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Prediction of Aphid Infestation by the Numbers of Overwintering Soybean Aphid Eggs

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ABSTRACT *Aphis glycines* Matsumura is a rampant insect pest on cultivated soybeans in *Jilin* Province. Prediction of its occurrence and infesting tendency is an important basis for effective control. Issues related with the application of overwintering egg numbers to predict the occurrence of soybean aphid were studied in this paper. The ratio of winter host numbers to summer host numbers and overwintering egg quantity in different areas of *Jilin* Province were compared. Based on data about overwintering egg quantities in winter hosts, *Rhamnus davaricus,* aphid numbers in early and pre-peak infestation stage from 1961 to 1981 in *Gongzhuling* district and aphid infestation level in *Siping* district, the relationship between overwintering egg quantity, and aphid number were analyzed. A prediction equation for forecasting aphid quantity and aphid infestation level by the overwintering egg quantity in *Gongzhuling* district was proposed.

The occurrence pattern of soybean aphid infestation, its prediction and control methods have been studied since 1952[1]. *Rhamnus davaricus* has been proved the overwintering host for soybean aphids in *Jilin* Province, and proposed that overwintering eggs of over 10,000/100 wattles indicate an early aphid outbreak in coming year. In normal years, the number of overwintering eggs was below 50/100 wattles, and the speed of aphid and environment conditions from late June to early July should be considered in the prediction of aphid outbreak[1, 2]. More than 20 years' forecasting practice proved it feasible to predict the infestation level of soybean aphid by the quantity of overwintering eggs. Yet there were still some questions need to be resolved. I. g. there were years in different areas in *Jilin* Province with very different numbers of overwintering eggs, but had similar levels of aphid infestation. The quantities of overwintering eggs/100 wattles in the east mountain areas were usually less than the quantities in the central plain areas, but the aphid infestation occurred earlier more severe in Spring. Were there some other important factors affecting the occurrence of aphid infestation? There were several species of aphids laying their overwintering eggs in their winter host *R. davaricus* (these eggs could be distinguished when they hatched in spring). The recorded data of overwintering eggs included eggs of several different aphid species. Was it feasible to use the overwintering egg numbers of mixed species to predict aphid infestation? In order to solve these questions and improve the precision and accuracy of forecasting, we conducted this study project. We analyzed the effect of summer host (soybean) to winter host ratios on the quantity of overwintering eggs in different areas. Based on the field survey data from 1961~1981, logarithmic transition method and statistical analyses were employed to study the correlation between the overwintering egg quantity in *Gongzhuling* district and aphid numbers in early and pre-peak stages, and the correlation between overwintering egg quantity and level of aphid infestation in *Siping* district. Several regression formulae for prediction were deduced.

1 Impact of winter host number on quantity of overwintering aphid eggs in *Jilin* Province.

Rhamnus have been verified the winter host of soybean aphid since the early 1950's [1]. No other winter host was found so far. *Rhamnus* is not a kind of tree for lumber in the agriculture district in *Jilin* Province, and is subjected to constant cut and grow like bushes. Its distribution is not even in different areas in *Jilin*. It is extensively distributed and commonly seen in the eastern mountain and hilly areas. In the central plain areas, it sporadically spreads along riversides or beside gutters. It is very scarce and difficult to found any in the west grassland. The summer host of soybean aphid is mainly cultivated soybeans in *Jilin*. In terms of cultivation area, there were 346666.6 hectares of soybean fields in the central areas (include *Changchun* and *Siping* districts), and about 153333.3 hectares in the east areas (include *Jilin*, *Tonghua* and *Yanbian* districts). The number of summer hosts affects the number of sex aphids migrating to their winter host. Areas with high numbers of summer hosts could offer high numbers of overwintering aphids. In terms of summer host number to winter host number ratio, the higher the ratio value, the higher the overwintering eggs/100 wattles, and vice versa. In normal years, the number of overwintering eggs in winter host in the central areas was more than that in the eastern areas. Taking the winter season in 1973 as an example (Table 1), the quantity of overwintering eggs in most areas of the

Table1 Comparing of quantity of overwintering eggs of soybean aphid in1973

	Sites of survey	Overwintering eggs (No./100 wattles)	Summer host to winter host ratio	
Central areas	*Changchuen* Institute of Agricultural Sciences	8,395	5	5/1 most soybean/least Rham.
	Riversides of *Zhangjiajie*, *Gongzhuling*	2,512	2	4/2 more soybean/less Rham.
	Riverside of *Nangweizi*, *Gongzhuling*	1,570	1	3/3 many soybean/little Rham.
Eastern areas	*Chennan Gongshe* in *Hailong* county	1,443	1	3/3 many soybean/little Rham.
	Zhuojia in *Yongjie* county	786	0.5	2/4 less soybean/ more Rham.
	Kuaidamao Gongshe in *Tonghua* county	39	0.2	1/5least soybean/ most Rham.

Province was higher than normal in 1973, and the quantities of overwintering eggs in the central areas was significant higher than those in the eastern areas. The quantities of overwintering eggs were proportional to the ratio of summer host numbers to winter host numbers in every site surveyed. The summer host to winter host ratio affected the number of overwintering eggs in different areas. Even in the same area, the overwintering egg numbers varied as the ratio of summer host to winter host changed from site to site. However, the population dynamics of the overwintering eggs kept the similar trend over these years. For example, the survey data from two sites in *Gongzhuling* district from 1966- 1974 were as follows: Site 1, *Zhangjiajie*, was 7.5 kilometers southeast from *Gongzhuling*, where most fields were dry and planted with soybean. *Rhamnus* trees sporadically grew on the ditch sides. Site 2, *Nangweizi*, was located at East Liao riverside 10 kilometers west of *Gongzhiling*. There were more paddy fields than soybean fields. *Rhamnus* trees grew along the East Liao riversides and were a little more abundant than in site 1. Therefore, the sizes of overwintering egg population were quite different in these two sites. The number of overwintering eggs at site 1 [*Zhangjiajie*] was usually more than that at site 2 (Table 2). When there were years with high overwintering egg populations, the overwintering egg population at both sites was high as in 1966, 1967, 1971, and 1973. The overwintering egg numbers were low at both sites if there were low overwintering egg numbers in other places as in 1969, 1970, 1972, and 1974. The tendency of overwintering egg populations in the two sites over years was in accordance with the infection levels of soybean aphid in *Siping* district. This further indicated that although the ratio of summer host to winter host at different places had great effects on the number of overwintering eggs, the ratio was a relatively stable factor at the same site and there was no need to consider its effect if applied to the survey data from the same site. In order to accumulate data of overwintering eggs and obtain accurate prediction model, it was necessary to choose representative-sampling sites with relatively stable data.

Table 2. Comparison of overwintering egg numbers at two sites near *Gongzhuling* and aphid infestation levels in *Siping* district from 1966 to 1974

Year / Site of survey	**1966 winter**	**1967 winter**	**1969 winter**	**1970 winter**	**1971 winter**	**1972 winter**	**1973 winter**	**1974 winter**
Site 1, *Zhangjiajie*	29,394	1,230	40	207	1,555	2	2,512	149
Site 2, *Nangweizi*	5,845	168	0	15	1,102	0	1,570	37
Infestation level in *Siping* next year	6	4	3	5	6	3	6	4

Note: egg numbers in the table is the overwintering eggs in winter, and infestation level is the situation of next year.

2 Correlation between overwintering egg quantity and aphid population in fields in *Gongzhuling* district

2.1 Methods of survey and data handling

2.1.1 Data of overwintering eggs: Two hundred to 300 One-year-old branches of *Rhamnus* grown on the riverbanks in *Zhangjiajie* were cut as samples during the winter of each year. Eggs on the tip 33 cm parts of all the wattles were examined and used to calculate the average eggs numbers per 100 wattles.

2.1.2 Data of aphid population in fields: Each year, one to two soybean plots at designated positions were chosen from the experimental farm of the Provincial Academy of Agricultural Sciences in *Gongzhuling* to study the aphid population. One hundred plants at fixed positions were selected from each plot to count the aphid numbers from June 5 to July 30 with an interval of 5 days. Aphids in all the central leaves and trifoliate leaves on the top of main stems were counted. According to the surveying data of 20 years, the dynamics of soybean aphid population in *Gongzhuling* could be divided into following three stages.

1) Initial stage of infestation: In normal years, aphids start to migrate to soybean fields in late May or early June. From data of years field investigation on aphid number in 100 plants, we found that aphids appeared in soybean fields as early as June 5 in a few years; in about half of the years, aphids emerged in soybean fields on June 10; and aphids found in soybean fields on June 15 in most of the years. 2) Pre-peak stage: aphid population increases dramatically after June 25. 3) Peak infestation stage (aphid number is at its peak and is about to decrease): It is usually in the middle or late July. Therefore, in practice, we defined the aphid data on June 15 as the initial state of infestation and the aphid number on June 25 as the infestation state of pre-peak stage. Aphid infestation levels in *Siping* district was classified into 6 grades (that is very slight, slight, mediate, slightly heavy, heavy, and severe infestation represented by numbers 1 through 6) [4].

Four sets of data represented the amount of overwintering eggs /100 *Rhamnus* wattles, the number of aphids /100 plants at the initial and pre-peak stage, and the infestation level in soybean fields from 1961 to 1981 were listed in Table 3. Data in 1963 was incomplete and thus excluded from the statistical analysis.

Table 3. The amount of overwintering eggs, aphid numbers in initial and pre-peak stage, and infestation levels from 1961 to 1981 in *Gongzhuling*, *Jilin* Province

Year	X, overwintering eggs /100 wattles*	Y_1, aphids /100 plants on June 6	Y_2, aphids /100 plants on June 25	Y_3, infestation level (grade)
1961	3,256	2,420	26,420	6
1962	1,599	502	412	4
1964	1,320	313	1,661	5
1965	3	5	1,342	4
1966	22	2	757	3
1967	29,394	9,828	18,303	6
1968	1,230	1,507	11,734	4
1969	123	0	215	4
1970	40	56	370	3
1971	207	53	66	5
1972	1,555	692	1,839	6
1973	2	0	8	3
1974	2,512	1,162	4,441	6
1975	298	31	4,210	4
1976	1,414	383	2,848	5
1977	2,489	1,883	12,490	5
1978	37.5	16	550	3
1979	2,639	558	10,582	4
1980	65	0	21	2
1981	13.5	6	86	2

*The overwintering eggs were the initial No.'s of that years, i. g. data of 1977 was from the survey between winter of 1976 to spring of 1977

2.2 The methods of calculation

Because most values in columns of Table 3 were in geometric series except a few extreme numbers, there was no significant correlation between these data if calculated by their original values. After original data were transformed into their logarithm values, correlation analyses were conducted again. The aphid values of zero on June 15, 1969, 1973, and 1980 were first substituted with value 2, and then did the logarithmic transformation. Setting the logarithmic value of overwintering egg as independent variable (X), the correlation coefficients between X and logarithm values of aphid amounts (y_1, y_2), and logarithmic value of infestation levels (y_3) were calculated. The significances of correlation were also determined. Regression equations between overwintering egg numbers and other variables were derived. The computing formulae were as follows:

Correlation coefficient: $r = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \Sigma y^2}}$ Regression equation: y= a + bx

Regression coefficient (b): $b = \frac{n\Sigma xy - \Sigma x\ \Sigma y}{n\Sigma x^2 - (\Sigma x)^2}$ $a = \frac{\Sigma(X^2)\Sigma y - \Sigma xy\ \Sigma x}{n\Sigma x^2 - (\Sigma x)^2}$

Take the correlation analysis between overwintering egg numbers and the aphid numbers per 100 plants on June 15 as an example. 1) We transform the overwintering egg numbers and aphid numbers into their logarithmic values; 2) then calculate the correlation coefficient between the two sets of data, which is 0.9.35; 3) determine the significance of correlation: from correlation coefficient table, we can get r= 0.6787 when number of freedom N= 20-2 = 18 and P= 0.001. Since the correlation coefficient between these two data sets is 0.9035, which is > 0.6787, we come to a conclusion that these two sets of data are very significantly correlated (P< 0.001). 4) Least square method is used to obtain the regression model for the prediction of aphid numbers on June 15 (y_1) by the overwintering egg numbers (x): y (log value of aphid numbers on June 15) = -0.4504+ 0.9801x (log value of overwintering eggs per 100 wattles).

2.3 Analysis and application of results

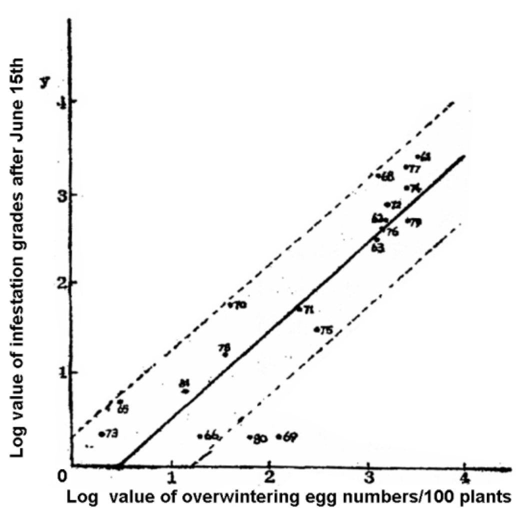
All the calculated results are shown in Table 4. Individual analysis is as the following:

Table 4. Correlation between overwintering eggs and aphid No. in fields in *Gongzhuling*, *Jilin*

Items	No. of years	Correlation coefficient (r_{xy})	Significant (p <)	Regression prediction equation (y =)	Standard deviation (SD)
Overwintering eggs and aphids /100 plants on June 15	20	0.9035	0.001	-0.4504+0.9801x	0.5211
Overwintering eggs and aphids /100 plants on June 25	20	0.7377	0.001	1.4113+0.6528x	0.6708
Overwintering eggs and aphid infesting levels	20	0.7260	0.001	0.3694+0.0946x	0.1006

*Original data were transformed into logarithmic values before calculation

2.3.1 The correlation between log values of overwintering eggs/100 wattles in *Gongzhuling* and log values of aphids in soybean fields on June 15 were very significant (r= 0.9035，P< 0.001). The intercept of the regression equation was -0.454, which indicated that aphid numbers on June 15 in soybean fields were always lower than the number of overwintering eggs /100 wattles. When the number of overwintering eggs/100 wattles was very low, it is possible that no aphids could be found in 100 plants in soybean fields. The amount of aphids in the fields increased as the density of overwintering eggs went up. The regression coefficient value of 0.9801 indicated that ratio of increased aphid amount in the fields to the increased overwintering eggs was close to one. Figure 1 showed that only two out of 20 years' data did not fit this regression equation.



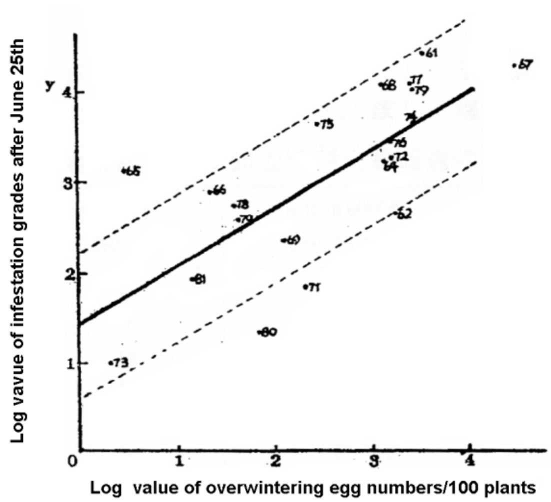


Fig 1 Regression of # of overwintering eggs to # of aphids on June 15

Fig 1 Regression of # of overwintering eggs to # of aphids on June 25

2.3.2 Correlation between log values of overwintering eggs and log values of aphids on June 25 was very significant (r= 0.7377, P< 0.001). The intercept and regression coefficient of the regression equation were 1.4113 and 0.6528 respectively, which indicated that there was always considerable amount of aphids /100 wattles on June 25 no matter how many overwintering eggs had been there (Figure 2). The aphid number increases as the overwintering egg number increases but at a ratio of 0.6528 to 1. As shown in Figure 2, only three out of the 20 dots (data of three years out of 20) fall out of the ranges of the regression lines.

2.3.3 Correlation between log values of overwintering eggs and log values of infesting levels was very significant (r= 0.7377, P< 0.001). The intercept and regression coefficient of the regression equation were 0.3694 and 0.0946 respectively, which indicated the aphid infestation levels was from mediate to light grade (grade 2.34) in normal years. Figure 3 also showed that only three years' data out of 20 did not fit this regression equation.

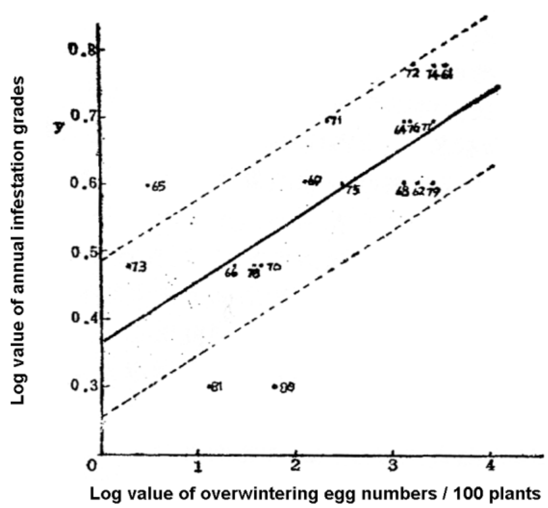


Figure 3 Regression of # of overwintering eggs to occurrence level of aphids

When we conduct forecast work with overwintering egg amounts from field survey, we may find out the three predicting values directly from Figure 1, 2, and 3 by the obtained overwintering egg amounts. For application convenience, after conducted the logarithmic transformation and applied the transformed data in the above mentioned regression equations, we listed the predicated aphid numbers on June 15 and June 25, as well as the predicated infestation levels corresponding to several common values of overwintering eggs in Table5, which may be used as reference in forecasting practice.

Table 5. Aphid forecast Index table using overwintering eggs in *Gongzhuling* district

Overwintering eggs /100 wattles	Aphids /100 plants on June 15	Aphids /100 plants on June 25	Aphid infesting levels in *Siping*
1	0	26	2.3
10	3	116	2.9
50	16	356	3.4
100	32	523	3.3
1000	309	2360	4.5
10000	2950	10589	5.6

3 Discussion

1) The above statistical analyses showed that the logarithmic values of overwintering eggs in *Gongzhiling* district were very significantly correlated with the log values of aphid numbers on June 15 and June 25 as well as the log values of the aphid infestation levels in *Siping* district ($P < 0.001$). Fitness rate of historical data reached 85 to 90%, which indicated that the three regression equations with overwintering egg numbers as independent variable may be used in long term prediction. For practical application, a series predictive indices regarding the use of overwintering eggs to forecast the amounts of soybean aphids in *Gongzhuling* district.
2) Difference in the summer host to winter host ratio in different areas in *Jilin* would affect the number of overwintering eggs/100 wattles. However, this ratio was a relatively stable value at the same site, thus can be used in general forecasting without worrying about its changing. When applied in different areas, the fluctuation of summer host to winter host ratio can not be ignored, and the above regression equations were not suitable anymore. In order to provide accurate aphid forecast, one should select representative sampling sites in the designated area with relatively stable overwintering egg numbers, and accumulated aphid data over years of survey. Then, regression analyses may be conducted on these data to deduce prediction equations suitable for the designated area.
3) Although the correlation between the amount of overwintering eggs and the amount of aphids as well as aphid infestation levels was very significant, there was only a single variable in the regression equations. Thus, among the data of 20 years, data of a few years did not fit the regression equations, which could be caused by factors as abnormal weather conditions, natural enemies. Comprehensive forecasts involving weather conditions, natural enemies as well as overwintering eggs will be discussed separately in another paper.
4) In fact, eggs of some other aphid species were also found in rhamnus, the overwintering host of soybean aphid. Moreover, there was few rhamnus in west of *Jilin*, and sometimes, it was difficult to find one in some counties or people’s communities. Because of these, we have questioned the traditional aphid prediction method. Therefore, we considered the correlation analyses employed in this article empirical, which only analyzed the correlation between two variables, i.e. data sets from many years’ field surveys. Although there was few eggs of other aphid species mixed in the overwintering egg counts, i.e. the independent variable in the predictive regression equations also included eggs of other aphid species, the accuracy of prediction was not affected by those mixing egg numbers. Regarding the scarceness of overwintering host in the West of *Jilin*, the aphids in soybean fields could be migrating from other areas, thus, the aphid infestation occurred late and the infestation level was light. More

study is needed to confirm the source of soybean aphid in these areas. Before getting this conclusion, it is necessary to study the relationship between infestation levels in the central areas and that in the West areas, and use their correlated trends to forecast.

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