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Pest Management of Bagworm in Southern Perak by Aerial Spraying with *Bacillus thuringiensis*

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ABSTRACT

Aerial spraying with a Bacillus thuringiensis *(Bt) product in Estate A resulted in 50% reduction of the* Pteroma pendula *population by 30 days after treatment (DAT). In Estate B, the bagworm population was completely under control whilst at Estate C, bagworm larval instars decreased by 90% from 0 to 30 DAT. The Bt aerial spray successfully reduced the bagworm population below the threshold of five bagworms per frond in Estates A and B. In Estate C which had a heavy and extensive outbreak, application of the Bt product successfully reduced the bagworm population but the period of application would have to be extended to bring the population below the threshold level. Implementation of the integrated pest management (IPM) system contributed to the successful control of bagworm outbreaks. The aerial spray using Bt had a synergistic effect with beneficial insects in the presence of beneficial plants, and provides long-term control of the bagworm.*

ABSTRAK

Selepas semburan udara, populasi ulat bungkus di Ladang A menurun sebanyak 50% daripada lima larva/pelepah 0 hari selepas rawatan (HSR) ke 2.5 larva/pelepah (30 HSR). Di Ladang B pula, populasi ulat bungkus telah dikawal sepenuhnya manakala di Ladang C, populasi ulat bungkus menurun sebanyak 90% dari 412 larva/pelepah (0 HSR) ke 40 larva/pelepah (30 HSR). Semburan udara Bt telah berjaya mengurangkan populasi ulat bungkus di bawah nilai ambang di Ladang A dan Ladang B, berbeza dengan Ladang C disebabkan serangan ulat bungkus yang amat serius di ladang tersebut. Aplikasi susulan semburan udara Bt di Ladang C perlu dijalankan bagi mengurangkan populasi ulat bungkus di bawah nilai ambang iaitu 5 per pelepah. Amalan sistem pengurusan perosak bersepadu yang lestari juga menyumbang kepada kejayaan program semburan udara Bt. Gandingan yang serasi di antara tanaman berfaedah, serangga bermanfaat dan Bt memastikan kawalan jangka panjang dan mengelakkan serangan ulat bungkus berulang.

Keywords: *Bacillus thuringiensis*, IPM, bagworm, aerial spraying.

INTRODUCTION

The bacteria *Bacillus thuringiensis* (Bt) is found abundantly in the soil. It has been used globally as an insecticide for the last 20 years. Bt bioinsecticides are also being recognised as the most successful product of biotechnology in the market (Adams *et al*., 1999). Bt is a spore-forming insect pathogen and has been extensively studied in various laboratories around the world for its potential as an effective biological control agent against various insect pests, including the bagworm (Lepidoptera: Psychidae) (Ramlah Ali and Mohd Basri, 1997; Ramlah Ali, 2000; Ramlah Ali and Mahadi, 2001).

Bt chromosome mapping shows that it is 'very closely related' to *Bacillus cereus*. The characteristics of Bt and *B. cereus* are found to be similar in a variety of laboratory tests, except that most Bt contains insecticidal proteins known as insecticidal crystal proteins (ICP). These crystals are proteins that are toxic only against target insects (Zuoari *et al*., 2002). Parasporal crystals and spores of *B. thuringiensis* constitute the active ingredients of commercially available products for the control of many lepidopteran larvae in agriculture and forestry (Navon, 2000; Hynes and Boyetchko, 2006). The variety of Bt studied in this article was *B. thuringiensis* var. *kurstaki* (Btk) which was used to kill bagworms.

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The mechanism of action involves solubilisation of the parasporal crystals and activation of the released proteins in the mid-gut of the target insect. The active toxins will then bind with specific receptor proteins and form pores through the membrane of the gut lining which lead to osmotic lysis. In addition, the spores present in the product formulation can germinate, forming more Bt cells resulting in septicemia and killing the target insect (Aronson, 2002).

Most chemical insecticides can also affect non-target organisms or persist in the environment. Their use should be reduced for the sake of human health (Hayes and Laws, 1991). Unlike chemicals, the insecticidal proteins of Bt are naturally derived and are highly specific against certain insect orders (Hofte and Whiteley, 1989; Ellar, 1994; Ramlah Ali and Mohd Basri, 1997). Therefore, biological insecticides such as Bt are often the insecticide of choice for aerial spray programmes. Bt is now being used in food crops, forage crops and forest species for the control of Lepidopterans and also of mosquitoes (Hofte and Whiteley, 1989; Hayes and Laws, 1991). Bt products have also been reported to be harmless to the oil palm pollinator, *Elaeidobius kamerunicus*, and beneficial insects associated with *Cassia cobanensis* (Mohd Najib *et al*., 2009).

The bagworm is a leaf-eating caterpillar concealed within its carrot-shaped bag, which is constructed from bits of material from the plant upon which it feeds. When disturbed, the bagworm merely pulls its head back into the bag for protection (Barlow, 1982). In Malaysia, bagworms are commonly found in many orchards, landscape plants and ornamental trees (Ahmad and Ho, 1980). There have also been reports of severe bagworm infestation on cabbage at the Cameron Highlands (Sudderuddin and Kok, 1978). However, recurring bagworm outbreaks only affect the oil palm plantations.

In early 2007, approximately 32 475 ha of oil palm estates and 5100 ha of smallholdings in Malaysia were infested by bagworms (Ramlah *et al*., 2007a). Currently, the oil palm industry still relies on chemical insecticides for treating young palms of less than 15 years. Control using broad-spectrum contact chemical insecticides often leads to the disruption of the natural balance of insects and their natural enemies that include predators, parasitoids and microbial pathogens (Wood, 1971; Basri *et al*., 1994).

The species of bagworm capable of causing outbreaks in the oil palm plantation are *Metisa plana* (Walker), *Pteroma pendula* (Joannis) and *Mahasena corbetti* (Tams). *M. plana* is the most serious and dominant pest of oil palm in Peninsular Malaysia (Sakaran; 1970; Norman *et al*., 1994; Norman and Basri, 2007, Ramlah *et al*., 2007a, b). Although *P. pendula* has been reported as the second most economically important bagworm (Basri *et al*., 1988; Ramlah *et al.*, 2007b), currently it seems to be equally as serious as *M. plana*, particularly in southern Perak. The species *M. corbetti* is rarely reported as a serious pest in Peninsular Malaysia, but it is a major defoliator and widely distributed in eastern Sabah (Wood and Nesbit, 1969; Young, 1971) and in some locations in Peninsular Malaysia, particularly in Johor (Basri *et al*., 1988) and Perak (Norman and Basri, 2007). From a survey conducted by Norman and Basri (2007), it was reported that *M. plana* was still the most widely distributed species followed by *P. pendula* in the oil palm plantations in Peninsular Malaysia.

Bagworms are a recurring problem in oil palm plantations, and several factors have been identified as causes for the outbreaks. Continuous use of chemical insecticides to control bagworm outbreaks, lack of beneficial plants in the plantation to attract natural enemies, and infestation in neighbouring plantations were reported as the contributing factors for bagworm outbreaks (Ramlah *et al*., 2007b). Bagworm outbreaks are also associated with the dry season, and many planters believe that bagworms feed more actively and spread faster in hot and dry weather (Chung and Sim, 1991). Integrated pest management (IPM) is an ideal method for controlling bagworm outbreaks in oil palm plantations. The synergism between bioinsecticides such as Bt and beneficial insects, together with established planting of beneficial plants to attract the beneficial insects, will ensure efficient control of bagworms in a long-term perspective (Basri *et al*., 1994; Ramlah *et al*., 2007a, b).

The World Health Organisation states that Bt products may be safely used for the control of insect pests of agricultural and horticultural crops as well as forests. Due to this safety declaration, Bt products have been applied in aerial spray programmes in Canada, the United States of America and New Zealand (Hales, 2004). In Malaysia, the application of Bt products was initiated in 2007 for the control of bagworms in southern Perak.

The Malaysian Palm Oil Board (MPOB) has formed a committee called the Committee on IPM of bagworm in Lower Perak involving all relevant agencies with the mission of controlling bagworm outbreaks especially in southern Perak (Ramlah *et al*., 2007b). The approach in combating bagworm outbreaks by a Bt aerial spray programme was sponsored by MPOB under the above-mentioned IPM project. This project was initiated in collaboration with the Malaysian Palm Oil Association (MPOA), Department of Agriculture, Sumitomo Malaysia, Aerotech (Australia) and Halex (M) Sdn Bhd.

The aerial spraying of biopesticides is a method of pest control which has been carried out in countries such as Canada, the United States and New Zealand, and has generally been state-sponsored. In these spray programmes, the pesticide can also be applied by ground sprayings.

Commonly used chemical compounds for aerial sprayings are Foray 48B and Dipel® ES which contain *B. thuringiensis kurstaki* (Btk). Btk is found naturally in the environment, and specifically targets the larvae of moths and butterflies (Claude, 2006). In New Zealand, the commercial product Foray 48B is registered for use in aerial and ground sprayings against the gypsy moth, the white-spotted tussock moth and the painted apple moth. It successfully controlled the white-spotted tussock moth in Auckland in 1996-1997.

In this article, we will discuss the effect of Bt applied via aerial sprays in three plantations which adopt different practices for controlling bagworm outbreaks.

MATERIALS AND METHODS

Aerial Spraying of Estates with Bt Product

This article focuses on aerial sprays with Bt for controlling bagworm outbreaks, which were conducted at Estates A, B and C in southern Perak. The total area covered by the aerial spray over Estate A was 1800 ha, while the areas for Estate B and Estate C were 450 and 7660 ha, respectively. In the past, Estate A used ground spraying of Bt, and there was good establishment of various beneficial plants for controlling bagworms, whereas the use of chemicals with and without the establishment of beneficial plants was practiced by Estates B and C, respectively.

Bagworms Census

Bagworm census were conducted at 0, 7, 14 and 30 days after treatment (DAT) with Bt. Ten percent of the infested area had to be censused, which works out to one frond/palm from every 10th palms. When the larval population is still in the early instars and the number is above the threshold level, control measures must be taken as soon as possible. The threshold level for *M. plana* and *P. pendula* has been established at 5-10 larvae/frond (Woods, 1971). If more than 70% of the population is at the pupal stage, the aerial spray must be postponed (Ramlah *et al*., 2007a, b). The control operation must be conducted once the eggs laid in the pupal bags hatched into early larval stages (Norman *et al*., 2004a, b; Ramlah *et al*., 2007a, b).

Bt Aerial Spraying to Control Bagworm Outbreaks at Southern Perak

The Bt product used for the aerial spray programme in southern Perak area was Dipel® ES consisting of 23.7% Bt subsp. *kurstaki* and 76.3% inert ingredients. The product is claimed to be harmless to humans and other non-target organisms. It is also non-toxic by ingestion or skin contact (Dipel® ES Material Sheet data, 2004). Dipel® ES is manufactured by Valent Biosciences Corporation, Illinois, USA. Sumitomo Inc. distributes the products in Malaysia, and the aerial sprays were conducted by AeroTech, Australia. The recommended dose for the product is 1 litre ha^{-1}. Although Bt is safe to humans, the aerial spraying should be conducted at least 100 m away from residential areas. A permit for conducting the aerial spray was obtained from the Department of Agriculture at least one week before application.

Participating Estates in the Bt Aerial Spraying Programme

Due to confidentiality issues, the estates have been anonymously listed as Estates A, B and C. Estate A is located in Hutan Melintang, Hilir Perak district. The first aerial spray was conducted at Estate A on 12 April 2007. The aerial spray was conducted using the Bt product with a total coverage of infested area amounting to 1800 ha. Bagworm infestations had long been a recurring issue in the estate. The majority of the bagworm population was *P. pendula*.

Estate B is located in Bagan Datoh, Hilir Perak district, and had a continuous recurring history of bagworm infestations, even though chemical insecticides had been used. The area infested by *P. pendula* in Estate B was approximately 450 ha. The aerial spraying of Bt was conducted on 12 May 2007.

Estate C is located in Sungkai, Hilir Perak. The bagworm, *M. plana*, has been the main leaf defoliator of oil palm in Estate C since the 1980s. Control measures such as spraying of chemical insecticides had been carried out to solve this problem. However, lack of coordination amongst the respective estates and smallholdings and the uncontrolled use of chemicals led to futile efforts.

In May 2004, an aerial spraying programme with trichlorfon was conducted over Estate C for an area of 10 363 ha. Although the chemical spray seemed to control the bagworms instantly, the effect was transitory. Aerial spraying of the chemical insecticide and the absence of beneficial plants led to a more serious outbreak in 2007. Estate C management decided to apply the Bt product for the control of a multi-stage multi-bagworm infestation.

The area infested seriously by bagworms covered approximately 7660 ha. For the convenience of aerial spraying, the area to be sprayed in Estate C was marked into five GPS (global positioning system) plots. The Bt aerial spray was conducted from 15 to 17 May 2007.

Data Analysis

Data were analysed using the analysis of variance (ANOVA) at P=0.05 and the LSD test to separate means. The analyses were conducted using SPSS software.

RESULTS

Bt Aerial Spraying at Estate A

The bagworm census shows that on day 0, the average number of pupae per frond was 3, ranging from 0-81 pupae/frond, while the average number of larvae per frond was approximately 5, ranging from 2-88 larvae/frond (*Table 1*). At seven DAT, the larvae number decreased by approximately 77% to 1.2 larvae/frond, ranging from 1-48 larvae/frond, indicating that the Bt product had significantly reduced the bagworm larva number (*Table 1*). However, a slight increase in the number of larvae was recorded beginning at 14 DAT until 30 DAT, rising from 1.2 to 2.5 larvae/frond (*Figure 1*). A substantial increase in the range of larva number from 1-51 to 1-165 larvae/frond was observed, although the average larva number increased only slightly from 14 to 30 DAT.

In contrast, the average pupa number decreased from 0 to 30 DAT, with 3 pupae/frond at day 0, decreasing to 0.6 at seven DAT, 0.3 at 14 DAT, and finally reverting to 0.6 pupae/frond at 30 DAT (*Table 1*). The situation was expected as at 0 DAT, some of the bagworms were in the pupal stage, therefore they escaped from the lethal effects of Bt, and each of the resultant female adults then laid eggs which hatched into about 100 larval instars.

Bt Aerial Spraying at Estate B

The census data shows that on day 0, most of the bagworms were in the early larval stages and actively feeding on the oil palm leaves. On day 0, the average number of larvae per frond was 39, ranging from 0-778 larvae/frond, while the average number of pupae per frond was approximately 0.01, ranging from 0 - 14 pupae/frond (*Table 2).* At seven DAT, the average larva number decreased by approximately 34%, from 39 to 26 larvae/frond, ranging from 0 - 1280 larvae/frond. There was an increased range of 0 - 1280 larvae/frond at seven DAT compared to 0 - 778 larvae/frond at 0 DAT, and this was ascribed to a localised increase in bagworm population in one sub-block. This localised increase in bagworm was treated using chemicals. Only 0.02 pupae/frond was recorded, ranging from 0-10 pupae/frond, at seven DAT. A significant reduction of 75% in the larva number was further recorded from seven DAT to 14 DAT. At 14 DAT, there were on average only 6 larvae/frond, ranging from 0 - 150 larvae/frond.

The average number of pupae recorded at 14 DAT was 0.2, ranging from 0-50 pupae/frond. At 30 DAT, no bagworms survived the Bt aerial spraying (*Figure 2*).

Bt Aerial Spraying at Estate C

The census data shows that on day 0, all the bagworms were still in the larval stages and no live pupa was recorded (*Table 3*). The bagworm census showed that at 0 DAT, the average larva number was 412 larvae/frond, ranging from 0-12 868 larvae/frond. After seven DAT, the larva number decreased by 57%, from 412 to 176 larvae/frond, ranging from 2-1520 larvae/frond. This is a huge decrease in the larva population considering the massive number of bagworms recorded at 0 DAT.

At 14 and 30 DAT, the larva population decreased gradually (*Figure 3*), resulting in a cumulative percentage mortality of 68.4% and 90.3%, respectively. At 14 DAT, the average larva number recorded was 130 larvae/frond, ranging from 0-1476 larvae/frond, while at 30 DAT, the average number recorded was 40 larvae/frond, ranging from 0-244. Although the bagworm larvae at 30 DAT were still in numbers above the threshold, the decrease in the larva population was 90% compared to the population at 0 DAT (*Figure 3*).

As the census data shows that the larva population of bagworms at Estate C was still above the threshold level for *M. plana*, which is 5-10 larvae/frond (Ramlah *et al*., 2007a, b), further treatment using aerial spray of Bt was required.

DISCUSSION

The aerial sprays with Bt over Estates A and B successfully reduced the bagworm infestations to below the threshold level. At Estate A, the

TABLE 1. AVERAGE AND RANGE OF LARVA AND PUPA NUMBER PER FROND FOR ALL BLOCKS AFTER AERIAL SPRAY WITH DIPEL® ES AT ESTATE A

DAT	Larva (per frond)		Pupa (per frond)	
	Number	Range	Number	Range
0	5.05±0.24	2 – 88	2.66±0.19	0 - 81
7	1.15±0.15	1 – 48	0.57±0.08	0 - 21
14	1.2±0.21	1 – 51	0.3±0.06	0 - 15
30	2.5±0.41	1 – 165	0.58±0.73	0 - 27

Note: N = 59, *i.e.* total number of sub-blocks in the estate. DAT – days after treatment.

TABLE 2. AVERAGE AND RANGE OF LARVA AND PUPA NUMBER PER FROND FOR ALL BLOCKS AFTER AERIAL SPRAY WITH DIPEL® ES AT ESTATE B

DAT	Larva (per frond)		Pupa (per frond)	
	Number	Range	Number	Range
0	38.73±3.73	0 - 778	0.01±0.04	0 – 14
7	25.56±5.02	0 - 1 280	0.02±0.14	0 – 10
14	6.36±0.95	0 - 150	0.18±0.09	0 – 50
30	0	0	0	0

Note: N = 251, *i.e.* total number of sub-blocks in the estate. DAT – days after treatment.

TABLE 3. AVERAGE AND RANGE OF LARVA AND PUPA NUMBER PER FROND FOR ALL BLOCKS AFTER AERIAL SPRAY WITH DIPEL® ES AT ESTATE C

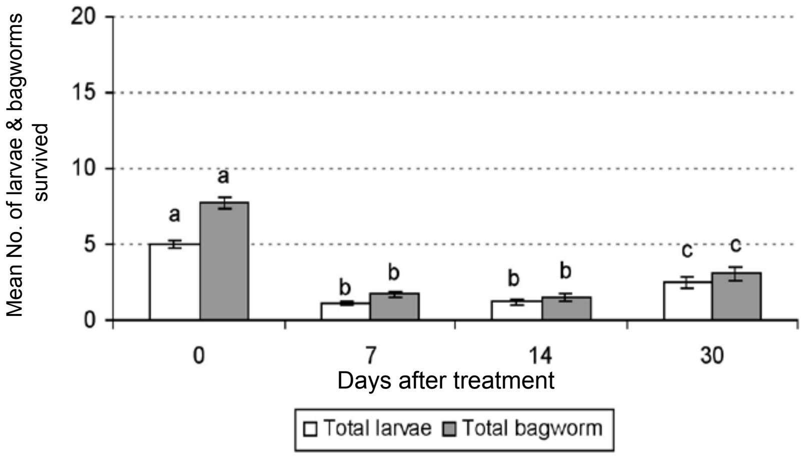
DAT	Larva (per frond)		Pupa (per frond)	
	Number	Range	Number	Range
0	411.87±236.49	0 – 12 868	0	0
7	176.11±38.16	2 - 1 520	0	0
14	129.87±34.18	0 - 1 476	0	0
30	39.89±8.15	0 - 244	13.46±2.03	0 - 74

Note: N = 5, *i.e.* total number of sub-blocks in the estate. DAT – days after treatment.

bagworm larvae at 30 DAT had been reduced to approximately 3 larvae/frond, whilst at Estate B, the larvae were completely controlled. The situation at Estate B was a success due to the management practices and also the right timing of the aerial spray. From the census data in *Table 2*, the aerial spray in Estate B was conducted at the most suitable time: when the bagworms were at the earliest larval instars and there was only 0.02 pupae/frond at 0 DAT. By 30 DAT, the bagworm population had decreased tremendously.

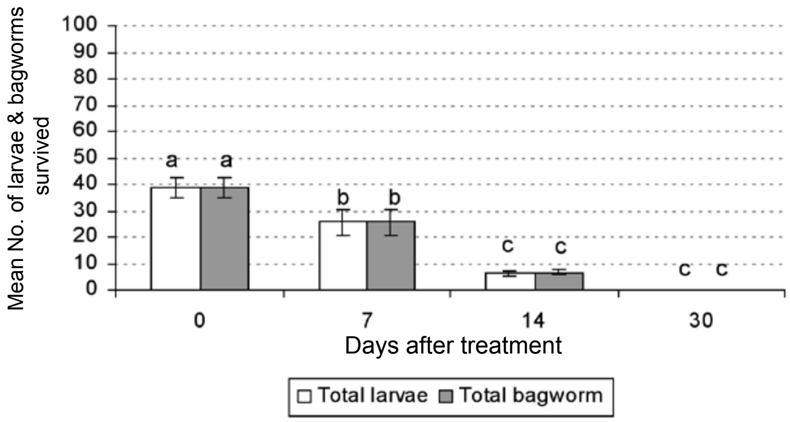
Despite the census data at Estate A, the Bt aerial spray was conducted to prevent damage by the existing high larva population in certain sub-blocks although pupae were present. During the pupa stage, the bagworms are resting and are unable to ingest the active ingredients of Bt. The pupa population that survived the aerial spray will subsequently emerge into a new generation of bagworms. This explains the increase in bagworm larvae at Estate A at 14 and 30 DAT (*Figure 1*). Correct timing for aerial spraying is crucial. However, with the good establishment of various types of beneficial plants in Estate A (*Figure 4*), the bagworm outbreak was easily managed. Knowledge in the bagworm life cycle is very important for managing the pest (Basri *et al*., 1988; Ramlah *et al*., 2007a, b).

Aerial spraying with Bt over Estate C failed to reduce the bagworm larvae below the threshold level even at 30 DAT. Based on the bagworm census at 0 DAT, all the bagworms were still in the larva stage and there were no live pupae. This should have been the most suitable time for the aerial spray to be conducted. However, other con-



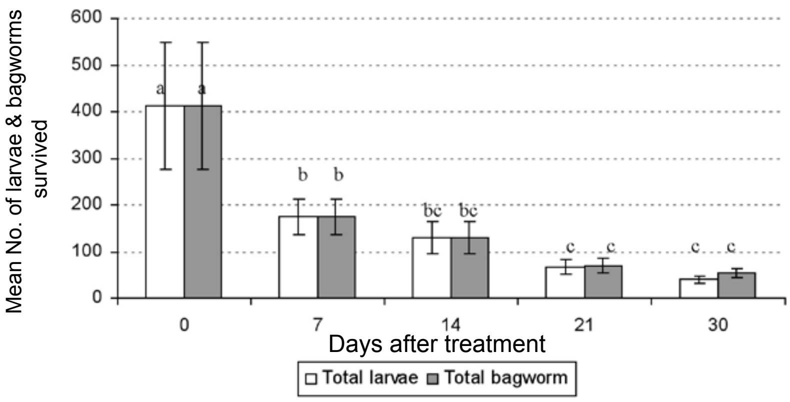
Note: bars in the different groups with the same letter are not significantly different at P=0.05, according to LSD test.

Figure 1. Mean total number of larvae and bagworms surviving after aerial spray with Dipel® ES at Estate A.



Note: bars in the different groups with the same letter are not significantly different at P=0, according to LSD test.

Figure 2. Mean total number of larvae and bagworms surviving after aerial spray with Dipel® ES at Estate B.



Note: bars in the different group with the same letter are not significantly different at P = 0.05, according to LSD test.

Figure 3. Mean total number of larvae and bagworms surviving after aerial spray with Dipel® ES at Estates C.

tributing factors need to be considered when conducting aerial sprays. Unlike Estates A and B, in Estate C the bagworm infestation was very serious with multi-stages of *M. plana* and *P. pendula*. Uncontrolled use of chemical insecticides over a long period may also have contributed to the massive outbreak in the area. As shown in *Table 3*, the average larva count at 0 DAT was 412 larvae/frond, which was approximately 11-fold higher than in Estate B and 80-fold more than in Estate A. Failure to establish beneficial plants in Estate C was another very important reason for the massive outbreak of bagworms (*Figure 5*). Although the census shows that the larva number had not been reduced to below the threshold level, the percentage of live larvae had decreased significantly by up to 90% at 30 DAT as compared to 0 DAT. To control the massive number of bagworm larvae by a single Bt aerial spray at Estate C seemed impractical due to the extent of the infested area, and also the seriously defoliated fronds would not have been able to hold any deposit of the Bt applied. Unlike chemical pesticides which show instant results, Bt is slow-acting, target-specific, produces no side effects and provides long-term control of bagworms (Ramlah *et al*., 2007b). The results obtained at Estate C have to be interpreted carefully in order to determine the best strategy for control using Bt.

Figure 4. Well-established beneficial plants in Estate A.

Figure 5. Lack of beneficial plant establishment in Estate C.

The situation in Estate C could be managed efficiently by implementing the most appropriate IPM system. The IPM strategy for bagworms emphasises the use of three biological control agents which have synergistic control effects on the pest, and which are environmental-friendly (Ramlah *et al*., 2007b), namely, Bt, beneficial insects and beneficial plants. Besides Bt, beneficial plants play a crucial role in controlling bagworm infestations by attracting beneficial insects such as predators and parasitoids. One beneficial plant, *Cassia cobanensis*, produces nectar as a food source for the beneficial insects (Basri *et al*., 1999). Observations on the three aerial spraying trials indicate that Estates A and B had implemented the correct IPM system by planting beneficial plants. *C. cobanensis*, *Antigonon leptopus* and *Turnera subulata* were observed along the main roads in Estate A, while well-established *A. leptopus* was observed in Estate B. In contrast, in Estate C, there was no establishment or existence of beneficial plants. The planting of beneficial plants attracts beneficial insects which synergise with Bt in efficiently and safely reducing the bagworm population to below the threshold level (Ramlah *et al*., 2007a, b). It is crucial to implement the IPM system with a Bt product as an alternative to chemical insecticide, because, unlike chemicals, Bt does not affect the beneficial insects (Mohd Najib *et al*., 2009).

Surveillance on human health impacts during Bt aerial sprays has been conducted in the United States (Washington and Oregon States), Canada and New Zealand (Claude, 2006). No significant change in physical health scores has been reported (Pearce *et al*., 2002). Similar observations were recorded in the southern Perak areas where the aerial sprays of Bt were conducted. Through verbal surveillance and survey, it was established that no adverse effect of the Bt aerial sprays on the plantation workers and occupants of the nearby residential areas was reported. Aerial sprays of the Bt product to control bagworms in the southern Perak plantation area have proven to be efficient in reducing the bagworm populations and were notably harmless to humans and the environment.

CONCLUSION

Aerial sprays of the Bt product conducted in the three estates significantly reduced the bagworm populations when coupled with beneficial insects and plants. However, in Estate C, the bagworms were still above the threshold after aerial spraying, possibly because of the massive outbreak ascribed to a previous aerial spray with chemical insecticide, and the situation was worsened by the absence of beneficial plants. With the implementation of the IPM system, the problems can be managed efficiently. Nevertheless, the correct timing of the aerial spray according to the bagworm's life cycle plays an important role in ensuring the effectiveness of Bt application. Planting of beneficial plants is vital in ensuring the synergistic effect between the Bt products and beneficial insects in controlling the bagworm population and to avoid reinfestation. In a scenario of a severe bagworm outbreak, repetition of the aerial spray application is necessary. Aerial sprays of Bt over the southern Perak areas seem to be the best way to combat bagworm outbreaks efficiently and safely.

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