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Optimum Spraying Time and Management Guidelines for Soybean Aphid Control

He, Fugang; Yan, Fanyue; Xin, Wanmin; Li, Xiaoping; Wang, Yanqin

(Institute of Plant Protection, Liaoning Academy of Agricultural Sciences, Shenyang, Liaoning)

Zhang, Guangxue

(Institute of Zoology, China Academy of Sciences, Beijing)

Abstract

In Liaoning Province, the population of soybean aphid, *Aphis glycines* Matsumura, increases the most rapidly in late June, which is the critical period for aphid control. The current guideline for spraying is 10,000 aphids per100 plants. This guideline may be relaxed to 23,800 - 40,700 for cultivar Tiefeng #18 and to 26,500 – 33,000 for cultivar Liaodou #3 in the plains region found in the middle and lower reaches of Liaohe River.

It is difficult to use aphid numbers as a management guideline in agricultural practice. According to our studies, the ratio of infested plants with rolled leaves is closely correlated to the aphid number per 100 plants. The linear regression equation is $\hat{y} = 4.283 + 1.8419x$ ($r = 0.90$), where $\hat{y}$ is the rolled leaf ratio and x is the aphid numbers per 100 plants.

Therefore, instead of aphid numbers per 100 plants, we propose to use the ratio of plants with rolled leaves as the management guideline for large-scale field control of soybean aphids, which is 10% for Tiefeng #18 and 8% for Liaodou #3.

Key words: Soybean aphid, optimum spraying time, economic threshold.

The soybean aphid, *Aphis glycines* Matsumura, is an important pest of soybeans, which may cause up to 50-70% yield losses in severely infested years. To set up reasonable guidelines and determine the appropriate time to take control measures is of extreme importance for integrated pest management of soybean aphid. Therefore, we conducted these studies from 1981 to 1988.

Materials and Methods

1. **Soybean cultivars:** Tiefeng #18 and Liaodou #3.

2. **Experiments on management guidelines**

Tiefeng #18 was spot-planted with equal plant space of 10 cm. Liaodou #3 was stripe-sown with a row space of 60 cm. Other field management was the same as normal field practice. Spraying of 1 to 1000 diluted 40% Rogor (dimethoate) emulsion was applied to control aphids. Applications started on June 5th, 10th, 15th, 20th, 25th, 30th and July 5th and 10th were considered as different treatments. Each treatment was replicated 3 times at an interval of 5 days. Controls were plots without spraying. The plot size of both treated and control plots was 15 m^2 and all plots were randomly arranged. Soybean yield was determined in the fall season. Additionally, we examined aphid numbers in some survey plots. Starting on June 5th, the aphid numbers on 100 plants randomly selected by the 5-point sampling method were examined and recorded at an interval of five days until the aphid numbers began to decline. Soybean yields in these plots were not determined. At the same time of each survey, we also randomly selected 100 plants from areas outside the survey plots and recorded the developmental conditions of trifoliate leaves, blooming, podding and leaf distortion. About 400-500 aphids were brushed off from these plants and examined for the numbers of aphids at different developmental stages under dissecting microscopes.

3. Studies on appropriate spraying time

Sowing method and other cultural practices were the same as mentioned above. Randomly arranged plots with the size of 15 m^2 were treated with 1 to 1000 diluted 40% Rogor emulsion. Sprayings were applied on June 10th, 15th, 20th, 25th, 30th and July 5th and 10th. There were 3 replicates in each treatment. No spraying was applied in the control plots. Yield was evaluated in the fall season.

4. Yield evaluation and measurement of aphid numbers

When soybean plants were mature, a two-meter wide soybean strip was randomly selected in each treated plot for soybean yield evaluation. Plants in the selected strips were harvested, threshed and estimated individually. Plant height, branch numbers, numbers of pod-bearing sections, total pod numbers, numbers of filled pods, yield per plant, seed count, 100-kernel weight and plot yield were recorded. Yield per plant and yield per plot were then used to calculate yield loss. Aphid numbers per plant were used to calculate the aphid numbers and cumulative daily aphid numbers (N_t) per 100 plants. Then we could analyze the relationship between aphid numbers and yield loss and the effects of aphid numbers on economic parameters. The equation can be expressed as follows:

$$N_t = \sum_{t=1}^{n} \sum_{t=0}^{m-1} N_i E^{\ln\left[\frac{N_{(i+1)}}{N_i}\right]^{\frac{t}{m}}}$$

Where m is the interval of days between surveys; N_i is the initial aphid number; $N_{(i+1)}$ is the final aphid number; n is the number of surveys; and E is a natural number.

Results and Analysis

I. Effect of soybean aphid infestation on soybean yield characters

1. Path analysis of yield characters for cultivar Liaodou #3

Quantitative characteristics such as plant height, numbers of filled pods, seed count, 100-kernel weight and aphid numbers per 100 plants were important factors associated with yield. Yield losses resulted from various degrees of damage these characteristics demonstrated from the aphid infestation. The results of path analysis showed contributing effects of the following parameters on the yield, listed in the order of importance: seed count, $P_3y = 0.9859$; number of filled pods, $P_2y = -0.9344$; average plant height, $P_1y = 0.5322$; 100-kernel weight, $P_4y = 0.1004$. The effects of aphids per 100 plants on the performance of these characteristics are listed in the order of significance as: seed count, $P_{53} = -0.5262$; 100-kernel weight, $P_{54} = -0.4791$; plant height, $P_{51} = -0.3643$; plot yield, $P_5y = -0.2742$; number of filled pods, $P_{52} = -0.0261$. The indirect influence among plant height, number of filled pods, seed count, and 100-kernel weight were $P_{12} = -0.1176$, $P_{23} = 0.952$, $P_{34} = -0.0286$.

Our results showed that (1) the aphid number per 100 plants had negative effects on yield, plant height, seed count, weight per 100 seeds. Among these, seed count was the most affected character, and 100-kernel weight was the second most affected character; (2) plant height, seed count, and 100-kernel weight all had positive effects on yield. Seed count affected the yield the most and plant height was the second most significant factor. The effects of aphid infestation on yield was realized through its effects on seed count; (3) the correlation coefficient between the number of filled pods and the yield was very small, and the path coefficient was negative because seed count were highly correlated with the yield and thus masked the effect of number of filled pods. The yield increased proportionally with the increase of seed count, but at a given level of seed count, the more filled pods we had, the lower the ratio of multiple-seed pods would be, and thus, had a negative effect on the yield.

2. Stepwise regression analysis on economic parameters of Tiefeng #18

After stepwise regression analysis on 10 economic parameters such as plant height, branches, etc. with yield loss for Tiefeng #18, models for yield prediction and yield loss were constructed. In the defined range of variance, only total pod number (x_3) and cumulative daily aphid number (x_{10}) were highly correlated with yield. The constructed models are as follows:

Yield prediction model: $\hat{y}_1 = 2.4707 + 0.2543x_3 - 0.0043x_{10}$ ……………………………… (1)

($r = 0.9967$, $s = 0.4417$)

Yield loss model: $\hat{y}_2 = 88.9957 - 1.134x_3 + 0.0217x_{10}$ ……………………………… (2)

($r = 0.9967$, $s = 1.9678$)

As shown in the above equations, the total pod number and cumulative daily aphids per 100 plants are the key factors that affected the yield of Tiefeng #18, which is different from the performance of Liaodou #3 and could be caused by their different characteristic of seed numbers per pod. The total pod numbers are directly proportional to the yield. The final soybean yield is determined by the productivity of the soybean plants, a good crop stand and stature as a basis for specific numbers of pods. Early branching, multiple branching and early canopy formations are critical to high yield. Cumulative daily aphid numbers are negatively correlated with soybean yield. That is, longer periods of high aphid infestation greatly affect the normal branching, floral differentiation, and pod bearing, and consequently, reduce pod numbers and yield.

II. Appropriate time for spraying

Late June is the developmental stage of soybean flowers, and is also the most rapid increasing period for aphid population. The aphid numbers per 100 plants jumped from 8000 to 15×10^4, and the coefficients of variation for both aphid numbers and cumulative daily aphid numbers per 100 plants reached their highest levels (Table 1).

Table 1. Aphid numbers ($\times10^4$) per 100 plants and coefficient of variation at different stages (Shenyang, 1988)

Date (month/day)	Developmental stage	Aphid No.	Cumulative daily aphid No.	Coefficient of variation for aphid No.	Coefficient of variation for cumulative daily aphid No.
6/10	Initiation of flower primordia	0.1066	0.2457	14.81	34.13
6/15	Calyces differentiation	0.4689	1.6587	4.40	6.75
6/20	Calyces differentiation	0.8089	4.9494	1.73	2.98
6/25	Calyces differentiation	3.3587	15.2400	4.15	3.08
6/30	Stamina differentiation	15.3833	61.0664	4.58	4.01
7/5	Pistil differentiation	15.0659	137.0281	0.98	2.24
7/10	Initiation of ovule, anther, and stigma	40.1222	277.8696	2.66	2.03

If a considerable proportion of the aphid population is made up of the alatoid nymph, which metabolizes and reproduces very quickly, then it is a devastating period of aphid infestation. The calyces differentiation period is the most luxuriant growing and developing period for soybean, and it is also the period that vegetative and reproductive growth concur. During this time, the amount of dry matter and nitrogen content in vegetative organs of soybeans, the dry matter in the flowers and pods are at their peak levels. It is also the critical period for nutrient synthesis and yield formation of soybean plants. If severe aphid infestation occurrs at this time, it will result in the withering or even shedding of flowers, reduced pods and seed count. The rapid growing aphids excrete large amounts of sticky honeydew on leaf surfaces, which favor the growth of molds. The vigorous growing molds form a sooty layer on leaf surfaces and thus greatly decrease the efficiency of photosynthesis of these leaves. Furthermore, the stress of aphid infestation reduces the height of plants, lowers their growth potential and thus decreases their competitive power against weeds. The yield loss would be minimized if control measures were taken at this time. Therefore, the critical period for control of soybean aphids is around June 25 (± 3 to 5 days) (Table 2).

Table 2. Effect of different timing spraying on soybean yield (Shenyang 1988)

Date (month /day)	Developmental stage	Plot yield (g)	Plant height (cm)	Filled pods(No.)	Seed count	Weight (g/100 seeds)	Yield loss (%)
6/05	2-3 leaves	117.00	48.80	27.22	53.61	13.68	74.67
6/10	3-4 leaves	133.00	51.76	33.09	64.88	13.86	73.39

6/15	4-5 leaves	140.66	48.26	22.65	44.47	13.90	66.02
6/20	4-5 leaves	220.80	64.40	33.36	69.46	14.97	52.27
6/25	Beginning bloom	367.26	62.23	52.36	109.46	14.65	28.48
6/30	Blooming	328.94	41.20	45.36	91.59	16.23	31.25
7/05	Blooming	227.59	60.66	38.72	78.10	14.48	50.61
7/10	Blooming	191.54	60.33	43.39	86.95	15.19	59.79

Note: cultivar was Liaodou #3.

III. Management guidelines

1. Model construction

(1) Stepwise regression analysis of data on Tiefeng #18 shows that total pod numbers and cumulative daily aphid numbers per 100 plants are key factors affecting yield of Tiefeng #18. Based on the analysis of quantitative correlation between 10 independent variables, we found that the total pod numbers are highly correlated with aphid numbers per 100 plants. The linear regression equation between these two is:

Yield forming model: $x_3 = 84.8552 - 0.6114x_9$ ………………………………………… (3)

($r = 0.885$)

We may get the yield loss model by substituting the equation (3) in equation (2):

$\hat{y}_4 = -9.1425 + 0.2657x_9 + 0.0772x_{10}$ ……………………………………………………… (4)

Then, the parabola equation between aphid numbers per 100 plants and yield loss would be:

$\hat{y}_5 = 0.4337 + 0.0776x_9 + 0.0171(x_9)^2$ ……………………………………………………… (5)

($F = 24.59^{\#\#}$)

Equation (5) could be used to calculate the guideline of aphid numbers per 100 plants during the critical period of soybean aphid infestation, and equation (4) may be used to calculate the guideline of cumulative daily aphid numbers per 100 plants.

(2) The parabola equation of aphids per 100 plants and yield loss for Liaodou #3 is:

$\hat{y}_6$ = -4.3045 + 1.955x_9 - 0.0252$(x_9)^2$

…………………………………………………………… (6)

(F = 7.64 $^{\#}$)

The linear regression equation of yield loss against cumulative daily aphids per 100 plants is:

$\hat{y}_7$ = -8.8591 + 0.1591x_{10}

……………………………………………………………………… (7)

(r = 0.86)

2. Calculation of permissible loss threshold during control

$$D = \frac{C}{P} + K + F = \frac{2.10}{0.60} + 90\% \div 300 = 1.2963$$

where C was the control cost (RMB *yuan*,¥) per *mu* (a measure unit in China, 1 *mu* = 0.1644 acre), which included C_1— insecticide cost ¥0.90 *yuan*/*mu*; C_2— labor fee ¥0.80 *yuan*/*mu*; C_3 – wear and tear of machinery ¥0.20 *yuan*/*mu*; C_4—ineffective loss ¥0.20 *yuan*; P was the sale price of soybean ¥1.2 *yuan*/kg; K was the control effect 90%; F was the soybean yield of 150 kg/*mu*; D was the permissible economic loss.

3. Calculation of management guidelines

(1) *The guideline of aphid numbers per 100 plants for Tiefeng #18*. According to equation (5), if

$\hat{y}_6$ = D = 1.2963, then the binomial becomes: 0.0171$(x_9)^2$ + 0.0776x_9 - 0.8626 = 0

$$x_9 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{-0.0776 \pm \sqrt{0.0776^2 - 4 \times 0.0171 \times (-0.8626)}}{2 \times 0.0171}$$

$$= 5.187 \times 10^4 \text{ aphids (100 plants)}$$

(2) *Guideline of cumulative daily aphids per 100 plants for Tiefeng #18*. According to equation (4), suppose $\hat{y}_4$=1.2963, x_9=5.187, thus, the management guideline for cumulative daily aphids per 100 plants is x_{10}=1.1736×10^6 aphids.

(3) *The guideline of aphid numbers per 100 plants for Liaodou #3*. As indicated in equation (6) with the permissible economic loss of $\hat{y}_6$ = D = 1.2963, we obtain the binominal as:

-0.0252$(x_9)^2$+1.955x_9-5.6008=0

$$x_9 = \frac{-1.955 - \sqrt{1.955^2 - 4 \times 0.0252 \times 5.6008}}{2 \times (-0.0252)} = 2.98 \times 10^4$$

(4) The guideline of cumulative daily aphids per 100 plants for Liaodou #3. As shown in equation (7), $x_{10} = 6.383\times10^5$ aphids. The guidelines of aphids per 100 plants are: 5.187×10^4 for Tiefeng #18, and 2.98×10^4 for Liaodou #3.

IV. Simplification of management guidelines

Using aphid numbers or cumulative daily aphid numbers per 100 plants as management guidelines in agricultural practice is very laborious and subject to inevitable errors of vision. Furthermore, these guidelines are hard for farmers to understand and accept because of the complicated counting and calculation. Based on our investigation, the percentage of plants with rolled leaves is highly correlated with aphid numbers. If we set the percentage of plants with rolled leaves as a management guideline, it will be much easier for practical use. The linear regression equation between the percentage of plants with rolled leaves ($\hat{y}_8$) and the aphid numbers (x_9) is: $\hat{y}_8 = 4.283 + 1.8419\ x_9$ ($r = 0.90$). If we use the percentage of plants with rolled leaves, instead of aphid numbers per 100 plants, as a management guideline, then the guidelines are:

Tiefeng #18: $\hat{y}_8 = 4.283 + 1.8419 \times 5.187 = 13.84\%$;

Liaodou #3: $\hat{y}_8 = 4.283 + 1.8419 \times 2.98 = 9.77\%$.

Therefore, we propose that, in the plains regions of the middle and lower reaches of Liaohe River, the management guidelines for soybean aphids control be rolled leave rates of 10% for Tiefeng #18 and 8% for Liaodou #3 (soybean plant with leaves rolled up to 30 degree on either direction of the leaf surface may be considered as a rolled leaf plant).