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Studies on Epidemiology and Prediction of Soybean Mosaic Virus

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***Abstract*-Some epidemiological factors of SMV were studied in Jinan, Shandong Province from 1984 to 1989. The results indicated that the resistance of soybean cultivars and the amount of primary inoculum sources dominated the dynamic aspects of SMV epidemics. It was found that soybeans were easily infected by SMV during seedling stage and the peak of disease incidence happened during flowering stage. During seedling stage higher temperature and less rain for spring cropping soybean and lower temperature and more rain for summer cropping soybean were favorable to disease development. Vector-transmission experiments with 13 species of aphid showed that *Myzus persicae*, *Aphis craccivora* and *A. glycines* were the major vectors, which played an important role in transmission of SMV in soybean fields. Models of disease occurrence forecast were established by means of stepwise regression and path analysis on 16 groups of data obtained in 5 years.**

***Keywords*- soybean mosaic virus, epidemiological factors, predictive model, aphid vectors**

Soybean Mosaic Virus (SMV) is one of the most widely distributed and highly harmful epidemics in the world, including China. As observed from its occurrence and epidemic properties, it has been proven that soybean seeds with the virus are the primary inoculum sources. Aphids, the vector in transmission of SMV in soybean fields, spread the virus in a non-persistent manner (Minghou Zhang, 1986). In order to define the epidemiological factors of SMV in certain conditions and establish models of disease occurrence forecast, studies were conducted in Jinan from 1984 to 1989. Methods and results are discussed below.

I. Methods

A. Relationship of Soybean cultivars, sowing time and disease occurrence

Six cultivars, -- Qihuang 10, Wenfeng 5, Fengshouhuang, 7588-13, Ludou 4 and Yunhuang 1 --were selected for this study. Sowing time consisted of 6 peroids in 2 seasons, which were spring (May 5th, May 15th, and May 25$^{th)}$ and summer (June 5th, June 15th, and June 25th). Every cultivar was sown in 2 rows every period (distance between rows was 0.5 m, length of rows was 6 m, distance between plants was 0.1 m). Every sowing time was taken as one treatment; arranged in order; repeated 3 times. The disease situation was investigated every 5 days after seedlings sprouted. The ratio of sick plants and a disease severity index were calculated. The severity of disease was divided into 5 levels: Level 0 - no symptoms; Level 1- leaves shriveled, plants didn't dwarf; Level 2- leaves wrinkled and shriveled, plants dwarfed; Level 3- leaves wrinkled and misshaped, plants dwarfed by 1/3; Level 4- sprouts shriveled or top of plants shriveled, plants dwarfed by more than 1/3.

B. *Vector aphid species*

Aphids in this study included 13 species, which were *Myzus persicae, Aphis craccivora, Aphis glycines, Aphis gossypii, Rhopalosiphum maidis, Longiunguis sacchari, Liaphis erysimi, Aphis sophoricola, Chaitophorus populeti, Macrosiphoniella sauborni, Macrosiphoniella smilioblouga, Schizaphis graminurm* and *Rhopalosiphum padi*. Aphids were fed for one hour with Qihuang 10's sick leaves and then put on Qihuang 10's healthy seedlings. One seedling received 5 aphids. After four hours, the aphids were removed from the seedlings. After vector-transmission these seedlings were put in an aphid-free net house and the disease situation was observed, compared to the seedlings without aphid vector.

C. Relationship between soybean growing season and aphid vector transmission

Wenfeng 5, a susceptible cultivar, was sown in 6 blocks on May 15th. The area of the blocks was 1.5×1.5 m^2. Forty-five plants were kept for observation. Six treatments, -- from sprouting stage to the third trifoliate leaf rolled stage; from branching stage to flowering stage; from flowering stage to pod formation stage; from pod formation stage to seed-fill stage; covered by net in the entire growing season; and uncovered in the entire growing season -- were put in order and replicated 3 times. The ratios of sick plants in treating blocks were investigated in the branching stage, flowering stage, pod formation stage and seed-fill stage, respectively.

D. Relationship between aphid population and disease occurrence

One golden yellow colored (33 mm dia.) container with plain water was used to trap aphids in the summer and spring soybean fields respectively (50 mm above the ground). The number and cultivars of winged aphids were checked daily. Also, 50 samples of Qihuang 10 and Ludou4 from 5 locations in summer and spring soybean fields were taken to investigate the cultivars and number of aphids in their cordiform leaves and 3 top trifoliate leaves. Soybeans' disease level and its corresponding growing seasons were recorded.

E. Forecast on disease epidemics

Two to four blocks of different soybean cultivars with different levels of disease resistance were chosen in this analysis. Their initial inoculum sources (ratio of inoculum sources) were checked every year and their dynamic disease situations were systematically investigated (following the same method as D, above). Five independent factors were set as: ratio of inoculum sources; weather conditions in soybean easily infected seedling stages (average temperature, rain-fall, rainy days from May 20th to June 10th of spring soybean; from June 20th to July 10th of summer soybean); and disease resistance levels, while soybean sick plants ratio in disease peak period and disease severity index were set as dependent factors. Models of disease occurrence forecast were established on notable related factors by statistical analysis.

Table 1 Levels of Soybean mosaic virus epidemic factors

Level	Ratio of inoculum sources (%)	From May 20th to June 10th			From June 20th to July 10th			Cultivar's disease resistance	Ratio of sick plants (%)	Disease severity index
		Temperature (°C)	Rain fall (mm)	Days in rain (d)	Temperature (°C)	Rain fall (mm)	Rainy days (d)			
1	0	<=20	<=10	<=4	<=25	<=50	<=4	Highly resistant	<=20	<=10
2	1-2	21	11-20	5	26	51-75	5-6	Moderately resistant	21-40	11-15
3	3-4	22	21-30	6	27	78-100	7-8	Moderately susceptible	41-60	16-21
4	>=5	>=23	>=31	>=7	>=28	>=101	>=9	Highly sesceptible	>=60	>=21

II. Results of experiments

A. Cultivar, sowing time and disease occurrence

Different soybean cultivars' resistance against soybean mosaic virus differed greatly. Disease susceptible cultivars were infected early and heavily, while disease resistant cultivars were infected late and lightly. The average indices of disease severity in 6 sowing times were: 31.3 for the highly susceptible cultivar Wenfeng 5; 14.7 for the moderately susceptible cultivar Qihuang 10, 14.4 for the moderately susceptible cultivar Fengshouhuang; 12.6 and 10.4 for moderately resistant cultivars 7855-13 and Ludou 4 respectively; and 5.9 for the highly resistant cultivar Yunhung 1. Different soybean sowing time also leads to a different disease situation. Spring late-sown soybeans were infected comparatively heavily, with six cultivars' average disease severity indices being 13.1, 12.5, and 15.7 for soybean sown on May 5th, 15th and 25$^{th.}$. However, summer early-sown soybeans were infected comparatively heavily, with six cultivars' average disease severity indices being 21.1, 15.2, and 11.7 for soybean sown on June 5th, 15th, and 25th.

B. Vector aphid species

Vector-transmission experiments with 13 species of aphids found in golden yellow traps, in soybean fields and in surrounding crops, vegetables, trees, and weeds show that both winged and non-winged *M. persicae*, *A. craccivora*, *A. glycines* were soybean mosaic virus vectors, while the other cultivars were not.

Table 2 Tests of Aphid vector transmission on SMV

Aphid species	Wing type	Sources	Number of total plants	Number of sick plants	Ratio of sick plants
M. persicae	Winged	Kale	17	4	23.5
	Non-winged	Kale	44	16	36.4
A. craccivora	Winged	Soybean, *Vigna unquiculata*	20	10	25.0
	Non-winged	Vegetable cowpea	88	18	20.5
A. glycines	Winged	Soybean	21	2	9.5
	Non-winged	Soybean	86	32	37.2
A. gossypii	Winged	Cotton, *Llex chinensis*	40	0	0
R. maidis	Winged	Sorghum	19	0	0
L. sacchari	Winged	Radish	14	0	0
L. erysimi	Winged	Sorghum	17	0	0
A. sophoricola	Winged	*Sophora japonica L.*	20	0	0
C. populeti	Winged	Poplar	20	0	0
M. sauborni	Winged	Dandelion	20	0	0
M. smilioblouga	Winged	*Artimisia argyi*	20	0	0
S. graminurm	Winged	Wheat	20	0	0
R. padi	Winged	Wheat	20	0	0
No inoculum (CK)	Winged	-	105	0	0
No vector (CK)	Winged	-	82	0	0

C. Soybean growing season and aphid vector transmission

The experiments, in which nets were used to prevent natural aphid vector transmission in different growing stages, showed the following. 1) By covering with net in the entire growing season, aphid vector transmission can be prevented. Only in the early seedling stage, sick seedlings with virose seeds appeared. The ratio of sick plants was stable in the entire growing season and declined in the late growing season. 2) Without nets (CK), soybeans were naturally easily infected. The ratio of sick plants in each growing stage was high, and the ratio could reach 73.1% in the peak disease period. 3) With short-term net covering, aphid vector transmission could not be completely prevented. However, soybeans were easily infected in the early growing season while gaining stronger resistance against disease over time. Ratios of sick plants with nets were lower than those without nets by 91.1%, 67.1%, 41.1% and 16.4% respectively for the periods from sprouts to third trifoliate leaf rolled; from branching to flowering; from flowering to pod formation; and from pod formation to seed-fill.

D. Aphid population and disease occurrence

Winged aphids trapped by golden yellow water traps were *M. persicae, A. craccivora, A. glycines, A. gossypii, L. sacchari, S. graminurm, Sitobion avenae, R. padi, L. erysimi, R. maidis, A. sophoricola, C. populeti, M. sauborni*, and *M. smilioblouga* etc. totalling 21 cultivars. *M. persicae, A. craccivora, A. glycines* showed regular population changes since large quantities of them were trapped, but other aphids did not demonstrate the change apparently, since the quantities trapped were small. Five years' cumulative 10-days-average quantities of aphids were 5,212. From this there were 2,326 *M. persicae***,** making up 44.6% of the total; 563 *A. craccivora*, making up 10.8%; 1,329 *A. glycines*, making up 25.5%; and 994 other aphids, making up 19.1%. Winged *M. persicae* appeared from May 20th to July 10th and peaked after May 20$^{th.}$. *A. craccivora* and *A. glycines* appeared in the entire growing season and had two migration peaks. The first migration peak of *A. craccivora* was from May 20th to June 10th, while *A. glycines'* was in early June; the second migration peak of *A. craccivora* was in early August, while *A. glycines'* was from July 20th to August 10th.

Although there were so many winged aphids species migrating into soybean fields, *A. craccivora, A. glycines* are the only non-winged aphids pests. *A. craccivora* started to reproduce as pests right after soybean seedling, then its population peaked at the branching stage (early June), declined in the flowering stage, and was occasionally found in the late growing period. *A. glycines* appeared late, only a few of them found in the seedling stage, then sharply increased from soybean flowering stage in late July to pod formation stage. The peak population was seen from the pod formation stage in early and middle August to seed-fill stage, then the population declined in late August.

A few inoculum sick sprouts appeared from soybean single leaf rolled period to the first trifoliate leaf rolled period. Spring soybean disease peaked from the spring soybean branching stage in late June to the flowering stage in early July, which was mainly due to the aphid vectors including winged aphids of *M. persicae, A. craccivora, A. glycines* and non-winged aphids of *A. craccivora*. Summer soybean disease peaks were in the branching stage, middle July, which was mainly due to the aphid vectors including winged aphids of *M. persicae, A. craccivora, A. glycines* and non-winged aphids of *A. glycines*. After July 20th, soybeans reached stages of pod formation and seed-fill. Although it was at the peak of non-winged aphids of *A. glycines*, soybeans had advanced to the disease resistant stage, and hot weather weakened disease symptoms. Thus, disease severity declines.

E. Forecast on disease epidemics

Sixteen groups of data obtained over 5 years were input to an IBM computer for stepwise regression and path analysis (Huidong Mo, 1985). The results are presented below.

1) *Spring soybean*

The ratio of sick plants was mainly affected by the ratio of inoculum sources ($Py_1x_1 = 0.619$), secondarily affected by cultivars' disease resistance ($Py_1x_3 = 0.252$) and average temperature in susceptible seedling stage from late May to early June ($Py_1x_2 = 0.238$). Disease severity index was mainly affected by cultivars' disease resistance ($Py_2x_3 = 0.403$), secondarily affectedly by ratio of inoculum sources ($Py_2x_1 = 0.33$) and average temperature in susceptible seedling stage ($Py_2x_2 = 0.303$).

2) Summer soybean

The ratio of sick plants was mainly affected by cultivars' disease resistance ($Py_1x_3 = 0.768$), secondarily affected by ratio of inoculum sources ($Py_1x_1 = 0.22$) and average temperature in susceptible seedling stage from late June to early July ($Py_1x_2 = 0.081$). Disease severity index was mainly affected by cultivars' disease resistance ($Py_2x_3 = 0.476$) and ratio of inoculum sources ($Py_2x_1 = 0.471$), secondarily affected by average temperature in susceptible seedling stage ($Py_2x_2 = 0.303$).

In summary, if there are more initial inoculum sources (ratio of inoculum sources), if the cultivar is susceptible to disease, and if temperature and rainfall are favorable at the seedling stage, then disease epidemics are more likely. The factors that notably affect SMV epidemics in field were chosen to set up the occurrence forecast model in Table 3.

Table 3 SMV occurrence forecast model

Cultivar of soybean	Occurrence factors (level values)			Forecast factors (level values)		Forecast formula	Corre-lation coeffi-cients (R)	Significance (F)
	x_1	x_2	x_3	y_1	y_2			
Spring soybean	Ratio of inoculum sources (%)	Average temper-ature	Cultivar's disease resistance	Ratio of sick plants (%)	Disease severity index	$\hat{y}_1 = 0.611x_1 + 0.311x_2 + 0.327x_3 - 0.91 \pm 0.671$ $\hat{y}_2 = 0.286x_1 + 0.362x_2 + 0.478x_3 - 0.96 \pm 0.846$	0.89 0.79	15.99 6.45
Summer soybean	Ratio of inoculum sources (%)	Rain-fall	Cultivar's disease resistance	Ratio of sick plants (%)	Disease severity index	$\hat{y}_1 = 0.186x_1 + 0.06x_2 + 0.859x_3 - 0.251 \pm 0.342$ $\hat{y}_2 = 0.463x_1 + 0.109x_2 + 0.619x_3 - 0.699 \pm 0.567$	0.96 0.92	52.98 23.16

III. Discussion

SMV epidemics were the consequence of integrative effects from hosts' disease resistance, initial inoculum sources and environmental factors. Results of the studies showed that, given a certain quantity of initial inoculum sources, soybean cultivar disease resistance was the major factor on SMV epidemics. Average temperature in spring soybean's susceptible seedling stage was in the range of18.9-22.8 °C. Moderately high temperature and little rainfall were favorable to disease epidemics. Average temperature in summer soybean susceptible seedling stage was in the range of 25.1-28 °C. Low temperature and plenty of rainfall are favorable to disease epidemics. Hot weather weakens disease symptoms while symptoms become apparent after rain, which was consistent with the opinion that low temperatures (18-20 °C) lead to more severe symptoms than high temperatures (27-30 °C) (Irwin, 1981).

Aphid vectors transmitted SMV by a non-persistent manner. Vector transmission distance was short. The ability of virus transmission was strong in the range of 20 m radius from the center of inoculum sources. The relationship between distance from inoculum sources center (M) and SMV's ratio of sick plants (x) fitted exponential regression ($y = 15.105 \bullet e^{-0.153x}$), which was consistent with results from previous studies (Minghou Zhang, 1986; Yongxuan Chen, 1988).

Simulation from historical data using epidemic forecast models based on four factors -- ratio of inoculum sources; cultivar's disease resistance; temperature; and humidity conditions in soybean seedling stage -- resulted in 81.3-87.5% accuracy. Forecasts of 1989 disease conditions matched the outcome. Thus, this forecast model can be used as a reference to quantity analysis of SMV yearly epidemics in semi-annual harvested soybean cropping areas.

IV. REFERENCE

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