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Dead-end trap cropping: a technique to improve management of the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae)

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Abstract

Use of non-glossy collards as a trap crop for control of the diamondback moth, *Plutella xylostella* (L.), in commercial fields of cabbage in New York was unsuccessful because it neither reduced the number of larvae on cabbage nor concentrated the insects on collards. In laboratory and outdoor screenhouse experiments, *P. xylostella* preferentially laid its eggs on the glossy-type *Barbarea vulgaris*, a common biennial weed, when compared with broccoli and cabbage. Ovipositional preference in the screenhouse trials varied from 24 to 66 fold for *B. vulgaris*. However, no larvae were able to develop on *B. vulgaris*. More importantly, cabbage plants in screenhouses with *B. vulgaris* had fewer eggs laid on them than cabbage plants in screenhouses without *B. vulgaris*. We therefore suggest that *B. vulgaris*, or another plant species that is highly attractive for egg laying, but on which *P. xylostella* larvae do not survive, may serve as a 'dead-end' trap crop and be more successful than trap crop types that may only have increased oviposition. However, candidate dead-end trap crops must also be evaluated for their effects on other insects, diseases and weed management before such plants can be recommended in an overall pest management program.

Keywords: Plutella xylostella; Diamondback moth; Trap crop; Barbarea vulgaris

1. Introduction

In response to visual, tactile and olfactory cues, insects often demonstrate preferences for particular plant species, cultivars or crop stages. These preferences can be exploited for pest management through the use of trap crops. Trap crops are composed of one or more plant species that are grown to attract a pest species in order to protect a nearby cash crop (Hokkanen, 1991). Protection may be achieved by preventing the pest from reaching the crop, or by concentrating the pest in a portion of the field where it can be managed. Trap crops may be manipulated in time or space to attract insects at a critical period in the phenology of the pest or crop, or both. Depending on the biology of the pest and the pest management tactics available, a pest population on a trap crop can be dealt with in several different ways. In some cases, plants may be able to withstand the damage and no further action is required. In other cases, trap crops may serve as a resource for natural enemies that can then increase and suppress the pest population (Zhao et al., 1991). If trap crops are used to attract and concentrate the pest species so it can be managed more effectively (but without regard to increasing natural enemy populations), then insecticides or cultural practices, such as destroying the trap crop, could be deployed. Although appealing as a benign and potentially effective method of pest management, trap cropping is not always successful. Trap crops have attracted more attention in developing countries where cosmetic standards for damage to cash crops are generally lower than in developed countries.

Trap cropping has been used for decades in several developing countries in efforts to control the diamondback moth, *Plutella xylostella* (L.), the most serious insect pest of crucifers worldwide (Talekar and Shelton, 1993). In some areas, trap cropping has been used because insecticides are not available or affordable, biological control has not been effective, or resistance to insecticides has developed. Trap cropping for *P. xylostella* in crucifers has primarily been through the use of white mustard, *Brassica hirta* (Moench), or Indian mustard, *B. juncea* (L.), which serve as preferred

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oviposition sites for *P. xylostella* (Talekar and Shelton, 1993). Charleston and Kfir (2000) noted that Indian mustard did not perform successfully as a trap crop in South Africa and reported similar failures in Taiwan, South East Asia and Canada. In India, Srinivasan and Krishna Moorthy (1992) tested Indian mustard as a trap crop for *P. xylostella* by planting one row between every 15–20 rows of cabbage (*B. oleracea* var. *capitata*), while in Sweden, Åsman (2002) planted a 30 cm-wide row of Indian mustard around small plots of cabbage (6 m^2). In both cases, the trap crop was reported to suppress damage to the cash crop. However, similar approaches have failed in Hawaii (Luther et al., 1996) and Texas (Bender et al., 1999). Despite these conflicting studies, some growers in the United States have expressed interest in further developing this technology. Much of this interest has been fueled by the difficulty in controlling *P. xylostella* due to its resistance to synthetic insecticides (Shelton et al., 1993a), including products containing *Bacillus thuringiensis* endotoxins (Shelton et al., 1993b) and most recently the novel insecticide, spinosad (Zhao et al., 2002).

While planting a trap crop highly preferred by the pest is key to successful trap cropping (Hokkanen, 1991), it is unclear whether white mustard or Indian mustard can provide reliable and effective control of *P. xylostella*. Collards have also been recommended as a trap crop for *P. xylostella* in cabbage (Boucher, 2000; Mitchell et al., 2000) because it produces foliage for a long period and can withstand relatively large populations of insects, characteristics lacking in Indian mustard. However, field studies in Florida using non-glossy collards as a trap crop indicated that the collard trap crop did not reduce populations of *P. xylostella* in cabbage under a commercial field situation (Mitchell et al., 2000).

We suggest that another approach to trap cropping for control of *P. xylostella* may be useful, and we term this strategy 'dead-end' trap cropping. This strategy utilizes a plant species that is highly attractive for oviposition but on which *P. xylostella* cannot survive. As an example of this strategy, we propose *Barbarea vulgaris* R. Br. (Brassicaceae), which is a biennial weed that reproduces by seed and taproot and is commonly found in the Northeastern and Midwestern United States along roadsides, in pastures and in old fields. Previous observations in the laboratory have indicated that *P. xylostella* will oviposit on *B. vulgaris*, but the larvae do not survive (Idris and Grafius, 1996). Shinoda et al. (2002) attributed this to a feeding deterrent, a monodesmosidic triterpenoid saponin. More recently, Agerbirk et al. (2003) identified the susceptibility of two types of *B. vulgaris* var. *arcuata*, a glossy (G) type and a pubescent (P) type, to *P. xylostella*. Rosette plants of the G type were fully resistant to *P. xylostella* when grown in the greenhouse or collected in the summer, but leaves collected during the late fall were less resistant. The P type was always susceptible. The authors identified 3-*0*-*β*-cellobiosyloleanolic acid and concluded that this triterpenoid saponin was positively correlated with increasing levels of resistance of *B. vulgaris* foliage to *P. xylostella*.

In this paper, we first examine the effectiveness of using non-glossy collards as a trap crop for *P. xylostella* in New York by comparing larval densities in commercial cabbage fields with and without the trap crop. We then examine the effectiveness of glossy *B. vulgaris* as a trap crop in a series of laboratory and outside screenhouse trials.

2. Materials and methods

2.1. Trap cropping with collards

Eight commercial cabbage fields were grown in Yates County, New York during 2001. Fields were divided into four pairs based on similarity of planting date, cabbage variety, size and location (e.g., bordered by woods). Field sizes ranged from 2 to 8.5 ha but within a matched pair of fields, the difference in size was $\leqslant$1.6 ha. Distance between fields within each pair was 0.5–1 km. All fields were rectangular with rows oriented parallel to the length of the field. One field within each pair was grown with four rows of collards (the non-glossy variety 'Champion') all bordering and parallel to the outside rows of the field. This variety was chosen because it has been recommended in the literature (Boucher, 2000). No collards were planted along the other two field edges. The remaining field in each pair was not bordered by collards.

On a weekly basis, each field was examined for *P. xylostella* larvae. In fields with cabbage only, four cabbage plants were inspected at each of six sites in the field for a total of 24 plants per sample date. Two of the six sites were located within the first five rows of the two longer sides of each field. In fields bordered by collards, the same procedure was used but an additional set of three collard plants was also examined in each border for a total of six collard plants inspected per field.

To avoid potential damage to the crop by *P. xylostella*, all fields were treated once with an insecticide (*Bacillus thuringiensis*) in mid-August when larval densities exceeded a threshold of 30% of plants infested with $\geqslant$1 larva (Reiners et al., 2003). Six of the eight sampling events were completed before fields were sprayed.

Analyzed data included only those dates for which all four paired fields were sampled within the same two-day period: 16 and 24 July, 7 August and 6 September. This helped eliminate any spurious differences between fields that may have been caused by other factors (e.g.

rainfall). Dynamics of *P. xylostella* larval populations were compared within cabbage fields that contained or did not contain a collard trap crop using a repeated measures analysis of variance (PROC GLM) (SAS Institute, 1999). For cabbage fields containing the collard trap crop, the same procedure was used to compare densities of *P. xylostella* larvae over time on cabbages in the center of the field, cabbages adjacent to the collards, and on the collards.

2.2. Laboratory assessment of *B. vulgaris*

Laboratory experiments were conducted at Cornell University's New York State Agricultural Experiment Station (NYSAES) in Geneva, New York in 2001. To confirm that our population of *P. xylostella* oviposit on *B. vulgaris* but larvae do not survive, we conducted the following tests using *B. vulgaris* and rapeseed, *Brassica napus* L. subsp. *oleifera*, perhaps the most attractive and suitable host for *P. xylostella* (Shelton et al., 1991). Seeds of a glossy *B. vulgaris* were obtained from wild *B. vulgaris* grown near Ithaca, NY. All plants were grown in a greenhouse in pots (18 cm diam) using a 50:50 mixture of Cornell soil mix and sand, and plants were approximately the same age when used for testing. A strain of *P. xylostella*, Geneva 88 (Shelton et al., 1993a), maintained in our laboratory was used in the bioassays. To compare oviposition between the two plant species, mated *P. xylostella* adults (2 males and 2 females) were placed into screened cages ($0.3 \times 0.3 \times 0.3$ m). Each cage contained five detached leaves (4–7 cm × 4–7 cm) from each plant species (total of 10 leaves per cage). Each leaf was placed in a separate 50 ml flask of water. The treatments had four replicates (cages). After 24 h, the number of eggs laid on each leaf was recorded. Egg-bearing leaves from two of the replicates were used to determine larval survival at 96 and 120 h. To compare oviposition on the two plant species, data were analyzed by a one-way analysis of variance (PROC GLM) (SAS Institute, 1999). Larval survival data were analyzed using a logit model with plant species as the sole factor (PROC GENMOD) (SAS Institute, 1999).

2.3. Screenhouse assessment of *B. vulgaris*

Based on results obtained from the laboratory experiments, additional experiments to compare *P. xylostella* oviposition and larval survival on cultivated *Brassica* varieties and *B. vulgaris* were conducted in outdoor screenhouses at NYSAES. Broccoli (*Brassica oleracea* L. var. *italica*), variety 'Packman', cabbage, variety 'Bobcat', and *B. vulgaris* were grown in a greenhouse in pots (18 cm diam) using a 50:50 mixture of Cornell soil mix and sand, as described above. Plants were acclimated outside at least 1 week before each experiment. When plants had approximately 12 leaves, they were placed in a screenhouse ($4.7 \times 3.2 \times 2.5$ m high) with a dirt floor and a transparent fiberglass ceiling. Plants were arranged in five rows, with seven plants in each row. The spacing between plants was 60 cm and the outermost plants were 30 cm from the screenhouse wall. One treatment consisted of a solid planting of either 35 cabbage or 35 broccoli plants. The other treatment consisted of 24 cabbage or broccoli plants and 11 *B. vulgaris* plants. In the treatment with *B. vulgaris*, the plants were arranged in the following design. The middle row contained all *B. vulgaris* plants, and the center plant was flanked on each side by two additional *B. vulgaris* plants. The resulting pattern of *B. vulgaris* formed a cross of 11 plants when viewed from above. The treatments were replicated three times and allocated to screenhouses in a completely randomized design. The experiment was performed once with cabbage and twice with broccoli between early June and late August 2001. The data for each trial were analyzed separately.

Approximately 25 adults of *P. xylostella* (Geneva 88) were released into each screenhouse and allowed to oviposit. After 72 h, five cabbage or broccoli plants, and five adjacent *B. vulgaris* plants, were removed from each screenhouse and the leaves examined for eggs using a dissecting microscrope. In screenhouses with only broccoli or cabbage, an additional five plants were taken. Thus, a total of 10 plants from each screenhouse were examined for eggs. To compare the numbers of *P. xylostella* eggs laid on cabbage or broccoli and on *B. vulgaris*, data were analyzed by a one-way analysis of variance (PROC GLM) (SAS Institute, 1999). Data were transformed using a $\log_{10}(x+1)$ function to stabilize the variance prior to analysis.

Survival of *P. xylostella* larvae on broccoli and *B. vulgaris* was also assessed in screenhouses. Five broccoli or *B. vulgaris* plants were placed in an empty screenhouse and infested with 20 *P. xylostella* eggs per plant using the method of Shelton et al. (1991). The eggs were allowed to hatch and the number of third instars was recorded 7–10 d later. Data were analyzed using a logit model with host as the sole factor (PROC GENMOD) (SAS Institute, 1999).

3. Results

3.1. Trap cropping with collards

Infestations of *P. xylostella* larvae in cabbage fields with and without a collard trap crop peaked at >1.5 larvae per plant (Fig. 1). The overall density of *P. xylostella* larvae on cabbage in fields with a trap crop did not differ significantly from the density on cabbage in fields without a trap crop ($F = 0.44$; df = 1, 3; $P = 0.55$), indicating that the collard trap crop failed

to reduce the infestation on cabbage. Similarly, the seasonal dynamics of larval populations in cabbage fields with and without a trap crop did not differ (date × treatment effect: $F = 1.44$; df = 3, 9; $P = 0.30$), suggesting that the collard trap crop did not affect *P. xylostella* colonization patterns during the season. Population levels of *P. xylostella* larvae dropped considerably after fields were sprayed with an insecticide in mid-August and larval densities remained low throughout the field until late August (Fig. 1). Larval populations began to increase in all fields in early September shortly before the crop was harvested.

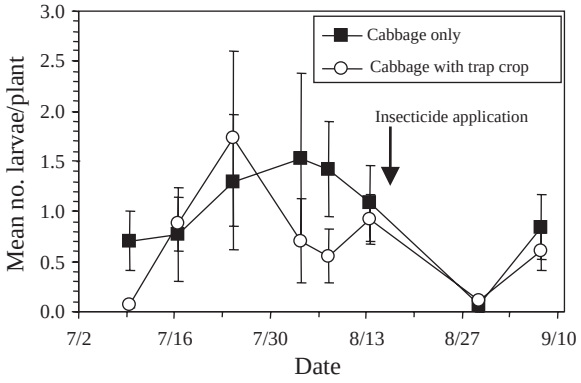

Fig. 1. Mean (±SEM) number of *P. xylostella* larvae per cabbage plant in fields that contained or did not contain a collard trap crop in New York in 2001 ($n = 4$). Fields with a trap crop had four rows of collards planted adjacent and parallel to the outside rows. The arrow signifies when fields were treated with insecticides to control *P. xylostella*.

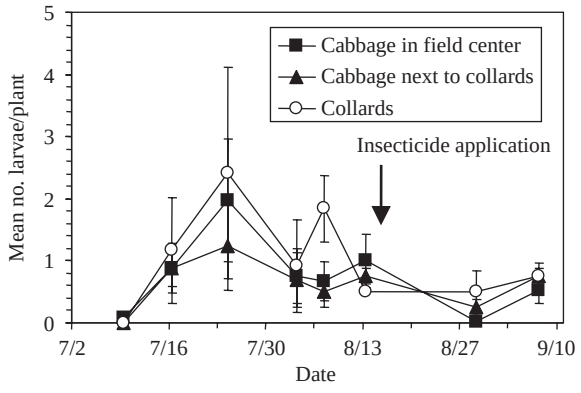

Fig. 2. Mean (±SEM) number of *P. xylostella* larvae per plant in cabbage fields containing a collard trap crop in New York in 2001 ($n = 4$). Fields with a trap crop had four rows of collards planted adjacent and parallel to the outside rows. The arrow signifies when fields were treated with insecticides to control *P. xylostella*.

The total number of *P. xylostella* larvae counted on collards, cabbages adjacent to collards and cabbages in the center of the field over the season was similar ($F = 2.48$; df = 2, 6; $P = 0.16$) (Fig. 2). Seasonal patterns of infestation on the plants were also similar (date × location within field: $F = 0.56$; df = 6, 18; $P = 0.76$).

3.2. Laboratory assessment of *B. vulgaris*

The number of *P. xylostella* eggs laid on *B. vulgaris* was 5.5-fold greater than the number of eggs laid on *B. napus* ($F = 11.04$; df = 1, 3; $P = 0.04$) (Table 1). However, 92% of the larvae reared on *B. napus* survived after 96 and 120 h, whereas significantly fewer larvae survived on *B. vulgaris* after 96 h ($X^2 = 181.12$; df = 1; $P < 0.01$) and none survived after 120 h ($X^2 = 274.63$; df = 1; $P < 0.01$) (Table 1).

3.3. Screenhouse assessment of *B. vulgaris*

P. xylostella tended to lay fewer eggs on cabbage and broccoli plants in screenhouses that contained a mixture of cabbage or broccoli and *B. vulgaris* than those that contained cabbage or broccoli alone (Table 2). These differences were significant in Experiments 1 and 3 (Experiment 1: $F = 9.99$; df = 1, 3; $P = 0.05$; Experiment 3: $F = 10.63$; df = 1, 3; $P = 0.05$) and approached significance in Experiment 2 ($F = 6.60$; df = 1, 3; $P = 0.08$). These results indicate that inclusion of *B. vulgaris* in a mixture with broccoli or cabbage reduced the number of *P. xylostella* eggs laid on broccoli or cabbage.

Adults laid significantly more eggs on *B. vulgaris* than on the cultivated hosts cabbage and broccoli (Table 2). These differences were significant in each experiment

Table 1
Ovipositional preference and larval survival of *Plutella xylostella* on yellow rocket, *Barbarea vulgaris*, and rapeseed, *Brassica napus* subsp. *oleifera*, in the laboratory

Plant type	*n*	Mean (+SEM) number of eggs laid per leaf during 24 h	Mean (+SEM) percentage of larvae surviving after[a]:	
			96 h	120 h
B. vulgaris	4	20.0±6.6a	8.8±0.6a	0a
B. napus	4	3.6±2.4b	91.9±1.4b	91.9±1.4b

Numbers followed by different letters in the same column are significantly different using ANOVA ($P > 0.05$).

[a] Eggs laid on leaves in two of the four replicates were kept to determine larval survival after 96 and 120 h. Numbers averaged 258 and 67 eggs per replicate for *B. vulgaris* and *B. napus*, respectively.

Table 2
Mean numbers of eggs per cultivated crucifer or yellow rocket, *Barbarea vulgaris*, after *Plutella xylostella* adults were released 3 days earlier in outdoor screenhouses that contained either all cultivated crucifers (i.e., cabbage or broccoli) or a mixture of cultivated crucifers and yellow rocket, *Barbarea vulgaris*

Experiment	Treatment	Mean (+SEM) number of eggs per plant[a]	
		On cabbage or broccoli plant	On *B. vulgaris*
1	Cabbage only	13.4±5.4A	—
	Cabbage + *B. vulgaris*	1.2±0.6Bb	31.6±4.1a
2	Broccoli only	5.8±2.0A	—
	Broccoli + *B. vulgaris*	0.8±0.6Ab	52.8±16.5a
3	Broccoli only	14.1±2.3A	—
	Broccoli + *B. vulgaris*	2.8±2.8Bb	66.0±2.5a

[a] Means followed by the same letter (upper case for different treatment, and lower case for different host plants) within each experiment are not significantly different using ANOVA ($P > 0.05$). Means were transformed by a $\log_{10}(x + 1)$ function before analysis, but untransformed means are presented. There were three replicates for each treatment.

Table 3
Mean percentage survival of *Plutella xylostella* through the third instar when eggs were placed on leaves of either broccoli or yellow rocket, *Barbarea vulgaris*

Experiment	Host	*N*	Mean (+SEM) percentage survival through third instar[a]
1	Broccoli	100	55.7±4.3a
	B. vulgaris	100	0b
2	Broccoli	100	38.0±3.4a
	B. vulgaris	100	0b

[a] Means followed by the same letter within each experiment are not significantly different (X^2; $\alpha > 0.05$).

(Experiment 1: $F = 41.78$; df = 1, 2; $P = 0.02$; Experiment 2: $F = 31.27$; df = 1, 2; $P = 0.03$; and Experiment 3: $F = 253.23$; df = 1, 2; $P = 0.01$) (Table 2). The mean numbers of eggs laid per plant on *B. vulgaris* were 26, 66 and 24 times greater than the numbers laid on cultivated hosts in each of three trials, respectively.

P. xylostella larvae did not survive on *B. vulgaris* (Table 3). Percentage survival of *P. xylostella* from the egg stage through the third instar was significantly greater on broccoli than on *B. vulgaris* in both Experiment 1 ($X^2 = 95.65$; df = 1; $P < 0.01$) and Experiment 2 ($X^2 = 57.71$; df = 1; $P < 0.01$).

4. Discussion

Considerable caution should be taken before using a recommended non-glossy variety of collards as a trap crop for *P. xylostella*. Our results did not indicate that a non-glossy collard trap crop reduced populations of *P. xylostella* in cabbage under a commercial field situation. Another report by Mitchell et al. (2000) in Florida stated similar results. They also found increased populations of *P. xylostella* on collards compared with cabbage, a trend that we suspect could lead to an increased risk of adult *P. xylostella* moving to cabbage over the course of the season.

An alternative approach, using a highly attractive plant species such as *B. vulgaris* as a dead-end trap crop, may have considerable promise. Compared with *B. napus*, *B.vulgaris* was >5.5 times as attractive for oviposition in a two-choice test in the laboratory, yet no larvae could survive on it. These survival results are similar to a report by Idris and Grafius (1996). When compared with cabbage or broccoli in a large screenhouse, preference by *P. xylostella* for *B. vulgaris* was much more dramatic. *P. xylostella* laid from 24 to 66 times as many eggs on *B. vulgaris* and again no larvae survived. More importantly, cabbage plants in screenhouses with *B. vulgaris* had fewer eggs laid on them than cabbage plants in screenhouses without *B. vulgaris*. Root and Tahvanainen (1969), working with *B. vulgaris* from the same area (Ithaca, NY) we used in our trials, provided a list of insects found on the foliage and stems of a large sample of *B. vulgaris*. With the exception of flea beetles (*Phyllotreta* spp.), very few of the insects were pests of cultivated crucifers, and many were predators or parasitoids of cruciferous pests. They suggest that "the dense stands of *B. vulgaris* that grow naturally in this location may act as a fortuitous trap crop" for cultivated crucifers. We suspect that the *B. vulgaris* they examined was the glossy type containing the saponin correlated with resistance described by Agerbirk et al. (2003). Although growers consider *B. vulgaris* a weed, it may have some advantages as a trap crop for management of *P. xylostella*. If grown from seed 2 to 3 weeks before cabbage or broccoli to compensate for its slower growth, it could be transplanted as a trap crop simultaneously with the main

crop. Because of its biennial nature, it would not flower while the cash crop is in the ground and thus should not exacerbate weed management. However, this tactic must be more thoroughly investigated before it is recommended as a commercial practice. Trap crops require land that would normally be used for production of a cash crop, so an agronomic and economic analysis of the benefits and liabilities of using a trap crop such as *B. vulgaris* would be required. In our screenhouse trial we used a high percentage of *B. vulgaris*, and this percentage would likely have to be reduced for commercial application of this trap crop. The influence of *B. vulgaris* on disease control and secondary insect problems also requires further research.

Other options for dead-end trap crops for crucifers exist. We are presently examining whether other plants that are highly attractive to *P. xylostella* for oviposition can be modified to become dead-end trap crops. Glossy-wax collards (Eigenbrode et al., 1992) are more attractive for oviposition than normal bloom collards (unpublished) and are being engineered to express proteins from *B. thuringiensis* (Earle and Shelton, unpublished). Broccoli has already been developed that can express Cry1A and Cry1C proteins from *B. thuringiensis* (Cao et al., 2002). Perhaps glossy Bt collards could be used as dead-end trap crops for *P. xylostella*. In such cases they may also play a role as part of an overall insecticide resistance management program.

In addition to the selection of an appropriate trap crop, it is also important to establish which spatial and temporal patterns of deployment will ensure the most effective trap crop system. Such studies should investigate not only the dispersal patterns of *P. xylostella* as it moves into the field, but also its behavior within the field. Improved knowledge of the movement patterns of *P. xylostella* will be necessary to design an effective trap cropping system for this serious pest of crucifers.

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