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# A study on system optimum control to diseases and insect pests of summer soybean

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*Abstract by authors*- The integrated effect of 15 controllable factors of soybean fields on diseases and insect pests, natural enemies and soybean yield was studied from 1993 to 1995. According to the criterion of good control to the pests, increase of soybean yield and protection of natural enemies, the 16 controllable factors were evaluated synthetically and the optimum system control to the disease and insect pests of summer soybeans were suggested as follows: soybean sown in the same maize hole (4 to 1) or soybeans interplanted in the maize field (9 to 2 rows), cultivar the variety ludou 4, sowing time on about 10 June, dressing seed with trace element fertilizer at 1800g/hm$^2$, dosages of fertilizer $N, P_2O_5, K_2O$ and Organic manure application at 45kg/hm$^2$, 60kg/hm$^2$, 150kg/hm$^2$ and 22500kg/hm$^2$ respectively. Mixture dressing seeds with phorate and carbendazim 0.36% and 0.1% of seed weight respectively, control soybean aphid with pirimicarb at 60g/hm$^2$, control soil insect with isofenphos-methyl at 67.5g/hm$^2$, and control leaf-eating insects and soybean borer with Bt at 3000g/hm$^2$. The technologies of optimum system control to the diseases and insect pests were made up in the three different modes including soybean sown in the same maize hole, soybeans interplanted in the maize field and monoculture soybeans. It demonstrated that the three techniques were significantly characterized by a good control to the disease and insect pests as well as an increase of the soybean yield and natural enemies.

*Key words*- summer soybean; disease and insect pests; controllable factor; integrated effect; system optimum control

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Soybean is the major crop in Shandong Province, where a high incidence of various diseases and insect pests attack the crop every year, severely threatening soybean production. Recently, Shandong province established general technical regulations for soybean protection from diseases and insects based on research results and practical experience from many years, which yielded positive results in practice. However, there are still several drawbacks to these general protection techniques: first, it is insufficient to treat the combination of various protection techniques and yield increasing techniques as the only objective; secondl the integrated effects of a series of controllable factors on disease, insect pests and soybean yields have not yet been systematically studied, while only the effects of single factors or a few factors on a single disease or insect pests have been studied. Thus, current general protection technical regulations are only a simple combination of protection techniques for single diseases and insect pests. It has not been systematically proven whether it represents optimum control. In order to optimize the technical regulation, especially systematically, the authors of the paper used system optimization methods based on optimum control techniques to study the integrated effects of 16 controllable factors of soybean fields in Jiaxiang and Heze of Shandong Province from 1993 to 1996. Results clearly showed us the integrated effects of these controllable factors and their optimum combinations on soybean disease and insect pests, natural enemies and soybean yields. Based on principles of disease and insect pest control as well as environmental protection, controllable factors were synthetically evaluated. The optimum control strategies on disease and insect pests of summer soybean were provided. Optimum control techniques on disease and insect pests were optimally combined in three different cultivation modes -- viz. soybean sown in the same maize hole; soybeans interplanted in the maize field; and monoculture soybeans. All the above optimized the general protection techniques from disease and insect pests of soybean.

## A. *Materials and methods*

### 1) *Experimental design and methods*

The experiment was divided into 3 phases. A gradual approach method was used in the first phase (1993-1994). First, treatments of controllable factors currently identified to lead to high yields formed the basic value set. Second, each factor treatment was revised to form different trial cases. Third, the optimum treatments of factors based on soybean yields identified from the trials formed the basic value set. Then each factor treatment was revised and put into trials again, gradually approaching the optimum point of each factor itself. The effects of controllable factors on disease and insect pests, natural enemies and soybean yields were studied by comparing cases. In the second phase (1995), based on experiments from the previous two years, $L_{27}(3)^{13}$ orthogonal table design schemes were adopted. Field trials were repeated. The effects of each factor on disease and insect pests, natural enemies and soybean yields were further identified. The area of an experiment field block was 100 $m^2$. In the third phase (1996), based on results from the previous three years, the controllable factors were simulated and evaluated. The system optimum control strategies for protection from disease and insect pests were determined. The system control techniques in three different modes -- soybean sown in the same maize hole, soybeans interplanted in the maize field and monoculture soybeans -- were combined and proven by demonstration trials. The demonstration field block's area was 666.7 $m^2$. In the above experiments, dosages of fertilizer $N, P_2O_5$, and $K_2O$ were applied to the soil, and a trace element fertilizer was utilized to dress the seed. The main factors and treatments of experiments are shown in Table 1.

Table 1 Principal factors and experimental treatments

| Year | Treat-ment | Planting mode | Cultivar | Sowing time | Trace fertilizer (g/hm$^2$) | N (kg/hm$^2$) | $P_2O_5$ (kg/hm$^2$) | $K_2O$ (kg/hm$^2$) | Organic manure (kg/hm$^2$) | Growth hormone (g/hm$^2$) | Covered plastic film |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 1 | Inter-planting | Ludou 2 | June 10$^{th}$ | 0 | 45 | 30 | 90 | 0 | 0 | |
| | 2 | Same hole | Ludou 4 | June 15$^{th}$ | 450 | 75 | 60 | 120 | 2500 | Ainong | |
| | 3 | Mono-culture | | June 20$^{th}$ | 750 | 105 | | | | | |
| | 4 | | | | 1050 | | | | | | |
| 1994 | 1 | Inter-planting | Ludou 2 | June 10$^{th}$ | 450 | 45 | 15 | 120 | 0 | | No covered film |
| | 2 | Same hole | Ludou 4 | June 15$^{th}$ | 750 | 75 | 30 | 150 | 22500 | | Covered film |
| | 3 | Mono-culture | Kefeng 6 | June 20th | 1050 | 105 | 60 | 180 | | | |
| | 4 | | Jufeng 1 | | | | | | | | |
| 1995 | 1 | Inter-planting | Ludou 2 | June 10$^{th}$ | 0 | 45 | 60 | 75 | | | |
| | 2 | Same hole | Ludou 4 | June 20$^{th}$ | 1050 | 75 | 120 | 150 | | | |
| | 3 | Mono-culture | Kefeng 6 | June 30$^{th}$ | 1800 | 150 | 180 | 225 | | | |
| 1996 | 1 | Inter-planting | Ludou 4 | June 10$^{th}$ | 1800 | 45 | 60 | 150 | | | |
| | 2 | Same hole | Ludou 4 | June 10$^{th}$ | 1800 | 45 | 60 | 150 | | | |
| | 3 | Mono-culture | Ludou 4 | June 10$^{th}$ | 1800 | 45 | 60 | 150 | | | |

*2) Investigation of effects and statistical analysis*

From soybean germination to harvest, each field block was sampled at 5 points. Each point had 20 plants, totaling 100 plants. The population densities of insect pest and natural enemies were determined every 5 days. During the harvest period, each block was sampled at 5 points, each point with 4 plants. Soybean and maize yields were measured. In order to remove errors resulting from individual observations, and to improve comparability, the statistical analysis took the summation of products of densities and times as an occurrence index, since disease and insect pest damage and natural enemy predation both were characterized by the two dimensions of density and time. The relationship was $S = \sum DT$, where $D$ was the average density between 2 consecutive investigations, and $T$ was the interval between 2 consecutive investigations.

*B. Results and analysis*

*1) The integrated effects of controllable factors on disease and insect pests*

*a) Soybean mosaic virus*

According to the design principles of orthogonal table, the ranges of each factors' treatments showed the order of effects. From Table 2, the order of effects of controllable factors on soybean mosaic virus was: Trace element fertilizer (42.5) > Planting mode (30.0) > $P_2O_5$ (22.5) > Sowing time (17.5) > $K_2O$ (15.0) > N (7.5) > Cultivar (5.0). Results showed that trace element fertilizer had the greatest influence on soybean mosaic virus, since there was a notable difference in the treatments for this factor.

From a functional perspective, it could be concluded that (1) trace element fertilizer could significantly reduce the occurrence of soybean mosaic virus; (2) monoculture soybeanss were heavily infested, while soybeans sown in the same maize hole and soybeans interplanted in the maize hole were just lightly infested. (3) among June 10$^{th}$, 15$^{th}$, 20$^{th}$, and 30$^{th}$ sowing times, soybeans sown from June 15$^{th}$ to 20$^{th}$ was heavily infested while soybeans sown earlier or later was lightly infested. (4) the more N, P, K were applied, the lighter the infestation would be. Besides applying more organic manure, spraying Ainong (growth hormone) on the laminas and covering with plastic film all could help resist the virus to some degree.

Table 2 Integrated effects of controllable factors on soybean mosaic virus

| Year | Treat-ment | Planting mode | Cultivar | Sowing time | Trace fertilizer | N | $P_2O_5$ | $K_2O$ | Organic manure | Growth hormone | Covered plastic film |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 1 | 14.0 | 28.0 | 20.5 | 107.0 | 107.0 | 107.0 | 107.0 | 107.0 | 107.0 | |
| | 2 | 32.5 | 107.0 | 107.0 | 99.5 | 39.0 | 97.8 | 40.0 | 57.0 | 7.5 | |
| | 3 | 107.0 | | 30.8 | 83.1 | 9.0 | 5.0 | 29.0 | | | |
| | 4 | | | | 27.4 | | | | | | |
| 1994 | 1 | 36.4 | 47.4 | 47.4 | 47.4 | 121.4 | 58.8 | 69.6 | 47.4 | | 47.4 |
| | 2 | 29.4 | 64.5 | 154.3 | 44.9 | 47.4 | 47.4 | 47.4 | 42.0 | | 24.3 |
| | 3 | 47.4 | 61.3 | 78.3 | 31.8 | 37.6 | 33.0 | 39.9 | | | |
| | 4 | | 65.4 | | | | | | | | |
| 1995 | 1 | 5.0 | 17.5 | 10.0 | 42.5 | 22.5 | 30.0 | 25.0 | | | |
| | 2 | 12.5 | 20.0 | 27.5 | 10.0 | 15.0 | 15.0 | 17.5 | | | |
| | 3 | 35.0 | 15.0 | 15.0 | 8.0 | 15.0 | 7.5 | 10.0 | | | |
| | Extreme difference | 30.0 | 5.0 | 17.5 | 42.5 | 7.5 | 22.5 | 15.0 | | | |
| | Order | 2 | 7 | 4 | 1 | 6 | 3 | 5 | | | |
| | Variance | 3.13 | <1 | <1 | 6.34** | <1 | 1.69 | <1 | | | |

b) *Aphis glycines* Matsumura

From Table 3, the rank order of different factors on *A. glycines* Matsumura (descending) was: (Jiaxiang) Planting mode (53990) > N (17640) > Sowing time (13480) > Trace fertilizer (12388) > $K_2O$ (10460) > $P_2O_5$ (8520) > Cultivar (5020); (Heze) Planting mode (270530) > Control Aphis glycines Matsumura (185800) > $P_2O_5$ (119350) > Cultivar (110230) > Sowing time (94710) > N (85410) > Trace element fertilizer (19250). Results show that planting mode, which had a significant difference in the treatments, had the greatest impact on *A. glycines* Matsumura.

From Table 3, the following inferences were made: (1) Planting mode: soybeans sown in the same maize hole and soybeans interplanted in the maize hole were infested significantly less than monoculture oybeans; (2) Among cultivars, Ludou 4 was comparatively less infested by Aphis; (3) the earlier the sowing time, the heavier the infestation; (4) for trace element fertilizer, when application was below 1800g/hm$^2$, infestation was heavier with the increase in the amount of fertilizer. However, when it was at 1800g/hm$^2$, infestation was very slight; (5) N: fertilizer N increased aphid infestation. (6) $P_2O_5$: infestation was lightest when applied at 60kg/hm$^2$. (7) $K_2O$: element K favored infestation of aphids. (8) Omethoate was observed to be better than Pirimicarb at controlling Aphis. In addition, more organic manure and spraying the growth hormone Ainong favored aphid infestation, while covering plants with plastic film helped to protect against of aphids.

Table 3 Integrated effects of controllable factors on *Aphis glycines* Matsumura

| Locale | Year | Treat-ment | Planting mode | Cultivar | Sowing time | Trace fertilizer | N | P O | K O | Organic manure | Growth hormone | Covered plastic film | Control Aphis glycines Matsumura |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jia xiang | 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 | 17130 | 24210 | | | | |
| | | 4 | | 27890 | | | | | | | | | |
| | 1995 | 1 | 62690 | 78700 | 85810 | 79060 | 68450 | 74140 | 72110 | | | | |
| | | 2 | 57780 | 74260 | 74110 | 82780 | 77700 | 75440 | 77380 | | | | |
| | | 3 | 111770 | 79280 | 72330 | 70400 | 86090 | 82660 | 82750 | | | | |
| | | Extreme difference | 53990 | 5020 | 13480 | 12388 | 17640 | 8520 | 10640 | | | | |
| | | Order | 1 | 7 | 3 | 4 | 2 | 6 | 5 | | | | |
| | | Variance | 109.59** | 0.93 | 6.60* | 4.96 | 9.57* | 2.59 | 3.48 | | | | |
| Heze | 1995 | 1 | 477180 | 396160 | 445610 | 402460 | 364540 | 338300 | - | | | | 403110 |
| | | 2 | 230960 | 351620 | 413210 | 413210 | 395140 | 413680 | - | | | | 310360 |
| | | 3 | 501490 | 461850 | 350900 | 393960 | 449950 | 457650 | - | | | | 496160 |
| | | Extreme difference | 270530 | 110230 | 94710 | 19250 | 85410 | 119350 | - | | | | 185800 |
| | | Order | 1 | 4 | 5 | 7 | 6 | 3 | - | | | | 2 |
| | | Variance | 47.47** | 6.51* | 4.9 | 0.2 | 3.96 | 7.71* | - | | | | 18.27** |

*c) Argyrogramma agnata* Staudinger

From Table 4, the ranking of effects of different factors on *Argyrogramma agnata* Staudinger in descending order was: Planting mode (912) > Trace fertilizer (792) > Sowing time (742) > $K_2O$ (361> Cultivar (293) > $P_2O_5$ (185) > N (176), where the first 4 factors had significantly different treatments, showing that planting mode, trace element fertilizer, sowing time, and K significantly affected *A. agnata* Staudinger.

From Table 4, the following inferences were made: (1) Planting mode: monoculture soybeanss were heavily infested while soybeans sown in the same maize hole and soybeans interplanted in the maize hole were lightly infested. (2) Trace element fertilizer: more trace element fertilizer reduced infestation. (3) Sowing time: late sowing favored infestation. (4) $K_2O$: element K reduced infestation. (5) Cultivar: Ludou 4 was comparatively lightly infested. (6) $P_2O_5$: P reduced infestation. (7) N: element N favored infestation. (8) Organic manure and growth hormone "Ainong reduced infestation at some level; (9) covering plants with plastic film favored infestation. In addition, Deltamethrin, Metriphonate and Bt controls of three-spotted *Plusia* were 53.1%, 62.5% and 53.0% respectively.

Table 4 Integrated effects of controllable factors on three-spotted Plusia

| Year | Treat-ment | Planting mode | Cultivar | Sowing time | Trace fertilizer | N | $P_2O_5$ | $K_2O$ | Organic manure | Growth hormone | Covered plastic film | Control three-spotted plusia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 1 | 947.5 | 1826.5 | 1574.0 | 2192 | 1574.0 | 3404.0 | 2128.0 | 1574.0 | 1574.0 | | 52.9 |
| | 2 | 1432.0 | 1574.0 | 1579.5 | 1972.5 | 1792.0 | 1727.5 | 1921.5 | 1291.5 | 1387.0 | | 59.1 |
| | 3 | 1574.0 | | 2003.5 | 1887.5 | 2199.5 | 1574.0 | 1574.0 | | | | 41.9 |
| | 4 | | | | 1574.0 | | | | | | | - |
| 1994 | 1 | 400.5 | 1152.0 | 685.5 | 918.5 | 650.5 | 911.0 | 864.5 | 685.5 | | 685.5 | 46.1 |
| | 2 | 393.5 | 655.5 | 1161.0 | 685.5 | 685.5 | 685.5 | 685.5 | 639.5 | | 774.5 | 68.0 |
| | 3 | 685.5 | 511.5 | 1304.5 | 556.5 | 801.0 | 530.0 | 530.0 | | | | 70.7 |
| | 4 | | 1305.5 | | | | | | | | | - |
| 1995 | 1 | 1032 | 1346 | 1046 | 1759 | 1295 | 1438 | 1619 | | | | |
| | 2 | 1245 | 1261 | 1387 | 1495 | 1455 | 1484 | 1344 | | | | |
| | 3 | 1944 | 1584 | 1788 | 967 | 1471 | 1299 | 1258 | | | | |
| | Extreme difference | 912 | 293 | 742 | 792 | 176 | 185 | 361 | | | | |
| | Order | 1 | 5 | 3 | 2 | 7 | 6 | 4 | | | | |
| | Variance | 25.24** | 2.69 | 15.29** | 18.05** | 1.05 | 1.03 | 3.94** | | | | |

*d) Clanis bilineata* walker

From Table 5, the rank order of effects of different factors on *C. bilineata* walker (descending) was: Planting mode (917) > Trace fertilizer (893) > Sowing time (786) >

Cultivar (477) > $P_2O_5$ (374) > N (319) > $K_2O$ (196), where the first 3 factors showed extreme differences in treatments. It showed that planting mode, trace element fertilizer, and sowing time significantly affected Clanis bilineata walker; cultivar somewhat affected Clanis bilineata walker.

From Table 5, the following inferences were made: (1) planting mode: monoculture soybeanss were heavily infested while soybeans sown in the same maize hole and soybeans interplanted in the maize hole were lightly infested; (2) Trace element fertilizer: more trace element fertilizer reduced infestation; (3) early sown soybeans were infested lightly while late sown soybeans were infested heavily; (4) cultivar Ludou 4 was comparatively lightly infested; (5) element N favored infestation. (6) $P_2O_5$ and $K_2O$: element P and element K reduced infestation. In addition, the growth hormone "Ainong" and plastic film could reduce infestation while organic manure showed no apparent effects on infestation. Metriphonate and Bts controls of *Clanis bilineata* Walker were 48.1% and 74.1% effective respectively.

Table 5 Integrated effects of controllable factors on Clanis bilineata Walker

| Year | Treat-ment | Planting mode | Cultivar | Sowing time | Trace fertilizer | N | $P_2O_5$ | $K_2O$ | Organic manure | Growth hormone | Covered plastic film | Control C. bilineata Walker |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 1 | 0.0 | 49.5 | 0.0 | 53.0 | 0.0 | 53.0 | 53.0 | 53.0 | 53.0 | | |
| | 2 | 13.0 | 53.0 | 37.5 | 61.0 | 53.0 | 23.5 | 10.5 | 42.5 | 19.0 | | |
| | 3 | 53.0 | | 53.0 | 0.0 | 61.0 | 13.0 | 0.0 | | | | |
| | 4 | | | | 0.0 | | | | | | | |
| 1994 | 1 | 98.5 | 140.0 | 137.5 | 198.5 | 111.5 | 181.5 | 186.5 | 137.5 | | 137.5 | |
| | 2 | 78.0 | 137.5 | 142.5 | 139.0 | 137.5 | 137.5 | 137.5 | 153.0 | | 67.5 | |
| | 3 | 137.5 | 96.0 | 197.0 | 137.5 | 145.0 | 137.5 | 119.5 | | | | |
| | 4 | | 205.5 | | | | | | | | | |
| 1995 | 1 | 1237 | 1404 | 976 | 1750 | 1170 | 1518 | 1437 | | | | 48.4 |
| | 2 | 938 | 1073 | 1307 | 1420 | 1350 | 1365 | 1349 | | | | 74.1 |
| | 3 | 1852 | 1550 | 1744 | 857 | 1498 | 1144 | 1241 | | | | - |
| | Extreme difference | 914 | 477 | 768 | 893 | 319 | 374 | 196 | | | | |
| | Order | 1 | 4 | 3 | 2 | 6 | 5 | 7 | | | | |
| | Variance | 17.70** | 4.32** | 10.73** | 14.74** | 1.84 | 2.56 | 0.70 | | | | |

*e) Leguminivora glycinivorella* Matsumura, *Etiella zinckenella* Treitschke

From Table 6, the ranking of effects of different factors on soybean borer in descending order was: Sowing time (173.2) > Trace element fertilizer (71.0) > $P_2O_5$ (45.2) > N (43.1) > Planting mode (40.4) > Cultivar (34.3) > $K_2O$ (33.0). Results showed that sowing time played the most important role followed by trace element fertilizer.

From Table 6, the following inferences were made: (1) sowing time: early sown soybeans were infested lightly while late sown soybeans were infested heavily; (2) Trace element fertilizer: more trace element fertilizer reduced infestation; (3) $P_2O_5$: element P reduced infestation; (4) N: element N favored infestation. (5) Planting mode: monoculture soybeanss were heavily infested while soybeans sown in the same maize hole and soybeans interplanted in the maize hole were lightly infested; (6) Cultivar: Ludou 4 was comparatively lightly infested while Ludou 2 was heavily infested; (7) $K_2O$: element K favored infestation. Organic manure, growth hormone "Ainong" and plastic film favored infestation of soybean borer. Deltamethrin, Bt and Metriphonate controls of soybean borer were 50.8%, 58.5% and 53.0% effective respectively.

Table 6 Integrated effects of controllable factors on soybean borer

| Year | Treat-ment | Planting mode | Cultivar | Sowing time | Trace fertilizer | N | $P_2O_5$ | $K_2O$ | Organic manure | Growth horm-one | Covered plastic film |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 1 | 24.1 | 44.6 | 15.8 | 63.5 | 32.9 | 32.9 | 21.4 | 32.9 | 32.9 | |
| | 2 | 27.1 | 32.9 | 31.4 | 41.3 | 34.2 | 31.9 | 32.9 | 34.8 | 39.3 | |
| | 3 | 52.9 | | 32.9 | 38.4 | 36.6 | 22.8 | 101.7 | | | |
| | 4 | | | | 32.9 | | | | | | |
| 1994 | 1 | 10.8 | 32.3 | 25.1 | 39.7 | 23.3 | 27.3 | 25.1 | 20.1 | | 21.7 |
| | 2 | 14.1 | 25.1 | 43.5 | 32.1 | 25.1 | 25.1 | 34.5 | 25.1 | | 25.1 |
| | 3 | 25.1 | 16.2 | 59.9 | 25.1 | 30.0 | 22.9 | 56.0 | | | |
| | 4 | | 34.5 | | | | | | | | |
| 1995 | 1 | 127.3 | 152.7 | 39.3 | 177.1 | 125.1 | 172.1 | 128.9 | | | |
| | 2 | 145.4 | 126.7 | 188.6 | 157.1 | 147.1 | 141.4 | 149.6 | | | |
| | 3 | 167.7 | 161.0 | 212.5 | 106.1 | 168.2 | 126.9 | 161.9 | | | |
| | Extreme difference | 40.4 | 34.3 | 173.2 | 71.0 | 43.1 | 45.2 | 33.0 | | | |
| | Order | 5 | 6 | 1 | 2 | 4 | 3 | 7 | | | |
| | Variance | 1.20 | 0.94 | 25.85** | 3.94** | 1.36 | 1.56 | 0.82 | | | |

*f) Other insect pests*

The rank order of effects of different factors on *Heliothis armigera* Hubner (descending) was: Planting mode (362) > Sowing time (323) > Cultivar (312) > $P_2O_5$ (300) > Trace element fertilizer (225) > N (142) > $K_2O$ (115). Results showed that planting mode played the most important role in infestation of *H. armigera* Hubner. Soybean sown in the same maize hole and soybeans interplanted in maize holes were lightly infested, while monoculture soybeanss were heavily infested; early sown soybeans were lightly infested, while late sown soybeans were heavily infested; Ludou 4 was lightly infested; Fertilizer $P_2O_5$ and $K_2O$ reduced infestation; Trace element fertilizer and fertilizer N favored infestation; Deltamethrin, Metriphonate and Bt's controls of *H.*

*armigera* Hubner were 53%, 60.4% and 58.8% effective respectively. The effect of Bt was the most stable.

*(1) Liriomyza sativae* Blanchard

The rank order of effects of different factors on *Liriomyza sativae* Blanchard (descending) was: Planting mode (712.5) > N (572.5) > Cultivar (567.5) > Sowing time (515.7) > $P_2O_5$ (387.5) > Trace element fertilizer (382.5). Results showed that planting mode played the most important role in infestation of *L. sativae* Blanchard. Monoculture soybeanss were infested more heavily than soybeans sown in the same maize hole and soybeans interplanted in maize holes; Element N favored infestation; Ludou 4 was lightly infested while Ludou 2 was heavily infested; Early sown soybeans were heavily infested while late sown soybeans were lightly infested; Element P reduced infestation; Trace element fertilizer favored infestation.

*(2) Holotrichia parallela* Mtschulsky

The rank order of effects of different factors on *H. parallela* Mtschulsky (descending) was: Planting mode (1.97) > N (1.49) > Cultivar (1.27) > Trace element fertilizer (1.13) > Sowing time (0.99) > $P_2O_5$ (0.30), where the first 3 factors had notable effects on *H. parellela* Motschulsky with quite large ranges of treatments. Monoculture soybeanss were heavily infested while soybeans sown in the same maize hole and soybeans interplanted in maize holes were lightly infested; Element N favored infestations; Ludou 4 was lightly infested while Kefeng 6 was heavily infested; Trace element fertilizer favored infestation; Early sowing lead to light infestation; Element P lead to light infestation; Phoxim and isofenphos-methyl controls of *H. parallela* Mtschulsky were 63.6% and 70.4% respectively. Isofenphos-mehyl was more effective.

*2) Integrated effects of controllable factors on natural enemies*

Soybeans have a large variety of natural enemies. Predatory natural enemies include the ladybird beetle, lacewing fly, syrphus fly, farmland spider etc. Parasitical natural enemies include *Trioxys auctus* Haliday, *Trichogramma dendrolimi* Matsumara in eggs of *Clanis bilineata* Walker, *Casinaria nigripes* Gravenhorst and *Apanteles ruficrus* Haliday in larvae of three-spotted plusia, etc. However, the ladybird is the most common natural enemy, especially *Propylaea japonica* Thuberg and *Harmonis axyridis* Pallas.

*a) Integrated effects of controllable factors on ladybird*

From Table 7, the rank ordering of effects of different factors on ladybird in descending order was: Planting mode (176) > N (142.6) > Sowing time (129) > Trace element fertilizer (89.5) > $K_2O$ (85.5) > Cultivar (81.5) > $P_2O_5$ (70.5). Results showed that planting mode, element N, sowing time, trace element fertilizer and element K had visible effects on ladybird with wide ranges of treatments.

From a functional perspective, the following inferences were made: (1) planting mode: the occurrence of ladybirds in soybean sown in the same maize hole or soybeans interplanted in maize holes was much greater than monoculture soybeans; (2) Element N reduced ladybirds; (3) Sowing time: early sowing lead to more occurrences while late sowing lead to fewer occurrences of ladybirds; (4) Trace element fertilizer: trace element fertilizer reduced ladybirds; (5) $P_2O_5$ and $K_2O$: element P and element K increased the number of ladybirds; (6) Cultivar: Ludou 4 was highly infested. (7) Organic manure, growth hormone “Ainong” and plastic film reduced the number of ladybirds; (8) Relationship between pesticide and growth period: During sowing time, pesticides used to dress seeds reduced *Holotrichia parallela* Motschulsky, and soybean borers had no effect on ladybirds. The kill rates of pirimicarb and omethoate, which were used against aphids, were 12.5% and 20.8% respectively. The kill rates of deltamethrin used against defoliators and Bt were 13.5% and –0.2% respectively, and Bt was harmless to ladybirds.

Table 7 Integrated effects of controllable factors on Ladybird

| Year | Treat-ment | Planting mode | Cultivar | Sowing time | Trace fertilizer | N | $P_2O_5$ | $K_2O$ | Organic manure | Growth hormone | Covered plastic film |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | | | | 0.0 | | | | | | |
| 1994 | 1 | 264.0 | 95.5 | 138.5 | 138.5 | 153.5 | 81.5 | 138.5 | 147.0 | | 138.5 |
| | 2 | 291.5 | 138.5 | 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 | 292.2 | 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 | | | |
| | Extreme difference | 176.0 | 81.5 | 129.0 | 89.5 | 142.5 | 70.5 | 86.5 | | | |
| | Order | 1 | 6 | 3 | 4 | 2 | 7 | 5 | | | |
| | Variance | 21.85** | 4.41 | 13.88** | 6.98* | 17.30** | 3.40 | 5.03 | | | |

*b) Integrated effects of planting modes on natural enemies*

Predators: the number of enemies on soybeans sown in the same maize hole or soybeans interplanted in maize holes was higher than monoculture soybeans, where the number of ladybirds was 84.0% and 86.5% higher than the one in monoculture soybeans; lacewing flies increased by 58.9% and 80.6%; spiders increased by 41.3% and 52.3%; syrphus flies were more evident than in monoculture soybeans. *Propylaea japonica* Thunberg and *Harmonis axyridis* Pallas were the major species in infestation, which made up62.4% and 10.3% in total number of ladybirds respectively. *Chrysopa sinica* Tjeder were the major species in lacewing fly, which made up57.9% of the total number of lacewing fly. *Epistrophe balteta* De Geer and *Syrphus corollae* Fabricius were the major species in Syrphus fly, which made up56.3% and 31.6% respectively. *Erigonidium gramincolum* Sandevall and *Misumenops tricuspidatus* (Fabricius) were the major species in spider, which made up33.8% and 26.2% respectively.

Parasites: the rate of parasitism in soybeans sown in the same maize hole or soybeans interplanted in maize holes was higher than monoculture soybeans. *Trioxys auctus* Haliday was the main aphid parasite whose rate increased by 23.9% and 29.9%

respectively. *Trichogramma dendrolimi* Matsumara was the main species living in eggs of *Clanis bilineata* walker and its parasitic rates increased by 13.0% and 20.5% respectively. *Casinaria nigripes* Gravenhorst and *Apanteles ruficrus* Haliday were major species living in larvae of *Argyrogramma agnata* Staudinger and they respectively made up 45.0% and 23.0% of the total number. Their parasitic rates increased by 18.7% and 25.3% respectively.

*3) Integrated effects of controllable factors on soybean yields*

The ranking of effects of controllable factors on soybean yields in descending order was (Table 8): Planting mode (1960.5) > Sowing time (537) > Trace element fertilizer (162) > Cultivar (159) > N (48) > $P_2O_5$ (37.5) > $K_2O$ (27). Results showed that planting mode, sowing time, trace element fertilizer and cultivar greatly affected soybean yields.

From the functional perspective (Table 8), the following inferences were made: (1) Planting mode: Monoculture soybeans had the highest yields, followed by soybeans interplanted in maize holes, while soybeans sown in the same maize holes had the lowest yields. This was because each mode had different planting densities of soybeans. However, from the standpoint of economic profitability, soybeans interplanted in maize holes and soybeans sown in the same maize holes would produce more profits of soybean and maize than monoculture soybeans. The increases in profits were about 33.3% and 33.2% respectively. Further experiments showed that the economic profits would reach the highest if 9 rows of soybeans were interplanted in 2 rows of maize or 4 plants of soybeans were sown in 1 maize hole. (2) Sowing time: early sowing lead to high yields while late sowing lead to low yields. (3) Trace element fertilizer: Dressing seeds helped increase yields. (4) Cultivar: Ludou 4 had high and stable yields based on 3 years experiments. (5) N: no apparent effects. (6) $P_2O_5$ and $K_2O$: Yields were highest when they were at 69kg/hm$^2$ and 150kg/hm$^2$. (7) Organic manure could improve yields (8) Growth hormone "Ainong" and plastic film had no apparent effects on yields. (9) Pesticides: Using isofenphos-methyl, phoxim, phosfolan-methyl, phorate to dress seeds and spraying isofenphos-methyl before sowing would increase yields by 11.2%, 11.5%, 13.6%, 21.7% and 17.8% respectively, among which phorate lead to the highest increase in yields. Using carbendazim, Triadimefon, thiram, Nongkang 120, and symbiotic bacterium to dress seeds could increase yields by 17.6%, -14.6%, 7.9%, 9.7% and 11.9% respectively, among which carbendazim gained the highest increase. Pirimicarb and omethoate, which were used against aphids, could increase yields by 28.6% and 13.0%. Phoxim, isofenphos-methyl, and Jiajilinhuanlin (an OP compound) could increase yields about 20.0%, 23.2% and 14.5% respectively, among which, isofenphos-methyl lead to the highest yields. Deltamethrin, Metriphonate and Bt, which were used against defoliators, increased the yields by 6.9%, 16.2%, and 13.7%, among which Metriphonate lead to highest yield increase. Bt. Deltamethrin, Metriphonate and Bt, which were used against *Leguminivora glycinivorella* Matsumura, increased the yields by 10.8%, 21.6% and 30.5% respectively, among which Metriphonate lead to the highest increase, followed by Bt.

Table 8 Integrated effects of controllable factors on soybean yield

| Year | Treat-ment | Planting mode | Cultivar | Sowing time | Trace fertilizer | N | $P_2O_5$ | $K_2O$ | Organic manure | Growth horm-one | Covered 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 | 1764.0 | 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 | 1510.5 | 2262.0 | 2206.5 | 2484.0 | 1612.5 | | | |
| | 4 | | 2557.5 | | | | | | | | |
| 1995 | 1 | 1087.5 | 1284.0 | 1645.5 | 1312.5 | 1414.5 | 1407.0 | 1369.5 | | | |
| | 2 | 556.5 | 1443.0 | 1407.0 | 1357.5 | 1381.5 | 1384.5 | 1395.5 | | | |
| | 3 | 2517.0 | 1435.5 | 1108.5 | 1483.5 | 1366.5 | 1369.5 | 1396.5 | | | |
| | Extreme difference | 1960.5 | 159.0 | 537.0 | 162.0 | 48.0 | 37.5 | 27.0 | | | |
| | Order | 1 | 4 | 2 | 3 | 5 | 6 | 7 | | | |
| | Variance | 729.22** | 5.75** | 51.36** | 5.11** | 0.42 | 0.26 | 0.16 | | | |

*4) System optimal control of disease and insect pests of soybean*

In order to control disease and insect pests, increase yields and protect the environment, controllable factors were artificially simulated from perspectives of disease and insect pest effects, natural enemies effects and yield effects, etc. The optimal control strategies for disease and insect pests of soybeans were as follows: soybeans sown in the same maize hole (4 to 1) or soybeans interplanted in the maize field (9 to 2 rows), cultivar ludou 4, sowing time on or about 10 June, dressing seed with trace element fertilizer at 1800g/hm$^2$, dosages of fertilizer $N, P_2O_5, K_2O$ and organic manure application at 45kg/hm$^2$, 60kg/hm$^2$, 150kg/hm$^2$ and 22500kg/hm$^2$ respectively, seed dressing with phorate and carbendazim 0.36% and 0.1% of seed weight respectively, controlling soybean aphid with pirimicarb at 60g/hm$^2$, controlling soil insect with isofenphos-methyl at 67.5g/hm$^2$, and controlling defoliators and pod borer with Bt at 3000g/hm$^2$. The technologies of optimum system control to the diseases and insect pests were made up in the three different modes including soybeans sown in the same maize holes, soybeans interplanted in the maize fields and monoculture soybeans (Table 1) and were demonstrated.

Results of our demonstrations showed that the system control technologies of soybean sown in the same maize hole, soybeans interplanted in maize holes and monoculture soybeans could be 87.9%, 83.3% and 71.2% effective on aphis, 89.2%, 81.2% and 59.6% effective on *Argyrogramma agnata* Staudinger, 86.1%, 85.7% and 69.4% effective on *Clanis bilineata* walker, 100%, 100% and 100% on *Liriomyza sativae* (Blanchard). In these three modes, the numbers of ladybirds increased by 256.7%, 204.2% and – 14.4%, respectively; The number of lacewing flies increased by 492.1%, 131.6% and –34.2% respectively; The number of spiders increased by 133.3%, 70.1% and –23.2% respectively. The yields in three modes were improved by 28.1%, 16.0% and 15.3% respectively. The three system control technologies significantly controlled disease and insect pests and improved yields. In particular, the number of natural enemies in the modes of soybean sown in the same maize hole and soybeans interplanted in maize holes increased sharply, significantly characterizing natural control of diseases and insect pests.

### *C. Discussion*

From system theory, a soybean field is an artificial ecosystem where the soybean is the producer, diseases and insect pests are consumers, and beneficial insects such as natural enemies are predators. Its main function is to produce soybean. The fundamental problem in systems study is optimization. Regarding the soybean field ecosystem, optimization means to improve soybean yields and quality, control disease and insect pests, and increase the number of natural enemies. Factors affecting the soybean field ecosystem can be classified into 2 groups: one group includes all the uncontrollable factors, such as humidity, moisture and rain-fall, etc; the other group includes all the controllable factors, such as planting modes, sowing time, fertilization and pesticide application, etc. There are also artificial factors, which are the factors to practice system control. This paper studied the integrated effects of major controllable factors on disease and insect pests of soybean, natural enemies, and soybean yields. Based on the principles of both controlling disease and insect pests and protecting the environment, controllable factors were synthetically evaluated and the optimal system control technologies were provided. This is not only the optimization of protection techniques on disease and insect pests, but also the optimization of the soybean field ecosystem, which is consistent with the need for sustainable development. Results of the study show that the system control technologies in three modes including soybeans sown in the same maize holes, soybeans interplanted in maize holes and monoculture soybeans not only effectively control the disease and insect pests of soybean, significantly increase soybean yields, but also improve the function of natural control. Especially in the modes of soybean sown in the same maize hole and interplanted in maize hole, the numbers of natural enemies increase dramatically, unifying economic, ecosystem, and societal benefits.

There are many system optimization methods, such as linear programming, nonlinear programming, dynamic programming, and system control etc. It is essential first to establish up mathematical models representing system characteristics in all these methods; however, it is very difficult to make models for systems like the soybean field ecosystem. In this study, an orthogonal optimization method was used based on system control theory. This method is suitable for the optimization study of ecosystems, and is worthy of further study.

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