Comparative effect of integrated pest management and farmers' standard pest controlpractice for managing insect pests on cabbage (Brassica spp.)

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Comparative effect of integrated pest management and farmers' standard pest control practice for managing insect pests on cabbage (*Brassica* spp.)

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Abstract

BACKGROUND: Studies were conducted on experimental cabbage plantings in 2009 and on experimental and commercial plantings in 2010, comparing farmers' current chemical standard pesticide practices with an integrated pest management (IPM) program based on the use of neem (Aza-Direct) and DiPel (*Bacillus thuringiensis*). In experimental plantings, the IPM program used six or eight applications of neem and DiPel on a rotational basis. The standard-practice treatments consisted of six or eight applications of carbaryl and malathion or control treatment.

RESULTS: The IPM treatments reduced pest populations and damage, resulting in a better yield than with the standard chemical or control treatment. When IPM treatment included three applications of neem plus three applications of DiPel (on a rotational basis in experimental fields), it again reduced the pest population and damage and produced a better yield than the standard practice. The lower input costs of the IPM program resulted in better economic returns in both trials.

CONCLUSIONS: The IPM components neem and DiPel are suitable for use in an IPM program for managing insect pests on cabbage (*Brassica* spp.).

1 INTRODUCTION

In the Mariana Islands, agricultural production has traditionally been for subsistence, and only a few commercial farms exist. Economic development plans in the Marianas call for the development and improvement of market-oriented sustainable agriculture for self-sufficiency, reduced imports and increased local produce.[1] Although vegetables such as cucumbers, eggplant, bell peppers, green onions and tomatoes have been grown seasonally in the region, head cabbage (*Brassica oleracea* L. var. *capitata*) and Chinese cabbage (*B. rapa* L.) have been grown continuously throughout the year, particularly on Guam, Rota, Saipan and Tinian. Cabbages are often attacked by a number of insect pests, particularly the looper, *Chrysodiexis chalcites* Esper (Lepidoptera: Noctuidae); the cutworm, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae); the corn earworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae); the webworm, *Hellula undalis* Guenée (Lepidoptera, Pyralidae); the diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae); the cluster caterpillar, *Crocidolomia pavanana* (Fabricius) (Lepidoptera: Pyralidae); the serpentine leaf miner, *Liriomyza brassicae* Riley (Diptera: Agromyzidae); the fleahopper, *Halticus tibialis* Reuter (Hemiptera: Miridae); and the cabbage aphid, *Brevicoryne brassicae* (L.) (Hemiptera: Aphididae).[2] A major limitation in production occurs with the pest complex consisting of *S. litura* and *L. brassicae*, which feed on cabbage. These pests may reduce yield by damaging the heads, causing them to be graded as non-marketable. *S. litura* is an extremely serious pest, the larvae of which can defoliate many economically important crops in the Pacific. Among the main crop species attacked by *S. litura* in the tropics are corn, vegetables such as aubergines/eggplant, tomato, Brassica, Capsicum and cucurbit vegetables. Other hosts include ornamentals, wild plants and weeds. Also, the larva of *L. brassicae* feeds as a leaf miner either on the upper or lower leaf surface and forms a linear serpentine mine. Apparently, the importance of *L. brassicae* can vary through time and space. *L. brassicae* is considered a potentially serious pest both of brassicacean plants and peas. In most of the Pacific region, both of these pests are considered to be extremely damaging agricultural pests.

Farmers in this region apply, in addition to *Bacilllus thuringienis* (DiPel), insecticides such as malathion (55%) and carbaryl (30%) as many as 8–10 times during each cropping period, a regime that not only is financially costly but also has been associated with ecological and toxicological hazards. Ecologically sound and cost-effective integrated pest management (IPM) programs are therefore being developed,[3,4] and many are being used,[5] but these programs must be adopted and implemented by farmers. The aim of the project described here was to replace these high-risk insecticides with a combination of a neem-based biopesticide (Aza-Direct) and DiPel, both of which are reported to be effective against many insect pests and have a low environmental impact. Some preliminary tests were carried out in a farmer's cabbage field (that of Mr Francisco M Atalig on Rota), in which neem was used against cabbage insect pests. The chemical was applied (as a spray) 8 times during the cropping period. The incidence of pests in the plot treated with neem was low compared with that in fields treated with DiPel, carbaryl and malathion, and a 30–40% higher yield of good-quality cabbage was obtained there. Research had therefore begun on whether available alternatives to farmers' current practice with the use of synthetic organic insecticides could be effectively used to produce a marketable cabbage crop.

2 EXPERIMENTAL METHODS

2.1 Cabbage seedlings

The hybrid cabbage seeds of K-K Cross (American Takii Incorporated, Salinas, CA) were sown in trays (40 × 30 cm) and raised in a nursery in the greenhouse (28–30 °C, 40–60% RH, 15 : 9 h light : dark photoperiod). The seedlings were grown for 30 days.

2.2 Field experiments

Field studies were carried out at two locations of the University of Guam Agricultural Experiment Station: the first at Yigo (13° 31.930′ N, 144° 52.351′ E) during September–December 2008, and the second at Inarajan (13° 61.963′ N, 144° 45.353′ E) during January–April 2009.

The treatment plots were 8 m × 8 m and separated from other plots by 1.5 m buffer zones designed to avoid spray drift or other treatment effects. Cabbage seedlings raised in the nursery were transplanted to the experimental plots, and all recommended agronomic practices were followed. At each of the two locations, 30-day-old cabbage seedlings were planted with 60 × 75 cm spacing. Three replicates, each of 11 treatments, produced a total of 33 plots. Each plot consisted of 12 rows of 12 cabbage plants, for a total of 144 plants per plot. The total area of the experimental cabbage field was 2781 m^2 (0.24 acre) at each site.

2.3 Integrated pest management treatments

The 11 treatments were applied in a randomized block design, as shown in Table 1.

The concentrations of treatment applications were as follows: Neem (1.2% azadirachtin) 10 mL L^{-1}; DiPel 15 g L^{-1}; carbaryl (50% wettable powder) 43 g L^{-1}; malathion (57% EC) 8 mL L^{-1}. The amount of fluid sprayed per application was 93.5 L ha^{-1} for small plants (up to 45 DAT) and 187.0 L ha^{-1} for larger ones (45 DAT until harvest). All the chemicals were applied with motorized backpack sprayers (Solo Brand; Forestry Suppliers, Jackson, MS). The sprayer was equipped with an adjustable, flat-spray, hollow-cone, jet-stream nozzle, and pressure was calibrated to deliver 20 gpa (185.35 L ha^{-1}) at 45 psi.

2.4 Comparative effectiveness of IPM and farmers' current practice

The IPM treatment chosen for comparison with farmers' current practice was three applications of neem alternating with three applications of DiPel, because this treatment combination proved significantly superior to other treatments in lowering damage and raising marketable yield. For the comparison study, 4047 m^2 (1 acre) plots of cabbage field at Yigo (June–September 2009) and Inarajan (October 2009–January 2010) were divided into equal quarters, and these four replicates were subjected to the chosen IPM treatment.

Table 1. Details of the treatments imposed on cabbage fields at Yigo and Inarajan on Guam

Treatment	Timing of treatment application (days after transplanting)
Control (no applications)	–
Neem, six applications	15, 30, 45, 60, 75 and 90
Neem, eight applications	15, 25, 35, 45, 55, 65, 75, and 85
DiPel, six applications	15, 30, 45, 60, 75, and 90
DiPel, eight applications	15, 25, 35, 45, 55, 65, 75, and 85
Neem, three applications, alternating with DiPel, three applications	15, 30, 45, 60, 75, and 90
Neem, four applications, alternating with DiPel, four applications	15, 25, 35, 45, 55, 65, 75, and 85
Malathion, six applications	15, 30, 45, 60, 75, and 90
Malathion, eight applications	15, 25, 35, 45, 55, 65, 75, and 85
Carbaryl, six applications	15, 30, 45, 60, 75, and 90
Carbaryl, eight applications	15, 25, 35, 45, 55, 65, 75, and 85

The plots representing farmers' current practice were five 1619 m^2 (0.4 acre) plots in cabbage fields owned by different farmers. Three of the plots were located on Guam, one in Dededo (13.52 °N, 144.84 °E, June–September 2010), one in Yigo (13.54 °N, 144.89 °E, August–November 2009) and one in Merizo (13.27 °N, 144.67 °E, October 2009–January 2010). The other two plots were in the Northern Mariana Islands, one on Saipan, at Tanapag (15.24 °N, 145.76 °E, September–December 2009), and the other on Rota, at Sinapalo (14.17 °N, 145.24 °E, November 2009–February 2010). Table 2 lists the treatments applied to IPM and current-practice plots. The farmers obtained a variety of insecticides from commercial sources and applied them according to their chosen schedules. The concentrations of treatment sprays used by the farmers were as follows: DiPel 15 g L^{-1}; carbaryl (50% wettable powder) 43 g L^{-1}; malathion (57% EC) 8 mL L^{-1}; lambda-cyhalothrin (Warrior 1CS) 15 mL L^{-1}. The total amounts of spray fluid per treatment in the farmer's fields ranged from 120 to 210 L ha^{-1}.

2.5 Damage and yield assessment

For both the 2009 and the 2010 studies, sampling was done weekly for 16 weeks. Incidence of attack by *S. litura* was measured as the number of insects found of each stage (eggs, larvae and pupae) and the number of holes on the leaves, and as the number of larval mines by *L. brassicae* observed. Ratings of the damage they caused on ten randomly selected plants in each treatment plot were recorded. Each cabbage head was evaluated for head infestation (immature pest stages on the head) and marketability using a standard 1–6 scale.[6] Similar observations of damage in the farmers' fields were recorded. At the end of the experiment, the crops were harvested and the yield was recorded for each treatment and farm plot. The data were averaged and expressed

Table 2. Details of the integrated pest management (IPM) and farmers' current practice (FCP) treatments imposed on cabbage fields. The IPM treatments were applied to fields at Yigo and Inarajan on Guam; the FCP treatments were chosen and applied by farmers at Dededo, Yigo and Merizo on Guam, and at Tanapag on Saipan and Sinapalo on Rota. Neem was applied as Aza-Direct. DiPel is a brand name for *Bacillus thuringiensis*, a bacterial biocontrol agent

Days after transplantation	IPM schedule	FCP 1	FCP 2	FCP 3	FCP 4	FCP 5
7	–	DiPel	Malathion	Warrior	–	Carbaryl
14	Neem	DiPel	DiPel	DiPel	Malathion	Malathion
21	–	–	Carbaryl	Malathion	–	–
28	DiPel	DiPel	DiPel	Carbaryl	Malathion	Carbaryl
35	–	DiPel	DiPel	Carbaryl	Malathion	Carbaryl
42	Neem	Carbaryl	DiPel	Malathion	Warrior	Carbaryl
49	–	DiPel	Carbaryl	Carbaryl	Malathion	Malathion
56	DiPel	DiPel	DiPel	Carbaryl	Warrior	Malathion
63	–	DiPel	DiPel	Malathion	Malathion	–
70	Neem	–	Carbaryl	Carbaryl	Warrior	Malathion
77	–	DiPel	–	Malathion	Malathion	Carbaryl
84	DiPel	DiPel	DiPel	Malathion	Warrior	–
No. applications	6	10	11	12	10	9

as the number of larvae and holes and as damage per plant and yield per hectare.

2.6 Evaluation of occurrence of natural enemies

Natural enemies (parasitoids and predators) of the pests were also counted for each treatment plot during sampling for the pests. Three cabbage leaves with eggs and ten larvae of *S. litura* from each plot were collected and incubated, and emergence of parasitoids was noted for measures of parasitism. Similarly, three cabbage leaves heavily infested with *L. brassicae* were collected and examined for any parasitoid emergence. All samples were placed individually in plastic boxes with a perforated top for aeration. They were transported to the laboratory and stored at room temperature until any parasitoids emerged.

2.7 Economic analysis of investment and benefits

At the end of the growing period, for each plot, the crop was harvested, the marketable yield was determined and the value of the crop (based on the current market price) was estimated. Here again, each cabbage head was evaluated for head infestation (immature pest stages on the head) and marketability using a standard 1–6 scale.[6] A head was considered marketable if it was free from damage, which corresponds to a rating of 1, 2 or 3 on Greene's scale. All data for pest control cost analysis were calculated on a per hectare basis. The costs of the pesticides and their application were as follows: IPM trial 1: neem = $64.50, DiPel = $58.81 and pesticide application = $64.73; IPM trial 2: neem = $63.85, DiPel = $57.86 and pesticide application = $68.43; FCP 1: DiPel = $105.57, carbaryl = $85.60 and pesticide application = $74.65; FCP 2: DiPel = $90.20, carbaryl = $82.14, malathion = $48.46 and pesticide application = $71.83; FCP 3: DiPel = $26.29, carbaryl = 92.45, malathion = $97.08, Warrior = $46.54 and pesticide application = $82.62; FCP 4: malathion = $172.15, Warrior = $101.43 and pesticide application = $62.82; FCP 5: carbaryl = $92.34, malathion = $74.50 and pesticide application = $81.06. The net profit for each plot was determined as the market value of the crop minus the input costs (labor, materials and insecticide application).

2.8 Statistical analysis

All the data were analysed by the SAS GLIMMIX procedure in SAS v.9.2.[7] The data for the holes and leaf mines made by larvae were analyzed with a generalized linear mixed model with a Poisson distribution, and a log-link was used to test the treatment and month effects for these count data. Averages of insect population or damage (holes and mines) on the ten plants in each plot were used as the dependent variable. For yield data (by site), a one-way ANOVA was performed, and, if the treatment effects were significant ($P < 0.05$), mean pairwise comparisons were performed on least squares by the least-squares difference method. If the treatment and/or month effects were significant, pairwise mean comparisons were performed with log-transformed LSMEANS.

3 RESULTS

3.1 Damage and yield assessment in the experimental plots

Table 3 presents the number of larval *S. litura*, the number of holes made in leaves by those larvae and the number of mines made by *L. brassicae* on the experimental plots. All three variables were significantly lower ($F_{10,279} = 155.9$, $P < 0.001$) on IPM treatment (neem plus DiPel) plots than on other plots. The control plots suffered the greatest damage from *S. litura* and *L. brassicae*. Results from all other treatments were intermediate.

The marketable yields of cabbage from the IPM plots at both locations were significantly higher than those on other plots ($F_{10,22} = 1.88$, $P < 0.05$) (Table 4). Overall, IPM treatments produced a yield about 50% higher than that from control plots, but IPM plots receiving six or eight applications did not differ significantly.

3.2 Damage and yield assessment in the comparison plots

The mean number of larvae, holes in leaves and leaf mines were all significantly ($F_{10,278} = 68.58$, $P < 0.05$) (Table 5) lower on the IPM plots than on those managed by farmers' current practices. Damage levels under the different forms of farmers' current practice did not differ significantly.

The average yield from the IPM plot ranged from 37 to 39 t ha^{-1}, whereas that from the farmers' plots ranged from 23 to 28 t ha^{-1} ($F_{10,22} = 4.94$, $P < 0.001$) (Fig. 1). Overall averages were 37.2 t ha^{-1} on IPM plots and 26.02 t ha^{-1} on farmers' plots.

Table 3. Mean numbers (± SE) of larvae of *Spodoptera litura*, holes made by those larvae and mines caused by *Liriomyza brassicae* recorded per cabbage plant grown on experimental plots at two locations on Guam[a]

	Yigo location			Inarajan location		
Treatment	Larvae	Holes	Mines	Larvae	Holes	Mines
Control (no applications)	36.6 ± 0.5 a	144.5 ± 0.3 a	61.4 ± 1.2 b	24.0 ± 0.6 a	111.8 a	56.8 ± 0.2 b
Neem, six applications	3.6 ± 0.7 c	34.8 ± 0.5 c	2.7 ± 1.8 c	2.8 ± 0.3 c	27.8 c	2.4 ± 0.6 c
Neem, eight applications	3.2 ± 0.3 c	32.6 ± 0.2 c	2.4 ± 0.5 c	3.6 ± 1.2 c	25.1 c	2.1 ± 1.4 c
DiPel, six applications	2.7 ± 1.2 c	35.3 ± 1.3 c	8.4 ± 1.0 a	3.1 ± 0.8 c	26.6 c	7.8 ± 0.2 a
DiPel, eight applications	2.4 ± 0.8 c	33.6 ± 0.9 c	9.1 ± 1.4 a	3.6 ± 1.3 c	26.4 c	8.2 ± 2.3 a
Neem, three applications, alternating with DiPel, three applications	0.5 ± 0.1 d	1.5 ± 0.2 d	0.2 ± 0.3 d	0.4 ± 0.2 d	0.0 d	0.0 ± 0.0 d
Neem, four applications, alternating with DiPel, four applications	0.4 ± 0.2 d	0.5 ± 0.1 d	0.0 ± 0.0 d	0.0 ± 0.0 d	0.0 d	0.0 ± 0.0 d
Malathion, six applications	3.5 ± 1.3 c	34.2 ± 1.2 c	6.2 ± 2.1 e	5.3 ± 0.2 e	27.5 c	4.4 ± 1.5 e
Malathion, eight applications	2.8 ± 0.5 c	32.5 ± 0.8 c	6.0 ± 1.4 e	5.8 ± 0.6 e	31.2 e	3.9 ± 1.7 e
Carbaryl, six applications	6.6 ± 0.6 e	38.2 ± 0.7 e	3.2 ± 0.8 c	6.2 ± 0.5 e	33.4 e	4.2 ± 1.6 e
Carbaryl, eight applications	5.8 ± 0.4 e	36.4 ± 0.6 e	2.8 ± 0.4 c	5.7 ± 1.3 e	32.7 e	4.1 ± 2.2 e

[a] Means within each column followed by the same letter are not significantly different at the $P < 0.05$ level (generalized linear mixed model using the Poisson distribution followed by pairwise mean comparisons). Each treatment was replicated 3 times.

Table 4. Marketable yield of cabbage from the experimental plots[a]

	Marketable yield (t ha^{-1})	
Treatment	Yigo location	Inarajan location
Control (no applications)	12.8 ± 1.6 a	15.2 ± 1.2 a
Neem, six applications	28.6 ± 0.4 b	29.2 ± 1.3 b
Neem, eight applications	29.4 ± 1.2 b	29.6 ± 0.7 b
DiPel, six applications	26.5 ± 1.1 b	25.6 ± 0.3 c
DiPel, eight applications	27.6 ± 0.9 b	24.8 ± 0.8 c
Neem, three applications, alternating with DiPel, three applications	36.2 ± 1.4 d	34.1 ± 0.7 d
Neem, four applications, alternating with DiPel, four applications	35.3 ± 1.6 d	36.6 ± 0.9 d
Malathion, six applications	27.3 ± 0.6 b	26.8 ± 0.6 c
Malathion, eight applications	28.2 ± 0.2 b	25.6 ± 1.3 c
Carbaryl, six applications	24.3 ± 0.4 c	24.6 ± 1.6 c
Carbaryl, eight applications	22.2 ± 0.6 c	24.3 ± 0.8 c

[a] Means within each column followed by different letters are significantly different at the $P < 0.05$ level (one-way ANOVA followed by LSMEANS by the least-squares difference method). Each treatment was replicated 3 times.

Table 5. Mean numbers (± SE) of larvae of *Spodoptera litura*, holes in leaves caused by those larvae and mines caused by *Liriomyza brassicae* on cabbage fields subjected to the IPM and FCP regimes described in Table 1[a]

Treatments	Larvae	Holes	Mines
IPM Trial 1, Yigo	1.2 ± 0.4 a	2.3 ± 0.5 a	0.8 ± 0.6 a
IPM, Trial 2, Inarajan	0.8 ± 1.1 a	1.2 ± 0.3 a	0.3 ± 0.1 a
FCP 1	9.3 ± 0.3 b	28.2 ± 0.6 b	12.6 ± 0.5 b
FCP 2	10.6 ± 1.3 b	31.7 ± 1.8 b	9.8 ± 1.0 b
FCP 3	8.9 ± 0.7 b	34.6 ± 1.3 b	11.3 ± 1.4 b
FCP 4	11.3 ± 0.3 b	33.6 ± 0.7 b	10.8 ± 0.3 b
FCP 5	9.5 ± 0.7 b	32.8 ± 0.4 b	9.7 ± 0.0 b

[a] Means within each column followed by the same letter are not significantly different at the $P < 0.05$ level (generalized linear mixed model with the Poisson distribution followed by pairwise mean comparisons). Each treatment was replicated 3 times.

3.3 Occurrence of natural enemies

No parasitoids or predators emerged from the field samples collected during the experimental period.

3.4 Economic analysis of investments and benefits

Costs incurred on the IPM plots averaged \$189.09 ha^{-1}; those on farmers' plots averaged \$298.34 ha^{-1}. The gross value of the harvest from the IPM plots was nearly \$1000 ha^{-1} more than that of the farmers' plots (Table 6).

4 DISCUSSION

Using IPM and other newer strategies to replace toxic chemical sprays for better pest control has been considered a top priority for sustainable agriculture in the new century. In this paper, studies not only on the insect control effects of an IPM practice versus farmers' standard practice but also on the economics of both practices have been reported. Although conservation of natural enemies is one of the goals of an IPM program (to achieve high levels of predation or parasitism to aid in pest management), no natural enemies were recorded in the present study. This could be due to prolonged use of toxic chemicals in the region. However, the goal of conservation of natural enemies can be accomplished through the use of reduced-risk insecticides.[8] Moreover, the reduced-risk insecticides have demonstrated high levels of pest control while diminishing deleterious effects on beneficial insects.[9,10]

Researchers have attempted to reduce insecticide usage in cabbage by developing action thresholds for pests on cabbage on the basis of sampling immature stages on leaves.[11] While these

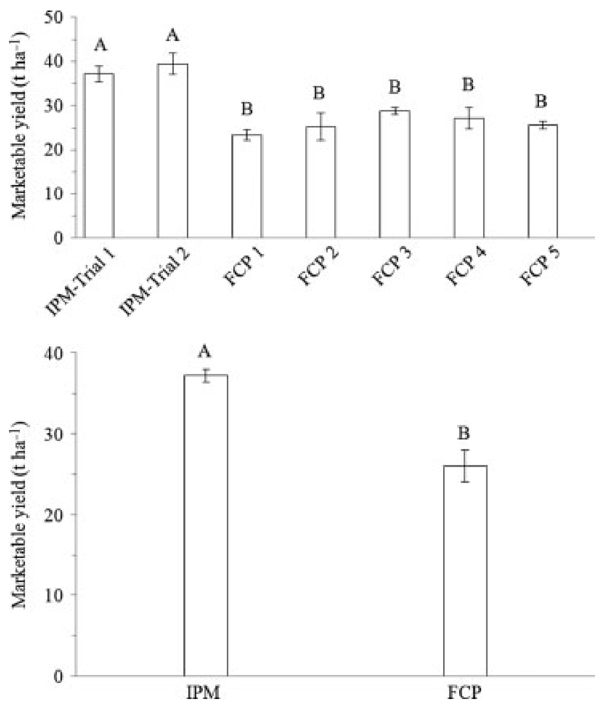

Figure 1. Marketable yields of cabbage from fields subjected to the treatments described in Table 1. Means marked by different letters are significantly different at the $P < 0.05$ level (one-way ANOVA followed by LSMEANS with the least-squares difference method). FCP: farmers' current practice.

action-threshold-based insecticide spray regimens can be used to replace the existing calendar-based spray regimen currently used to manage pests on cabbage in the Pacific, thresholds vary considerably among regions. A research-based action threshold that is appropriate for timing insecticide applications to control pests in Micronesian cabbage fields has not been identified. The findings from the present study are based on large-plot experiments, and these results are assumed to work well in large-scale, commercial production in Micronesia.

Although, as the present study demonstrated, the farmers' practice of using the insecticides carbaryl and malathion was effective in reducing the *S. litura* larval population and the damage it causes, as well as the number of mines caused by *L. brassicae*, and produced yields significantly higher than those of the control plots, these insecticides have serious disadvantages. Both are toxic to fish[12] and bees,[13] and both can be hazardous to human health during application if not handled carefully.[14] Because they are broad-spectrum insecticides, they are toxic to beneficial insects as well as to pests,[15] so their overuse can lead to outbreaks of aphids and spider mites.[16,17] Because carbaryl is one of the most frequently used carbamate insecticides and is widely used for the control of a variety of pests on fruit, vegetables, forage and many other crops in the Pacific and other parts of the world, this problem could be serious.[18]

A possible alternative is the use of microbial agents such as DiPel, a primary biocontrol agent of insect pests.[19] Kurstaki (DiPel DF) is another bacterium well known for suppression of a variety of insect pests. It is effective against caterpillars: the cabbage looper, cabbageworm, grape leaffolder, hornworm, cutworm, sod webworm, tobacco budworm and several other lepidopterous species.[20] In the present study, DiPel was toxic only to caterpillars and proved no more effective, and sometimes less effective, than malathion and carbaryl. Prior studies strongly support the use of DiPel in IPM programs for the control of *Plutella xylostella* on cabbage[4] and *Helicoverpa armigera* on cotton,[21] but many *B. thuringienis* products are known to break down quickly in sunlight.[22] Because the weather in Micronesia is sunny, humid and hot throughout the year, depending solely on DiPel to control insect pests is not advisable.

In the present study, the neem-based product Aza-Direct was shown to be significantly more effective than the control when it was used alone. In the last decade, plant extracts with insecticidal properties have evoked substantial scientific and practical interest as natural means of insect and mite pest control in agriculture. While the seeds contain most of the principal active ingredient (azadirachtin), the leaves and other tree parts also contain significant amounts.[23] Neem trees produce several terpenoid compounds with insect antifeedant and growth-regulating properties and show only low toxicity towards mammals and other vertebrates. A neem-based insecticide is an ideal candidate for inclusion in IPM programs[4] because of its low toxicity to natural enemies[21] of pests and its safety in the environment. Furthermore, no phytotoxicity has been observed in any plant tissues.[24] Neem is also less toxic to insect pollinators.[25] Neem biopesticides may therefore be well suited for inclusion in IPM programs,[4,21,25] but their known lack of rapid knockdown poses a challenge for promoting neem in pest control markets, where people have come to expect instantaneous results.[26] The alternation of neem with DiPel, as evaluated in the present study, is cheaper than the use of synthetic organic insecticides primarily because of the lower number of applications needed to control *S. litura* and *L. brassicae*. The resulting higher crop yields further increased the cost effectiveness of the IPM treatments. The $671.72

Table 6. Costs and revenues from the cabbage fields described in Tables 1 and 4. IPM and economic analysis of investment versus benefit in the IPM program and farmers' practice[a]

Treatments	Number of applications	Pest-control costs (\$ ha^{-1})	Gross revenue (\$ ha^{-1})	Net revenue (\$ ha^{-1})
IPM, trial 1, Yigo	6	188.04	4043.40	1042.42
IPM, trial 2, Inarajan	6	190.14	4018.23	998.12
FCP 1	10	265.82	3624.20	342.40
FCP 2	11	292.63	3712.54	318.12
FCP 3	12	344.98	2986.32	298.13
FCP 4	10	340.40	3526.17	368.12
FCP 5	9	247.90	3482.24	416.00

[a] All spray volumes on IPM plots were 185.35 L ha^{-1}; those on farmers' fields ranged from 188.35 to 202.15 L ha^{-1}.

difference between the net value of the harvest on IPM plots and that on farmers' plots demonstrates the obvious advantage of IPM over the farmers' current practices. The present results are consistent with those of Burkness and Hutchison[8] who reported that an IPM program (with either spinosad or indoxacard) resulted in a significantly lower percentage of infected cabbage plants than did the conventional program or an untreated control. These results differ somewhat from those of Edelson *et al*.[3] who reported that the greater number of applications of biorational techniques [*B. thuringiensis* and/or fatty acid soap applications and inundate releases of *Chrysoperla carnea* (Neuroptera: Chrysopidae)] required for effective control of insect pests on broccoli frequently caused these biorational treatments to be more costly than the synthetic organic insecticides. The IPM approach of alternating neem and DiPel can keep pests from causing significant problems, with minimum risk to humans and the desirable components of their environment. This kind of approach can be expected to continue to be a dominant theme in agriculture.[27]

5 CONCLUSIONS

An IPM regime consisting of commercially available products (neem and DiPel), applied alternately, was cost competitive for management of the pest complex attacking cabbage crops on Guam. This regime should be promoted among the Pacific islands and other parts of the tropical world.

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