# Reduction of Diamondback Moth (Lepidoptera: Plutellidae) Infestation in Head Cabbage by Overhead Irrigation

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**ABSTRACT** A study was conducted in 1992 and 1993 at the Pinney Purdue Research Station in Wanatah, IN, to investigate the impact of overhead irrigation on diamondback moth, *Plutella xylostella* (L.), infestation in head cabbage, *Brassica oleracea* L. var. *capitata*. When irrigation water was applied to cabbage by Whiz head, Mini head, or Buckner head sprinklers, diamondback moth infestations were reduced by 37.5–63.9% compared with a drip-irrigated control. All sprinkler heads resulted in significantly fewer diamondback moth numbers compared with the control, but no differences were noted among overhead irrigation treatments. Irrigation timed and applied daily with the Mini head sprinkler resulted in greatest reduction in diamondback moths. Sprinkler treatments applied between 1500 and 1700 hours continuously, 2000 and 2200 hours continuously, and 2000 and 2330 hours intermittently resulted in an average 53.7, 72.9, and 85.9% reduction in diamondback moth infestation, respectively. Best results were obtained by intermittent daily application of overhead irrigation between 2000 and 2330 hours.

**KEY WORDS** *Plutella xylostella*, overhead irrigation, cultural control

HEAD CABBAGE, *Brassica oleracea* L. var. *capitata*, and other Cruciferae are a widely cultivated vegetable group subject to attack by numerous insects (Metcalf & Metcalf 1993). Worldwide, the most serious insect pest of cabbage is the diamondback moth, *Plutella xylostella* (L.). It is estimated that over $1 billion is spent annually on its control (Talekar 1992). Concern over increasing economic losses from diamondback moth attack has resulted in the convening of two international conferences and over 1,400 published papers dealing with diamondback moth biology, ecology, and management (Talekar et al. 1990).

Diamondback moths have developed resistance to all classes of insecticides. Resistance to carbamates and organophosphates was documented first, principally in tropical regions, followed by resistance to pyrethroids, organochlorines, and insect growth regulators (Sun et al. 1978, Liu et al. 1982, Chen & Sun 1986, Tabashnik et al. 1987, Fahmy & Miyata 1992, Ismail et al. 1992, Kobayashi et al. 1992). Diamondback moths can develop resistance to the microbial insecticide *Bacillus thuringiensis* (Tabashnik et al. 1990). Currently, diamondback moth resistance to insecticides is widespread throughout North America (Shelton et al. 1993).

Insecticide resistance develops as a result of selection pressure (Roush & Tabashnik 1990). Control strategies that minimize exposure of diamondback moth to pesticides may be helpful in managing resistance by reducing the intensity of selection. The implementation of overhead irrigation, as a cultural control measure, on watercress (*Rorippa nasturtium-aquaticum* Hayek) in Hawaii is effective in suppressing diamondback moth (Nakahara et al. 1986). In field studies in 1983 and 1984 at the Asian Vegetable Research and Development Center, Shanhua, Taiwan, significantly fewer diamondback moth larvae and pupae were recovered on sprinkler-irrigated than on surface-irrigated cabbage (Talekar et al. 1986). In addition, trials conducted in Florida from 1987 through 1990 showed reduced effectiveness of insecticides for diamondback moth control when the materials were applied on head cabbage that was grown using drip irrigation compared with sprinkler-irrigated cabbage, indicating that diamondback moth infestation can be reduced by overhead irrigation (Jansson 1992).

The objectives of this research were to examine the influence of a variety of irrigation systems on diamondback moth infestations in head cabbage and to evaluate the effectiveness of daily timed overhead irrigation for reduction of diamondback moth on head cabbage.

## Materials and Methods

This study was conducted at the Pinney Purdue Research Farm in Wanatah, IN, in 1992 and 1993 on a well-drained Tracy sandy loam soil of 0–2% slope (U.S. Department of Agriculture 1982). Plots

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were 6 by 6 m and were 1.5 m apart. Four rows of cabbage were planted per plot. Fertilizer (10:20:10 2,000 kg [AI]/ha N:P:K) was broadcast and preplant incorporated. An emulsifiable concentrate (E) formulation of Treflan 4 E (0.85 kg [AI]/ha) was also preplant incorporated for weed control. Head cabbage seedlings ('OS Cross') were transplanted 0.6 m apart within a row and 1.5 m apart between rows when plants were at the five-leaf stage. All plots were sprinkler-irrigated immediately after planting. No insecticides were used in these trials.

**Comparison of Irrigation Systems.** In 1992 and 1993, an experiment investigating the effect of irrigation on diamondback moth field populations was conducted and repeated on three separate occasions. Cabbage was planted on 21 May and 18 August 1992 and on 19 May 1993. Experimental design was a randomized complete block with four treatments and three replicates. Treatments included one surface-applied drip irrigation system (as a control) and three different overhead sprinkler types. All irrigation systems were calibrated to deliver 1.25 cm of water per application. Water requirement for cabbage at this site was 2.5 cm/wk. Irrigation was applied when rainfall was inadequate for maximum plant growth. The drip irrigation was a plastic T-tape system placed adjacent to the transplants. The sprinkler treatments applied water in a variety of ways. The Olson SPJ 6600 Mini head (Olson Irrigation Systems, Santee, CA) was a mist sprinkler that took 6 h to deliver the water requirement (Fig. 1A). The Buckner P-15 spray head (Buckner, Fresno, CA) was a stationary, full-circle head that delivered water in an upright fan shaped pattern (Fig. 1B) and needed 1 h for application of the water. The Nelson Whiz head (Nelson, Walla Walla, WA) was a revolving head with a large droplet size and also took 1 h for application (Fig. 1C). Sprinkler heads in all treatments were placed in the center of the plot and mounted on 0.65-m polyvinylchloride plastic risers at a density of one head per treatment per plot. In-line butterfly valves were installed on the risers to control the flow of water through the heads.

Irrigation water was applied on 20 and 28 May; 2, 10, 11, 16, 19, 24, 26, and 30 June; and 1 and 8 July 1992 for repetition 1; on 19 and 24 August; 1, 5, 9, 11, 14, 19, 21, and 29 September; and 5 October 1992 for repetition 2; and on 20 and 26 May; 1, 11, 14, 17, 21, and 29 June; 1, 7, and 12 July 1993 for repetition 3. All irrigation occurred between 1400 and 2000 hours.

**Timed Irrigation.** In 1993 an experiment that examined the effect of timed irrigation on diamondback moth was conducted. Two repetitions of this trial were performed. Cabbage was planted on 19 May and 11 August 1993. The experiment was designed as a randomized complete block with four treatments and three replicates. Drip-irrigated cabbage served as the control treatment, and water was applied between 1500 and 1700 hours.

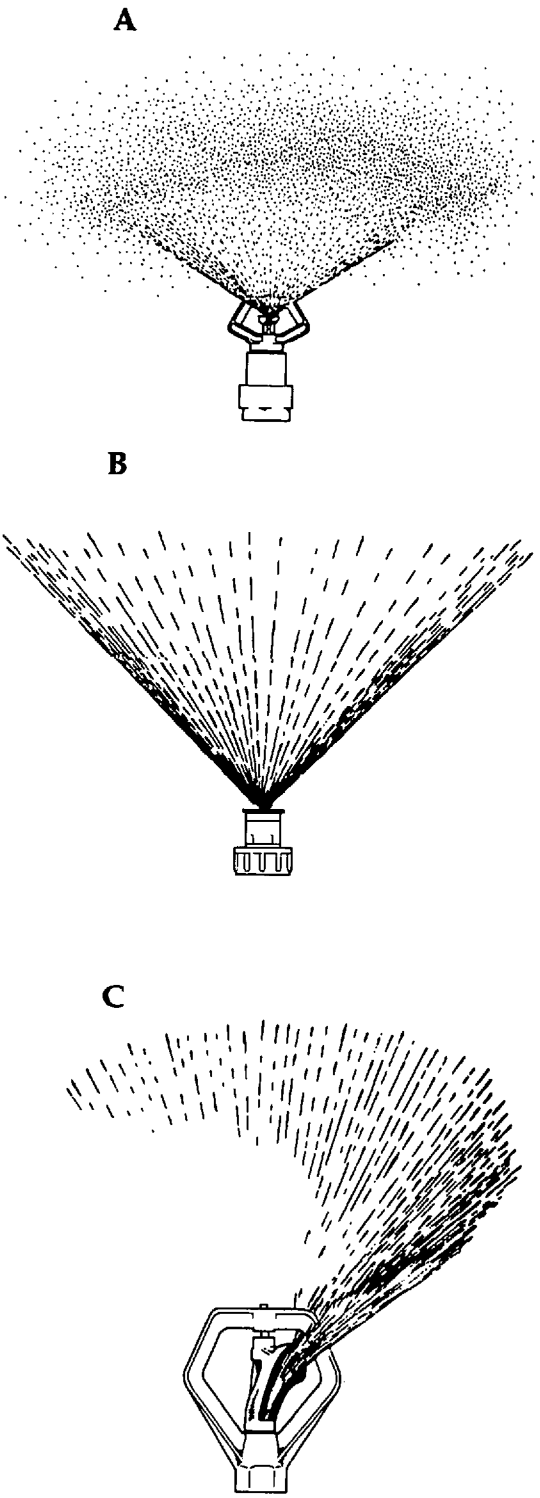


**Fig. 1.** Sprinkler treatments for irrigation experiments. (A) Mini head. (B) Buckner head. (C) Whiz head. (All drawings approximately one-third normal size.)

**Table 1. Mean number of diamondback moth larvae + pupae in head cabbage subjected to various irrigation treatments at Pinney Purdue, planted 21 May 1992**

| Sampling dates | No. diamondback moths per six plants | | | | $F$ (df = 3, 2) | $P$ |
|---|---|---|---|---|---|---|
| | Buckner head | Mini head | Whiz head | Drip irrigation | | |
| 2 June | 0 | 0 | 0 | 0.3 | 1.00 | 0.4547 |
| 10 June | 0.7 | 1.0 | 1.7 | 1.3 | 2.50 | 0.1565 |
| 17 June | 4.3 | 4.0 | 8.3 | 11.3 | 1.29 | 0.3583 |
| 24 June | 10.0 | 12.3 | 16.0 | 25.0 | 3.10 | 0.1105 |
| 1 July | 13.7a | 16.3a | 19.0a | 38.0b | 7.33 | 0.0225* |
| 8 July | 9.7a | 17.7a | 20.3a | 39.3b | 6.45 | 0.0263* |
| 14 July | 26.7a | 22.7a | 34.7ab | 57.7b | 17.96 | 0.0021** |
| Total | 65.1a | 74.0a | 100.0ab | 172.9b | 18.18 | 0.0040** |
| % reduction | 62.3 | 57.2 | 42.2 | | | |

Means within a row followed by the same letter are not significantly different (Fisher's protected least significant difference); *, $P$ = 0.05; **, $P$ = 0.01.

The three overhead irrigation treatments were as follows: (1) 1500–1700 hours *daytime continuous,* (2) 2000–2200 hours *evening continuous,* and (3) 2000–2330 hours *evening intermittent.* The evening intermittent sprinkling consisted of alternating 30 min on and 30 min off of irrigation time within that time. The continuous treatments were on during the entire irrigation period. The Olson SPJ 6600 Mini head sprinkler was used to allow for the longest possible time for the irrigation water to be applied. All irrigation treatments were calibrated to deliver 2.5 cm of water per week and were applied daily. Each separate treatment was electronically regulated by a one-station irrigation controller (Model Mini I-24, Batrow, Short Beach, CT) connected to a solenoid (Buckner model 620018, Buckner) actuated plastic valve (Buckner model 20321). Irrigation was operated regardless of rainfall. Placement of the drip irrigation tubing and sprinkler heads in the plots was as previously described.

**Diamondback Moth.** Three hundred to 600 laboratory-reared diamondback moth adults (1:1 male to female ratio) were released in the plots after transplanting on 21 May 1992, 19 May 1993, and 11 August 1993. In addition, resident populations of diamondback moth larvae were observed in adjacent canola (*Brassica napus* L.) fields at the time of cabbage planting. Another 300–400 adults were released into the field on 27 October 1992 to encourage the establishment of an overwintering population.

**Data Collection.** Data collection began 1–2 wk after planting for the 21 May 1992, 19 May 1993, and 11 August 1993 trials. Sampling was delayed an additional 2 wk for the 18 August 1992 trial because of intensive electrical storms. Weekly whole-plant counts of diamondback moth larvae and pupae were taken from six plants closest to the risers in the sprinkler-treated areas. Drip irrigation plots that bordered on a sprinkler treatment were occasionally subjected to windblown water droplets along the edge of the plot. Only those cabbage plants in the drip irrigation treatment that were farthest away from the sprinkler plots, and thus not subject to drifting overhead irrigation, were sampled. Diamondback moth larvae and pupae that were encountered during the sampling process were left on the plants. Any other pests found were removed and destroyed. A visual determination of percentage injury to whole cabbage plants by all leaf defoliators was assessed weekly. Estimation of injury was on those plants that were sampled for diamondback moth larvae and pupae.

**Statistical Analysis.** Diamondback moth counts were transformed by $\log(x + 1)$ for data analysis by analysis of variance (ANOVA) (Gagnon et al. 1989). Data were compared weekly and also summed for comparison of total diamondback moths during a sampling period. Mean separation was determined by Fisher's protected least significant difference. Regression analysis was used to determine the relationship between injury and diamondback moths.

## Results

**Comparison of Irrigation Systems.** In the 21 May 1992 planting, diamondback moth numbers increased steadily throughout the course of the trial (Table 1). Overhead irrigation treatments resulted in significantly lower diamondback moth counts on the final three sampling dates. At the diamondback moth peak population on 14 July, infestation was 39.9–60.7% lower in sprinkler-irrigated cabbage compared with the drip-irrigation control. Sprinkler irrigation resulted in significantly fewer total diamondback moths during the sampling period ($F$ = 18.18; df = 3, 2; $P$ = 0.004).

The 18 August 1992 planting had low populations of diamondback moths for the study period (Table 2). Significantly fewer diamondback moths were observed in the sprinkler irrigation treatments on three of the four sampling dates. Overall, there were significantly more diamondback moths on drip-irrigated cabbage for the entire sampling period ($F$ = 11.84; df = 3, 2; $P$ = 0.019).

Diamondback moth numbers in the 19 May 1993 study peaked on 16 June and generally declined throughout the remainder of the planting

**Table 2. Mean number of diamondback moth larvae + pupae in head cabbage subjected to various irrigation treatments at Pinney Purdue, planted 18 August 1992**

| Sampling dates | No. diamondback moths per six plants | | | | $F$ (df = 3, 2) | $P$ |
|---|---|---|---|---|---|---|
| | Buckner head | Mini head | Whiz head | Drip irrigation | | |
| 16 Sept. | 5.7a | 10.0a | 11.0ab | 16.0b | 4.95 | 0.0224* |
| 23 Sept. | 6.7a | 5.7a | 4.7a | 17.0b | 5.70 | 0.0344* |
| 30 Sept. | 1.3 | 1.3 | 5.0 | 7.7 | 1.45 | 0.3179 |
| 7 Oct. | 9.0a | 8.0a | 7.3a | 22.3b | 5.70 | 0.0344* |
| Total | 22.7a | 25.0a | 28.0a | 63.0b | 11.84 | 0.0190* |
| % reduction | 63.9 | 60.3 | 55.6 | | | |

Means within a row followed by the same letter are not significantly different (Fisher's protected least significant difference); *, $P = 0.05$.

(Table 3). Significant treatment differences for diamondback moths occurred on 10 June and 13 July. At the 13 July sampling date, diamondback moth infestation was 33–57.1% less on cabbage subjected to overhead irrigation. Total number of diamondback moths was significantly greater on drip-irrigated cabbage than on cabbage associated with any of the sprinkler treatments ($F = 5.06$; df = 3, 2; $P = 0.0441$).

Injury to head cabbage in this experiment was positively correlated with number of diamondback moths in all repetitions. Regressions for the relationship between diamondback moth counts and percentage injury were highly significant in the 21 May 1992 ($F = 32.83$; df = 1, 82; $P = 0.0001$; $R^2 = 0.286$), 18 August 1992 ($F = 31.97$; df = 1, 46; $P = 0.0001$; $R^2 = 0.410$), and 19 May 1993 ($F = 177.90$; df = 1, 82; $P = 0.0001$; $R^2 = 0.684$) plantings.

**Timed Irrigation.** Diamondback moth numbers were low for the 19 May planting in the timed overhead irrigation plots, peaking on 16 June and either declining or remaining static until the final sampling date (Table 4). Counts in the drip-irrigated control were consistently higher, peaked on 16 June, and were steady for the remainder of the trial. Significant treatment differences for diamondback moth infestations were found on all but the first sampling date. On the 16 June peak, there was 60.8–86.9% fewer diamondback moths in the timed overhead irrigation treatments when compared with drip irrigation. Generally, numbers of diamondback moths in the evening intermittent sprinkling treatment were lower than in the daytime continuous treatment and usually lower than in the evening continuous treatments. Total diamondback moth counts for the course of the trial were significantly less in the timed overhead irrigation treatments when compared with those in the control ($F = 45.32$; df = 3, 2; $P = 0.0002$). The evening intermittent treatment provided greatest overall suppression of diamondback moths with significantly lower numbers than the daytime continuous treatment. Use of the evening intermittent regime maintained diamondback moth populations below one larva or pupa per plant throughout the entire growing period.

Diamondback moth counts were low and remained low in the 11 August planting (Table 5). Significantly fewer diamondback moths were observed on five sampling dates in the timed overhead irrigation treatments. Weekly diamondback moth counts were lowest in the evening intermittent trial. Significant treatment differences for total diamondback moth counts for the entire trial were recorded. Evening irrigation produced the greatest overall reduction of diamondback moths resulting in significantly lower infestations than daytime continuous-sprinkling and drip-irrigation treatments ($F = 51.86$; df = 3, 2; $P = 0.0001$).

As number of diamondback moths increased, percentage injury to cabbage increased. Regression relationships were highly significant for the 19 May ($F = 73.31$; df = 1, 82; $P = 0.0001$; $R^2 = 0.472$) and 11 August ($F = 5.21$; df= 1, 82; $P = 0.0001$; $R^2 = 0.300$) plantings. Greatest injury to cabbage was sustained when diamondback moth numbers were highest.

## Discussion

The use of overhead irrigation alone significantly reduced diamondback moth infestations in field-

**Table 3. Mean number of diamondback moth larvae + pupae in head cabbage subjected to various irrigation treatments at Pinney Purdue, planted 19 May 1993**

| Sampling date | No. diamondback moths per six plants | | | | $F$ (df = 3, 2) | $P$ |
|---|---|---|---|---|---|---|
| | Buckner head | Mini head | Whiz head | Drip irrigation | | |
| 2 June | 0 | 0 | 0 | 0 | | |
| 10 June | 1.0a | 4.7b | 0.7a | 2.3ab | 15.48 | 0.0100** |
| 16 June | 40.3 | 44.0 | 40.0 | 58.7 | 1.27 | 0.4985 |
| 23 June | 22.7 | 18.0 | 18.3 | 32.7 | 1.69 | 0.3390 |
| 29 June | 12.7 | 7.3 | 12.7 | 19.3 | 2.63 | 0.1253 |
| 7 July | 5.3 | 9.7 | 9.7 | 19.3 | 4.03 | 0.0913 |
| 13 July | 14.0a | 13.0a | 20.3ab | 30.3b | 5.26 | 0.0359* |
| Total | 96.0a | 96.7a | 101.7a | 162.7b | 5.06 | 0.0441* |
| % reduction | 41.0 | 40.6 | 37.5 | | | |

Means within a row followed by the same letter are not significantly different (Fisher's protected least significant difference); *, $P = 0.05$; **, $P = 0.01$.

**Table 4. Mean number of diamondback moth larvae + pupae in head cabbage subjected to timed irrigation treatments at Pinney Purdue, planted 19 May 1993**

| Sampling dates | No. diamondback moths per six plants | | | | $F$ (df = 3, 2) | $P$ |
|---|---|---|---|---|---|---|
| | Evening intermittent 2000–2330 hours | Evening continuous 2000–2200 hours | Daytime continuous 1500–1700 hours | Drip irrigation | | |
| 2 June | 0 | 0 | 0 | 0 | | |
| 10 June | 0.3a | 0.3a | 0.7a | 7.0b | 7.73 | 0.0175* |
| 16 June | 5.0a | 12.3ab | 15.0bc | 38.3c | 20.47 | 0.0015** |
| 23 June | 4.3a | 7.0ab | 11.3b | 15.7b | 5.37 | 0.0390* |
| 29 June | 2.0a | 3.3ab | 8.0bc | 21.7c | 8.95 | 0.0124* |
| 7 July | 3.3a | 5.3a | 4.7a | 16.3b | 11.28 | 0.0070** |
| 13 July | 4.3a | 3.3a | 5.3a | 17.3b | 15.57 | 0.0031** |
| Total | 19.2a | 31.5ab | 45.0b | 116.3c | 45.32 | 0.0002** |
| % reduction | 83.5 | 72.9 | 61.3 | | | |

Means within a row followed by the same letter are not significantly different (Fisher's protected least significant difference); *, $P = 0.05$; **, $P = 0.01$.

grown head cabbage. All sprinkler treatments were effective in lowering diamondback moth numbers when compared with drip irrigation. Diamondback moth infestations were 37.5–63.9% less for sprinkler-irrigated head cabbage over the course of three trials and 2 yr (Tables 1–3). Although there were no significant differences between sprinkler treatments for diamondback moth infestation, the Buckner head and Mini head sprinklers did result in consistently fewer diamondback moth larvae and pupae.

In diamondback moth life-table studies done in Canada, Harcourt (1963) determined that rainfall is a major mortality factor affecting diamondback moth larvae from egg hatch through the middle of the last instar. Mortality in these growth stages averaged 56% and occurred when the insects were exposed to mean rainfall of 3.4 cm during that portion of their generation. Larvae at this age were susceptible to being washed off the host plants by the water. They then were unable to regain their position on the plant or were drowned in puddles of water that formed on the ground or in the leaf axils. In our comparison of irrigation systems experiment, an average of 13.8 cm of water was applied to cabbage in each of the repetitions. Thus, sprinkler irrigation alone, when applied as needed, reduces the number of diamondback moth larvae on cabbage by simulating rainfall.

When overhead irrigation was applied on a daily, timed basis in 1993, diamondback moth infestations were reduced by 46.1–88.2% (Tables 4 and 5). The most effective reduction of diamondback moths occurred using evening intermittent sprinkling. In a study on watercress in Hawaii, Tabashnik & Mau (1986) determined that 70% of diamondback moth adult oviposition occurred between the hours of 1700 and 2300. Irrigation during that time was effective in suppressing diamondback moths on watercress by reducing the number of eggs laid per plant. Therefore, the most important contribution of overhead irrigation toward reduction of diamondback moth infestation on head cabbage may be a result of timely application.

Results from our investigation demonstrate the potential for use of overhead irrigation as a management tool for the control of diamondback moths on head cabbage. Diamondback moth infestation can be reduced simply by using an over-

**Table 5. Mean number of diamondback moth larvae + pupae in head cabbage subjected to timed irrigation treatments at Pinney Purdue, planted 11 August 1993**

| Sampling dates | No. diamondback moths per six plants | | | | $F$ (df = 3, 2) | $P$ |
|---|---|---|---|---|---|---|
| | Evening intermittent 2000–2330 hours | Evening continuous 2000–2200 hours | Daytime continuous 1500–1700 hours | Drip irrigation | | |
| 17 Aug. | 0.3a | 0.7a | 0.3a | 2.3b | 6.14 | 0.0293* |
| 24 Aug. | 0.3 | 0.7 | 1.3 | 2.7 | 2.93 | 0.1218 |
| 31 Aug. | 1.0a | 2.3ab | 3.3bc | 5.7c | 7.82 | 0.0170* |
| 7 Sept. | 0.7ab | 0.3a | 3.0b | 3.3b | 4.66 | 0.0521* |
| 14 Sept. | 0.3 | 1.7 | 2.7 | 3.7 | 4.03 | 0.0691 |
| 21 Sept. | 0a | 0a | 1.0ab | 1.7b | 9.57 | 0.0106** |
| 28 Sept. | 0a | 0.3a | 0.3a | 2.7b | 20.50 | 0.0015** |
| Total | 2.6a | 6.0a | 11.9b | 22.1c | 51.86 | 0.0001** |
| % reduction | 88.2 | 72.8 | 46.1 | | | |

Means within a row followed by the same letter are not significantly different (Fisher's protected least significant difference); *, $P = 0.05$; **, $P = 0.01$.

head system, rather than drip irrigation, to supply head cabbage water requirements. The most effective use of sprinkler irrigation would be to apply the water daily, intermittently in the evening hours, thus maximizing the disruptive nature of the system. Control of diamondback moths is most important during the first 30–45 d after transplanting (Chen & Su 1986). Insecticide applications have been recommended during that time when numbers of diamondback moth larvae are greater than one per plant because injury to the growing points of young plants can cause heads to fail to form. Daily evening intermittent sprinkling, over an extended period, maintained diamondback moths in our studies below the one per plant threshold without the use of an insecticide, whereas cabbage subjected to drip irrigation averaged three larvae per plant. In addition, as a consequence of lower diamondback moth infestation, sprinkler-irrigated cabbage exhibited lower feeding injury. Variation in cabbage injury attributable to diamondback moths ranged from 28.6 to 68.4%. Reduction in injury, because of lower infestation, can result in less insecticide use.

Currently, intermittent overhead irrigation systems are being used for diamondback moth control in commercial watercress fields in Hawaii (Nakahara et al. 1986). This system operates daily and places >100,000 liters of water per ha/d on the crop. Watercress is an aquatic crucifer that is adapted to withstand a saturated aqueous environment. The application of excessive water on head cabbage for diamondback moth control has not been considered feasible and could increase the incidence of disease (Talekar & Shelton 1993). However, our data indicate that modification of this system for dry-land head cabbage production is practical on a well-drained soil. In particular, no disease was observed in any of the irrigation treatments. The incorporation of this approach to diamondback moth management into cabbage cropping systems may enhance effective cultural control methods. In addition, minimizing insecticides in a pest management program may provide a more favorable environment for natural enemies and maintain the utility of those insecticides still effective against diamondback moths.

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