicola* (79.41%), 2 - *Nezara pallidoconspersa* (9.24%), 3 - *Pseudotheraptus wayi* (0.66%), 4 - *Nezara prunasis* (8.19%), 5 - *Atelocera raptoria* (0.63%), 6 - Light brown bug (0.63%), 7 - *Anoplocnemis curvipes* (0.21%), 8 - *Encosternum delegorguei* (0.21%), 9 - Dark brown bug (0.21%), 10 - *Dysdercus nigrofasciatus* (0.63%).

Table 2. Seasonal breakdown of sex ratio of *B. natalicola* recovered in an unsprayed cultivar orchard by making use of the branch shaking method.

Month	Number of females collected	Number of males collected	Male/female ratio
Dec	3	1	1:3
Jan	18	7	1:2.57
Feb	15	9	1:1.67
Mar	26	13	1:2
Apr	11	7	1:1.57
May	3	3	1:1
June	7	11	1:0.64
July	2	5	1:0.4
Total	85	56	1:1.52

stinkbugs were 325 stinkbugs/ha (range 56 bugs/ha during early December – 723 bugs/ha during the end of January). Apart from one *N. pallidoconspersa* and two *A. raptorial* nymphs, only *B. natalicola* nymphs were recovered during this study. This is important as it indicates that apart from *B. natalicola* most other pentatomids probably do not breed in macadamias. Average nymphal density was 0.6/tree (range: 0 – 1.8 nymphs/tree). Calculated at 278 trees/ha average nymphal density was 167/ha (range: 0 – 500 nymphs/ha). Densities for adults and nymphs combined therefore ranged from 56 – 1223 individuals/ha.

Although fewer females were located during winter towards the end of the season, the average female biased sex ratio was 1:1.52 (**Table 2**).

By the end of July 2011, 490 stinkbugs were recovered with the branch shaking method, indicating that this technique has some merit as an alternative monitoring tool. From November 2010 to March 2011 the two spotted bug was the most dominant specie and comprised ±94% of the weekly catches. From March 2011 onwards, numbers of the two spotted bug decreased while numbers of *N. pallidoconspersa* and *N. prunasis* increased. The two spotted bug were still dominant but only represented 61% of the total number of species (**Figure 4**). The reason for this is unclear at the moment, but large stands of the alternative host of *N. pallidoconspersa*, castor oil (*Ricinus communis*), occurred in close proximity to the macadamia orchard. Flowering and seed formation normally occurs from February onwards and by March most of seeds dropped and are unavailable for these stinkbugs. Nearby growing macadamias was then probably used as an alternative feeding source. No immature stages and hence no breeding of these insects were observed in macadamias, which confirms previous observations that macadamia is probably not a preferred host. This only emphasise the

Table 3. Theoretical damage inflicted by the pentatomid complex on an unsprayed mixed cultivar orchard at the ARC-ITSC in Nelspruit.

Date	Number of bugs collected/week/tree [a]	Number of nuts damaged/day (a x 0.625 x 278) [b]	Number of nuts damaged/week (b x 7)	Cumulative number of nuts damaged/week
23 Nov	0.4	70	490	581
29 Nov	1.3	226	1581	2071
07 Dec	0.4	70	490	2561
21 Dec	1.6	278	1946	4507
10 Jan	1.4	243	1701	6208
17 Jan	1.8	313	2191	8399
27 Jan	3.2	556	3892	12291
09 Feb	2.5	434	3038	15329
15 Feb	2.2	382	2674	18003
25 Feb	2.9	504	3528	21531
4 March	2.4	417	2919	24450
11 March	2.3	400	2800	27250
18 March	1.3	226	1581	28831
24 March	2.0	348	2436	31267
15 Apr	1.5	261	1827	33094
20 Apr	2.3	400	2800	35894
29 Apr	2.3	400	2800	38694
6 May	1.7	295	2065	40749
13 May	1.2	209	1463	42212
19 May	1.7	295	2065	44277
27 May	1.3	226	1581	45858
3 June	1.7	295	2065	47923
10 June	2.2	382	2674	50597
15 June	2.1	365	2555	53152
24 June	1.8	313	2191	55343
1 July	0.6	104	728	56071
6 July	1.5	261	1827	57898
21 July	1.4	343	1701	59599
29 July	0.2	35	243	59842

dynamic relationship between stinkbugs and their various host plants. Many of the aspects highlighted in this section are expected to vary considerably between regions and even between farms in a production region because of differences in the vegetation of each area.

Accuracy of branch shaking monitoring method

Previous research indicated that the two spotted bug fed ±0.625 times/day/individual bug. All of the following calculations were done on the assumptions that each nut will only be damaged once and that the feeding frequency remains uniform for the entire season.

Calculated at an average yield of 5.6 kg NIS/tree at an average mass of 10.2 g/nut, each tree then produces ±550 nuts. Based on a plant spacing of 6 X 6 m (278 trees/ha), approximately 152 900 nuts are therefore produced/ha. Because damaged nuts do not drop readily after December, damage is essentially additive. According to **Table 3**, which is based on the actual number of insects collected during 2010/11, approximately 60 000 nuts (38.98%) could therefore be damaged by the stinkbug complex under unsprayed conditions up to the end of July 2011. This is still a significant underestimation, especially if the real damage percentage of 80.67% (30 nuts/tree x 5 trees; SD ±7.42) is considered.

Egg scouting

According to **Figure 5** first eggs were observed early in January. The number of eggs peaked towards the end of February and by April very few new egg rafts were observed on the main stems of mature Nelmak 2 trees. Eggs were, however, occasionally observed in the stinkbug cage (**Figure 7**) during May, which indicates that while lower temperatures may limit oviposition it does not completely prevent it. This observation is supported by the presence of 4th instar nymphs during the last week of July in the unsprayed orchard.

Parasitism typically is density dependant and peak parasitism percentage was reached approximately three months after peak egg occurrence.

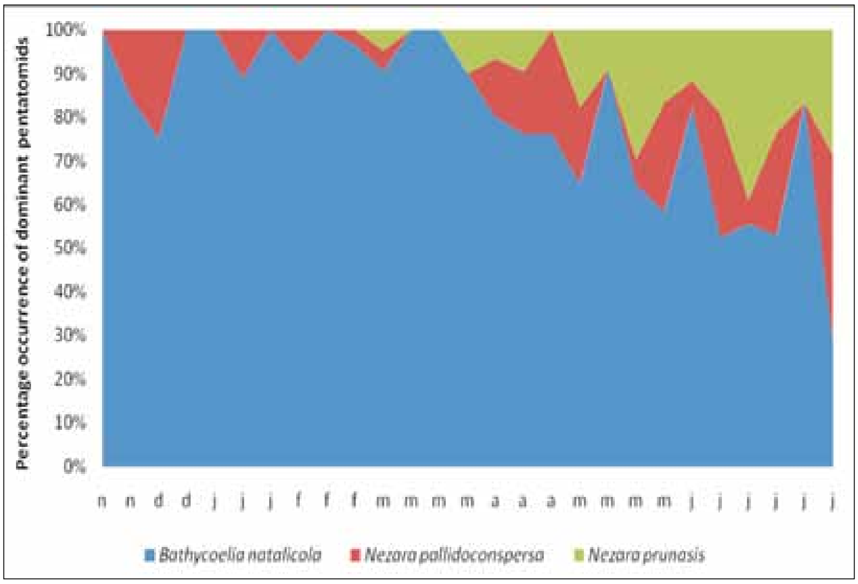

Figure 4. Relative seasonal abundance of the three most dominant pentatomid species recovered from a mixed cultivar orchard at the ARC-ITSC in Nelspruit.

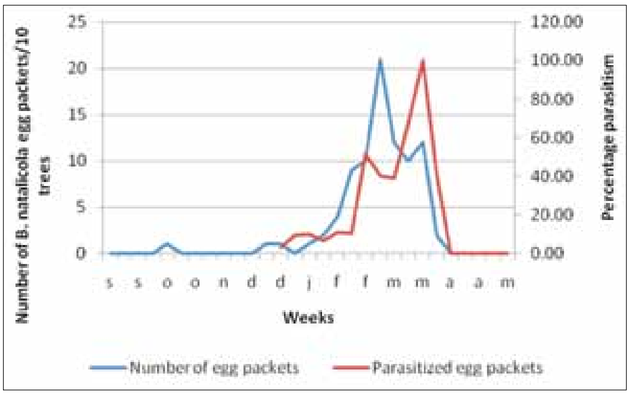

Figure 5. Relative seasonal abundance of egg parasitoids associated with *B. natalicola* in a mature Nelmak 2 orchard at the ARC-ITSC in Nelspruit.

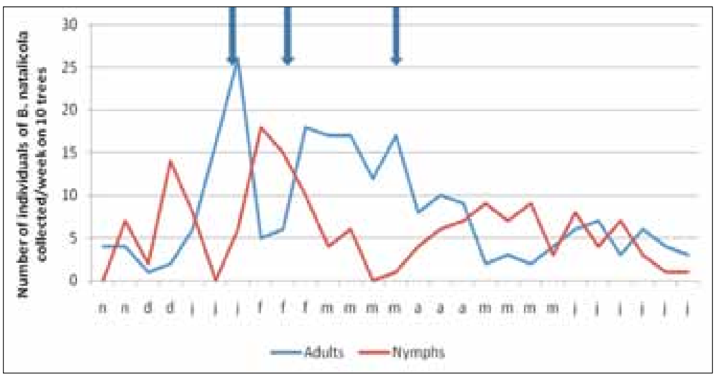

Figure 6. Relative seasonal abundance of adults and nymphs of *B. natalicola* in a mixed cultivar orchard in Nelspruit (Arrows indicate peak occurrence of adults as predicted with degree-days).

Figure 7. Field cage that was constructed over a 791 macadamia tree to facilitate biological observations of stinkbugs.

Degree-day models for the two spotted bug

No oviposition (Figure 5) and therefore no nymphal stages (**Figure 6**) were observed in the unsprayed orchard immediately after flowering. It is speculated that female stinkbugs cannot derive sufficient sustenance for egg development from small developing nuts. However, nine weeks after full flowering (end of November) the physiology of a macadamia tree changes drastically (Joubert, 1986) and first nymphal stages were observed. For this reason the end of November was selected as the departure point for the accumulation of degree-days. Damage done to the nuts during the first nine weeks originated from the overwintering population present in the orchard as well as from individuals immigrating into the orchards from surrounding bush.

Schoeman (2011) indicated that 5^{th} instar nymphs required ±490 degree-days to complete its cycle. Figure 5 indicates that the initial population peak of adult stinkbugs could be accurately predicted. Later in the season predictions appear to be less accurate, indicating that more research is still required to refine this technique.

In an attempt to increase the accuracy of degree-day models, a large (27 m^3) cage was built over an unsprayed 791 tree at the ITSC in Nelspruit. This cage will be filled with stinkbugs and will subsequently be monitored on a weekly basis.

CONCLUSIONS

Residual effect of synthetic pyrethroids

The residual effect of lambda-cyhalothrin and beta-cyfluthin was quantified. Both products did not have a significant initial knockdown effect, but had a prolonged residual action. At the end of the study period (5 days post application) both products still induced significant mortality of *N. pallidoconspersa*.

Branch shaking technique

The branch shaking technique work and sufficient quantities of stinkbugs were recovered to assess populations of economically important stinkbugs. An intrinsic negative aspect of this method is that results are dependent on the quality, dedication and training of insect scouts.

Nut dissection technique

The nut dissection technique is effective for the first 9 weeks post flowering. Thereafter aborted nuts (before physiological maturity is reached) must be regarded as a good indication of considerable insect activity in the orchard.

Egg monitoring technique

Eggs are normally deposited in large numbers from the beginning of January – April. Although small numbers of egg packets may occur during other times of the year, it must be regarded as exceptional. Eggs are normally deposited on main stems as well as main branches on the bottom ±3 m of especially older and denser macadamia trees. It is often more difficult to locate eggs on young and therefore more exposed trees.

Degree-day models

The degree-day models still need some refinement but results portrayed in Figure 6 looks promising. Upper and lower threshold temperatures will still have to be quantified in the laboratory.

Practical application of insect scouting

Previous scouting sheets were complicated and relied on the unnecessary identification of various stinkbug species. Research has proven that stinkbugs with relative short mouthparts are still able to inflict damage up to harvest (Schoeman, 2009). A simplified scouting sheet relying on seasonal occurrence of the various alternative techniques as well as the dichlorvos technique is suggested in **addendum 1**.

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ADDENDUM 1

Suggested simplified scouting sheet for stinkbugs in macadamias

Orchard/block number:						Date
Cultivars:						Time
Scout name:						
	Stinkbugs Knock down spray Entire season	Stinkbugs branch shaking Nov - May	Eggs (P) parasitized (L) alive Jan - April	Nut dissection: small nuts Sept - Dec	Out of season drop Dec - Feb	Notes
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Total						
Av./ tree						