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Impact of initial densities of the convergent lady beetle on tobacco aphid populations in tobacco

(Kesan kepadatan awal kumbang pemangsa coccinellida terhadap populasi kutu daun tembakau pada pokok tembakau)

H. Mohd. Norowi* and P. J. Semtner**

Key words : *Hippodamia convergens, Myzus nicotianae,* tobacco, initial ratio, field cages, population dynamics

Abstrak

Kesan nisbah awal populasi kumbang pemangsa coccinellida (KPC), *Hippodamia convergens* Guerin-Meneville, dan populasi kutu daun tembakau (KDT), *Myzus nicotianae* Blackman terhadap perkembangan populasi KPC dan populasi KDT serta hasil tembakau awet panas telah dikaji. Kajian ini dijalankan dengan mewujudkan beberapa nisbah awal populasi KPC:KDT (1:25, 1:50, 1:100, 1:200, and 1:300) pada pokok tembakau awet panas yang ditanam di dalam beberapa sangkar yang dibina khas di ladang. Nisbah-nisbah awal yang digunakan telah dibandingkan dengan tembakau yang tidak dikawal daripada serangan KDT dan tembakau yang di serang oleh KDT tetapi tidak mempunyai populasi KDT.

KPC dapat mengurangkan perkembangan populasi KDT terutama pada awal musim (sebelum hari yang ke-40 populasi KDT dilepaskan). Nisbah-nisbah awal ini tidak mempengaruhi kadar bertelur KPC, tetapi pada kadar yang rendah, iaitu 1:300 dalam tahun 1985 dan 1:200 dalam tahun 1986, berkemungkinan dapat memendekkan jangkamasa pembentukan KPC. KPC dapat mengurangkan kerosakan ekonomi yang disebabkan oleh KDT pada beberapa nisbah, tetapi kadar pengawalannya tidak memadai. Kesan-kesan pemasangan sangkar pada perkembangan populasi KDT dan pertumbuhan pokok tembakau juga dibincangkan.

Abstract

Field cage studies were conducted to determine the impact of various initial ratios of the convergent lady beetle (CLB), *Hippodamia convergens* Guerin-Meneville, to tobacco aphid (TA), *Myzus nicotianae* Blackman, on CLB and TA populations and cured leaf yield in flue-cured tobacco. Initial ratios of CLB:TA (1:25, 1:50, 1:100, 1:200 and 1:300) were established on the flue-cured tobacco confined under field cages. The initial CLB:TA ratios were compared to uninfested tobacco and tobacco infested with TA but with CLB excluded.

CLB suppressed TA population development, especially during the first 40 days after TA became established. The initial CLB:TA ratios did not influence the ovipositional rate of CLB, but the lower ratio of 1:300 in 1985 and 1:200 in

*Basic Research Division, MARDI, P.O. Box 12301, 50774 Kuala Lumpur, Malaysia
**Virginia Polytechnic Institute and State University Southern Piedmont Agric. Expt. Station, P.O. Box 448, Blackstone, Virginia 23824, U.S.A.
Authors' full names : Mohd. Norowi Hamid and Paul J. Semtner

1986 may have shortened the development period for CLB. CLB reduced the economic damage caused by TA at some ratios, but control was inadequate at all ratios. The effect of cages on TA population development and tobacco growth are discussed.

Introduction

The tobacco aphid (TA) *Myzus nicotianae* Blackman, was described as separate tobacco-feeding species closely related to green peach aphid, *M. persicae* (Sulzer) (Blackman 1987). The convergent lady beetle (CLB), *Hippodamia convergens* Guerin-Meneville, is a common predator of TA, on tobacco (Kulash 1949). Its seasonal abundance is closely synchronized with TA populations (Mohd. Norowi 1987). However, CLB alone cannot keep TA populations below the economic injury level on tobacco. In sorghum fields, two main factors limiting CLB effectiveness in regulating greenbug [*Schizaphis graminum* (Rondani)] population are its late arrival into the fields and its highly mobile behavior (Anon. 1975). It is important to determine whether these factors limit the success of CLB in regulating TA populations on tobacco. Hence, the predation rates of CLB on TA populations on tobacco were examined when these two factors were eliminated.

Cages have been used to investigate the predator/prey relationships in the field (Hodek et al. 1965; van den Bosch et al. 1969; Richman et al. 1980; Abdul-Sattar and Watson 1982; Reed et al. 1984). However, the disadvantage of using field cages is that they alter several environmental conditions such as temperature and humidity (Fye et al. 1969). The predator/prey relationship may also be affected because immigration and emigration are prevented.

This study was conducted to determine the influence of CLB on the population dynamics of TA on tobacco. The impact of CLB to TA initial ratios on the development of TA and CLB populations on flue-cured tobacco grown in field cages was assessed. The impact of the initial ratios on tobacco yield parameters was also evaluated.

Materials and methods

The study was conducted at the Virginia Polytechnic Institute and State University, Southern Piedmont Agricultural Experiment Station, Blackstone, Virginia in 1985 and 1986. Experimental plots consisted of six flue-cured tobacco plants (cv. Coker 319, two rows of three plants spaced at 51 cm apart and 122 cm between rows), grown in 1.8 m x 1.8 m x 1.8 m cages covered with saran screen (32 x 32 mesh) (Chicopee, Gainesville, Georgia). In 1985, the tobacco plants were transplanted on 2 May and caged 60 days (1 July) later. In 1986, the tobacco plants were transplanted on 16 May and caged 38 days (24 June) later. Standard practices of tobacco production in Virginia were followed (Jones 1985), but no chemical sucker control was applied after topping (removal of plant terminal bud). The caged plots were arranged in randomized complete block design containing six initial ratios of CLB:TA and a control with four replications. In 1985, the treatments were (A) no CLB or TA present (control to determine cage effect), (B) 1 CLB:50 TA, (C) 1 CLB:100 TA, (D) 1 CLB:200 TA, (E) 1 CLB:300 TA, and (F) TA alone (control for CLB effect). These initial ratios were selected based on the investigation of lady beetle predation on sugar beet aphid by Hodek et al. (1965). They found that at the initial ratio of 1:50 (lady beetle to aphid), the lady beetle could suppress aphid population to subeconomic level. In 1986, the CLB:TA ratios were changed to (B) 1:25, (C) 1:50, (D) 1:100, and (E) 1:200; treatment A and F were the same as those in 1985. The highest initial ratio (1:50) was changed to 1:25 (CLB to TA) as the results of the preliminary analysis of 1985 showed that ratio 1:50 could not prevent economic damage caused by TA on tobacco.

Table 1. Initial numbers of tobacco aphid and convergent lady beetle released into each cage, Blackstone, Virginia, 1985-1986

		1985			1986		
Cage no.	Treatment	Initial* CLB:TA ratio	No. of CLB released	No. of TA released	Initial* CLB:TA ratio	No. of CLB released	No. of TA released
1	F	TA only	0	4 715	TA only	0	2 100
2	A	No CLB, or TA	0	0	No CLB, or TA	0	0
3	D	1:200 (1:195.33)	30	5 860	1:100 (1:118.00)	3	53 540
4	B	1:50 (1:50.73)	55	2 790	1:25 (24.67)	52	1 283
5	C	1:100 (1:100.00)	31	3 100	1:50 (49.58)	19	942
6	E	1:300 (1:296.16)	16	4 738	1:200 (203.75)	20	4 075
7	D	1:200 (1:194.25)	8	1 554	1:100 (1:97.69)	13	1 270
8	B	1:50 (1:49.95)	38	1 898	1:25(1:24.95)	151	3 768
9	C	1:100 (1:99.38)	26	2 584	1:50 (1:49.44)	9	445
10	F	TA only	0	2 118	TA only	0	1 950
11	E	1:300 (1:319.40)	10	3 194	1:200 (1:199.36)	16	3 190
12	A	No CLB,or TA	0	0	No CLB, or TA	0	0
13	B	1:50 (50.42)	60	3 025	1:25 (1:24.00)	21	504
14	E	1:300 (1:300.00)	25	7 500	1:200 (1:181.43)	7	1 270
15	F	TA only	0	2 780	TA only	0	2 800
16	D	1:200 (1:195.00)	20	3 900	1:100 (1:97.81)	32	3 130
17	A	No CLB, or TA	0	0	No CLB, or TA	0	0
18	C	1:100 (1:98.21)	28	2 750	1:50 (1:49.11)	28	1 375
19	C	1:100 (1:98.48)	46	4 530	1:50 (1:49.58)	12	595
20	D	1:200 (1:199.23)	13	2 590	1:100 (98.64)	22	2 170
21	A	No CLB, or TA	0	0	No CLB, or TA	0	0
22	E	1:300 (1:295.00)	18	5 310	1:200 (1:197.62)	21	4 150
23	B	1:50 (1:50.36)	42	2 115	1:25 (1:24.44)	9	220
24	F	TA only	0	1 580	TA only	0	1 200

* The approximate and actual (in brackets) ratios used

Tobacco aphid (TA) introduction
One week before releases were made, tobacco plants in all cages were sprayed with pirimicarb (*Pirimor*[T]) at the rate of 0.28 kg a.i./ha to eliminate early TA infestations. The TA was collected from adjacent tobacco fields and uniformly distributed on the test plants by placing aphid-infested tobacco leaves with a specific number of TA on each plant. One or two days later, the TA populations were examined and a second infestation was made if the TA populations were not established.

Convergent lady beetle (CLB) introduction
The beetles were introduced into the cages after the TA colonies had established. The CLB adults were collected from adjacent fields and introduced into the cages on the same day. Most of the beetles collected during May and June were overwintered adults. According to Lee (1980), ca. 57% of overwintered adults are females. The number of CLB released into each cage varied according to the total number of aphids present and the predetermined initial ratio for each cage *(Table 1)*. In 1985, the CLB was released on the same day for all treatments. However, the CLB introductions in 1986 were varied according to treatments. The beetles were introduced 2-3 days after the TA introductions for treatment B (1:25) and C (1:50), and 6-7 days after the TA introductions for treatment D (1:100) and E (1:200).

Data collection and statistical analysis
The TA and CLB populations in each cage were monitored at least once a week, until all tobacco leaves had been harvested. Insect counts were started on the day of CLB

introduction. The countings were made inside the cages. The cages were opened and closed by means of a long zip (ca. 1.8 m) which was fitted to one side of the saran net. The cage was zipped up during insect counting. The TA population sampling involved a procedure adapted from one described by Tappan (1963). The aphids on the under surface of the leaves, between the fourth and sixth lateral veins on the right side of the midrib were counted. The eight uppermost leaves with a minimum length of 10 cm were sampled on each plant. The CLB population development was monitored by counting the number of eggs and larvae on each plant. The eggs and larvae on the screen were not sampled since there were found in relatively small numbers. Meanwhile, the CLB adult populations were determined by counting the number in each cage (those found on plants and the screen). The adults found on the screen were counted since there was a large number of them which tended to fly when the tobacco plants were disturbed during sampling of TA and CLB eggs and larval populations.

The cumulative proportional population growth rates of TA, and CLB egg, larva and adult for each treatment were determined with simple regression analysis of logit cumulative proportion (P) against the number of days after TA introductions. The logit P's were calculated using the formula.

Logit $P = \text{Ln}(P/1\text{-}P)$

where P = cumulative proportional development of TA or CLB egg, larval, and adult populations. P values of 0 and 1.0 were discarded from the analysis since only cumulative proportion greater than 0, but less than 1.0 can be transformed to logit value. The slope estimated in this analysis represented the cumulative proportional growth rate of each population in each treatment. Significant effects of treatment on slopes were determined with analysis of covariance (ANACOVA). If ANACOVA tests showed significant (p = 0.05) differences between slopes, then Tukey's procedure was used to separate the different slopes (Zar 1984). In addition, the cumulative proportional growth rate of TA populations to reach 37 500 and 110 000 in 1985 and 1986, was also calculated. These two levels were chosen because there was no further increase in cumulative population in one of the treatments for 1985 [e.g. treatment B(1:50)] and 1986 [e.g. treatment D(1:100)].

Tobacco leaves were harvested and cured as they ripened. The United States Development Authority (USDA) marketing service grader placed standard commercial grades on cured-leaves for each priming from each plot. Yield (kg/ha), returns ($/ha), and quality index (0-100, 0 = the lowest quality, and 100 = the highest quality) were determined using a modification of Wernsman and Price (1975). The reductions in yield, returns and quality index were compared with treatment A (no TA or CLB present), in each replicate. Likewise, the reduction in TA populations in each treatment was compared with number of TA in treatment F (TA only) of each replicate. Analysis of variance (ANOVA) was performed on arcsine transformation of these parameters. Significant means were separated with Duncan's multiple range test (p = 0.05) (Steel and Torrie 1980).

The influence of cages on sunlight, temperature, and humidity were examined using simple linear regression analysis on data obtained inside and outside the cages during the 1986 study. In the analysis, the inside variates are dependent variables (y) and the outside variates, independent variables (x). The sunlight inside the cages were recorded with a Li-Cor Inc. Quantum Sensor, Lincoln, Nebraska. The humidity and temperature were recorded with DATAPOD 220^{R} (Omnidata International, Logan, Utah) and POLYCORDER (Omnidata International, Logan, Utah). The climatological data outside the cages were obtained from a weather station located ca. 100 m from the experimental site. Comparisons were made for relative humidity, temperature and sunlight (PAR -

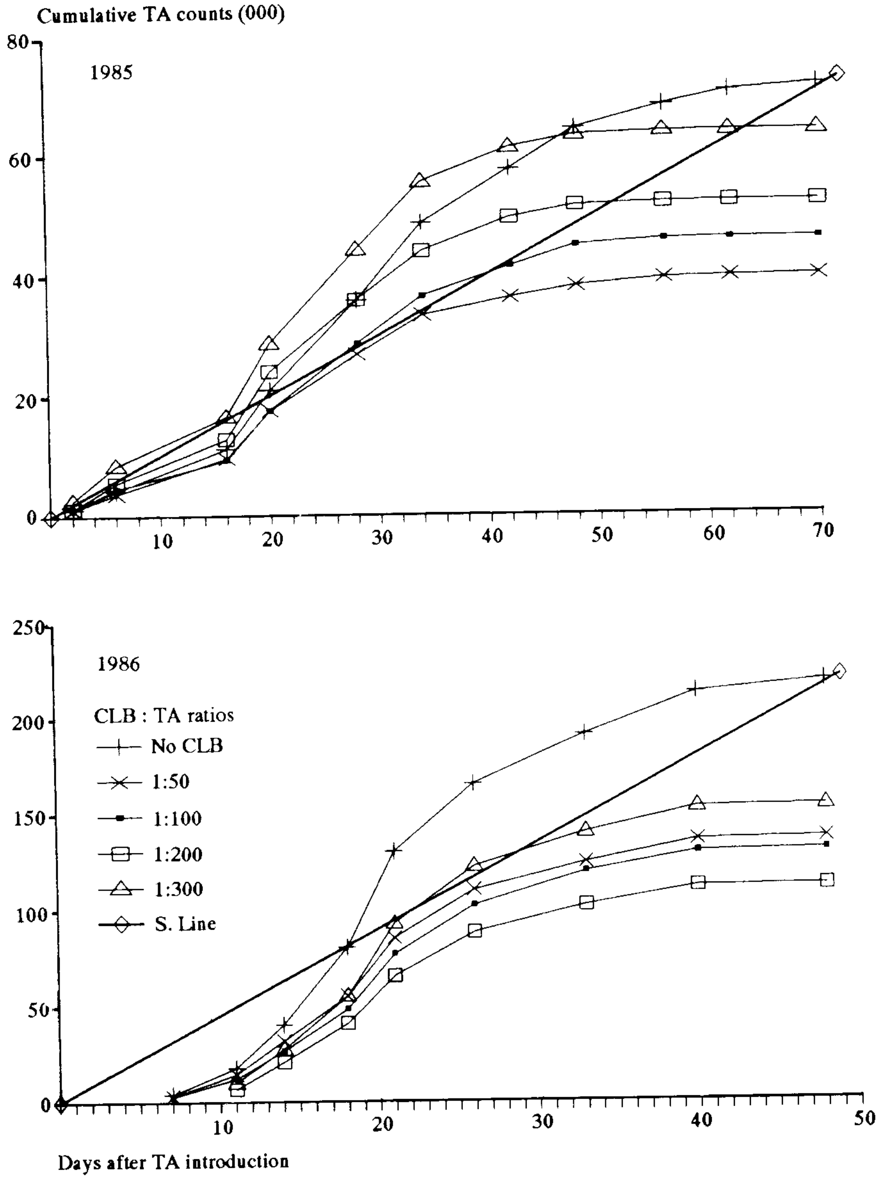

Figure 1. Cumulative TA on tobacco receiving different initial CLB:TA ratios, Blackstone, Virginia, 1985-1986 (note: the actual ratios were changed for 1986 figure)
(a standard line to show if TA population accumulated at the same rate each day during the experimental period viz. 1 029 and 4 490 TA/day for 1985 and 1986 respectively)

photosynthetically active radiation). Statistical analyses were performed with Proc GLM of SAS (Anon. 1985).

Results and discussion

Impact of initial CLB:TA ratios on TA population

In *Figure 1* the slopes of all cumulative curves were almost similar to that of the

Table 2. Slope estimates for cumulative proportional growth of TA populations receiving different initial CLB:TA ratios, on flue-cured tobacco in field cages, Blackstone, Virginia, 1985-1986

Initial CLB:TA ratio	Entire season		Early season[+]	
	Estimate[++] of slope	r^2	Estimate[++] of slope	r^2
1985				
1:50	0.14b	0.99**	0.17a	0.99**
1:100	0.15bcd	0.98**	0.20b	0.96**
1:200	0.17d	0.98**	0.23b	0.97**
1:300	0.16cd	0.99**	0.18a	0.99**
TA only	0.13a	0.99**	0.23b	0.97**
1986				
1:25	0.23a	0.98**	0.32b	0.99**
1:50	0.24a	0.98**	0.31b	0.99**
1:100	0.22a	0.97**	0.23a	0.97**
1:200	0.22a	0.97**	0.38c	0.98**
TA only	0.21a	0.96**	0.38c	0.99**

**$p < 0.001$

[+]Analysis was done on cumulative proportion of TA populations to reach 37 500 and 110 000 in 1985 and 1986 respectively

[++]The slope was estimated using linear regression analysis between logit cumulative proportions of TA populations and number of days after TA introduction.

Values in each column and year with the same letter are not significantly different ($p < 0.05$) by Tukey's Test

standard line in the early part of 1985, 1-16 days after TA introduction (which indicate that the counts on succeeding dates were similar). In the middle of the season (ca. 20-42 days after TA introduction), the slope of cumulative curves of TA population counts in treatment B(1:50), C(1:100), and D(1:200) continued to be similar to that of the standard line, but the slope of cumulative curves for TA population in treatment E(1:300) and F(TA only) was higher than that of the standard line. This shows that the TA population in these two treatments increased faster than that given by the standard line. About 42 days after TA introduction, all curves levelled off except TA populations in treatment F(TA only), which continued to increase though its slope was lower than that of the standard line. Cumulative TA counts were highest in treatment F(TA only) followed by treatment E(1:300), D(1:200), C(1:100) and B(1:50).

In 1986, the results followed almost the same pattern as those in 1985. All slopes of TA cumulative population development were higher than the slope of the standard line except at the beginning of the experiment (7-11 days after TA introduction). They were nearly parallel to the standard line between ca. 17-25 days after TA introductions. After this point, all slopes of TA cumulative population curves were lower than that of the standard line, but the slope for TA population in treatment F(TA only) was higher than those for TA population in other treatments. However, the cumulative TA counts during the experiment were not related to the initial CLB:TA ratios. The TA population in treatment F(TA only) was the highest, followed by populations from treatment E(1:200), B(1:25), C(1:50) and D(1:100).

The estimate of slopes for cumulative proportional growth of TA population for the entire and early seasons showed significant differences ($p = 0.05$) in 1985, but not in

Table 3. Mean reduction of cumulative TA counts in treatments receiving different initial CLB:TA ratios, on flue-cured tobacco in field cages, Blackstone, Virginia, 1985-1986

	1985		1986	
Treatment (%)	Initial CLB:TA ratio	Mean reduction (%)*	Initial CLB:TA ratio	Mean reduction (%)*
B	1:50	35.75a	1:25	33.75a
C	1:100	30.75ab	1:50	39.50a
D	1:200	18.50ab	1:100	47.25a
E	1:300	2.00b	1:200	27.00a
F	GPA only	0.0b	GPA only	0.0b

* Means in each column with the same letter are not significantly different (p <0.05) using Duncan's Multiple Range Test
Mean reduction percentage = [(TA counts in treatment F–TA counts in each treatment) x 100] – TA counts in treatment F

1986 *(Table 2)*. In 1985, the cumulative proportional growth rate of TA population in cages with the initial ratio of 1:200 (CLB:TA) for the entire season was significantly higher than that of TA population in cages with 1:50 (CLB:TA) initial ratio, and TA populations without CLB. However, the differences in cumulative proportional growth rate of TA population in the early season was significant (p = 0.05) in both years. In 1985, the cumulative proportional growth rate for TA population without CLB was higher than those for TA population receiving 1:50 and 1:300 of CLB:TA initial ratios, but did not differ significantly from other treatments. Similar trends were also observed in 1986. The cumulative proportional growth rates of the TA population without CLB and TA population receiving the 1:200 CLB:TA initial ratios were significantly (p = 0.05) higher than the cumulative proportional rates of TA population that were treated with other initial CLB:TA ratios.

From the tabulated data on the reduction of TA population the effects of the initial CLB:TA ratios were more pronounced in 1985 *(Table 3)*. Treatment B which received the highest initial ratio showed highest reduction of cumulative TA population counts. There were significantly (p = 0.05) greater reductions in TA population in treatment B(1:50) than in treatment E(1:300), but there were no significant (p = 0.05) differences among the other treatments. In 1986, the initial CLB:TA ratios did not significantly affect the cumulative counts of TA population in cages.

Impact of initial CLB:TA ratios on CLB population

In 1985, the population growth curves were very similar to each other, but treatment E(1:300) consistently showed higher cumulative numbers for eggs, larvae and adults *(Figure 2)*. The slopes of each curve for CLB egg, larval, and adult population before reaching their peaks were almost similar to the standard line, except the slopes in treatment E(1:300) which were consistently higher, especially during 20-47 days after TA introduction for CLB egg and larval population and 20-40 days after TA introduction for adult population. However, no distinct difference was observed in 1986 *(Figure 3)*. The cumulative growth curves of CLB egg, larval and adult population in each treatment were also almost similar to each other. Their slopes were lower than that of the standard line in the early part of the study (before ca. 14 and 25 days after TA introduction), but were higher during the later part of study, until they reached the

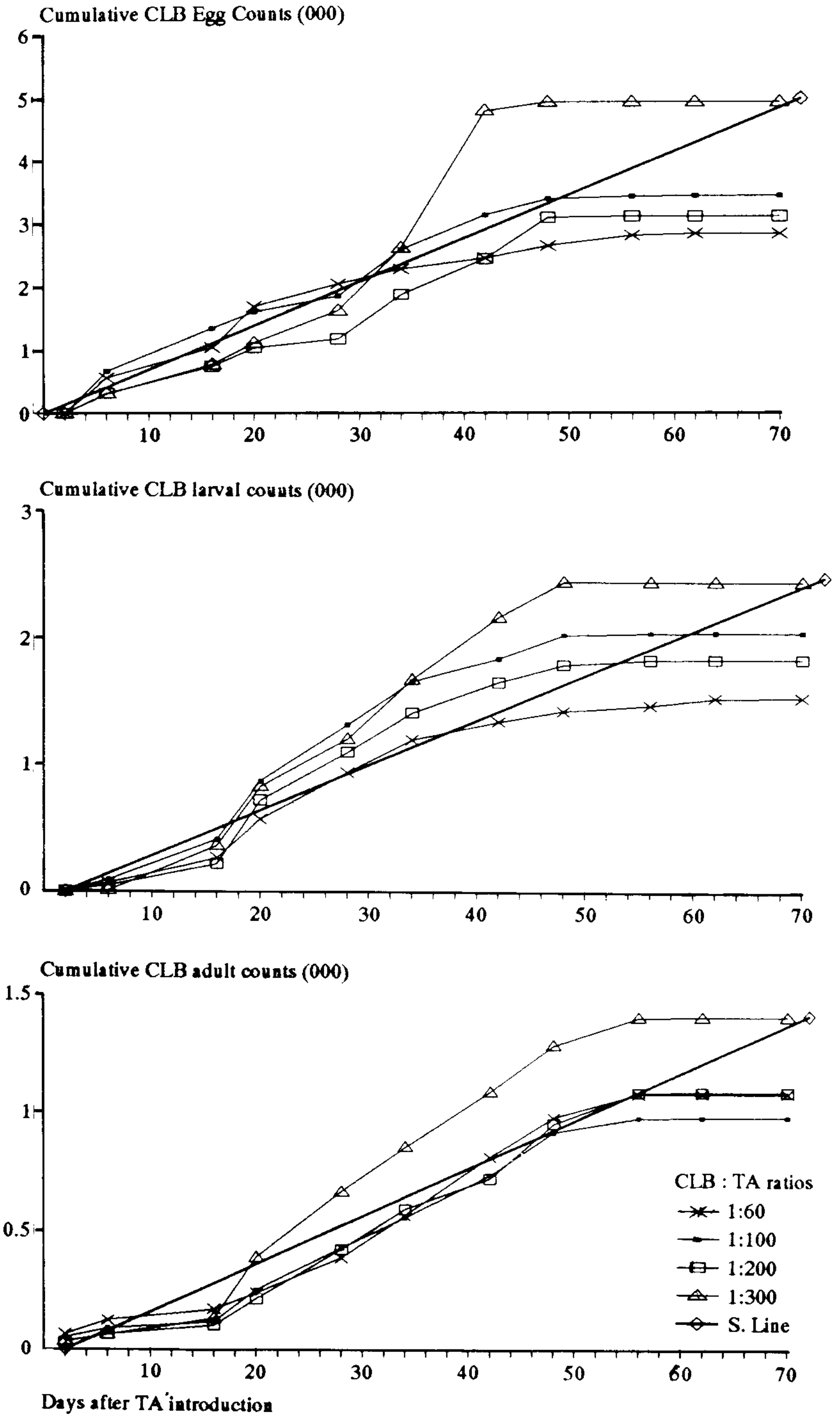

Figure 2. Cumulative CLB counts on tobacco receiving different initial CLB :TA ratios, Blackstone, Virginia, 1985.
(a standard line to show if CLB egg, larval, and adult populations accumulated at the same rate each day during the experimental period viz. 75 eggs, 40 larvae and 20 adults of CLB/day respectively)

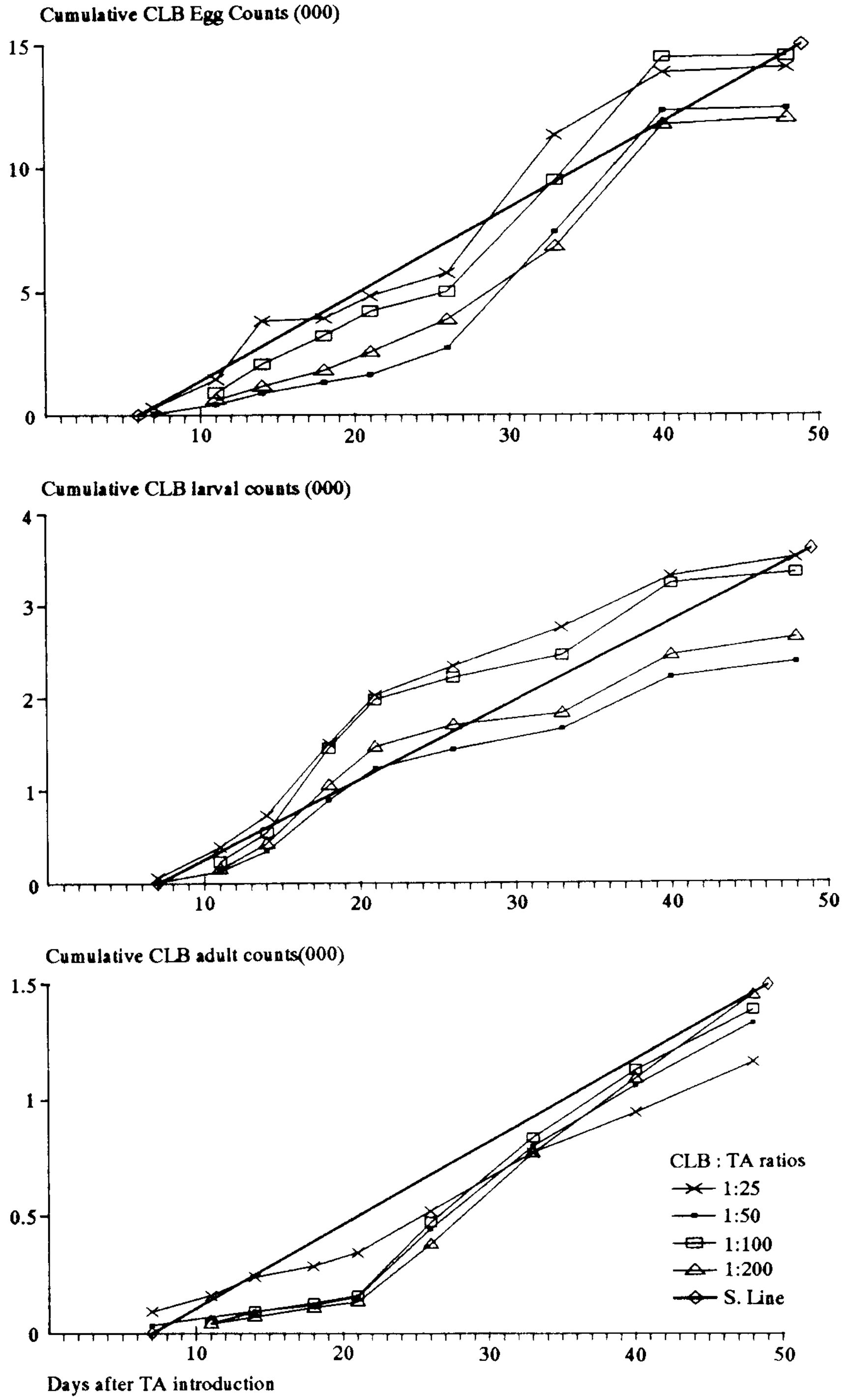

Figure 3. Cumulative CLB counts on tobacco receiving different initial CLB :TA ratios, Blackstone, Virginia, 1986
(a standard line to show if CLB egg, larval, and adult populations accumulated at the same rate each day during experimental period viz. 320 eggs, 85 larvae and 35 adults of CLB/day respectively)

plateau (for egg population) or until the study was over (for larval and adult population). The ANOVA on their cumulative population counts *(Table 4)* showed no significant (p = 0.05) effects of initial CLB:TA ratios, except in 1985 where significantly more CLB larvae were found in treatment E(1:300) than in treatment C(1:50). In 1986, initial CLB:TA ratios had no significant effects on the cumulative population counts of CLB egg, larva and adult.

Analysis of the cumulative proportional growth rates of CLB population *(Table 5)* showed that the initial CLB:TA ratios did not influence the cumulative proportional growth rate of CLB egg population in either year, but influenced the cumulative proportional growth rates of CLB larval population in 1985, and the CLB adult population for both 1985 and 1986. The growth rate of larval population in treatment B(1:50) was significantly lower than those in treatment C(1:100) and D(1:200). However, it was not significantly different from the growth rate of larval population with

Table 4. Mean cumulative CLB population counts in each treatment receiving different initial CLB:TA ratios, Blackstone, Virginia 1985-1986

Initial CLB:TA ratio	CLB stage Egg	Larva	Adult
1985			
1:50	712.0a	384.5b	268.3a
1:100	862.5a	515.0ab	243.3a
1:200	781.0a	461.3ab	269.8a
1:300	1 235.3a	616.3a	348.5a
1986			
1:25	3 522.0a	877.0a	291.5a
1:50	3 111.5a	595.0a	334.0a
1:100	3 637.3a	836.5a	348.0a
1:200	3 006.3a	661.5a	364.0a

Means in each column and year, with the same letter are not significantly different (p <0.05) using Duncan's Multiple Range Test

Table 5. Slope estimates for cumulative proportional growth of CLB populations in different treatments on flue-cured tobacco in field cages, Blackstone, Virginia, 1985-1986

1985 Initial CLB:TA ratio	Estimate⁺ of slope	r^2	1986 Initial CLB:TA ratio	Estimate⁺ of slope	r^2
Egg					
1:50	0.11a	0.95 **	1:25	0.22a	0.93 **
1:100	0.13a	0.90 **	1:50	0.24a	0.88 **
1:200	0.14a	0.84 **	1:100	0.14a	0.95 **
1:300	0.15a	0.84 **	1:200	0.21a	0.88 **
Larva					
1:50	0.13a	0.98 **	1:25	0.18a	0.92 **
1:100	0.16bc	0.97 **	1:50	0.17a	0.91 **
1:200	0.17c	0.98 **	1:100	0.18a	0.92 **
1:300	0.15abc	0.98 **	1:200	0.21a	0.91 **
Adult					
1:50	0.10a	0.97 **	1:25	0.11a	0.99 **
1:100	0.11a	0.97 **	1:50	0.15b	0.98 **
1:200	0.11a	0.99 **	1:100	0.17c	0.99 **
1:300	0.13b	0.99 **	1:200	0.16bc	0.99 **

** p <0.001
⁺The estimates for the slope of simple linear regression analysis between logit cumulative proportion of CLB egg, larva and adult populations and number of days after TA introduction. Values in a column with the same letter (for egg, larva, and adult populations) are not significantly different (p <0.05) as indicated by Tukey's Test

treatment E(1:300). As to why this was so is not known. The results also showed that the growth rate of CLB adult population with the lowest CLB:TA initial ratios (i.e. 1:300 in 1985 and 1:200 in 1986) were higher than those treated with the highest CLB:TA ratios (i.e. 1:50 in 1985 and 1:25 in 1986).

Impact of initial CLB:TA ratios on yield and quality of tobacco

Reductions in returns and yield were not significant in 1985 but were significant in 1986 *(Table 6)*. Treatment D(1:100) of 1986 had significantly less yield reduction than treatment F(TA only). Likewise, treatment D(1:100) had significantly (p = 0.05) lower reduction in returns than treatment B(1:25), E(1:200) and F(TA only). The differences in the reduction in quality index of tobacco leaves were significant (p = 0.05) in both years. In 1985, treatment B(1:50) was significantly lower than treatment E(1:300) and F(TA only). In 1986, there was no direct relationship between the reduction in quality index and the CLB:TA initial ratios. Treatment D(1:100) had significantly less reduction in quality index than treatment B(1:25) and F(TA only). Hence, treatment B(1:25) was not as effective as expected. Although treatment B(1:50) of 1985 and treatment D(1:100) of 1986 had less reductions in quality index, their lowest reductions were still too high (65.25% and 51.50% for 1985 and 1986 respectively). Thus, the reduction of TA populations by CLB was not enough to reduce the injury caused by TA.

Results from simple regression analysis between the data of variates obtained inside and outside the cages revealed that the cages significantly reduced the light intensity [inside light = 114.57 + 0.84 outside light, r^2 = 0.64 (p <0.001), and df = 291], and humidity during the day [inside humidity = -18.50 + 1.15 outside humidity, r^2 = 0.84 (p <0.001), and df = 114]. But, the cages increased the temperature [inside temperature = -3.68 + 1.13 outside temperature, r^2 = 0.97 (p <0.001), and df = 290]. The reduction in light intensity may have exerted a significant effect on the results because it affected the tobacco growth.

Although the duration of the study differed between years, results obtained were similar. The initial CLB:TA ratios used in this study failed to produce a pronounced effect on TA populations. However, it did show that the CLB (larvae and adults) could suppress the number and cumulative proportional growth rates (in early seasons) of the TA population. Although the TA population was reduced, reductions were not enough to prevent economic damage. The cage conditions appeared to favour TA development. Kulash (1949) reported that shading during part of the day favours the development of the TA population. In addition, the cages reduced the impact of rainfall and storms on tobacco plants. These two climatic factors are considered important factors for aphid mortality (Walker et al. 1984). Cages also prevented the emigration of aphids, and the emigration or immigration of CLB.

The initial CLB:TA ratios did not influence the cumulative proportional growth rates of CLB egg populations. Thus, the initial CLB:TA ratios used in this study did not seem to influence the cumulative population development of CLB eggs. This was probably because TA density inside the cages was above the CLB satiation point. Hence, CLB adults had oviposited maximum number of eggs per day. According to Clausen (1963), each adult lady beetle consumed ca. 50 aphids/day when plenty of aphid were present. Meanwhile, Mohd. Norowi (1987) observed that each CLB adult consumed ca. 64 TA adults per day when 100 TA adults/day were provided. Furthermore, Mills (1982) had proven with a mathematical model that after the satiation point, any increase in the number of prey eaten will not influence the ovipositional rates of predators. However, the cumulative proportional growth rates of CLB adult populations were affected by the initial

Table 6. Mean reductions in yield, returns, and quality index of flue-cured tobacco with different initial CLB:TA ratios, Blackstone, Virginia, 1985-1986

Treatment	Initial CLB:TA ratio	Reduction in yield (%)	Reduction in returns (%)	Reduction in quality index (%)
1985				
A	No CLB, or TA	0.00b	0.00b	0.00d
B	1:50	12.75ab	24.25a	65.25c
C	1:100	20.75a	36.00a	82.50abc
D	1:200	9.75ab	24.25a	73.75bc
E	1:300	20.25a	26.25a	91.25ab
F	TA only	24.00a	28.25a	95.25a
1986				
A	No CLB, or TA	0.00c	0.00c	0.00c
B	1:25	39.50ab	63.75a	79.50a
C	1:50	32.25b	53.50b	57.25b
D	1:100	29.75b	51.50b	51.50b
E	1:200	42.00ab	64.25a	72.75ab
F	TA only	49.00a	69.25a	79.00a

Means in each column and year with the same letter are not significantly different ($p < 0.05$) using Duncan's Multiple Range Test

CLB:TA ratios used. The TA population growth in each treatment probably affected the population growth rates of immature stages of CLB. Larger numbers of TA resulted in more aphids being eaten during the larval stage and therefore speeded the development of CLB (Murdoch 1977). This may speed up adult emergence.

In these studies the CLB alone could not maintain the TA population on tobacco, below the economic injury level. However, the shading effects produced by the cages not only favoured the TA population growth, but also enhanced injury to tobacco. For instance, lack of sunlight caused a reduction in reducing sugars (Tso et al. 1970). TA infestations also removed significant amounts of reducing sugar from tobacco leaves P52 (Cheng and Hanlon 1985). Thus, the use of cages increased the possibility of producing low quality cured leaves. Cages also increased the incidence of sooty mold fungus (*Fumago vagans* Pers.) which produced more honeydew and reduced ventilation. The increased accumulation of honeydew was mostly due to the elimination of insects that feed on it, and the reduction in rain impact. Sooty mold also reduced the leaves ability to recover sunlight. Furthermore, sooty mold itself resulted in lifeless leaves when cured (Mistric and Clark 1979).

Despite some negative effects encountered in this study, the use of cages is a useful technique as it provides a quantitative assessment of predator/prey relationship under field conditions. The information is meaningful in providing quantitative values for models that can be used to predict the impact of predator on their prey population (Grant and Shepard 1985). The negative effect of cages in this study may be reduced if larger cages or wider plant spacing were used.

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