Management of Yellowmargined Leaf Beetle *Microtheca ochroloma* (Coleoptera: Chrysomelidae) Using Turnip as a Trap Crop

RAMMOHAN BALUSU,[1] ELENA RHODES,[2] OSCAR LIBURD,[2] AND HENRY FADAMIRO[1,3]

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ABSTRACT The yellowmargined leaf beetle, *Microtheca ochroloma* Stål, is a major pest of cruciferous vegetable crops in organic production systems. Very few organically acceptable management options are currently available for this pest. Field studies were conducted at a research station in Alabama and at a commercial organic vegetable farm in Florida to investigate the effectiveness of turnip, *Brassica rapa rapa*, as a trap crop for *M. ochroloma*. In the research station trial with cabbage planted as the cash crop, perimeter planting of turnip as a trap crop effectively reduced beetle numbers and crop damage below levels recorded in the control. During the first season of our on-farm trial, with napa cabbage and mustard as the cash crops, using turnip as a trap crop effectively reduced both beetle numbers and cash crop damage below levels found in the control plots, but economic damage was still high. In the second season, beetle populations were too low for significant differences in damage levels to occur between the trap crop and control plots. Together, these results suggest that turnip planted as a trap crop can be an effective control tactic for cruciferous crops, like cabbage, that are much less attractive to *M. ochroloma* than turnip. In crops, like mustard and napa cabbage, that are equally or only slightly less attractive than turnip, planting turnip as a trap crop would have to be used in combination with other tactics to manage *M. ochroloma*.

KEY WORDS trap crop, yellowmargined leaf beetle, *Microtheca ochroloma*, organic pest management, crucifers

Crucifer vegetable crops, in particular *Brassica* spp. (Brassicaceae), have an estimated market value in the United States of over $1 billion (United States Department of Agriculture–National Agricultural Statistics Service [USDA-NASS] 2000). These vegetables are grown throughout the United States, but the most valuable cruciferous crops in the southern United States are broccoli, cabbage, cauliflower, turnip, and collards. Although these crops are traditionally produced using conventional production practices, organic crucifer vegetable production is an emerging industry in the southern United States.

The yellowmargined leaf beetle, *Microtheca ochroloma* Stål (Coleoptera: Chrysomelidae), is presently the most devastating pest of organic and low-input crucifer vegetable production in many parts of the southern United States. This beetle, which was first recorded in the United States in Mobile, Alabama, in 1947 (Chamberlin and Tippins 1948), is now widely distributed in the southern United States with major field infestations reported in Alabama, Georgia, Florida, Louisiana, Mississippi, South Carolina, North Carolina, Oklahoma, and Texas (Oliver and Chapin 1983, Ameen and Story 1997a). *Microtheca ochroloma* is regarded as an oligophagous insect, and it feeds on plants in the family Brassicaceae. The beetle is a cool-season pest that is typically active from late September until early December in Alabama. It overwinters as adults that become active again from mid-March to early June in Alabama. However, in Florida, due to mild winter temperatures, the beetle is active throughout the winter, from October to late April. During the hot summer months, they aestivate on wild hosts before migrating into crucifer fields from the edges inward (R. R. Balusu, personal observation). Eggs are laid under the foliage of crucifer plants and the larvae pass through four instars. The pupae are commonly found above ground attached to leaves or debris (Chamberlin and Tippins 1948). The total developmental period under standard laboratory conditions is ∼27 days, and the beetle has multiple generations per year (Ameen and Story 1997a). Both adults and larvae feed initially on foliage and cause severe defoliation. Even after complete depletion of foliage, the beetle will continue to feed on exposed tubers of turnips and radishes, causing entire crop loss. Although all members of the Brassicaceae family may be severely damaged, the beetle has noted preferences for certain crucifer host plants such as turnip and napa cabbage (Ameen and Story 1997b, Balusu and Fadamiro 2011).

Microtheca ochroloma has traditionally been managed in conventional vegetable production systems in the southern United States using multiple applications

[1] Department of Entomology and Plant Pathology, 301 Funchess Hall, Auburn University, Auburn, AL 38649.
[2] Department of Entomology and Nematology, Bldg. 970 Natural Area Drive University of Florida, Gainesville, FL 32611.
[3] Corresponding author, e-mail: fadamhy@auburn.edu.

of synthetic, broad-spectrum foliar insecticides such as chlopyrifos, malathion, and diazinon (Story et al. 1997, Holmes and Kemble 2008). *Microtheca ochroloma* rarely causes major damage in conventional vegetable production systems due to its susceptibility to synthetic insecticides, but it poses a major threat to organic vegetable production, as organic farmers cannot use synthetic insecticides. The Organic Material Review Institute-approved insecticides, such as Entrust (spinosad) and PyGanic (pyrethrins), are the only effective *M. ochroloma* control options currently available to organic growers (Balusu and Fadamiro 2012). However, there are a number of potential negative consequences that are associated with the reliance on these therapeutic or temporary control tactics including development of insecticide resistance and negative impact on beneficial insects. Furthermore, because these insecticides are expensive to use and need repeated applications, many organic vegetable growers are reluctant to use these materials. Thus, there is a critical need to develop alternative methods with limited reliance on insecticides for *M. ochroloma* management in organic crucifer production in the region.

Perimeter trap cropping (PTC) is a type of cultural pest management tactic, in which a host plant that is attractive to colonizing pests is planted to encircle the cash crop, often limiting pesticide use to this border where the pest is concentrated as it enters the field (Adler and Hazzard 2009). Multiple studies have demonstrated the potential of PTC in controlling vegetable pests in a variety of crops (Ludwig and Kok 1998, Bender et al. 1999, Smith 2000, Boucher et al. 2003, Badenes-Perez 2005, Smith and Liburd 2012). The following key ecological aspects of *M. ochroloma* make the perimeter trap cropping approach a good candidate for managing this pest. 1) The beetles show a strong preference for specific cruciferous species. Turnip has been shown to be a more highly attractive host plant than cabbage (Balusu and Fadamiro 2011). Therefore, turnip has great potential for use as a trap crop; 2) Adults aestivate during summer and migrate into cruciferous crops from field edges, allowing them to encounter the perimeter trap crop before they come into contact with the main crop. Their colonization on the trap crop in the perimeter before dispersing into the main crop can lead to effective management of the beetle by limiting insecticide applications to the trap crop on the edges rather than spraying the entire field. The objective of this study was to determine the effectiveness of planting turnip around the perimeter of other cruciferous crops (main crops) as a trap crop to manage *M. ochroloma*. We hypothesized that turnip trap cropping will successfully reduce *M. ochroloma* densities and damage in the main crop. Specifically, 1) we compared the attractiveness of trap crop with that of the main crop in terms of larval and adult densities and 2) we assessed the damage on the main crops with and without a trap crop border.

Materials and Methods

This study was conducted over three growing seasons—Spring 2012, Fall 2012, and Spring 2013 at two locations: E.V. Smith Research Center, Shorter, Alabama, and a commercial organic vegetable farm in Starke, Florida. The following treatments were evaluated at each location: 1) perimeter planting of turnip along the four borders of a main crop two weeks before planting main crop and 2) main crop without perimeter trap crop. The experimental design and other agronomical practices at the research station were slightly different from those at the commercial vegetable farm (on-farm) due to limited availability of space and other resources at the commercial farm. Specifically, plot size and plant spacing were comparatively larger in the research station trials than in the on-farm trials.

Research Station Trials. The research station trials were conducted at the E.V. Smith Research Station (Shorter, Alabama). The experimental plots, each 12 by 12 m, consisted of five raised beds of 10.7 m long by 0.76 m wide covered with white plastic mulch and irrigated through drip tape (Berry Plastics, Evansville, IN). A single row of the main crop (cabbage variety 'Farao') was transplanted into a raised bed with plant spacing of 0.3 m in-row and 1 m between-rows. Three rows of densely planted (plant spacing of ~0.15 m in-row and between-rows) turnip trap crop (var. 'purple top white globe') were transplanted in a raised bed (0.76 m wide) around the border on all four sides of the main cabbage crop, so that it completely encircled the cabbage main crop (i.e., perimeter trap cropping). This narrow strip of densely planted turnip trap crop acted as a fortress wall to prevent the insects from breaching the trap crop barrier. The control plots had a similar layout as the treatment plots but with no turnip trap crop border. A 60 m long buffer zone was maintained between the control and treatment plots. The experiment was replicated three times with a distance of 3.65 m separating the replicates.

Seedlings were raised from seeds purchased from Johnny's Selected Seeds (Winslow, ME) under controlled greenhouse conditions (26 ± 2°C and 55 ± 5% relative humidity [RH]). Three-week-old seedlings were transplanted in the field. Prior to the transplanting, the plants were placed outside for 3–4 d for acclimation and hardening. In Spring 2012, Fall 2012, and Spring 2013, trap crop plants (turnip) were transplanted on March 12, September 15, and March 19, respectively. The trap crop was planted two weeks in advance of the main crop so that the trap crop was available at the beginning of *M. ochroloma* migration and activity. Standard agronomic practices such as fertilizer application and irrigation were used to raise the crops (Holmes and Kemble 2008).

Ten randomly selected plants were sampled weekly from the cabbage main crop, turnip trap crop, and control plots and inspected for *M. ochroloma* adult and larval densities. If or when the density of *M. ochroloma* on the turnip trap crop exceeded a nominal threshold of 2–3 adults per plant, the turnip plants were sprayed with Entrust SC (Dow AgroSciences LLC, Indianapolis, IN) at the label rate (364 ml product/ha). At harvest, 10 plants were selected at random from each treatment and rated for insect damage. The damage ratings were based on a scale of 1–6 modified after

Smith's (2000) and Maletta et al.'s (2004) methods as follows: 1 = very light defoliation (<10%); 2 = light defoliation (10–30%); 3 = moderate defoliation (30–50%); 4 = heavy defoliation (50–70%); 5 = very heavy defoliation (70–90%); and 6 = complete (total) defoliation (>90%).

Data on the number of adults and larvae were not normally distributed, and transformation did not adequately correct this anomaly. Thus, a nonparametric test based on Kruskal–Wallis test ($P \leq 0.05$; JMP 7.0.1, SAS Institute 2007) was performed on the data. Pairwise means separation was used to determine the significant differences among the trap crop and main crop treatments on a given sampling date. Data on insect damage ratings at harvest met the assumptions of parametric tests and were analyzed by one-way ANOVA.

On-Farm Trials. In the on-farm trial in a commercial vegetable grower's field in Florida, the main crop was determined by the cooperating grower, and it was a mixture of two cruciferous plants, napa cabbage and mustard, that were alternated with each other with three rows of each. Thus, the experimental design was a factorial experiment with treatment and main crop as factors. There were three replicates of two plots each. One plot (cash crops surrounded by trap crop) in each replicate was bordered by turnip as the trap crop, whereas the other (cash crop alone) was not. Treatments were assigned randomly in each replicate. Experimental plots were 7.6- by 7.6-m blocks that were separated by 6-m unplanted buffer zones.

In the Spring 2012 growing season, turnip was direct seeded by hand into the two outside rows of each trap crop plot on 13 January 2012. Turnip plants were fertilized with NatureSafe 10-2-8 (Nature Safe Natural & Organic Fertilizers, Cold Springs, KY) on 10 February 2012. A late freeze the following weekend killed most of the turnip plants on one side of each treatment plot, so these areas were replanted on 16 March 2012. The cash crops were direct seeded by hand on 10 February 2012 after the addition of NatureSafe 10-2-8 to the beds. Germination was sporadic, so replanting with a seeder occurred on 16 March 2012. The turnip border was sprayed weekly with Entrust at the label rate of 364 ml product/ha beginning on 6 March 2012, the first sampling date, as beetles were already present in the plots at this point. Weeding was performed as necessary and occurred on 16 March, 26 March, and 18 April 2012. It was necessary to apply Dipel at the label rate of 1 kg/ha on napa cabbage on 3 April 2012 to manage an armyworm (*Spodoptera* sp.) infestation.

In the fall 2012 season, the turnip was direct seeded by hand into the two outside rows and at the end of each cash crop row on 10 October 2012. Turnip plants were fertilized with NatureSafe 10-2-8 at a rate of 67 kg/ha at planting and again on 16 November 2012. Mustard and napa cabbage were direct seeded by hand into planting trays in the Small Fruit and Vegetable IPM greenhouse at the University of Florida (Gainesville, FL) and allowed to grow for 4 wk with an average RH of 65% and temperature of >25°C. Mustard and napa cabbage seedlings were transplanted into the field on 20 November 2012. NatureSafe 10-2-8 was applied to the unplanted rows on 16 November 2012 at a rate of 67 kg/ha and 98 kg/ha for the mustard and napa cabbage, respectively. A second application at the same rate was applied on 20 December 2012. The turnip plants were monitored weekly for *M. ochroloma* by counting the number of adults and larvae on 10 turnip plants in each plot. If the density of *M. ochroloma* on the turnip trap crop exceeded a nominal threshold of two to three adults per plant, the turnip plants were sprayed with Entrust (Dow AgroSciences LLC, Indianapolis, IN) at the previously mentioned label rate. This occurred once on 20 December 2012.

In both seasons, plots were evaluated weekly by sampling 10 randomly selected plants per cash crop from each treatment for *M. ochroloma* densities. In the Fall 2012 season, the trap crop was also sampled for *M. ochroloma* densities using the same method as previously discussed. At harvest, 10 plants were selected at random from the trap crop (only in Fall 2012 season) and the main crops in each treatment and rated for insect damage. The damage ratings were based on a scale of 1–6 as described above for the research station trials.

In the Spring 2012 season, for the period after the replanting, *M. ochroloma* adult and larval data were first $\log_{10}(X + 0.1)$ transformed, based on a maximum likelihood analysis, to meet the assumptions of ANOVA and then analyzed using repeated-measures ANOVA with treatment and crop as factors. The harvest crop damage data were analyzed using two-way ANOVA with treatment and crop as factors.

In the Fall 2012 season, the last four weeks of *M. ochroloma*, data were analyzed with repeated-measures analysis, as very few adult beetles were collected prior. Adult and larval data were $1/\text{sqrt}(X + 0.1)$ transformed, based on a maximum likelihood analysis, to meet the assumptions of ANOVA and analyzed as in the previous season. The harvest evaluation data were analyzed as in the previous season. The Tukey–Kramer honestly significant difference (HSD) comparison test was used to determine treatment differences with cash-crop-alone plots, cash crops bordered by trap crop plots, and the turnip trap crop itself as treatments.

Results

Research Station Trials. In Spring 2012, the results from the non-parametric analysis using Kruskal–Wallis rank test showed that there was a significant difference in the number of adults observed during most sampling dates (Fig. 1A). Significantly more adults were found on the trap crop than on the main crop on 29 March ($\chi^2 = 59.20$, df = 2, $P < 0.0001$), 4 April ($\chi^2 = 32.92$, df = 2, $P < 0.0001$), 10 April ($\chi^2 = 46.26$, df = 2, $P < 0.0001$), and 25 April ($\chi^2 = 13.26$, df = 2, $P = 0.0013$), indicating that turnip is an effective trap crop for *M. ochroloma.* Similarly, the mean number of adults in cabbage plots with trap crop was about five times lower than that in cabbage plots without trap crop (mean ± SE: with trap crop, 0.37 ± 0.1; control, 1.83 ± 0.23). The adult abundance on turnip plants dropped significantly after the trap crop perimeter was

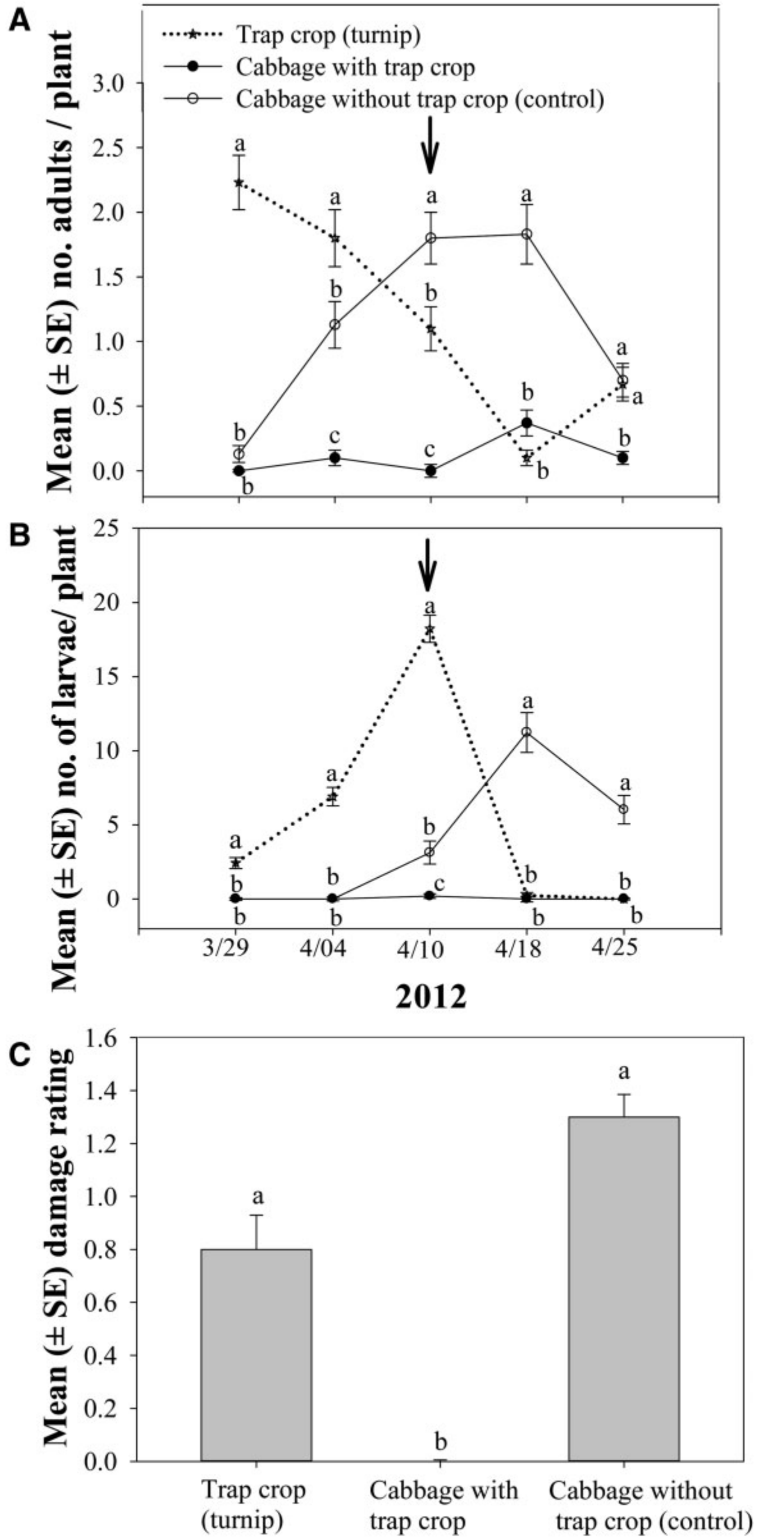

Fig. 1. Mean (±SE) number of *M. ochroloma* adults (A), Larvae (B), and Damage rating (C) in plots planted to turnip (trap crop) or to cabbage (cash crop) with or without the turnip trap crop in Alabama in Spring 2012. Means having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.005$). Arrow indicates the date trap crop sprayed with insecticide.

sprayed with insecticide on April 10, and the pest population remained low throughout the sampling period.

The number of larvae per plant in turnip trap crop increased rapidly and peaked on 10 April, dropped significantly after the trap crop was treated with insecticides, and remained low through the rest of the sampling period (Fig. 1B). The mean number of larvae on turnip (trap crop) was significantly greater than that on cabbage (main crop) and on the control on 29 March ($\chi^2 = 36.97$, df = 2, $P < 0.0001$), 4 April ($\chi^2 = 60.12$, df = 2, $P < 0.0001$), and 10 April ($\chi^2 = 61.99$, df = 2, $P < 0.0001$).

The reduced beetle numbers also resulted in significantly lower damage ratings on the cabbage crop (main crop) when they were protected by perimeter trap crop compared with the cabbage crop within the unprotected perimeter (control; $F \leq 52.13$, df = 2, 85, $P \geq 0.0001$; Fig. 1C).

In Fall 2012, mean adult abundance was significantly greater in the turnip trap crop than in cabbage (main crop) or in the control on 10 October ($\chi^2 = 3.89$, df = 2, $P < 0.0025$), 17 October ($\chi^2 = 7.05$, df = 2, $P < 0.002$), 31 October ($\chi^2 = 19.13$, df = 2, $P < 0.0001$), 7 November ($\chi^2 = 43.34$, df = 2, $P < 0.0001$), and 22 November ($\chi^2 = 3.76$, df = 2, $P < 0.0114$). There were eight times as many beetles in the trap crop (turnip) compared with control on 7 November (mean ± SE: trap crop, 3.23 ± 0.04; and control, 0.4 ± 0.14), indicating that turnip is an effective trap crop in attracting *M. ochroloma* and delaying their colonization on cabbage (Fig. 2A). Application of insecticide on the trap crop resulted in a rapid drop in adult numbers.

Similar trends were observed for larvae. The mean number of larvae per plant from 17 October to 7 November was significantly higher on turnip plants than that on cabbage in treatment and control plots (17 October, $\chi^2 = 24.3$, df = 2, $P < 0.0001$; 31 October, $\chi^2 = 50.18$, df = 2, $P < 0.0001$; 7 November, $\chi^2 = 56.22$, df = 2, $P < 0.0001$), but no significant differences were observed on either cabbage with or without trap crop ($P > 0.05$; Fig. 2B). At the harvest, cabbage damage ratings in the trap crop plots were not significantly different from those in the control ($P > 0.05$; Fig. 2C).

In Spring 2013, infestation of *M. ochroloma* adults in the turnip trap crop peaked at >2.5 adults per plant (Fig. 3A). Compared with cabbage, the mean number of adults on turnips in the perimeter of the treatment plot was significantly higher (2 April, $\chi^2 = 26.3$, df = 2, $P < 0.0001$; 9 April, $\chi^2 = 51.33$, df = 2, $P < 0.0001$; 16 April, $\chi^2 = 59.66$, df = 2, $P < 0.0001$). However, the density of beetles on cabbage in plots with trap crop did not differ significantly from the density on cabbage plots without a trap crop ($P > 0.05$; Fig. 3A). In this season, *M. ochroloma* larvae were not detected in the plots throughout the sampling period. Although data indicated no significant effect of perimeter trap crop on damage ratings of the main crop ($P > 0.05$; Fig. 3B), damage on the trap crop was significantly different from that on the control ($F \leq 43.89$, df = 2, 85, $P \geq 0.0001$).

With the exception of the cabbage butterfly (*Pieris rapae*) in Spring 2012, no other crucifer insect pests were noticed during the sampling period.

On-Farm Trials. *Spring 2012.* After the first two sampling weeks, consistently lower numbers of *M. ochroloma* were recorded from the cash crops bordered by the trap crop plots than from the cash crops alone plots (Fig. 4).

For adults, there were no significant time × replicate, time × treatment, time × crop, or time × treatment × crop interactions (all $F = 2.69$; df = 5, 30; $P < 0.07$). In addition, there was no treatment × crop interaction ($F = 0.15$; df = 1, 6; $P < 0.71$). Because none of the interactions were significant, main effects pooled over time are presented. There were significantly more adults ($F = 38.19$; df = 1, 6; $P < 0.0008$) in the cash crops alone plots (11.7 ± 5.8) than in the cash crops surrounded by trap crop plots (2.8 ± 0.6). There was no difference in the number of *M. ochroloma* between the cash crops (mustard: 10.3 ± 5.8, napa cabbage: 4.2 ± 0.8, $F = 2.01$; df = 1, 6; $P < 0.21$).

For larvae, there were no significant time × replicate, time × treatment, time × crop, or time × treatment × crop interactions, (all $F = 0.96$; df = 5, 30; $P < 0.42$). There was also no treatment × crop interaction ($F = 0.03$; df = 1, 6; $P < 0.88$). Because none of the interactions were significant, main effects pooled over time are presented. There were significantly more larvae ($F = 11.68$; df = 1, 6; $P < 0.01$) in the cash crops alone plots (2.8 ± 2.1) than in the cash crops surrounded by trap crop plots (1.7 ± 0.8). There was no difference in the number of larvae between the cash crops (mustard: 3.2 ± 1.6, napa cabbage: 1.6 ± 0.9, $F = 4.92$; df = 1, 6; $P < 0.07$).

With the harvest evaluation data (Fig. 4C), there was no significant treatment × crop interaction ($F = 0.1$; df = 1, 11; $P < 0.76$). The damage rating was significantly higher ($F = 32.46$; df = 1, 11; $P < 0.0005$) in the cash crops alone plots (3.8 ± 0.3) than in the cash crops surrounded by trap crop plots (2.3 ± 0.1). The damage rating was also higher ($F = 7.58$; df = 1, 11; $P < 0.025$) on mustard (3.4 ± 0.2) than on napa cabbage (2.7 ± 0.2).

Fall 2012. Low numbers of *M. ochroloma* were collected throughout the sampling period (Fig. 5). There were slightly higher numbers of *M. ochroloma* in the cash crops bordered by the trap crop plots. Also, low numbers of *M. ochroloma* were collected from turnip (Fig. 5).

For adults, there were no significant time × replicate, time × treatment, time × crop, or time × treatment × crop interactions (all $F = 1.43$, df = 3, 18; $P < 0.26$). There was also no treatment × crop interaction ($F = 0.07$; df = 1, 8; $P < 0.79$). Because none of the interactions were significant, main effects pooled over time are presented. There were significantly higher ($F = 29.49$; df = 1, 8; $P < 0.0006$) numbers of adults in the cash crops bordered by trap crop plots (0.47 ± 0.13) than in the cash crops alone plots (0.17 ± 0.07) and the turnip trap crop itself (0.06 ± 0.02). There was also a significant difference between the two cash crops ($F = 29.10$; df = 1, 8;

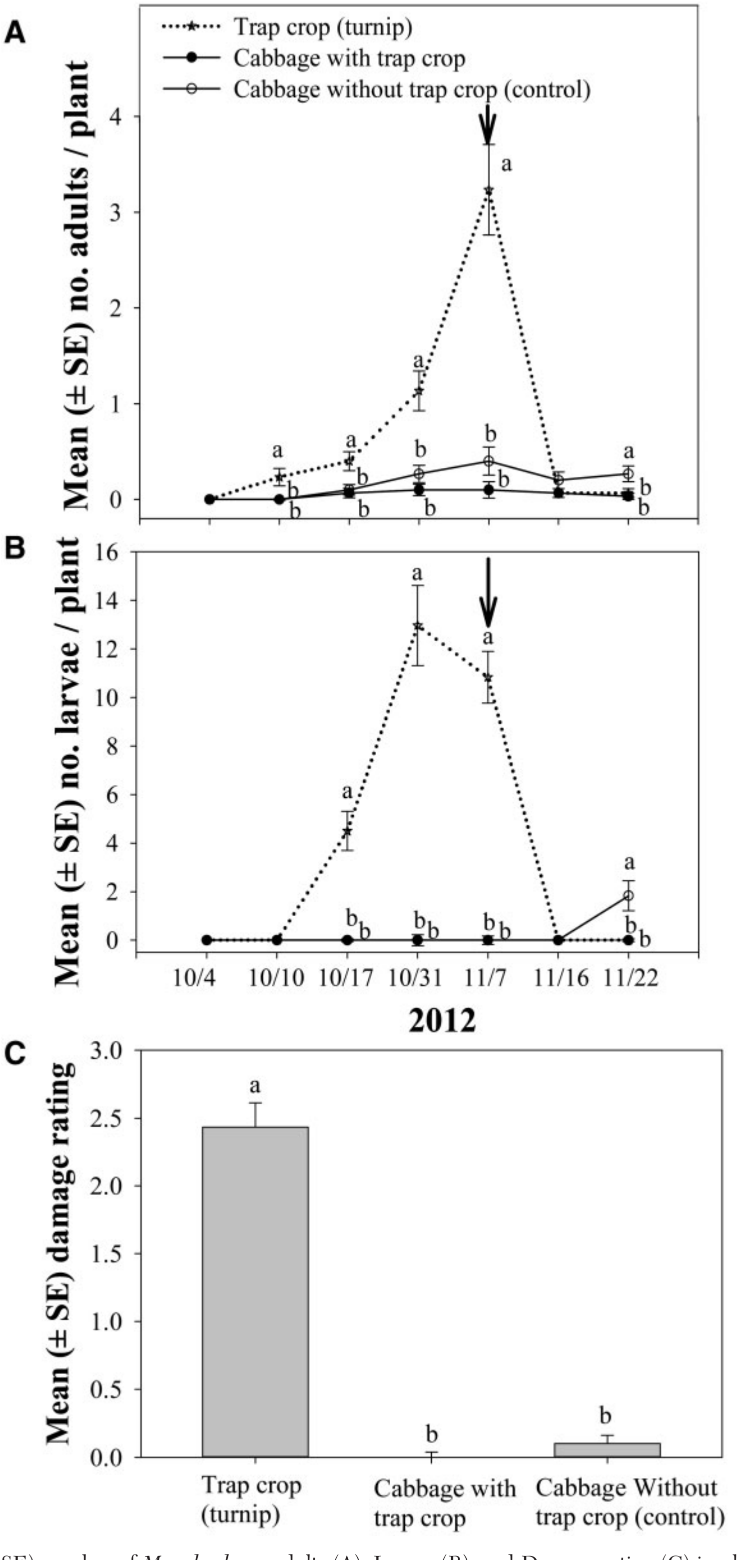

Fig. 2. Mean (±SE) number of *M. ochroloma* adults (A), Larvae (B), and Damage rating (C) in plots planted to turnip (trap crop) or to cabbage (cash crop) with or without the turnip trap crop in Alabama in Fall 2012. Means having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.005$). Arrow indicates the date the trap crop was sprayed with insecticide.

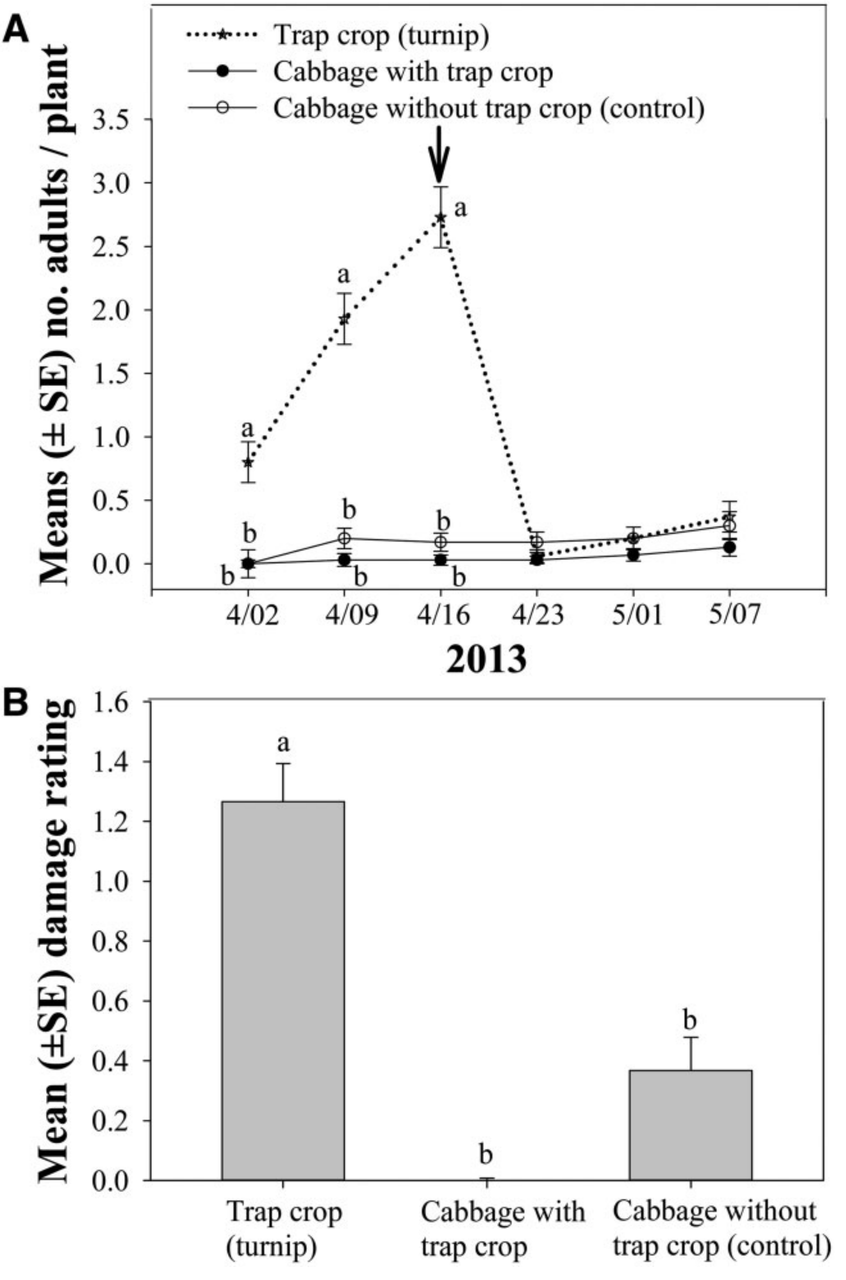

Fig. 3. Mean number of *M. ochroloma* adults (A), Larvae (B), and Damage rating (C) in plots planted to turnip (trap crop) or to cabbage (cash crop) with or without the turnip trap crop in Alabama in Fall 2013. Means having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.005$). Arrow indicates the date the trap crop was sprayed with insecticide.

$P < 0.0007$). There was an average of 0.13 ± 0.05 and 0.51 ± 0.13 adults per plant in the mustard and napa cabbage, respectively.

For larvae, there were no significant time × replicate, time × treatment, time × crop, or time × treatment × crop interactions (all $F = 2.58$, df = 3, 18; $P < 0.08$). There was also no treatment × crop interaction ($F = 0.30$; df = 1, 8; $P < 0.60$). Because none of the interactions were significant, main effects pooled over time are presented. There were significantly higher ($F = 13.61$; df = 1, 8; $P < 0.006$) numbers of larvae in the cash crops bordered by the trap crop plots (0.41 ± 0.12) than in the cash crop alone plots (0.08 ± 0.02). The turnip trap crop itself (0.15 ± 0.04) was not significantly different from other treatments. There was no significant difference between the two

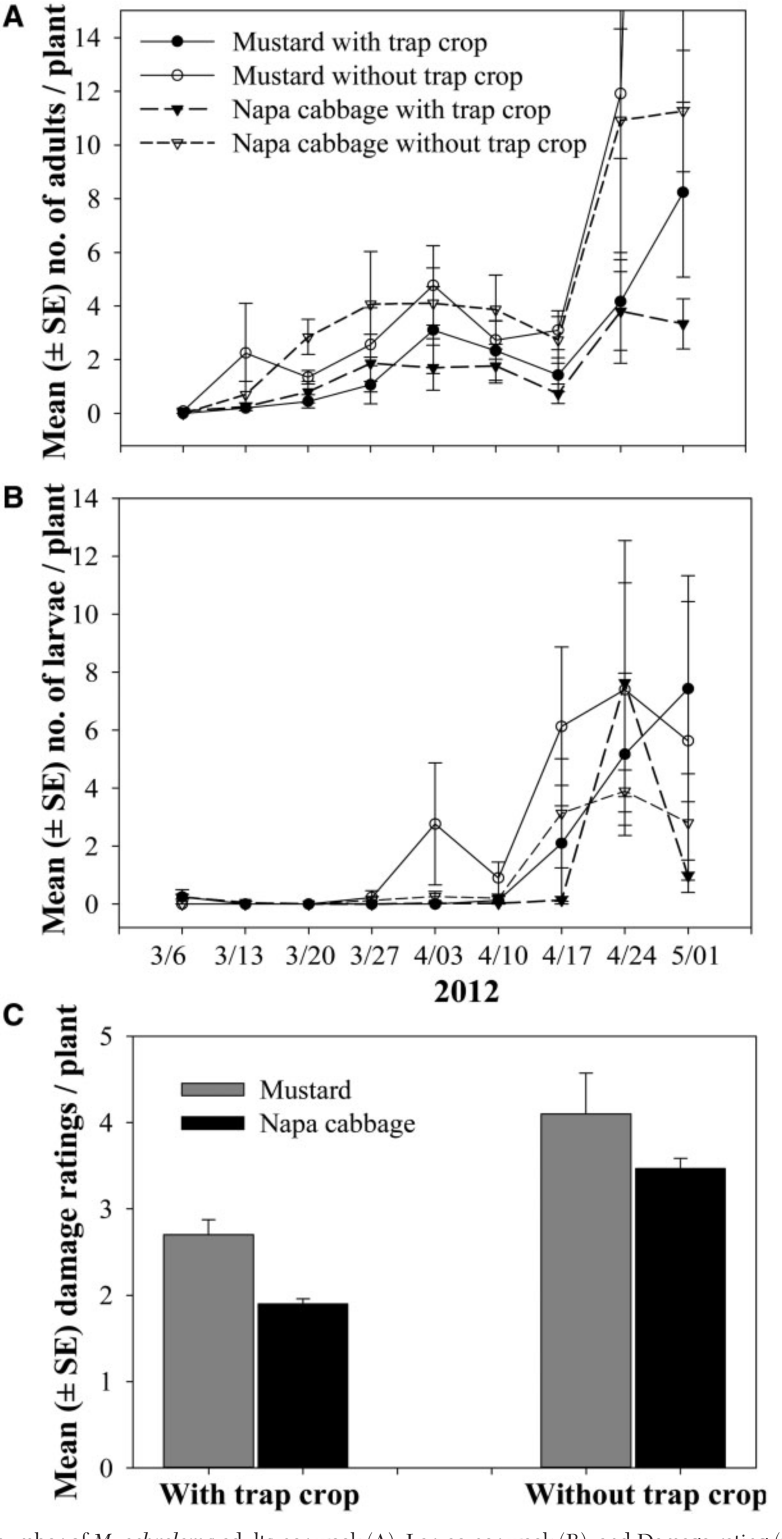

Fig. 4. Mean number of *M. ochroloma* adults per week (A), Larvae per week (B), and Damage rating (C) from plots with and without turnip planted as a trap crop from the Spring 2012 season of the on-farm trial. Error bars represent SEMs. No data were collected from the turnip trap crop itself, as it was sprayed weekly.

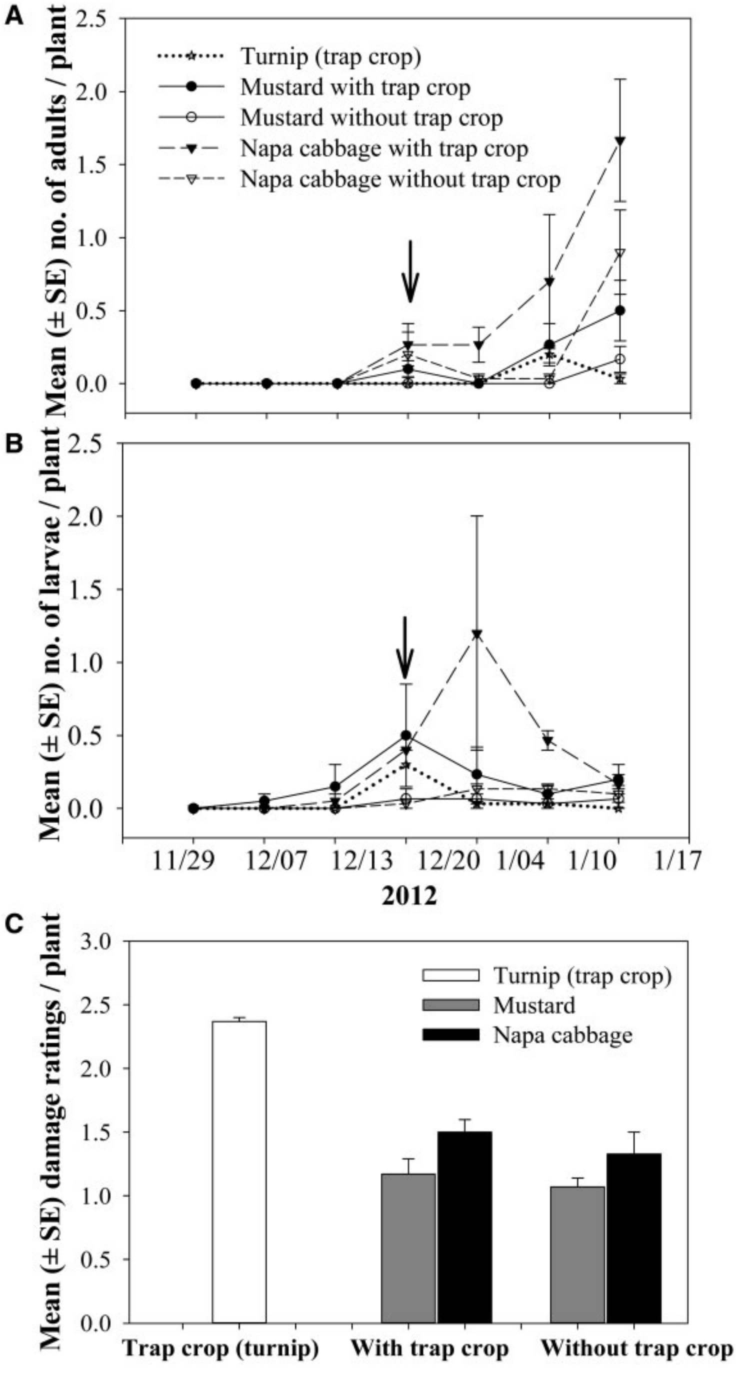

Fig. 5. Mean number of *M. ochroloma* adults per week (A), Larvae per week (B), and Damage rating (C) from plots with and without turnip planted as a trap crop and from the turnip trap crop itself from the Fall 2012 on-farm trial. Error bars represent SEMs. The arrow indicates the date the turnip trap crop was sprayed.

cash crops ($F = 4.82$; df = 1, 8; $P < 0.06$). There was an average of 0.16 ± 0.05 and 0.33 ± 0.11 larvae per plant in the mustard and napa cabbage, respectively.

With the harvest data (Fig. 5C), there was no significant treatment × crop interaction ($F = 0.10$; df = 1, 14; $P < 0.76$). There was a significantly higher damage rating ($F = 42.65$; df = 2, 14; $P < 0.0001$) in the turnip trap crop itself (2.4 ± 0.03) than in the cash crops alone plots (1.2 ± 0.1) and the cash crops bordered by the trap crop plots (1.3 ± 0.1), which were not significantly different from each other. The damage rating was significantly higher ($F = 7.79$; df = 1, 14; $P < 0.02$) in napa cabbage (1.4 ± 0.1) than in mustard (1.1 ± 0.1).

Discussion

The data from the research station trials, which showed significant reduction in insect densities and crop damage in cabbage plots bordered by turnip, indicate that the use of turnip as a trap crop is an effective control method for *M. ochroloma* when cabbage is the cash crop. Turnip is a much more preferred host plant than cabbage (Ameen and Story 1997b,c; Balusu and Fadamiro 2011). Therefore, the beetles are likely to stay in the turnip trap crop until the plants are defoliated and, or, the beetle population reaches a high enough level for beetles to begin to disperse. The replacement of defoliated turnip plants or application of Entrust prevented either of these scenarios from occurring.

Mustard and napa cabbage are also preferred by *M. ochroloma* over cabbage and collards (Ameen and Story 1997b,c; Balusu and Fadamiro 2011). Even so, the data from the spring 2012 on-farm trial showed a reduction in beetle numbers and crop damage in plots with turnip planted as a trap crop. Unfortunately, the reduction was not enough to prevent economic damage. The absence of turnip plants as a trap crop at the end of each cash crop row and the death of some of the turnip plants as a result of a late freeze likely contributed to these high numbers as did the small buffer zone between plots and the proximity to other *M. ochroloma* host plants being grown on the farm.

The Fall 2012 on-farm trial was an outlier. The beetle population was very low, and the slightly higher beetle population in the trap crop plots did not result in higher plant damage levels. It appears that *M. ochroloma* adults were moving from the trap crop into the cash crops probably because the trap crop was not sprayed often enough, as the beetle population remained low. It was often chilly on the sampling dates, which causes the *M. ochroloma* adults to stop moving and probably hide under foliage. The presence of beetle damage indicated that beetles were present even though no beetles were seen on the leaves. Clearly, the decision to spray the trap crop must be based on both beetle numbers and damage assessment.

The only time the number of beetles differed between the two cash crops in the on-farm trials was in the Fall 2012 season when there were more beetles recorded on napa cabbage than on mustard. This may have resulted from the chilly weather on the sampling dates. Inactive adult beetles were often found between the cabbage leaves, as the structure of the plant allowed them to rest there once the cabbage began to head. The structure of mustard leaves does not allow for this, probably resulting in less beetles being recorded from mustard. The higher number of beetles resulted in a higher damage rating in napa cabbage. In contrast, there was no difference in the beetle numbers between the two cash crops in the Spring 2012 on-farm trial season, and a higher damage level was recorded in mustard. Napa cabbage plants have a much higher density of leaves than mustard plants once they begin to head, which possibly caused the mustard plants to progress though the damage rating levels at a faster rate than the napa cabbage plants.

Shelton and Badenes-Perez (2006) defined conventional trap cropping as a practice of using more attractive host plants to attract pest to protect target (cash) crop from pest attack, by preventing the pests from reaching the cash crop and, or, concentrating the pest in the trap crop for economical management. The results of this study showed that turnip is more attractive to *M. ochrloma* than cabbage and may be used as a trap crop to effectively manage *M. ochroloma* in cabbage and other less attractive cruciferous crops. With crops, such as mustard and napa cabbage, that are equal in attraction to or only slightly less attractive than turnip, a border planting of turnip as a trap crop cannot be used as a stand-alone tactic to manage high beetle populations. Turnip has also been reported as an effective trap crop for managing other crucifer pests such as cabbage stem flea beetle [*Psylliodes chrysocephala* (L.)] (Barari et al. 2005), pollen beetle (*Meligethes* spp.; Cook et al. 2004), and cabbage seed weevil [*Ceutorhynchus obstrictus* (Marsham)] (Cook et al. 2004, Carcamo et al. 2007). Furthermore, brassica plants such as India mustard (*Brassica juncea* (L.)) (Luther et al. 1996), wild mustard (*Barbarea vulgaris* (L.)) (Shelton and Nault 2004), and collard (*Brassica oleracea*) (Mitchell et al. 2000) planted as perimeter trap crops were also shown to be effective in reducing damage by *Plutella xylostella* (L.) in cabbage crops. Plant odors, particularly isothiocyanates (derived from breakdown of glucosinolates—sulfur-containing compounds found in cruciferous vegetables), were shown to be responsible for attraction of *M. ochroloma* to turnip over other brassica plants (Balusu 2011).

In the Fall 2012 research station trials, although turnip was capable of intercepting *M. ochroloma* on the borders, the abundance of beetles (adults and larvae) in the cabbage field with the trap crop was not significantly different compared with that in the cabbage field without the trap crop (control). The orientation of the treatment and control plots with respect to the direction of the beetle migration seems to be responsible for this apparent lack of significant difference. In Fall 2012 and Spring 2013, the field was laid out in such a way that the source of beetles (previous season research plots) was closer to the treatment plots. Therefore, colonizing beetles encountered the treatment plots before the control plot, possibly allowing for the pest to be intercepted by the highly attractive trap crop border. However, the lower abundance of beetles on the cash crop in comparison with that on the trap crop indicated that it is possible to intercept and control adult *M. ochroloma* on the perimeter rows of the trap crop before they reach the centrally located cash crop. Furthermore, the results suggest that control of *M. ochroloma* at the initial stages of colonization can be achieved by planting an attractive trap crop along the field borders, and this may eliminate or reduce the need for insecticide application on the cash crop.

Trap cropping is a useful strategy that has great potential to control insect pests in various cropping systems. This strategy is even more important in organic systems where there are limited tools available for pest management. The present study demonstrated turnip as a potential perimeter trap crop for management of *M. ochroloma* in organic crucifer vegetable production systems. Trap cropping may eliminate the need for insecticide application in the main crop, thereby reducing the cost of pest control, selection pressure for resistance development, and impact on non-target beneficial organisms. Additional studies are needed to further evaluate trap cropping in combination with other tactics for managing high populations of *M. ochroloma* in commercial vegetable production systems.

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