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Study on the Optimum Control of Soybean Aphid

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Abstract: Based on the optimum control theory [(1)], integrative effect of 11 controllable factors of soybean field on soybean aphid (*Aphis glycines* Matsumura), natural enemies and summer soybean yield was studied systematically by the approaching optimum point and Orthogonal design L_{27} $(3)^{13}$ from 1993 to 1996. According to the criterion of not only good control of the pest and increase of soybean yield but also protection of natural enemies, the controllable factors were evaluated synthetically and optimum system control of soybean aphid was suggested as follows: soybean sown in the same maize hole (4 soybean plants to 1 maize plant) or soybean interplanted in maize field (9 rows of soybeans to 2 rows of maize), cultivar Lusoybean 4, sowing time about 10 June, dressing seeds with trace fertilizer at 1800 g/ha, dosage of fertilizer N, P_2O_5 and K_2O application at 45, 60 and 150 kg/ha, dosage of solid manure application at 22500 kg/ha, control soybean aphid with Pirmicarb at 60 g/ha. The technologies of optimum control of soybean aphid were made up in the three different modes including soybean sown in the same maize hole, soybean interplanted in maize field and monoculture soybean. It was demonstrated that the results of control to soybean aphid were 93.5%, 83.9% and 71.8%, soybean growth rates were 28.1%, 16% and 15.3%, respectively, densities of natural enemy in the two interplanting modes were as much treble as that of the control.
Key words: *Aphis glycines*, controllable factor, integrative effect, optimum control.

Soybean aphid *Aphis glycines* Matsumura is an important pest of soybean. Its development is affected by the following two categories of factors. One is uncontrollable factors, i.e. climatic factors, such as temperature, humidity, precipitation, etc. The other is controllable factors including mainly planting mode, cultivar, sowing time, application of fertilizer and chemical. The latter is the important target of system control, but integrative effects of controllable factors on soybean aphid has not yet been studied systematically. We studied the integrative effects of 11 controllable factors on soybean aphid, natural enemies and soybean yield during 1993-1996, and suggested the optimum system control of soybean aphid.

1 Materials and Methods

1.1 Experiment design and methods

The experiments were conducted in 3 different stages. The approaching optimum point was used in stage 1 (1993-1994). The controllable factors were chosen from the high yielding factors and formed the basic value set. The basic value set from chosen optimum values was set up on the basis of the soybean yield in the previous experiments. Further experiments were performed on the changed levels. The optimum values were approached gradually, and then the effects of controllable factors on soybean aphid, natural enemies and soybean yield were compared in turn. In stage 2 (1995), the field experiments were conducted on the basis of the previous experiments. Orthogonal design L27 $(3)^{13}$ was utilized to check the effects of all factors on the soybean aphid, natural enemies and soybean yield. The experiments studied 11 controllable factors in a $100m^2$ plot. In stage 3 (1996), the controllable factors were evaluated synthetically, the optimum control of soybean aphid was performed in 3 different control strategies: soybean sown in the same maize hole, interplant of soybean and maize and monoculture of soybean. The demonstration experiments were carried out in a 0.07ha plot. The applications of N, P and K

were based on the soil conditions. The soybean seeds were dressed by trace fertilizer. The experimental factors and levels are shown in table 1.

Table 1 Experimental factors and levels

Year	Factors & levels	Planting modes	Cultivars	Sowing time (month,date)	Trace fertilizer (g/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Solid manure (kg/ha)	Growth regulator (kg/ha)	Plastic film	Chemical dosage/ha
1993	1	Interplant	Lusoybean 2	6,10	0	45	30	90	90	0		
	2	Same hole	Lusoybean 4	6,15	450	75	60	120	120	22500		
	3	Monoculture		6,20	750	105	90	150	150			
	4				1050							
1994	1	Interplant	Lusoybean 2	6,10	450	45	15	120	120	2	No	
	2	Same hole	Lusoybean 4	6,15	750	75	30	150	150	22500	Yes	
	3	Monoculture	Kefeng 6	6,20	1050	105	60	180	180			
	4		Jufeng 1									
1995	1	Interplant	Lusoybean 2	6,10	0	45	60	75	75			Pirmicarb 60 g
	2	Same hole	Lusoybean 4	6,15	1050	75	120	150	150			Omethoate 150 ml
	3	Monoculture	Kefeng 6	6,30	1800	150	180	225	225			Control
1996	1	Interplant	Lusoybean 4	6,10	1800	45	60	150	150			Pirmicarb 60 g
	2	Same hole	Lusoybean 4	6,10	1800	45	60	150	150			Pirmicarb 60 g
	3	Monoculture	Lusoybean 4	6,10	1800	45	60	150	150			Omethoate 150 ml

1.2 Investigation and statistic of results

The 5-point diagonal sampling technique was applied from seedling to harvest, and the densities of aphid and natural enemies were investigated every 5 days. The same sampling technique was used to check the yields of soybean and maize in the harvest stage with 4 plants checked per point. To exclude the survey error and increase the comparability, the sum of products of aphid density and time was set as index, because the development and damage of aphid and the predation of natural enemies were influenced by both density and time [(2)]. The formula is $S=\sum DT$, where S is the developmental index of soybean aphid, D is the average aphid density of adjacent 2 surveys, and T is the interval between the adjacent 2 surveys.

2 Results

2.1 Integrative effects of controllable factors on soybean aphid, natural enemies and soybean yield

2.1.1 Soybean aphid

The integrative effects of controllable factors on soybean aphid are shown in table 2. Standard least squares (R) of factors indicate their ranking orders. The ranked importance of the effects by

different factors in 2 experimental plots were shown as follows: Jiaxiang: planting mode > N >sowing time > trace fertilizer > K_2O > P_2O_5 > cultivar; Heze: planting mode > chemical control > P_2O_5 > cultivar > sowing time > N > trace fertilizer. The planting mode had biggest effect on soybean aphid, and significant differences existed among different factors. Light infestations of soybean aphid occurred when soybean and maize were sown in the same hole, and interplanted soybean was significantly infested less than monoculture. Lusoybean 4 had lighter infestation of soybean aphid. Earlier sown soybean was infested severely. The infestation became heavier as the dosage of trace fertilizer increased if the dosage was less than 1800 g/ha, while the light infestation happened when 1800 g/ha was applied. The increase of N would benefit aphid. The soybean had lightest infestation under the dosage of 60 kg/ha of P_2O_5, but the aphid would benefit from K_2O. Omethoate had slightly better control of soybean aphid than Pirimicarb. The increase of solid manure and application of growth regulator Ainong also increased soybean aphid densities, while the plastic film inhibited aphids.

Table 2 Integrative effects of controllable factors on soybean aphid (∑DT)

Location	Year	Factors & levels	Planting modes	Cultivars	Sowing time	Trace fertilizer	N	P_2O_5	K_2O	Solid manure	Growth regulator	Plastic film	Chemical control
Jiaxiang	1993	1	11050	29740	19690	13570	6980	35060	13570	13570	13570		
		2	13570	25303	13570	26240	13570	13570	20360	24320	20780		
		3	35960		13880	48310	13860	40970	24270				
	1994	1	10790	27540	38450	20640	21200	29780	19140	24210		24210	
		2	13530	24210	27950	24210	24210	24210	15250	35290		20270	
		3	24210	21745	24210	33610	30670	17630	24210				
		4		27890									
	1995	1	62690	78700	85810	79060	68450	74140	72110				
		2	57780	74260	74100	82780	77700	75440	77380				
		3	111770	79280	72330	70400	86090	82660	82750				
		R	53990	5020	13480	12388	17640	8520	10640				
		Ranking order	1	7	3	4	2	6	5				
		F	109.59**	0.93	6.60**	4.96	9.57**	2.59	3.48				
Heze	1995	1	477180	396160	445610	402460	364540	33830	-				403110
		2	230960	351620	413120	413210	395140	413680	-				310360
		3	501490	461850	350900	393960	449950	457650	-				496160
		R	270530	110230	94710	19250	85410	119350	-				185800
		Ranking order	1	4	5	7	6	3	-				2
		F	47.47**	6.51**	4.90	0.20	3.96	7.71**	-				18.27**

2.1.2 Natural enemies

Many natural enemies were found in the soybean fields. The predators included ladybugs, lacewings, hover flies etc. Aphidiidae were the main parasitoids. The ladybugs were very common in the field and had best control of aphid. *Propylaea japonica* (Thunberg) and *Harmonia axyridis* (Pallas) were two main species of ladybugs, and represented 62.4% and 10.3% of all ladybugs, respectively. The ranked importance of the effects of controllable factors on ladybugs is displayed in table 3. Jiaxiang: planting mode > N > sowing time > trace fertilizer > K_2O > cultivar > P_2O_5. Heze: planting mode > P_2O_5 > cultivar > sowing time > N > trace

fertilizer. The planting mode had biggest effect on the ladybugs in both plots. The field with soybean sown in the same maize hole and interplanted field had more ladybugs distinctly than that of monoculture. More ladybugs were found on the Lusoybean 4 and in the early sown fields. The increase of trace fertilizer and N inhibited the ladybugs, while P_2O_5 and K_2O benefited the ladybugs. The increase of trace fertilizer, application of growth regulator Ainong and plastic film inhibited the ladybugs as well. The mortality of ladybugs was 12.5 % and 20.5 % by Pirimicarb and Omethoate respectively. The soybean fields with soybean sown in the same maize hole and the interplanted fields had more lacewings, hover flies, Aphidiidae and spiders than those of monoculture of soybean. The lacewings increased by 80.6 % and 58.9 % in 2 plots. The predacious spiders increased by 52.3 % and 41.3 %, and the parasitism rates increased by 29.9 % and 23.9 % respectively.

Table 3 Integrative effects of controllable factors on ladybugs ($\sum$DT)

Location	Year	Factors & levels	Planting modes	Cultivars	Sowing time	Trace fertilizer	N	P_2O_5	K_2O	Solid manure	Growth regulator	Plastic film	Chemical control
Jiaxiang	1993	1	154.5	52.0	94.0	94.0	94.0	53.0	28.5	94.0	94.0		
		2	138.5	94.0	49.5	80.5	75.5	86.5	94.0	41.0	78.0		
		3	94.0		36.0	41.0	70.5	94.0	104.0				
		4				0							
	1994	1	264.0	95.0	138.5	138.5	153.5	81.5	138.5	147.0		138.5	
		2	291.5	138.0	138.0	111.5	138.5	103.0	139.5	138.5		68.5	
		3	138.5	116.0	130.0	76.0	131.5	138.5	157.5				
		4		123.5									
	1995	1	284.0	208.5	292.0	239.0	258.0	177.0	155.0				
		2	234.0	249.5	171.0	237.5	252.5	201.5	229.5				
		3	108.0	168.0	163.0	149.5	115.5	247.5	241.5				
		R	176.0	81.5	129.0	89.5	142.5	70.5	86.5				
		Ranking order	1	6	3	4	2	7	5				
		F	21.85**	4.41	13.88**	6.98**	17.31**	3.40	5.03**				
Heze	1995	1	603.5	507.5	660.0	582.0	659.5	383.0	-				12.5
		2	843.5	762.5	631.5	566.0	556.5	430.5	-				20.8
		3	254.5	432.0	410.0	553.5	485.5	888.0	-				
		R	589.0	330.0	250.0	28.5	174.0	505.0	-				
		Ranking order	1	3	4	6	5	2	-				
		F	84.42**	28.09**	17.60**	0.19	7.19**	73.06**	-				

2.1.3 Soybean yield

The ranked importance of the effects of controllable factors on soybean yield are shown in table 4: planting mode > sowing time > trace fertilizer > cultivar > N > P_2O_5 > K_2O. The first 4 factors produced significantly different yields, and became the main factors affecting the soybean yield. The soybean yields: monoculture > interplant > soybean sown in the same maize hole. However, the economic benefits of soybean sown in the same maize hole and interplant were 33.2 % and 33.3 % higher than that of monoculture. Further experiments showed that soybean sown in the same maize (4 soybean plants to 1 maize plant) and soybean interplanted in the maize field (9 rows of soybeans to 2 rows of maize) had the highest economic benefits. Soybean fields sown earlier showed higher yields. Dressing seeds with trace fertilizer and solid manure could increase the yield significantly. Lusoybean 4 had stable and higher yield in the 3-year experiments. N, growth regulator Ainong and plastic film had no significant benefit to the soybean yield. Higher yields were attained from 60 kg/ha of P_2O_5 and 150 kg/ha of K_2O respectively. The soybean

yields increased by 13.0 % and 28.6 % compared to control experiments when applied 60 kg/hm^2 of Pirimicarb and 150 ml/hm^2 of Omethoate.

Table 4 Integrative effects of controllable factors on soybean yield (kg/hm^2)

(Jiaxiang)

Year	Factors & levels	Planting modes	Cultivars	Sowing time	Trace fertilizer	N	P_2O_5	K_2O	Solid manure	Growth regulator	Plastic film
1993	1	921.0	1582.5	2464.5	1812.0	2032.5	2032.5	1897.5	2032.5	2032.5	
	2	742.5	2031.0	2029.5	2032.5	1764.5	2559.0	2032.5	2590.5	2086.5	
	3	2032.5		1587.5	2173.5	1747.5	2086.5	2055.0			
	4				2409.0						
1994	1	1237.5	2076.0	2206.5	2206.5	2437.5	2373.0	1807.5	2206.5		2206.5
	2	696.0	2206.5	1846.5	2242.5	2289.0	2206.5	2206.5	2584.5		2067.5
	3	2206.5	2445.0	1501.5	2262.5	2206.5	2484.5	1612.5			
	4		2557.5								
1995	1	1087.5	1284.0	1645.5	1321.5	1414.5	1407.0	1369.5			
	2	556.5	1443.0	1407.0	1357.5	1381.5	1384.5	1395.0			
	3	2517.0	1435.5	1108.5	1483.5	1366.5	1369.5	1396.5			
	R	1960.5	159.0	537.0	162.0	48.0	37.5	27.0			
	Ranking order	1	4	2	3	5	6	7			
	F	729.22**	5.75**	51.36**	5.11**	0.42	0.26	0.16			

2.2 Optimum control

According to the criterion of not only good control of the pest and increase of soybean yield but also protection of natural enemies, the controllable factors were evaluated synthetically and optimum system control of soybean aphid was suggested as follows: soybean sown in the same maize hole (4 soybean plants to 1 maize plant) or soybean interplanted in maize field (9 rows of soybean plants to 2 rows of maize), cultivar Lusoybean 4, sowing time about 10 June, dressing seeds with trace fertilizer at 1800 g/ha, dosage of fertilizer N, P_2O_5 and K_2O application at 45, 60 and 150 kg/ha, dosage of solid manure application at 22500 kg/ha, control soybean aphid with Pirimicarb at 60 g/ha. The optimum control of soybean aphid by soybean sown in the same maize hole, interplant and monoculture is shown in table 1.

The optimum control effects on soybean aphid were 93.5 %, 83.9 % and 71.8 % respectively in the 3 planting modes (soybean sown in the same maize hole, soybean interplanted with maize and monoculture of soybean). The ladybugs increased by 276.3 %, 201.1 % and -57.2 %. The lacewings increased by 492.1 %, 131.6 % and 34.2 %. The predacious spiders increased by 133.3 %, 70.1 % and -23.2 %. The soybean yields gained at 28.1 %, 16.0 % and 15.3 %. Soybean sown in the same maize hole and interplant had best control of soybean aphid and showed higher soybean yields, and the densities of natural enemies were treble. Soybean aphids were controlled preferably and the soybean yield increased obviously under the monoculture of soybean, but the natural enemies decreased.

The control of soybean aphid should be based on the control index and aphid development, and on the protection and utilization of natural system.

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