The Great Lakes Entomologist

Volume 38
Numbers 1 & 2 - Spring/Summer 2005 *Numbers 1 & 2 - Spring/Summer 2005*

Article 1

April 2005

Impact of Simulated Insect Defoliation and Timing of Injury on Cabbage Yield in Minnesota

Eric C. Burkness
University of Minnesota

Gloria J. Gingera
University of Saskatchewan

W. D. Hutchison
University of Minnesota

IMPACT OF SIMULATED INSECT DEFOLIATION AND TIMING OF INJURY ON CABBAGE YIELD IN MINNESOTA

Eric C. Burkness[1], Gloria J. Gingera[2], and W. D. Hutchison[1, 3]

ABSTRACT

In 1992 and 1994, field studies were done to assess the tolerance of transplanted cabbage to simulated insect defoliation and to determine if the defoliation level and growth stage at which defoliation begins influences final yield. In both years, 6 defoliation levels ranging from 0-100% were applied to transplanted cabbage at 4 time intervals. The time intervals began at transplanting, pre-head and head stages and continued until either head stage or harvest. For both years, the only time interval with significantly higher yield than the transplant to harvest interval (longest interval) was the head to harvest interval (shortest interval) and significant yield loss occurred only when defoliation was >12.5%. Results suggest that transplanted cabbage can withstand relatively low levels of defoliation before yield loss occurs but that yield loss is also related to the duration over which defoliation occurs. In early growth stages, to protect yield, pest management practices should focus on reducing the interval over which damage occurs. The use of cultural practices that delay the onset of defoliation or allow avoidance of pests could protect yield. These strategies may include using transplants to shorten the time from planting to harvest or using planting dates that allow significant plant growth (i.e., head stage) before defoliators are able to infest the crop and cause significant damage. In addition, management strategies that reduce pest populations can also protect yield but at the head stage should switch to managing pests to protect marketability by reducing aesthetic damage and head contaminants.

The primary lepidopteran pests of cole crops are similar throughout the United States and Canada. Diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), imported cabbageworm, *Pieris rapae* (L.) (Lepidoptera: Pieridae), and cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae), have been reported as the most consistent lepidopteran pests on cabbage in Florida and Georgia (Workman et al. 1980), New York (Shelton et al. 1982), California (Wyman and Oatman 1977), Virginia (Kok and McAvoy, 1989), Minnesota (Cranshaw and Default 1982, Wold-Burkness et al. 2005) and in Ontario (Stewart et al. 1990).

To facilitate adoption of integrated pest management (IPM) programs for cole crops, action thresholds for the lepidopteran pest complex have been developed in North America. Threshold levels for lepidopteran pests on fresh market cabbage were initially developed in Florida (Greene 1972) at 0.1 cabbage looper larvae per plant with insecticide applications starting at the pre-cupping growth stage or whenever insects were first present. Shelton et al. (1982), in upstate New York, recommended 0.5 cabbage looper equivalents (CLE) per plant to ensure 95% of the crop without any head injury. The CLE method was useful for integrating the impact of each of the three lepidopteran pests, where 20 diamondback moth larvae and two imported cabbage worm larvae were found to be

[1]University of Minnesota, Department of Entomology, 1980 Folwell Ave., St. Paul, MN 55108-6125.
[2]University of Saskatchewan, Department of Plant Sciences, 51 Campus Drive, Saskatoon, SK S7N 5A8.
[3]Corresponding author: (email: hutch002@umn.edu).

equivalent to the damage of one cabbage looper larva. Both Chalfant et al. (1979) and Workman et al. (1980) suggested one to two initial feeding sites (new holes) per plant could be tolerated without a marketable loss in fresh market cabbage. A presence-absence threshold has been developed based on the presence or absence of any of the three pests (Shelton et al. 1983). This method is attractive because of considerable reductions in sampling costs. However, because of high crop value and potential for damage by any member of the pest complex, insecticides are often used on a weekly schedule. Presently, the primary problem with insecticide use is the loss of efficacy attributed to resistance by the diamondback moth. Liu et al. (1982) documented moderate resistance to four synthetic pyrethroids (permethrin, cypermethrin, decamethrin and fenvalerate) for one strain of diamondback moth in China, and a substantially greater resistance to the same pyrethroids by a second strain. More recently, Liu et al. (2003) discovered that populations of *P. xylostella* and *T. ni* from South Texas were less susceptible to indoxacarb and lambda-cyhalothrin than populations from Minnesota. Of equal concern are reports of resistance in *P. xylostella* to the bacterium, *Bacillus thuriengiensis* var. *kurstaki* in Hawaii (Tabashnik et al. 1990), and to synthetic insecticides in North America (Shelton et al. 1993). Because Minnesota growers continue to use more preventative spray schedules and we have had difficulty using the present threshold for *T. ni* (W. D. Hutchison unpublished data), we elected to conduct a pest injury study to simulate a broad range of defoliation levels.

Specifically, our objective was to determine the amount of leaf damage (percent defoliation) that transplanted cabbage could withstand during selected intervals from transplant through harvest before significant yield loss occurred under dryland production systems in southern Minnesota. Simulated insect damage was intended to simulate the effects of actual insect defoliation on the plant.

METHODS AND MATERIALS

Established seedlings (2-3 leaf stage) of a representative fresh market cabbage hybrid (Gourmet) were transplanted into a commercial production field in Apple Valley, Minnesota, 26 June 1992 and 3 May 1994. Plants were placed in single row plots, 8.4 meters in length with approximately 0.6 m between rows. Permethrin (Pounce 3.2EC, FMC Corporation, Philadelphia, PA) at 0.25 lb AI/hectare, methomyl (Lannate 1.8 L, E.I. duPont de Nemours and Company, Wilmington, DE) at 1.11 lb AI/hectare, and metasystox-R (Gowan Company, Yuma, AZ) at 1.24 lb AI/hectare were applied at 10 day intervals (4 total applications) to suppress aphid and lepidopteran feeding damage.

The experiment consisted of six defoliation levels applied at four different time intervals. The two-factor study was arranged as a split-plot design with defoliation timing as the main plot, split by defoliation levels; with each treatment replicated four times. Levels of defoliation were 0, 12.5, 25, 50, 75 and 100%. The four time intervals were: 1) transplant until heading; 2) transplant to harvest; 3) pre-heading (or cupping, 10-13 leaf stage) to harvest; and 4) heading to harvest. Pre-heading was defined as the period when the leaves were starting to cup or curl over to form heads, but a firm head was not yet present. Heading was defined when 90% of the plants in the control plots formed firm heads.

A "scissor" defoliation method similar to that of Stewart et al (1990) was used throughout the study. The midrib of the leaf was assumed to be the vertical line on the leaf that divided it into equal halves. An imaginary horizontal line was drawn to cut the leaf into quarter sections. Each quarter section was then assumed to equal 25% of the leaf area. In the 25% treatment, the top right hand quarter of the leaf was removed; for 50%, the top and bottom of the right hand side were removed; for 75%, the top and bottom quarters from the right hand side and the top quarter section of the left hand side of the leaf were removed. In the 12.5% defoliation level, one half of the top right hand quarter section of the leaf was removed; and for 100%, the top and bottom quarter sections of the right and left hand side of the leaf were removed. In each case, the midrib of the leaf was left intact. The first defoliation occurred 7 July, 1992, eleven days after transplanting in year one, and 16 May 1994, thirteen days after transplanting in year two. Subsequent defoliation dates are summarized in Table 1. Only new growth on each plant within each single-row plot was defoliated on each date. Previously defoliated leaves were not defoliated a second time.

Yield for each treatment was evaluated by harvesting each plot 9 September in 1992 and 13 and 14 July in 1994. Within each 8.4 m plot, two 3 m sections of row were harvested. The first 0.6 m were left standing, the next 3 m were harvested, 1.2 m were left standing, 3 m harvested, and last 0.6 m left standing. Each plant within each 3 m section was harvested with four wrapper leaves. Heads were then counted and bagged. Each bag was weighed using a digital field scale (Doran Scale Inc.). Final yield per plot was averaged for the two 3 meter sections, and adjusted to a constant 10 head per plot basis.

Data analysis. Yield data from the simulated insect defoliation experiments were analyzed for each year separately as split-plot designs with main (time) and nested (defoliation) factors. Means were separated using the Ryan-Einot-Gabriel-Welsch multiple range (REGWQ) test ($P = 0.05$) (SAS Institute 1995). Yield response-defoliation curves were fitted using non-linear regression (PROC NLIN, SAS Institute 1995) and a 3-parameter Weibull model (Hutchison and Campbell 1994, Burkness and Hutchison 1998):

$$y = a * EXP\,[-1 * (x / b)^{c}] \qquad x,a,b,c > 0 \tag{1}$$

where y = average loss in yield (kg), x = percent defoliation, a = maximum yield (y-intercept), b = scale parameter, and c = shape parameter. Parameter estimates for each timing treatment were compared using Welch's unpaired t (Oehlert 2000) with a Bonferroni adjustment for multiple comparisons. This analysis was used to create simultaneous 95% confidence intervals for differences in a, b and c parameter estimates between timing treatments. If the confidence interval between each pair wise combination included zero, parameter estimates were considered to not be significantly different with an error rate of 0.05 (Koch et al. 2003).

RESULTS AND DISCUSSION

In 1992, the time period of weekly defoliations for transplant to head encompassed 4 weeks (timing 1), the transplant to harvest covered 8 weeks (timing 2), pre-head to harvest continued for 6 weeks (timing 3) and head to harvest lasted 4 weeks (timing 4). In 1994, the time period over which weekly defoliations were done for transplant to head was 5 weeks (timing 1), transplant to harvest was 8 weeks (timing 2), pre-head to harvest was 5 weeks (timing 3) and head to harvest was 4 weeks (timing 4). In 1992 and 1994, both timing of defoliation and defoliation level were significant (Table 2). The interaction between timing of defoliation and defoliation level for mean yield was only significant in 1992 (Table 2). No significant yield loss occurred in either year when results from the 12.5% defoliation treatment were compared to 0% defoliation treatment (Table 3). Significant yield loss occurred at all defoliation levels greater than 12.5% when compared to the 0% defoliation level and defoliation levels higher than 12.5% were significantly different from each other (Table 3). In 1992 and 1994, the transplant to harvest interval (timing 2) had the lowest average yield and was significantly lower than the head to harvest interval (timing 4), which had the highest average yield in both years (Table 3).

In 1992 and 1994, all yield response curves for the different timing intervals had a similar shape (Figs. 1 and 2). Compared to the 0% defoliation treatment, for all timings in both years, significant yield loss did not occur until

Table 1. Defoliation event, timing and date of defoliation for simulated insect defoliation of 'Gourmet' cabbage, Apple Valley, MN 1992 and 1994.

	1992		1994	
Defoliation event	**Date**	**Timings Defoliated**[a]	**Date**	**Timings Defoliated**[a]
1	7/7	1 and 2	5/16	1 and 2
2	7/14	1 and 2	5/25	1 and 2
3	7/21	1, 2, and 3	5/31	1 and 2
4	8/6	1, 2, and 3	6/8	1, 2, and 3
5	8/13	2, 3, and 4	6/13	1, 2, and 3
6	8/20	2, 3, and 4	6/21	2, 3, and 4
7	8/27	2, 3, and 4	6/28	2, 3, and 4
8	9/1	2, 3, and 4	7/7	2, 3, and 4

[a] The four time periods were: 1) transplant to heading; 2) transplant to harvest; 3) pre-heading (or cupping, 10-13 leaf stage) to harvest; and 4) heading to harvest. Pre-heading was defined as the period when the leaves were starting to form heads, but a firm head was not yet present. Heading was defined when 90% of the plants in the control plots formed firm heads.

Table 2. Yield response of 'Gourmet' cabbage following simulated insect defoliation; Split plot ANOVA for 1992 and 1994, Apple Valley, MN.

Variables	**Degrees of freedom**	**Sums of squares**	**Mean squares**	***F*-value**	***P* > *F***
ANOVA (1992)					
time	3	31.45	10.48	3.62	0.0181
defoliation	5	2628.15	525.63	181.39	0.0001
time × rep	9	37.04	4.12	1.42	0.1999
time × defol.	15	172.96	11.53	3.98	0.0001
replicate	3	72.76	24.25	8.37	0.0001
ANOVA (1994)					
time	3	30.21	10.07	7.01	0.0004
defoliation	5	990.86	198.17	137.95	0.0001
time × rep	9	68.96	7.66	5.33	0.0001
time × defol.	15	28.57	1.90	1.33	0.2166
replicate	3	8.03	2.68	1.86	0.1458

Table 3. Simulated insect defoliation of cabbage: Yield response for defoliation level and timing of defoliation, Apple Valley, MN, 1992 and 1994.

Defoliation (%)	Mean (± SEM) yield/10 heads (kg) 1992	Mean (± SEM) yield/10 heads (kg) 1994	Timing of Defoliation	Mean (± SEM) yield/10 heads (kg) 1992	Mean (± SEM) yield/10 heads (kg) 1994
0	15.80 (± 0.5) a	10.61 (± 0.6) a	Transplant – Head	11.06 (± 1.1) ab	7.09 (± 0.7) ab
12.5	15.76 (± 0.7) a	9.68 (± 0.4) ab	Transplant – Harvest	10.00 (± 1.4) b	6.43 (± 0.8) b
25	13.58 (± 0.6) b	8.89 (± 0.3) b	Pre-head – Harvest	10.31 (± 1.3) ab	6.52 (± 0.8) b
50	11.33 (± 0.7) c	7.09 (± 0.3) c	Head – Harvest	11.43 (± 0.9) a	7.84 (± 0.6) a
75	6.21 (± 0.7) d	4.24 (± 0.4) d			
100	1.54 (± 0.4) e	1.45 (± 0.3) e			
$P > F$	0.0001	0.0001		0.0181	0.0004

Means within column followed by the same letter are not significantly different ($P = 0.05$); Ryan-Einot-Gabriel-Welsch multiple (REGWQ) range test.

25 or 50% defoliation. In 1992 and 1994 the transplant to head and head to harvest (Fig. 1a and d; Fig. 2a and d) intervals experienced a more gradual decline in yield as defoliation level increased than the transplant to harvest and pre-head to harvest (Fig. 1b and c; Fig. 2b and c) intervals. Higher yields in the head to harvest defoliation period could be explained by a shorter time interval of defoliation for the 3-4 week period vs. 8 weeks for the transplant to harvest interval. Despite the apparent differences in yield among timing treatments, the analysis of parameter estimates derived from the Weibull model (Table 4) indicated no differences in maximum yield (yield potential) between timing treatments. In addition, the rate of defoliation at which yield loss occurred was not significantly different between defoliation timings (Fig. 3a and b). This is further evidence that the growth stage where defoliation occurs does not influence yield loss, but rather the duration and therefore the cumulative amount of defoliation determines yield loss (Fig. 3a and b).

Previous experiments have been conducted which attempt to simulate the effects of feeding habits of various lepidopteran pests on cole crops. In Minnesota, Cranshaw and Default (1982) concluded that only total defoliation (100% defoliation with the midrib left intact) consistently affected head weights of broccoli plants. However, they also concluded that pre-heading insecticide treatments on broccoli may be eliminated since final yields ('Premium crop' and 'Southern Comet') were not affected by the loss of a significant (> 50%) amount of foliage. Wit (1985) found that for spring cabbage plants to show a 3% decrease in yield, they could tolerate 25% defoliation during the transplanting stage, but only 5% defoliation during the head stage. Shelton et al. (1990) determined that cabbage plants can tolerate some levels of continuous leaf feeding before and after head formation. Studies performed by Stewart et al. (1990) confirmed that cauliflower was able to withstand several defoliations of up to 36% leaf damage before a decrease in yield occurs. These studies all indicate that, in general, cole crops have the ability to compensate for defoliation events and in some cases may tolerate relatively high levels of defoliation.

The ability of cabbage to withstand up to 25% defoliation without significantly affecting yield may be explained by the large amount of leaf area (photosynthetic area) that accumulates early in the growth of the plant, and may create an excess of leaf area (Harris 1974). Yield loss is also affected by the time interval over which damage occurs. Wit (1985) found that for spring cabbage, the most consistent yield losses occurred when defoliation was initiated at transplanting and continued to harvest. The longer the damage period (i.e., transplant to harvest) the more likely a yield reduction will occur because overall defoliation levels per plant are likely to be higher. In 1992 and 1994, the head to harvest damage interval was 4 and 3 weeks, respectively, and resulted in the highest yields (Table 3). Conversely, the transplant to harvest interval was 8 weeks in both years. Therefore the goal of managing defoliating pests on cabbage is to reduce the damage interval which should reduce overall defoliation levels.

Yield loss in cabbage is a result of both the magnitude of defoliation and duration over which the defoliation occurs. Regardless of the growth stage at which defoliation is initiated the yield loss follows the same general trend as the amount of defoliation increases. Results suggest that cultural practices that delay the onset of defoliation or allow avoidance of pests could protect yield. These strategies may include using transplants to shorten the time from planting to harvest or using planting dates that allow significant plant growth (i.e., head stage) before defoliators are able to infest the crop and cause significant damage. In addition, management strategies that reduce pest populations can also protect yield. These strategies may include the use of insecticides or biological control measures. As Shelton et al. (1990) have concluded, cabbage may tolerate low levels of insect feeding before and after head formation without resulting yield loss. Therefore, reducing pest populations below levels that can

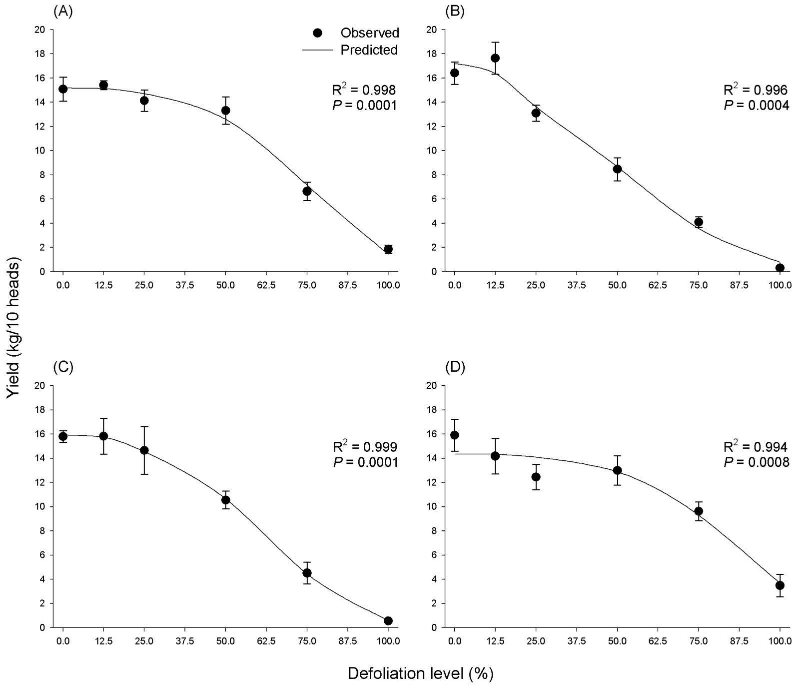

Figure 1. Yield response of simulated insect defoliation plots for timing interval 1-4 for 1992, Apple Valley, MN. Timing intervals were as follows: 1) transplant to heading (A), 2) transplant to harvest (B), 3) pre-heading (or cupping, 10-13 leaf stage) to harvest (C), and 4) heading to harvest (D). Non-linear regression was done using a 3-parameter Weibull function (equation 1, see text).

cause 12.5% defoliation should protect yield. For fresh-market cabbage, the need to protect the marketability of the head may require the use of insecticides. To minimize the presence of pests on or in the head at harvest (contaminants) and to reduce direct feeding on the head, the use of insecticides that provide a rapid decrease in the pest population may be necessary.

Our findings are similar to those of Shelton et al. (1982) where they proposed that insect levels may be allowed to increase prior to the heading stage without suffering a loss in yield or marketability of cabbage, but treatment must occur upon initiation of the head. This should allow pest populations to reproduce without the selection pressure of insecticides and delay the development of resistance. However, we also propose that pest management, based on treatment thresholds, is necessary in early growth stages (transplant to head) to reduce the interval over which damage occurs and preserve cabbage yield. Once the crop has reached the head stage, yield protection may not be the main consideration as the time between the head stage and harvest is too short for significant yield loss to occur under normal pest populations. At head stage, the primary concern becomes minimizing defoliation damage and pest presence (contaminants) to preserve the marketability of the cabbage head, especially for

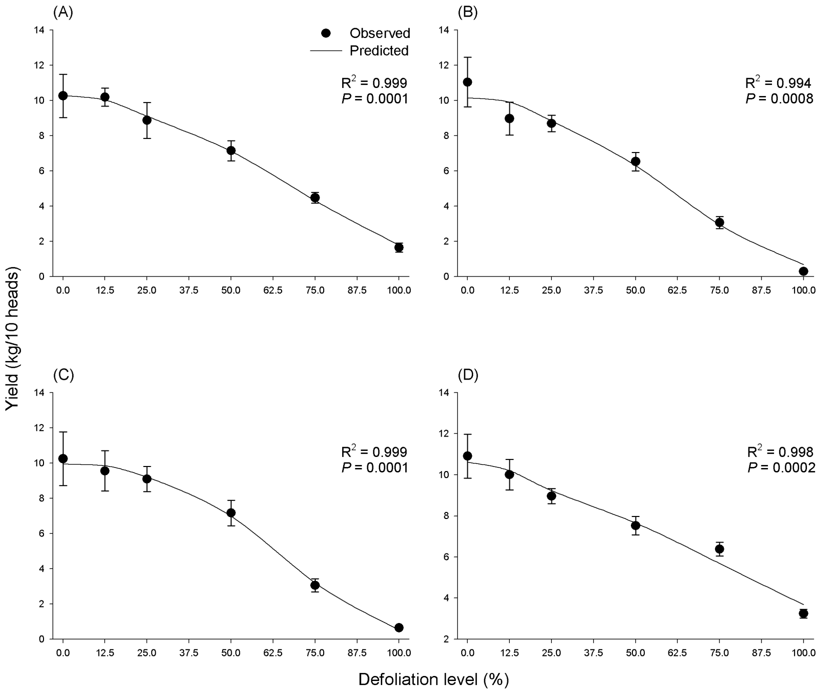

Figure 2. Yield response of simulated insect defoliation plots for timing interval 1-4 for 1994, Apple Valley, MN. Timing intervals were as follows: 1) transplant to heading (A), 2) transplant to harvest (B), 3) pre-heading (or cupping, 10-13 leaf stage) to harvest (C), and 4) heading to harvest (D). Non-linear regression was done using a 3-parameter Weibull function (equation 1, see text).

fresh-market sale. Again, the best way to maintain cabbage quality and minimize pest resistance to insecticides is through the use of treatment thresholds. Marketability ratings have been created for cabbage to indicate the salability of a cabbage crop (e.g., Greene et al. 1969; Hines and Hutchison 2001). With this information, growers and crop consultants should be able to tailor pest management recommendations that both preserve yield and marketability. In addition, knowledge of these relationships should instill more confidence in established thresholds (Shelton et al. 1983, Hines and Hutchison 2001) available for the North Central U.S.A.

ACKNOWLEDGEMENTS

Special appreciation is extended to Gary and Brian Pahl (Pahl's Farms) for allowing us to have access to a commercial production field for the study. We also thank Dave Bartels, Patricia Bolin, Andy Bowen, Charlie Demerjian, Mike Espinosa, Chad Fossey, Brad Granley, Patrick O'Rourke, Joseph Rinkleff, Tina Sonterre and Rob Trefz for technical assistance throughout the study.

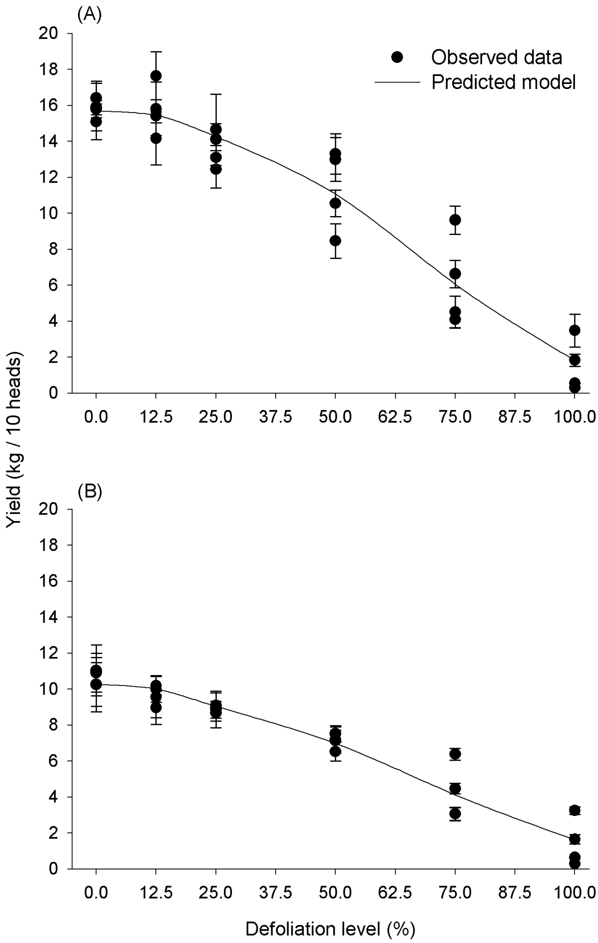

Figure 3. Yield response of simulated insect defoliation plots for the combined timing intervals in 1992 (A) and 1994 (B), Apple Valley, MN. Timing intervals that were combined for each year were as follows: 1) transplant to heading, 2) transplant to harvest, 3) pre-heading (or cupping, 10-13 leaf stage) to harvest, and 4) heading to harvest. Non-linear regression was done using a 3-parameter Weibull function (equation 1, see text).

Table 4. Parameters statistics for the Weibull model for yield loss response of cabbage to simulated insect defoliation at selected time intervals, 1992 and 1994, Apple Valley, MN.

Timing of Defoliation	***a*** **(± SEM)**[a]	***b*** **(± SEM)**[a]	***c*** **(± SEM)**[a]	***F***	r^2
1992					
Transplant – Head	15.17 (± 0.43) a	4.68 (± 0.11) a	6.26 (± 0.92) a	646.52*	0.998
Transplant – Harvest	17.26 (± 0.88) a	3.67 (± 0.20) a	3.71 (± 0.70) a	276.19*	0.996
Pre-head – Harvest	15.92 (± 0.09) a	4.17 (± 0.02) a	5.18 (± 0.14) a	17167.30*	0.999
Head – Harvest	14.35 (± 0.81) a	5.11 (± 0.24) a	6.28 (± 2.06) a	164.62*	0.994
1994					
Transplant – Head	10.28 (± 0.16) a	4.33 (± 0.07) a	3.84 (± 0.26) a	2793.91*	0.999
Transplant – Harvest	10.15 (± 0.62) a	4.04 (± 0.25) a	4.28 (± 1.08) a	169.90*	0.994
Pre-head – Harvest	9.94 (± 0.21) a	4.28 (± 0.08) a	5.24 (± 0.51) a	1322.49*	0.999
Head – Harvest	10.68 (± 0.50) a	4.61 (± 0.26) a	2.87 (± 0.63) a	452.25*	0.998

Means within a column followed by the same letter are not significantly different; 95% confidence intervals (constructed using Welch's unpaired t with a Bonferroni adjustment for multiple comparisons) for the difference in parameter estimates between treatments include zero.

[a] Curves were fit to the data using a 3-parameter Weibull model: $y = a * EXP\ [-1 * (x\ /\ b)^c]$; $x,a,b,c > 0$, where y = average loss in yield (kg), x = percent defoliation, a = maximum yield (y-intercept), b = scale parameter, and c = shape parameter.

*$P < 0.001$.

LITERATURE CITED

Burkness, E. C., and W. D. Hutchison. 1998. Action thresholds for striped cucumber beetle (Coleoptera: Chrysomelidae) on 'Carolina' cucumber. Crop Protection 17: 331-336.

Chalfant, R. B., W. H. Denton, D. J. Schuster, and R. B. Workman. 1979. Management of cabbage caterpillars in Florida and Georgia by using visual damage thresholds. J. Econ. Entomol. 72: 411-413.

Cranshaw, W. S., and R. J. Default. 1982. Effect of artificial defoliation on broccoli yield. Great Lakes Entomol. 18: 55-57.

Greene, G. L. 1972. Economic damage thresholds and spray interval for cabbage looper control on cabbage. J. Econ. Entomol. 65: 205-208.

Greene, G. L., W. G. Genung, R. B. Workman, and E. G. Kelsheimer. 1969. Cabbage looper control in Florida - a cooperative program. J. Econ. Entomol. 62: 798-800.

Harris, P. 1974. A possible explanation of plant yield increases following insect damage. Agro-Ecosystems. 1: 219-225.

Hines, R. L., and W. D. Hutchison. 2001. Evaluation of action thresholds and spinosad for Lepidopteran pest management in Minnesota cabbage. J. Econ. Entomol. 94: 190-196.

Hutchison, W. D., and C. D. Campbell. 1994. Economic impact of sugarbeet root aphid (Homoptera: Aphididae) on sugarbeet yield and quality in southern Minnesota. J. Econ. Entomol. 87: 465-475

Koch, R. L., W. D. Hutchison, and R. C. Venette. 2003. Survival of monarch butterfly, *Danus plexippus* (Nymphalidae), larvae on milkweed near Bt cornfields. J. Lepid. Soc. 57: 92-99.

Kok, L. T., and T. J. McAvoy. 1989. Fall broccoli pests and their parasites in Virginia. J. Entomol. Sci. 24: 258-265.

Liu, M. Y., Y. J. Tzeng, and C. N. Sun. 1982. Insecticide resistance in the diamondback moth. J. Econ. Entomol. 75: 153-155.

Liu, T. -X., W. D. Hutchison, W. Chen, and E. C. Burkness. 2003. Comparative susceptibilities of diamondback moth (Lepidoptera: Plutellidae) and cabbage looper (Lepidoptera: Noctuidae) from Minnesota and South Texas to λ-cyhalothrin and indoxacarb. J. Econ. Entomol. 96: 1230-1236.

Oehlert, G. W. 2000. A first course in design and analysis of experiments. W. H. Freeman and Company, New York. 659 pp.

SAS Institute. 1995. SAS/STAT User's Guide, Version 6. Fourth ed. SAS Institute Inc., Cary, NC.

Shelton, A. M., J. T. Andaloro, and J. Barnard. 1982. Effects of cabbage looper, imported cabbageworm, and diamondback moth on fresh market and processing cabbage. J. Econ. Entomol. 75: 742-745.

Shelton, A. M., M. K. Sears, J. A. Wyman, and T. C. Quick. 1983. Comparison of action thresholds for lepidopterous larvae on fresh-market cabbage. J. Econ. Entomol. 76: 196-199.

Shelton, A. M., C. W. Hoy, and P. B. Baker. 1990. Response of cabbage head weight to simulated Lepidoptera defoliation. Entomol. Exp. Appl. 54: 181-187.

Shelton, A. M., J. A. Wyman, N. L. Cushing, K. Apfelbeck, T. J. Dennehy, S. E. R. Mahr, and S. D. Eigenbrode. 1993. Insecticide resistance of diamondback moth (Lepidoptera: Plutellidae) in North America. J. Econ. Entomol. 86: 11-19.

Stewart, J. G., K. B. McRae, and M. K. Sears. 1990. Response of two cultivars of cauliflower to simulated insect defoliation. J. Econ. Entomol. 83: 1499-1505.

Tabashnik, B. E., N. L. Cushing, N. Finson, and M. W. H. Johnson. 1990. Field development of resistance to *Bacillus thuringiensis* in diamondback moth (Lepidoptera: Plutellidae). J. Econ. Entomol. 83: 1671-1676.

Wit, A. K. H. 1985. The relation between partial defoliation during the preheading stages of spring cabbage and yield, as a method to assess the quantitative damage induced by leaf-eating insects. J. Appl. Entomol. 100: 96-100.

Wold-Burkness, S. J., W. D. Hutchison, J. C. Lee, R .L. Hines, P. C. Bolin, and G. E. Heimpel. 2005. A long-term survey of parasitoid species composition and parasitism of *Trichoplusia ni* (Lepidoptera: Noctuidae), *Plutella xylostella* (Leipidoptera: Plutellidae), and *Pieris* (=*Artogeia*) *rapae* (Lepidoptera: Pieridae) in Minnesota cabbage. J. Entomol. Sci. 40: 211-221.

Workman, R. B., R. B. Chalfant, and D. J. Schuster. 1980. Management of the cabbage looper and diamondback moth on cabbage by using two damage thresholds and five insecticide treatments. J. Econ. Entomol. 73: 757-758.

Wyman, J. A., and E. R. Oatman. 1977. Yield responses in broccoli plantings sprayed with *Bacillus thuringienses* at various Lepidopterous larval density treatment levels. J. Econ. Entomol. 70: 821-824.