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Response of cabbage head weight to simulated Lepidoptera defoliation

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Abstract

Studies were conducted to determine the effects of continuous constant amounts of artificial defoliation through the preheading and heading growth stages on head weight of cabbage. High levels of continuous artificial defoliation caused a reduction in head weight in all three years of the study, but the highest yield was always attained at some low level of preheading or heading defoliation. These results demonstrate that cabbage is tolerant to some levels of continuous defoliation before and after head formation. Results from this study are incorporated into a cost-benefit analysis to estimate an economic threshold.

Introduction

In Upstate New York, ca. 20% of the 4200 ha of cabbage is under contract to private pest management consultants who recommend treatment decisions for the lepidopterous complex (*Plutella xylostella* (L.), *Artogeia rapae* (L.), and *Trichoplusia ni* (Hübner)) based on a sampling procedure (Hoy *et al.*, 1983) and thresholds. Action thresholds are based on larval units, an index that weighs each species in this complex based on its relative amount of foliage consumption (Shelton *et al.*, 1982 and Hoy *et al.*, 1986). These action thresholds were derived by comparing various treatment regimes against naturally occurring populations and evaluating marketability and weight at harvest. While these action thresholds were being used and evaluated in commercial acreage, the effect of simulated lepidopteran defoliation on cabbage head weight was being tested in research plots.

Although the damage standards to the head and wrapper leaves for fresh market and processing cabbage heads are different (Shelton *et al.*, 1982), head weight is an important factor for both and it is important to quantify the effect defoliation has on the harvested head weight, regardless of cosmetic injury to the head. Under the usual conditions in upstate New York, cabbage plants can be subjected to defoliation prior to head formation or during head formation (see Andaloro *et al.*, 1983 for growth stages). Early season defoliation may result in more severe yield loss than later season defoliation because it occurs on plants which have relatively little total foliage and the holes created by the larvae will become enlarged as the leaf expands, resulting in a greater proportion of the possible photosynthetic area removed than if the holes were created in fully expanded leaves. Preliminary observations by growers have indicated that this type of feeding may cause distortion of the leaves and delay plant maturation. All three species may chew holes in leaves and, due to overlap in generations and different time of infestations of the three species, this defoliation can be fairly continuous.

Previous reports have investigated the effects of reducing photosynthetic area on the growth rate and yield of cabbage plants. Samson & Geier (1983) found that the growth rate of cabbages depended largely on their photosynthetic area, which continually increases during early development but remains constant later. Additionally, they tested the effects of both single and multiple infestations of *A. rapae* on final head weight and found that, generally, yields fell in direct proportion to increases in pest density for single infestations, but for multiple infestations, previous damage exacerbated the effect of subsequent damage levels. In another trial, Wit (1985) determined the effects of four different defoliation levels applied at a single time on preheading cabbage and found that sensitivity to defoliation increased during the period from transplanting to head-formation. While these previous studies serve as guidelines to pest control decisions, there are enough regional differences in our area in cabbage growing conditions (mainly edaphic and climatic, and regional and temporal differences in the pattern of defoliation by lepidopteran pests) to necessitate further work.

This study was done to examine the effects of simulated defoliation on cabbage head weight. This relationship of head weight and defoliation is then linked to a cost-benefit analysis to estimate an economic threshold.

Materials and methods

Experiments were conducted in 1980, 1981, and 1982 on the Robbins Vegetable Research Farm near Geneva, NY where cabbage was transplanted on 16, 2, and 7 July, respectively. A single planting (20 rows with 20 plants per row) of cabbage, cv. 'Roundup', was made each year. Rows were spaced 0.9 m apart, with plant spacing of 41 cm. The middle 16 plants from each of the middle 12 rows in the planting were used as the experimental units in a randomized complete block design.

We simulated infestations of lepidopteran pests by defoliating cabbage plants artificially in a factorial experiment with four levels of defoliation occurring continuously during two periods of crop development. The defoliation levels were 0, 2, 5, and 10 holes removed weekly with a 4 cm diameter cork borer throughout the specified period (total amount of foliage per plant removed per week was 0, 25.1, 62.8, and 125.7 cm^2, respectively). The holes were made in a spatial pattern which, based on our experience, simulated the pattern of feeding by these pests on the plant, i.e., the most holes were removed from the middle and upper frame leaves. The two periods during which this defoliation took place were preheading and heading, with head initiation defined as the presence of a ca. 7 cm diameter firm ball of leaves at the center of the plant (29, 17, and 20 August respectively in the three years of the study).

To prevent additional defoliation by insects, the entire planting was sprayed on a fortnightly basis with permethrin. When plants were mature,

Table 1. Average weight of cabbage heads in plots treated with varying levels of preheading and heading artificial defoliation

Preheading defoliation (cm^2)	Heading defoliation (cm^2)	Yield (kg/head)		
		1980	1981	1982
0	0	4.61	3.41	4.03
0	25	4.80	3.14	4.29
0	63	4.19	3.29	3.80
0	126	3.26	2.63	2.93
25	0	4.36	3.57	4.13
25	25	4.55	3.30	4.40
25	63	4.52	3.52	2.79
25	126	3.50	2.50	3.02
63	0	4.14	2.87	3.93
63	25	4.39	2.77	3.96
63	63	2.71	2.49	2.79
63	126	1.86	1.87	2.25
126	0	3.17	2.32	3.19
126	25	3.55	2.55	3.07
126	63	1.96	1.98	2.60
126	126	2.27	1.66	1.98

they were evaluated for their response to these artificial defoliation levels on 20, 1, and 8 October for the three years, respectively. Each head, together with its four surrounding loose wrapper leaves, was weighed individually. These data were subjected to analysis of variance, with polynomial contrasts made for linear, quadratic, and cubic effects of defoliation during each period and for the interactions between periods.

Results and discussion

Although yield varied from year to year, high levels of weekly defoliation consistently reduced the average weight of cabbage heads (Table 1). Results of the analysis of variance indicate significant effects of defoliation in each defoliation period for each year (Table 2). In addition, the interaction between defoliation periods was significant for 1980 and 1982, indicating that the effects of heading defoliation are different for different levels of preheading defoliation, and vice versa. In every case except preheading defoliation in 1982, the relationship of defoliation to head weight was nonlinear, indicated by the significance of the quadratic or cubic contrasts. The significance of the cubic function indicates that little differences in yield occur between low levels of defoliation, larger differences between moderate levels, and little differences between high levels.

Between year differences, probably due to climatic conditions, were evident in the yield response to artificial defoliation. The qualitative response to continuous artificial defoliation was similar over the three years of this study with little reduction in yield at low levels of defoliation and a decline at moderate to high levels (Fig. 1). However, quantitative differences were evident between the three years of the study, both in maximum head weight and head weight at given levels of defoliation.

In each of the three years of the continuous defoliation study, the maximum observed yield was at some low to moderate level of preheading or heading defoliation, or both, rather than with no defoliation throughout. Although this phenomenon was consistent throughout the study, we do not feel justified in claiming an overcompensatory

Table 2. Analysis of variance statistics for cabbage head weight predicted by weekly levels of preheading and heading defoliation during 1980–1982 in Geneva, NY. Significant variance ratios for the interaction term indicates that the effect of heading defoliation depends on the amount of preheading defoliation, and vice versa. Significant variance ratios for linear effects indicate that a trend is present (defoliation reduces head weight); significance in the quadratic and/or cubic terms indicates that the effects are not linear (tolerance or overcompensation)

Source of variation	degrees of freedom	1980		1981		1982	
		Sum of squares	Variance ratio	Sum of squares	Variance ratio	Sum of squares	Variance ratio
Preheading defoliation	3	78.07	93.79**	38.78	39.73**	31.03	22.09**
Linear effect	1	72.26	260.42**	34.60	106.38**	31.00	66.19**
Quadratic effect	1	0.21	0.76	0.013	0.04	0	0
Cubic effect	1	5.60	20.19**	4.16	12.79**	0.03	0.07
Heading defoliation	3	75.83	91.10**	22.44	22.99**	63.83	45.43**
Linear effect	1	66.46	239.51**	20.99	64.52**	56.89	121.47**
Quadratic effect	1	0.35	1.25	1.34	4.12*	0.08	0.17
Cubic effect	1	9.02	32.51**	0.11	0.34	6.86	14.64**
Pre x Head Interaction	9	21.85	8.75**	3.35	1.15	8.68	2.06*
Residual	165	45.78		53.67		77.28	

** Significant at $P \leq 0.01$.
* Significant at $P \leq 0.05$.

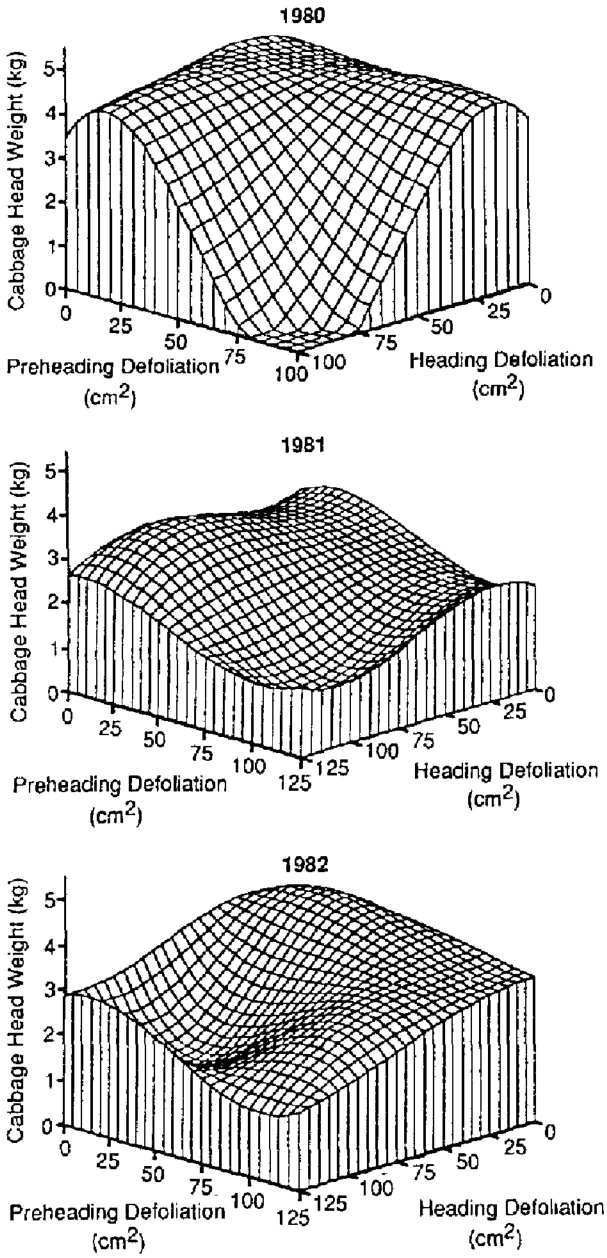

Fig. 1. Cabbage head weight predicted by weekly area of defoliation during the preheading and heading periods in Geneva, NY, 1980–1982. Predictions are based on the polynomial regression including linear, quadratic, cubic and all interaction terms for preheading and heading leaf area removed.

response to defoliation in cabbage, because the difference between these maximum observed mean yields and observed mean yield at 0 defoliation preheading and heading is of the same magnitude as the standard error of the differences between these means. However, these results are contrary to the notion, still held by many of the growers in our area, that any defoliation will reduce yield. Even if the defoliation occurs weekly, we have shown that yield will not suffer at some defoliation levels in our area.

This result conflicts with some of the previously published work on effects of defoliation in cabbage, which suggested a linear decrease in yield with increasing defoliation (Straka, 1979; Samson & Geier, 1983; Wit, 1985). However, our data agree with results of Samson & Geier (1983) who found that multiple infestations, which our studies imitated, led to a greater decrease in yield than would be expected from the sum of losses due to single infestations. Important differences between this study and previous studies are the defoliation regimes used, the different location in which the study took place, and the special type of cabbage (spring cabbage with a short growing period) which was used by Wit (1985). The difference in response of head weight to defoliation between this study and the others could be due to any of these factors.

Despite the likelihood that the response in yield to these levels of defoliation will be different each year due to different growing conditions, we may be able to gain some insight into the amount of defoliation the cabbage will usually withstand without loss of head weight. Using the polynomial regression coefficients for preheading and heading defoliation levels, the full model with linear, quadratic, cubic, and all interaction terms, gives the plots of predicted yield as a function of preheading and heading defoliation in Figure 1. We can calculate the decrease in yield that would be equal in value to a given control strategy by the following formula, based on the approximate stand density and price of processing cabbage in New York:

$$\text{yield loss (kg/plant)} = \frac{\text{control cost (\$/ha)}}{\underset{(24{,}700\ \text{plants/ha})}{\text{plant density}} \times \underset{(\$0.033069/\text{kg})}{\text{price of product}}}$$

If we assume the average number of insecticide applications is four, and the total cost of these applications is $74.10 per ha, including application cost (approximate cost of four applications of permethrin plus labor costs), then we can estimate the yield loss necessary to justify the cost of these sprays as 0.0907 kg per plant. By subtracting this amount from the maximum yield attained each year we can solve for the amount of defoliation necessary to cause this loss using our regression equations. The amount of heading defoliation that would result in a given yield loss depends on the

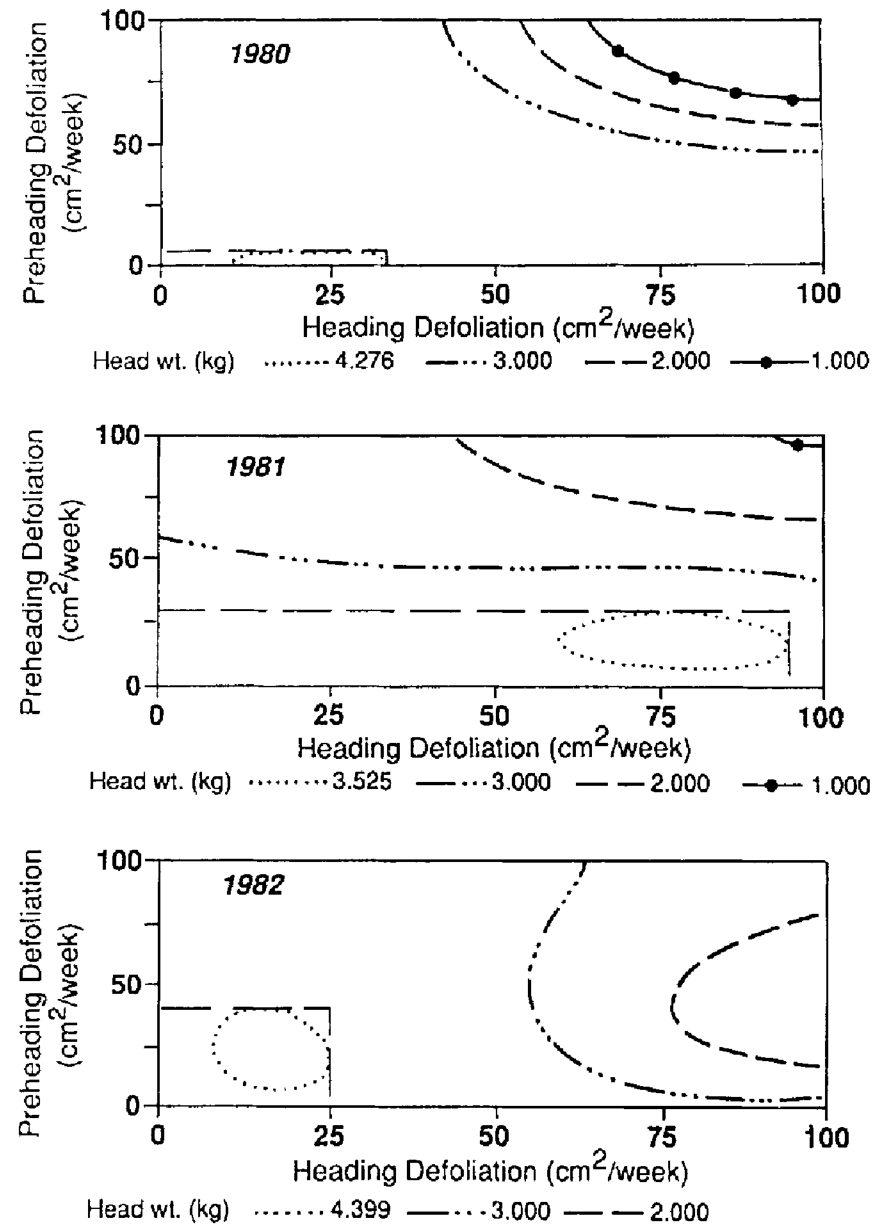

Fig. 2. Contour plots of cabbage head weight predicted by preheading and heading defoliation in Geneva, NY, 1980–1982. Head weights of 4.726 kg per head in 1980, 3.525 in 1981, and 4.399 in 1982, represent losses from the maximum yield in each year that are approximately equivalent in value to four applications of permethrin. Defoliation levels that result in each of these losses (identified by the boxes on each plot) give approximate economic thresholds after conversion to larval units (see text). The area inside the boxes in each plot identifies the amount of defoliation that does not result in enough yield loss to justify four applications of permethrin. Contour lines for yields of 1, 2 and 3 lbs/head are provided as points of reference only.

amount of preheading defoliation already incurred, and vice versa. Thus, the amount of defoliation that would justify the control strategy described above is a contour of the response surfaces in Figure 1. These contours are plotted in Figure 2, and can be used to define the amount of defoliation necessary to justify the control strategy: for 1980, 6 cm^2/week preheading and 34 cm^2/week heading; for 1981, 29 cm^2/week preheading and 95 cm^2/week heading; for 1982, 39 cm^2/week preheading and 25 cm^2/week heading.

Although the amount of preheading defoliation (6–39 cm^2) and heading defoliation (25–95 cm^2) per week varies between years, a three year average would indicate that pest populations must cause approximately 25 cm^2 preheading defoliation per week, but sometimes less, and approximately 25 cm^2 heading defoliation per week, but sometimes more, before the control strategy described above would be economically justified to reduce defoliation levels. The exact amount will depend on the growing conditions present. This amount of defoliation would be caused in one week at typical summer temperatures (20 °C) by an average population density of approximately 0.5 late instar *T. ni* larvae per plant, or 0.5 larval units per plant, feeding daily for seven days. Thus, in the hypothetical case where the same number of larval units occur on the plant over time under specific growing conditions, we have an approximate economic threshold, although our weekly defoliation regime still only approximates the continuous feeding senario. Often, however, larval units per plant vary from week to week, and the population density may exceed this level only occasionally, making the pattern of defoliation over time more complex. The results given in the present study would be most applicable to situations where pest population densities increase slowly and control measures are not completely effective in eliminating the pests, resulting in relatively constant amounts of defoliation over time, and when populations of the different species overlap in time. The approximate economic threshold under these conditions is considerably lower than the existing action thresholds for processing cabbage at these growth stages (Hoy *et al.*, 1986). Thus, the study provides an important insight to adjustments that must be made to action thresholds for cabbage pests when defoliation is continuous rather than during occasional brief episodes.

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Résumé

Effet de la défoliation (réelle ou simulée) par des lépidoptères sur le poids des pommes de choux

L'étude a porté sur le poids des pommes de choux (Brassica oleracea) soumis à différentes intensités de défoliations répétées avant et pendant la formation des pommes. Pendant les trois années de l'étude, huit intensités de défoliation continue ont réduit le poids des pommes, mais le poids le plus élevé a toujours été obtenu avec une faible défoliation avant et pendant la formation des pommes. Ceci montre que le chou tolère une certaine défoliation avant et pendant la formation des pommes. Les résultats de cette étude ont été utilisés dans une analyse coût-bénéfice pour estimer le seuil économique de défoliation.

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