Phenology of *Lygus lineolaris* (Hemiptera: Miridae) in Minnesota June-Bearing Strawberries: Comparison of Sampling Methods and Habitats

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ABSTRACT Field studies were conducted in southeastern Minnesota from 2000 to 2002 to determine the phenology of *Lygus lineolaris* in various habitats and to compare yellow and white sticky traps as a sampling method for adult *L. lineolaris*. Strawberry fields were sampled for *L. lineolaris* adults using yellow sticky traps, and nymphs were sampled using the standard white pan beat method. Adult *L. lineolaris* abundance in alfalfa, an adjacent fence-row, and a wooded habitat were also compared. The nonlinear relationship between cumulative trap catch and cumulative degree-days was modeled with a two-parameter cumulative Weibull function to predict early-season adult capture using yellow sticky traps. Adult *L. lineolaris* were detected in bearing-year strawberries at the onset of vegetative growth in all years. Yellow sticky traps caught significantly higher densities of adult *L. lineolaris* than white sticky traps. The Weibull model predicted 50% capture at 10 DD (>12.4°C), which corresponds to the vegetative strawberry growth stage. *L. lineolaris* nymphs were not detected until the blossom stage. Alfalfa harbored significantly higher densities of *L. lineolaris* than other habitats during early-season sampling (i.e., March–June). Late-season sampling (July–September) revealed significantly higher densities in bearing-year strawberries. These results suggest that monitoring at the onset of vegetative growth, using yellow sticky traps, will be an efficient method for detecting early *L. lineolaris* adult activity.

KEY WORDS tarnished plant bug, strawberry, phenology, sticky trap, sampling

UNDERSTANDING THE DISPERSAL AND phenology of an insect pest in the crop, through reliable sampling methods, is the first step in making informed pest management decisions. By documenting the phenology of an insect population, one can determine which life stages are present at the time when the crop is most susceptible to damage. Insect life stage(s) associated with specific crop growth stages will determine which sampling tool the grower chooses and ultimately the method of control (Pedigo 1989).

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae), is a key economic pest of strawberry, *Fragaria x ananassa* Duchesne (Schaefers 1981). Both adults and nymphs feed on the blossom buds, blossoms, and developing green fruit, resulting in deformed fruit that is unmarketable (Allen and Gaede 1963, Handley and Pollard 1993). Several sampling tools have been used when monitoring for *L. lineolaris.* For adults, these tools include sticky traps (Cooley and Schloemann 1992, Rose 1996) and vacuum/suction devices (Snodgrass 1993, Vincent and Lachance 1993, Zalom et al. 1993), and for nymphs, the white pan beat method (Mailloux and Bostanian 1988, Gleason and Lewis 1992, Kovach et al. 1993).

The phenology of *L. lineolaris* in strawberries has been described for Quebec (Bostanian et al. 1990) and Manitoba growing conditions (Gerber and Wise 1995), where nymphs were considered the most damaging life stage. Based on these observations, an economic injury level (EIL) and an economic threshold (ET) were established for nymphs (Mailloux and Bostanian 1988). This led to recommendations of sampling using the white pan beat method and spraying only when the suggested ET of 0.25 nymphs/blossom cluster is exceeded (Mailloux and Bostanian 1988, Kovach et al. 1993). This threshold has proven effective in many areas; however, there are perhaps just as many who do not follow these guidelines and spray early in the season by targeting the adults (e.g., Wold 2003, Wold and Hutchison 2003). Cooley and Schloemann (1992) suggest a hybrid approach, combining white sticky trap monitoring for adults and the white pan beat method for nymphs.

White sticky traps have been used for over 30 yr to monitor *L. lineolaris* migrating into apple orchards (Prokopy et al. 1979, 1982). When used in an apple orchard, Prokopy et al. (1979) found that, numerically, the nonreflective white sticky traps attracted the most *L. lineolaris* adults compared with reflective white, yellow, and clear traps. However, there was no

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statistical difference between the yellow and nonreflective white traps. This finding agrees with an earlier study that found *L. lineolaris* to have no preference to a specific hue in apple orchards (Prokopy and Owens 1978). However, white sticky traps are favored, because in addition to capturing *L. lineolaris,* they also have the benefit of capturing the European apple sawfly (*Hoplocampa testudinea*), which is a key pest of apple (Prokopy and Owens 1978). Over the years, strawberry growers have adopted white sticky traps into their management program despite the question of their usefulness (Rose 1996).

In addition to determining the best sampling methods for *L. lineolaris,* another key factor is to determine the source of *L. lineolaris* population in strawberries. It has been reported that *L. lineolaris* overwinters in alfalfa (Khattat and Stewart 1980) and various habitats adjacent to strawberry fields. To determine the proper location or habitat to monitor for the emergence of overwintering adults, the phenology of *L. lineolaris* should be established in common habitats surrounding strawberry fields.

The purpose of this study was to address the following objectives: (1) evaluate the efficacy of yellow and white sticky traps as a method to detect adult *L. lineolaris* activity; (2) document the phenology of *L. lineolaris* in June-bearing strawberries, alfalfa, woods, and fence-row habitats; and (3) determine when the early season adult *L. lineolaris* population is most abundant.

Materials and Methods

Experiments were conducted in southeastern Minnesota in Houston County (43°31′ N, 91°42′ W). Strawberry fields were managed using standard cultural practices in the years before the research (Hancock 1999). All fields were hand weeded throughout the season. Fields used in the experiments did not receive insecticide applications during the course of the trial.

Sticky Trap Color Comparison, 2000–2001. In-field experiments were conducted to determine which sampling tool, yellow or nonreflective white sticky traps (Gempler's, Belleville, WI), is most effective in detecting adult *L. lineolaris* activity in strawberries. Sticky traps were placed in a 2.0-ha bearing-year field of 'Glooscap' (2000), a 1.6-ha field of 'Annapolis' (2001), and a 2.0-ha establishment-year field of 'Honeoye' (2000). Bearing-year strawberry fields were defined as being in at least the first year of production (i.e., harvestable crop); establishment-year strawberry fields were defined as being nonproductive, meaning new bare-root strawberry plants were transplanted into the field immediately before sampling. Twelve pairs of yellow and white sticky traps (15.2 by 15.2 cm) were stapled to wooden stakes 7.6 cm above the plant canopy (Ridgway and Gyrisco 1960, Rose 1996). Yellow and white traps were placed side by side at the field edge and at 1, 1.8, and 7.3 m into the field and replicated three times in 2000. In 2001, yellow and white traps were placed at the field edge and at 1.8 and 7.3 m into the field and replicated four times.

Sticky traps were collected and changed weekly from 5 to 30 May, for a total of four sample dates in 2000, and from 21 April to 8 June, for a total of eight sample dates in 2001. Data were transformed for counts (SQRT) and analyzed using PROC TTEST ($P = 0.05$; SAS Institute 1995).

Adult *L. lineolaris* Habitat Comparison, 2000–2002. Habitats were sampled for *L. lineolaris* adults to determine if *L. lineolaris* occurred at higher densities at any one particular habitat. In all years, we sampled for adult *L. lineolaris* in an alfalfa field, a bearing-year strawberry field, and a fence-row. In 2000 and 2001, we also sampled for adults in an establishment-year strawberry field and a wooded area. Yellow sticky traps were placed 7.6 cm above the plant canopy and stapled to a wooden stake. In each year, 9 traps were placed in alfalfa, (four traps spaced 4.5 m apart, replicated three times, each replication was 9.1 m apart), 3 along a fence-row (9.1 m apart), and 12 in a bearing-year strawberry field. In 2000 and 2001, 12 traps were placed in an establishment-year strawberry field. In 2000, traps were placed at the field edge and at 1, 1.8, and 7.3 m into the field and replicated three times. In 2001, traps were placed at the field edge and at 1.8 and 7.3 m into the field and replicated three times. In addition, in 2000 and 2001, 12 traps were placed in a wooded area (four replications of 3 traps; each trap is 4.5 m apart, each replication is 9.1 m apart).

Traps were changed weekly from 5 May through 20 September (17 sample dates) in 2000, from 21 April through 22 August (17 sample dates) in 2001, and from 10 March through 20 June in 2002 (17 sample dates). Data from each year were transformed for counts (SQRT) and analyzed with PROC GLM and the Ryan-Einot-Gabriel-Welsch multiple range test ($P = 0.05$; SAS Institute 1995).

***Lygus lineolaris* Phenology in Strawberry, 2000–2002.** Bearing-year strawberries were sampled for *L. lineolaris* adults using yellow sticky traps. Yellow sticky traps were placed 7.6 cm above the plant canopy and stapled to a wooden stake. In 2000, three sticky traps were placed at the field edge, and three were placed at 0.9, 2.7, and 3.6 m into the field. In 2001, four sticky traps were placed at the field edge, and four at 1.8 and 7.3 m into a 1.6-ha field. In 2002, three sticky traps were placed at the field edge, and three at 1.8, 3.6, and 10.9 m into a 2.0-ha field.

In 2000, traps were changed weekly from 5 May through 20 September (17 sample dates), in 2001, from 21 April through 22 August (17 sample dates), and in 2002, from 10 March through 20 June (17 sample dates). Sampling for nymphs was done using the standard white pan beat method (e.g., Kovach et al. 1993), which consisted of randomly selecting five blossom-clusters/1 m of row and tapping each one into a white pan. In 2000, fields were sampled from 5 May through 8 June (six sample dates), in 2001, from 5 May through 5 July (nine sample dates), and in 2002, from 14 May through 13 June (six sample dates). Data from each year were transformed for counts (SQRT) and ana-

Table 1. Number (mean ± SEM) of adult *L. lineolaris* per sticky trap in an establishment-year strawberry field and a bearing-year bearing strawberry field, southeastern Minnesota, 2000–2001

Treatment	2000				2001	
	Establishment-year		Bearing-year		Bearing-year	
	Adults/trap	*n*	Adults/trap	*n*	Adults/trap	*n*
Yellow	0.33 ± 0.08	48	0.33 ± 0.13	48	0.32 ± 0.08	96
White	0.02 ± 0.02	48	0	48	0.03 ± 0.01	96
df	94		94		190	
P	0.003		0.01		0.001	
t	2.55		3.75		3.24	

Means compared within each column. Means within each column were significantly different ($P < 0.05$), PROC TTEST (SAS 1995). Data were transformed by square root for counts; untransformed means are presented.

lyzed separately with PROC GLM (SAS Institute 1995).

Prediction of Peak Adult *L. lineolaris* Capture in Strawberry, 2001–2002. Yellow sticky trap data collected in 2001 and 2002 from bearing-year strawberry fields were pooled to develop a model to predict early-season capture of the emerging overwintering adult *L. lineolaris* population. Adult capture was expressed as a cumulative proportion of total capture in cumulative degree-days. Weather information for degree-day determination was obtained from the Midwestern Regional Climate Center (Champaign, IL). Air temperature degree-days accumulated from 1 January were calculated using Forecaster software (Ascerno and Moon 1989), which uses a double sine-wave method. The lower developmental threshold was set at 12.4°C (Bostanian et al. 1990).

Data were modeled using a two parameter version of the Weibull model (Pinder et al. 1978, Wagner et al. 1984, McBrien and Judd 1998) and fit to each year's data. The Weibull model has been used to describe the distribution of insects completing a developmental stage in response to time or temperature, and it is known to be a robust model (Wagner et al. 1984). The form of the Weibull model is as follows:

$$f(x) = 1 - \exp\left[-\left(\frac{x}{\eta}\right)^{\beta}\right] \qquad [1]$$

where $f(x)$ represents the probability of emergence at cumulative degree-days (x), η represents the rate of emergence, and β describes the overall shape of the Weibull model. Values for each parameter were calculated with nonlinear regression using PROC NLIN, DUD method (SAS Institute 1995) (e.g., Nowatzki et al. 2002). The NLIN procedure requires cumulative emergence data, degree-days, the function, and an initial range of values for each parameter.

Welch's unpaired t (Oehlert 2000) was used to create 95% confidence intervals for the parameter estimates for each year. Confidence intervals were used to test for significant differences between years. If the confidence intervals were equal to zero, the parameter estimates were considered to not be significantly different at an error rate of 0.05, and data were pooled.

Results

Sticky Trap Color Comparison, 2000–2001. In both years of the study, yellow sticky traps consistently performed better at detecting adult *L. lineolaris* than white sticky traps, whether in an establishment-year field or bearing-year field (Table 1). In the comparison of white versus yellow in the establishment-year field, white sticky traps failed to capture a single adult *L. lineolaris* (Table 1). In the bearing-year field, white sticky traps only detected a single adult *L. lineolaris* on one sample date during both years (10 April 2001 and 22 May 2002; Fig. 1).

Adult *L. lineolaris* Habitat Comparison, 2000–2002. Data were separated into early season (Table 2), the period of time up to strawberry harvest, and late season (Table 3), which represents the period of time after berry harvest. In all years, during the early season, the density of *L. lineolaris* adults was highest in alfalfa, with an average of 0.49 adult *L. lineolaris*/trap, and lowest in the woods, with 0.02 *L. lineolaris*/trap (2000: $P = 0.001$, $F = 4.71$; 2001: $P = 0.0001$, $F = 7.27$; 2002: $P = 0.002$, $F = 7.43$; Table 2). In addition, adult *L. lineolaris* were rarely detected in the establishment-year strawberry field (Table 2). As the early-season sampling approached berry harvest, the density of

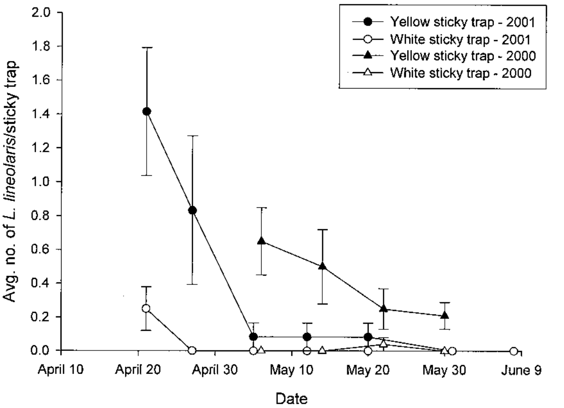

Fig. 1. Comparison of densities of adult *L. lineolaris* captured on yellow and white sticky traps in a bearing-year strawberry field, southeastern Minnesota, 2001–2002

Table 2. Number of adult *L. lineolaris* (mean ± SEM) caught on yellow sticky traps in early season (March–June), in selected habitats of southeastern Minnesota, 2000–2002

Location	2000		2001		2002	
	L. lineolaris/trap	*n*	*L. lineolaris*/trap	*n*	*L. lineolaris*/trap	*n*
Alfalfa	0.49 ± 0.15a	63	0.78 ± 0.18a	81	0.89 ± 0.24a	93
Fence row	0.05 ± 0.05b	21	0.44 ± 0.30ab	27	0.28 ± 0.11b	39
Bearing-year strawberry	0.21 ± 0.05ab	84	0.35 ± 0.08ab	108	0.15 ± 0.05b	120
Establishment-year strawberry	0.21 ± 0.07ab	84	0.01 ± 0.01b	108	—	—
Woods	0.02 ± 0.01b	84	0.06 ± 0.04b	81	—	—
F	4.71		7.27		7.43	
df	4,11		4,11		2,11	
P	0.001		0.0001		0.002	

Means within columns followed by the same letter are not significantly different ($P > 0.05$); Ryan-Einot-Gabriel-Welsch test.
Data were transformed by square root for counts; untransformed means are presented.

adult *L. lineolaris* decreased in alfalfa and began to increase in the bearing-year strawberry field.

After berry harvest, the adult *L. lineolaris* population increased in all habitats (Fig. 2), with the bearing-year strawberry fields harboring the highest numerical density of adult *L. lineolaris.* In 2001, the bearing-year strawberry field had higher densities of *L. lineolaris* compared with other habitats ($P = 0.0001$, $F = 24.65$; Table 3). As in the early season, very few adult *L. lineolaris* were detected in the woods and the establishment-year strawberry field (Table 3).

***Lygus lineolaris* Phenology.** In 2000, sampling began during the blossom stage of strawberry, at which time both adults and nymphs were detected (Fig. 2A). The overwintering adult population decreased throughout the blossom stage and green berry stage, at which time the nymph population became more abundant. The nymph population continued to increase throughout the sampling period and peaked during the ripe berry stage. The F_1 (first generation) adult population was present before berry harvest and peaked at 3.2 adults/trap during early August (Fig. 2A).

In 2001, sampling began earlier, during the vegetative stage, at which time the overwintering adults were detected (Fig. 2B). Nymphs were not detected until the second sample date, which was during the blossom stage. Similar to 2000, the nymph population became more abundant throughout the sampling period and peaked during the ripe berry stage (Fig. 2B). The overwintering adult population decreased throughout the sampling period, and the F_1 adult population was present and most abundant after harvest and peaked at 10.8 adults/trap in early August (Fig. 2B).

In 2002, traps were placed in the field considerably earlier (February), and adults were not captured until the fourth sample date, which was during the vegetative stage (12 April, Fig. 2C). The overwintering adult population decreased throughout the rest of the sampling period and was rarely detected after the white bud stage (Fig. 2C). Sampling for nymphs began during the white bud stage; however, nymphs were not detected until the ripe berry stage, which was also the stage at which the nymph population was most abundant.

Prediction of Peak Adult *L. lineolaris* Capture, 2001–2002. Adult trap catch data for 2001 and 2002 were modeled separately using a two-parameter version of the Weibull function. The Welch's unpaired *t* indicated no significant differences in the parameter estimates between years (Table 4); thus, data from both years were pooled. The observed relationship between degree-days and cumulative trap catch and the fitted Weibull model are shown in Fig. 3. The Weibull function explained 99% of the variation between cumulative degree-days and cumulative proportion trap catch ($F = 1615.67$). Cumulative proportion of adult *L. lineolaris* capture peaked (50% capture) at 10 DD, which was during the vegetative stage; was 90% after 50 DD, which corresponds to the green bud stage; and reached 100% at 200 DD, which was the ripe berry stage (Fig. 3).

Table 3. Number of adult *L. lineolaris* (mean ± SEM) caught on yellow sticky traps in late season (July–September), in selected habitats off southeastern Minnesota, 2000–2001

Location	2000		2001	
	L. lineolaris/trap	*n*	*L. lineolaris*/trap	*n*
Alfalfa	0.74 ± 0.14a	90	1.92 ± 0.46b	72
Fence row	1.00 ± 0.21a	30	2.63 ± 0.88b	24
Bearing-year strawberry	1.31 ± 0.21a	120	4.66 ± 0.49a	96
Establishment-year strawberry	1.03 ± 0.18a	120	0.66 ± 0.15c	96
Woods	0.07 ± 0.03b	120	0.11 ± 0.04c	72
F	9.52		24.65	
df	4,11		4,11	
P	0.0001		0.0001	

Means within columns followed by the same letter are not significantly different ($P > 0.05$); Ryan-Einot-Gabriel-Welsch test.
Data were transformed by square root for counts; untransformed means are presented.

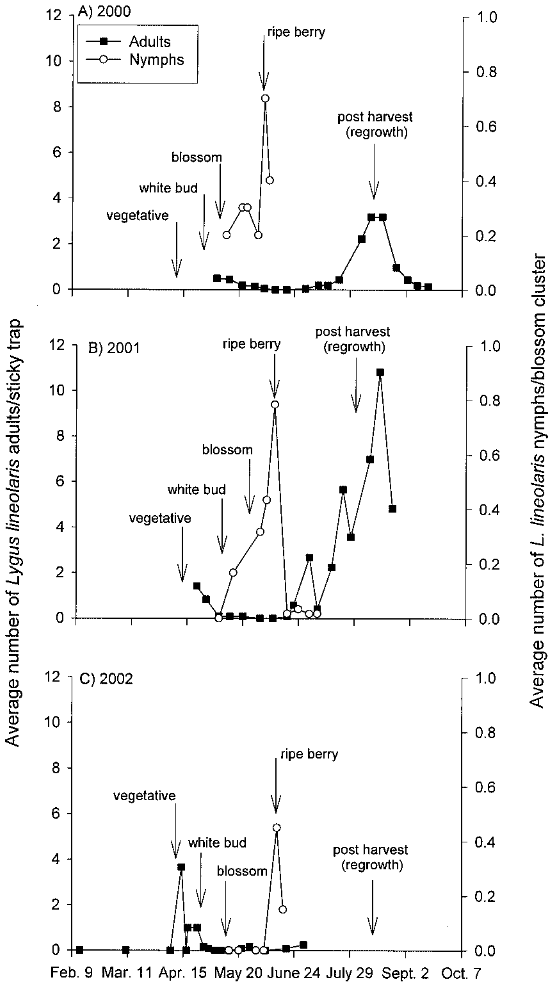

Fig. 2. Phenology of *L. lineolaris* in bearing-year strawberry fields; adults were sampled using yellow sticky traps, and nymphs were sampled using the standard white pan beat method. Southeastern Minnesota: (A) 2000, (B) 2001, and (C) 2002.

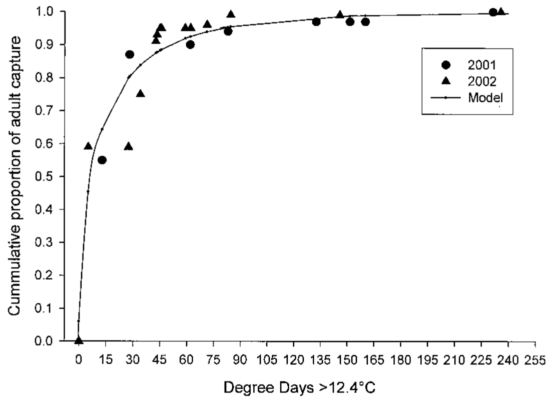

Fig. 3. Observed cumulative capture of adult *L. lineolaris* fit with Weibull function in degree-days accumulated from 1 January, southeastern Minnesota, 2001–2002.

Discussion

The yellow sticky trap was an effective tool for detecting the emerging overwintering adult *L. lineolaris* population. Results from the white and yellow comparisons definitively illustrate that yellow traps are more consistent in detecting adult *L. lineolaris* than white traps in Minnesota. In the bearing-year field, white sticky traps only detected a single adult *L. lineolaris* on one sample date during both years. The yellow trap also worked well in all habitats and crops tested. Thus, the yellow trap will be useful for future phenology studies with *L. lineolaris* in multiple crops or on-farm landscapes. With regard to strawberry, the yellow sticky trap seems to be useful as an early warning indicator of the presence of absence of *L. lineolaris* activity and a practical method for use in an integrated pest management (IPM) program (e.g., Fadamiro et al. 2003).

Table 4. Weibull model parameters for proportion of adult *L. lineolaris* capture, 2001–2002

Year	n^a	η^b	df	β^c	F	R^2
2001	8	14.97 ± 2.08	6	0.70 ± 0.13	1682.80	0.99
2002	16	10.85 ± 2.88	12	0.55 ± 0.11	701.89	0.99

Means are not significant; 95% confidence intervals for the difference in parameter estimates between years included zero (Welch's unpaired *t*).

[a] Number of observations.

[b] Eta (η) = parameter controlling the rate of emergence.

[c] Beta (β) = parameter controlling overall shape of the curve.

Understanding the phenology of an insect pest as well as the use of an effective sampling method is a critical factor in developing an IPM program. With the use of an appropriate sampling method during critical crop growth stages, optimum timing of insecticide applications can be achieved, and subsequently, control costs are reduced (e.g., Hutchison et al. 2001).

Populations of *L. lineolaris* are known to be high in alfalfa (Khattat and Stewart 1980), especially early in the season, and it was likely a major source of *L. lineolaris* in this on-farm system. Our observations of *L. lineolaris* counts in the woods are in agreement with Khattat and Stewart (1980), suggesting that it is not a preferred habitat. We found adult *L. lineolaris* numbers increased on traps in strawberry, in early spring (March–April), just as the first strawberry leaves were emerging. Mailloux and Bostanian (1991) also found that adults migrate to strawberry fields at this time of the season. Conversely, Schaefers (1981) credits the early blossom of the strawberry as the attractant for *L. lineolaris*, suggesting adult activity is not observed until that time.

Mailloux and Bostanian (1991) reported early nymph activity at the green bud stage. However, in our study, nymphs were not detected until the first blossom (2000), mid-blossom (2001), and ripe berry stages (2002). In addition, nymphs did not reach damaging levels (>0.25/blossom cluster; Mailloux and Bostanian 1988) in any year until the green berry stage, which is considered to be the least susceptible to damage (Allen and Gaede 1963). Because we did not detect a significant number of nymphs until the green berry stage, control efforts would be more effective if adult *L. lineolaris* were targeted (Wold and Hutchison 2003).

The Weibull model provided a good description of the capture of adult *L. lineolaris* as they emerged from overwintering ($r^2 = 0.99$). Peak adult capture was predicted to occur very early in the season, at 10 DD, during the vegetative stage. In addition, the model established that adult *L. lineolaris* are present throughout the development of the strawberry fruit. However, given the low number of degree-days required for peak adult capture, there is little room for error in calculation and therefore may be of little practical use for growers. With the rapid emergence of *L. lineolaris* early in the season, growers should not rely solely on degree-day accumulation, but rather on the combination of degree-day accumulation and sticky trap capture. The combination of these two monitoring tools should help to ensure that the peak of adult *L. lineolaris* emergence is not missed.

In summary, we found that the yellow sticky trap is a useful tool to detect emerging adult *L. lineolaris* during the early stages of growth. Using the Weibull function, we were able to predict that the peak capture of adult *L. lineolaris* occurred during the vegetative stage. In addition, we found that adult *L. lineolaris* remained active throughout the susceptible stages of strawberry. Based on 3 years of phenology data, we found that nymphs are not active during the susceptible stages of strawberry growth, and therefore, the current published ET based on nymphs is not appropriate for *L. lineolaris* management in Minnesota.

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