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Effect of soybean variety and pest management on the sustainable production

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Abstract. Pests are one of the limiting factors in increasing soybean production. Pest control carried out by farmers using pesticides is feared to threaten the sustainability of soybean production in Indonesia. This study aimed to identify the effect of different pest management systems and various soybean varieties on pest population dynamics, abundance and diversity of natural enemies, plant damage, and soybean production. A split plot design with three replications was applied, where the main plot was pest management systems i.e. (1) control (which received neither chemicals nor integrated pest management), (2) chemical control, and (3) integrated pest management, and the sub-plot was soybean varieties i.e. (1) Anjasmoro, (2) Demas 1, and (3) Dering 1. Results indicated that variety affects pest diversity and abundance, however, it affected leaf damage, pod damage, and production. The pest management systems influenced the diversity and abundance of pests and natural enemies, plant damage, and production. Interaction between variety and pest management system affected plant damage. We conclude that the use of resistant varieties combined with integrated pest management could reduce plant damage, maintain the natural enemy population, and optimize soybean production.

Keywords: IPM, natural enemy, pesticide, leaf damage, pod damage

1. Introduction

Soybean is one of the most valuable crops globally. It has benefits as a good source of protein in the human diet, oilseed crops, feed for livestock and aquaculture, and also used as biofuel in developed countries. Indonesian soybean production has increased slightly, but because the consumption of and demand for soybean have also risen over the years, Indonesia has to import soybeans. In 2021, Indonesia imports 2.5 million tons of soybeans [1]. Several factors affect soybean production, such as the unavailability of sustainable quality seeds, new high-yielding varieties that have not yet developed at the farm level, limited production area, a climate that is difficult to predict, soybean prices are less profitable for farmers, and pest disease [2,3].

In Indonesia, there are over 111 species of arthropods reported as soybean pests [4]. It is grouped into plant seed, leaf-eating, and pod-feeding pests [5]. The bean fly, *Ophiomyia phaseoli* Tr., is an important pest for soybean plant seed. Bean fly infestation that occurs in less than 10 days old plant will result in plant death, while late infestations will cause stunted plants and produce a small number of pods [6]. The main soybean leaf-eating pests include whitefly (*Bemisia tabaci*), soybean aphid (*Aphis glycines*), *Tetranychus cinnabarinus*, *Empoasca* spp armyworm (*Spodoptera litura*), *Chrysodexis chalcites*, leaf-folder (*Lamprosema indicata*), and *Phaedonia inclusa* [5, 7]. Yield losses due to the leaf-eating pest, such as armyworm can reach 80% and even 'puso' [7]. The most destructive pod-feeding pests is pod sucking bug, pod borer, and pod worm. The soybean yield losses due to these pests were between 20-100% [8, 9]. According to Asadi et al. [10] soybean yield loss due to pest attacks depends on the soybean growth phase and plant resistance level. Moreover, pest infestation also decreases seed vigor, increases production costs, and even product rejection by consumers [11, 12]. So far, farmers are still using chemical insecticides to control soybean pests [13, 14].

Plant characteristics such as secondary metabolites, nutritional resources, and morphology, may affect arthropod–plant interactions. This can be considered to enhance plant resistance and control pest populations [15]. The resistant varieties have a negative effect on the biology, physiology, and behaviour of insects [16]. Therefore, the use of resistant varieties can minimize yield losses. Unfortunately, soybean varieties that are resistant to leaf-eating pests are not available yet. In addition to using resistant varieties and chemical pesticides, the soybean pest population can be controlled by various methods, such as sex pheromones, botanical pesticides, biological insecticides, and trap crop [17, 18, 19, 20].

This study aimed to identify the effect of different pest management systems and various soybean varieties on pest population dynamics, abundance and diversity of natural enemies, plant damage, and soybean production.

2. Materials and Methods

2.1. Study Site and Experimental Design

This study was conducted at the research station of North Sumatra Assessment Institute for Agricultural Technology, Deli Serdang District, North Sumatra, Indonesia (3°29'48" N; 98°54'22" E, and 22 m above sea level) from January to June 2018.

Three soybean varieties, i.e *Anjasmoro*, *Demas 1*, and *Dering 1*, were used in this study. Each variety was cultivated with three dIifferent pest management methods. First, pest control without human intervention (control); second, pest control using chemical pesticides scheduled basis (eight times application); and three, integrated pest management (IPM). The IPM treatment consists of several treatments, namely seed treatment (*Bacillus polymixa* and *Pseudomonas flourescens*; Rhizomax®, Wish Indonesia), corn plant (*Zea* mays) as a barrier plant, pheromone (Fero Grayak®, Rumah Bio Indonesia), pest population monitoring, application of botanical pesticide (azadirachtin 0.003 g-l, Agri Neem®, Rumah Bio Indonesia) and chemical pesticide (cypermethrin 2 ml-l, lambda-cyhalothrin 2 ml-l). This study used a split plot design with a randomized complete block design pattern using three groups. The pest management method was treated as the main-plot while the soybean variety was treated as a sub-plot. The distance between treatment was 5 m between the sub-plot and 250 m between the main-plot.

2.2. Plant Cultivation

Soybean seeds were planted with a spacing of 40 cm x 15 cm on the 10 m x 10 m field sized for each sub-plot. The plant was fertilized with 50 kg-ha urea, 50 kg-ha SP36, and 50 kg-ha KCl at the time of planting. Weeding was carried out on plants 21 and 35 days after planting (DAP). In the treatment of pest control using chemical pesticides, it was applied eight times. Cypermethrin 2 ml/l was applied on plants 8 DAP on the treatment chemical pesticide. For control leaf-feeder and pod borer caterpillars were applied lambda-cyhalothrin 2 ml-l on was 21 until 63 DAP with an interval of seven days, while soybean pod sucker was controlled using deltamethrin 2 ml-l on 56 DAP [21].

Five rows of corn were planted around the IPM sub-plot one week before soybean. Corn seeds were planted with a spacing of 70 x 20 cm. The plants were fertilized according to Zubachtirodin et al [22].

2.3. Arthropod Observation

In this study, we observed the soybean pest population, diversity, and abundance of natural enemies. The pest population was observed from 1 to 10 weeks after application (WAP) (Table 1). All herbivorous insects were observed from the sample plant directly in the morning before pesticide application. Natural enemies were collected using a yellow pan trap (five pans per sub-plot). Observation of natural enemies started at 4 to 8 WAP with intervals of 14 days. All natural enemies were identified to morphospecies level.

Table 1. Observation schedule of soybean pest population and number of samples observed

Pests	Plant age (weeks after planting)										Sample size
	1	2	3	4	5	6	7	8	9	10	
Ophiomya phaseoli	√	√	√								30 plants on diagonal
Lamprosema indicata			√	√	√	√					3 plots with a size of 1 m^2 each
Spodoptera litura	√	√	√	√	√	√	√	√	√	√	30 plants on diagonal

2.4. Plant Damaged

Soybean damage was determined by the rate of leaf and pod damage. Leaf damage was assessed by counting the number of leaves that were damaged by leaf-feeding caterpillars. The observation started at three until eight WAP with intervals of seven days. Ten plants were sampled in diagonal. The intensity of leaf damage was determined by the following formula $I = \frac{\sum_{i=0}^{V} (ni\ x\ vi)}{V\ x\ N}\ x\ 100\%$

Note: I = intensity of attacks; N = total number of leaves; V = highest score; ni = number of leaves in each score; and vi = score. The visual score of leaf damage followed the score used by CIAT [23].

Observation of pod damage due to pod-feeding pests was carried out at harvest time. All pods from fifteen clumps of plants diagonally in each plot were collected. A number of damaged and undamaged pods were counted for the calculated pod damage percentage.

2.5. Yield

The yield component per plant was counted at the R8 stage. Ten randomly selected soybean plants from the diagonal of each sub-plot were used to count the number of filled pods per plant and 100-seed weight. Seed yield was calculated by harvesting three units measuring 2 x 5 m in each sub-plot and adjusting the yield to 18% moisture content.

2.6. Data Analysis

All data were analyzed using ANOVA with Duncan Multiple Range Test (DMRT) at the level p ≤ 0.05 as a post hoc test to compare the means of each treatment. The data was transformed using $\sqrt{(x + 0.05)}$.

3. Results and Discussion

3.1. Soybean pest population

Pests emergence on soybean fields was related to the phase of plant growth. Bean fly *O. phaseoli* began to appear in the early vegetative phase (1-3 WAP), with a population peak at 2 WAP. Soybean leaf folder *L. indicata* and armywarm *S. litura* attack plants in the early vegetative phase (1 – 2 weeks after planting) until the generative phase (6 – 10 WAP). While the emergence of pod-sucking bug *R. linearis* and pod borer *E. zinckenella* began when the plant began to form pods.

The results showed that the soybean pest population was not significantly different in soybean varieties but different in pest management treatments (Table 2). At two WAP, the number of bean fly found a range between 0.72 – 1.43 per clump of plants. The highest number of bean fly was found in the uncontrolled treatment and IPM, however, the two treatments were not significantly different. The high number of bean fly found in the IPM treatment was due to the research site grows soybeans at the end of the season. According to Tengkano [6] soybeans grown for more than 10 days in one field cause soybean plants to be susceptible to bean fly. At three WAP, the highest number of bean fly was found only in the uncontrolled treatment and was significantly different with both insecticide and IPM treatment. The low number of bean fly found in the IPM treatment suspected that insecticide application at 14 days after planting (after pest population monitoring).

Leaf-eating caterpillars began to attack soybean plants one week after planting. The first pest infestation was armyworm and follow by the soybean leaf folder. The effect of various pest management on the soybean leaf folder population was shown on four to six weeks after planting (Table 2). All pest management methods significantly reduced the soybean leaf folder population compared to treatment without pest control. At four WAP, insecticide applications significantly reduced the leaf folder population after two applications. However, the leaf folder population increased again in the fifth and sixth week after planting although insecticide application was still carried out. The same thing was also reported by Indiati and Bedjo [24], they found that the population of soybean leaf-eating caterpillars increased one day and one week after the application of lambda-cyhalothrin 2 ml/L. We suspect that the increase in pest population is due to the negative effects of the scheduled and continuous use of this insecticide. Several reports have mentioned the negative effects of synthetic pyrethroid insecticides on Lepidoptera [25, 26]. Therefore, it is necessary to conduct further studies to determine the negative impact of lambda-cyhalothrin on the Indonesian populations of *L. indicata*.

The population of armyworms was influenced by pest management methods. The lowest armyworm population was found in the IPM treatment and was significantly different from other treatments (Table 2). A combination of sex pheromone and azadirachtin was able to suppress armyworm populations in the vegetative phase. Samudra et al [19] reported that synthetic sex pheromones (Fero Grayak®) were effective in capturing male *S. litura* from 1 – 8 weeks after pheromone installation. While azadirachtin affected some biological aspects of *S. litura*, namely feeding behavior, growth, and development [27, 28, 29]. Soybean pest control with a combination of various pest control components can increase the population of beneficial insects, especially general predators and parasitoids compared to the application of chemical insecticides.

3.2. Plant damage

Leaf-eating caterpillars attacked soybean plants starting one week after planting, but the effect of treatment was seen four weeks after planting. Therefore, plant damage data presented also starts four weeks after planting. Table 3 showed that both the average leaf and pod damage were significantly different between types of pest management and varieties. In the types of pest management, the lowest both leaf and pod damage intensity was observed in IPM, but it was not significantly different from the insecticide. The low plant damage in IPM treatment indicated that the combination of sex pheromones and botanical pesticides at the beginning of soybean growth and the use of chemical pesticides based on pest populations monitoring were effective in controlling the population of leaf-eating and pod-feeding pests so that damage caused was also low. The Synthetic sex pheromone used in our study was effective in capturing *S. litura* adults in the Indonesian population [19]. The effectiveness of azadirachtin to control larvae of *L. indicata* assigned *S. litura* has been reported [30, 31] According to Mordue and Nisbet [32] active compound of neem affects several insect physiological activities such as feeding activity, reproductive ability, moulting process, chitin-forming, etc.

Our results showed that soybean variety affects leaf and pod damage. The highest intensity of leaf damage was observed in both *Anjasmoro* and *Dering 1*, while the highest intensity of pod damage was observed in *Anjasmoro* (Table 3). The difference in the response of soybean varieties to pest attacks was related to the trichomes present in both leaves and pods. The effect of pest attack on plants is influenced by the density of trichomes on the plant surface and trichome length [33, 34, 35].

The interaction between pest management and soybean varieties significantly affected leaf damage at six and eight weeks after planting. The lowest leaf damage was found in the interaction between insecticide and *Demas 1* and between IPM and *Demas 1*, it was significantly different from other interactions (Tabel 4 and 5).

Table 2. Effect of soybean variety and pest management on the population of bean fly *Ophiomyia phaseoli*, soybean leaf folder, and armyworm

Treatment	Plant age (weeks after planting)									
	1	2	3	4	5	6	7	8	9	10
Bean fly *Ophiomyia phaseoli* population (individuals/clumps of plants)										
Pest management (P)										
Control	0.32	1.43 b	1.13 b	-	-	-	-	-	-	-
Insecticide	0.27	0.72 a	0.24 a	-	-	-	-	-	-	-
IPM	0.21	1.38 b	0.47 a	-	-	-	-	-	-	-
F	1.32	18.10	111.18	-	-	-	-	-	-	-
P value	0.36	0.01	0.00	-	-	-	-	-	-	-
Soybean variety (V)										
Anjasmoro	0.27	1.18	0.60	-	-	-	-	-	-	-
Demas 1	0.28	1.13	0.57	-	-	-	-	-	-	-
Dering 1	0.26	1.22	0.68	-	-	-	-	-	-	-
F	0.02	0.16	0.25	-	-	-	-	-	-	-
P value	0.98	0.85	0.79	-	-	-	-	-	-	-
Soybean leaf folder population (individuals/clumps of plants)										
Pest management (P)										
Control	-	0.30	1.44	2.19 c	2.30 c	2.59 c	-	-	-	-
Insecticide	-	0.30	1.26	0.81 a	1.00 b	2.26 b	-	-	-	-
IPM	-	0.30	1.04	1.37 b	0.63 a	0.48 a	-	-	-	-
F	-	0.16	2.64	18.39	95.07	234.68	-	-	-	-
P value	-	0.86	0.19	0.01	0.00	0.00	-	-	-	-
Soybean variety (V)										
Anjasmoro	-	0.26	1.26	1.41	1.33	1.70	-	-	-	-
Demas 1	-	0.30	1.26	1.52	1.30	1.85	-	-	-	-
Dering 1	-	0.33	1.22	1.44	1.30	1.78	-	-	-	-
F	-	0.26	0.09	0.29	0.05	0.64	-	-	-	-
P value	-	0.77	0.91	0.75	0.96	0.55	-	-	-	-
Armywoisrm Population (individuals/clumps of plants)										
Pest management (P)										
Control	0.09	0.08	1.06 b	1.67 b	1.47 b	1.80 b	1.35 a	1.16 a	0.99 b	1.03 b
Insecticide	1.00	0.03	0.97 b	1.60 b	1.53 b	1.90 b	1,96 b	1.66 b	1.43 c	0.96 b
IPM	0.00	0.03	0.26 a	0.85 a	0.74 a	1.00 a	1.64 ab	1.16 a	0.65 a	0.41 a
F	3.98	1.93	13.12	77.73	11.13	16.71	80.28	6.49	29.85	11.57
P value	0.11	0.26	0.02	0.00	0.02	0.01	0.00	0.05	0.00	0.02
Soybean variety (V)										
Anjasmoro	0.07	0.02	0.79	1.18	0.99 a	1.50	1.74	1.30	1.07	0.83
Demas 1	0.07	0.03	0.67	1.51	1.35 b	1.60	1.72	1.22	1.01	0.75
Dering 1	0.05	0.09	0.83	1.43	1.39 b	1.59	1.49	1.25	0.99	0.83
F	0.03	0.61	0.22	1.57	6.99	0.20	0.95	0.19	0.28	0.26
P value	0.97	0.56	0.80	0.25	0.01	0.82	0.42	0.83	0.76	0.77

Value followed by the same letter in the same column is not significantly different in DMRT at 5% of significant level.

Table 3. Effect of pest management and soybean variety on soybean plant damage by leaf-eating caterpillar and pod-feeding pests

Treatment	Leaf Damage (%)			Pod Damage (%)
	4 WAP	6 WAP	8 WAP	
Pest Management (P)				
Control	11.89 a	22.07 a	28.90 a	18.65 a
Insecticide	8.52 b	18.42 b	22.68 b	14.92 b
IPM	7.93 b	19.14 b	21.11 c	14.43 b
F	15.44	53.50	107.90	8.081
P value	0.013	0.001	0.00	0.004
Soybean variety (V)				
Anjasmoro	10.74 a	20.01 b	25.70 a	19.49 a
Demas 1	7.06 b	17.55 c	21.11 b	15.53 b
Dering 1	10.53 a	22.02 a	25.88 a	12.97 c
F	10.89	64.48	92.10	24.41
P value	0.002	0.00	0.00	0.00
Interaction				
P x V	ns	*	*	ns

Value followed by the same letter in the same column is not significantly different in DMRT at 5% of significant level.

Table 4. Interaction between pest management and soybean varieties on leaf damage by leaf-eating caterpillar at six weeks after planting

Pest Management	Intensity of Leaf Damage (%)		
	Anjasmoro	Demas 1	Dering 1
Control	22.03 aA	21.71 aA	22.48 aA
Insecticide	18.61 bB	14.72 bC	21.87 aA
IPM	19.49 bB	16.24 bC	21.70aA

The numbers followed by the same small letter in the same column are not significantly different in the DMRT test at 5% of significant level. The numbers followed by the same capital letter in the same row are not significantly different in the DMRT test at 5% of significant level

3.3. Diversity and abundance of natural enemies

In this study, we collected 38,592 individuals of natural enemies consisting of 12 ordo, 44 families, and 102 morphospecies. The natural enemies found were dominated by parasitoids (92.4%) consisting of 47 morphospecies, 20 families, and two ordo. Eulophidae, Scelionidae, Braconidae, Trichogrammatidae, and Pteromalidae were the families that have the highest abundance of individuals. While predators were dominated by families Coccinellidae, Formicidae, Oxyopidae, and Lycosidae.

Species richness and abundance of natural enemies were influenced by pest management methods, but not by soybean varieties. The lowest species richness of both parasitoids and predators was found in soybean fields that were sprayed with insecticide. A number of parasitoid morphospecies ranged from 12 – 20 morphospecies depending on the age of the plant, while predator was ranging from 9 – 31 morphospecies (Tabel 6). This effect was also shown in the abundance of parasitoids and predators. Parasitoid abundance on fields sprayed with insecticide at four and six weeks after planting were 454 and 350.67, respectively, and was significantly different from other treatments. While in eight WAP, the parasitoid population in soybean fields sprayed with insecticide and IPM was not significantly different (Table 7). This is due to the application of insecticides to reduce the population of pod-feeding pests on seven weeks after planting. Pest control using pesticides in soybean production systems was reported to be able to suppress pest populations so that yield losses can be reduced [36, 37, 38]. Unfortunately, most parasitoids were sensitive to insecticides [39, 40, 41].

Table 5. Interaction between pest management and soybean varieties on leaf damage by leaf-eating caterpillar at eight weeks after planting

Pest Management	Intensity of Leaf Damage (%)		
	Anjasmoro	**Demas 1**	**Dering 1**
Control	29.91 aA	26.17 aB	30.63 aA
Insecticide	25.16 bA	18.16 bB	24.71bA
IPM	22.04 cA	18.49 bB	22.32 bA

The numbers followed by the same small letter in the same column are not significantly different in the DMRT test at 5% of significant level. The numbers followed by the same capital letter in the same row are not significantly in DMRT test at 5% of significant level.

Table 6. Effect of varieties and pest management on natural enemies diversity in soybean cultivation

Treatment	Parasitoid			Predator		
	4 WAP	**6 WAP**	**8 WAP**	**4 WAP**	**6 WAP**	**8 WAP**
Pest Management (P)						
Control	19.33 b	20.89 c	12.44 c	38.11 b	45.11 b	26.11 b
Insecticide	12.44 a	7.78 a	4.67 a	31.33 a	17.11 a	9.78 a
IPM	18.78 b	14.44 b	9.33 b	38.56 b	45.22 b	26.89 b
F	25.95	73.94	34.28	5.68	198.32	76.61
P value	0.00	0.00	0.00	0.01	0.00	0.00
Soybean variety (V)						
Anjasmoro	16.56	15.11	9.67	37.22	36.56	21.78
Demas 1	16.78	13.78	8.33	35.00	35.11	20.22
Dering 1	17.22	14.22	8.44	35.78	35.78	20.78
F	0.20	0.79	1.22	0.44	0.19	0.51
P value	0.82	0.47	0.32	0.65	0.83	0.61
Interaction						
P x V	ns	ns	ns	ns	ns	ns

Value followed by the same letter in the same column is not significantly different in DMRT at 5% of significant level.

3.4. Production

Our results showed that pest management systems and soybean varieties significantly influenced soybean production (Tabel 8). There was no interaction between the pest management system and soybean varieties. In the pest management systems, soybean production varied between 13.10 to 20.04 kg per m^2. The highest yield was found in IPM and it was not significantly different from production in insecticide plots. These results indicate that technological components in IPM plots can suppress pest populations equivalent to insecticides. The insecticide was applied when the pest population is above the control threshold. Lambda-cyhalothrins effective for controlling pod borer in cowpea [42, 43].

Table 7. Effect of varieties and pest management on natural enemies abundance in soybean cultivation

Treatment	**Parasitoid**			**Predator**		
	4 WAP	**6 WAP**	**8 WAP**	**4 WAP**	**6 WAP**	**8 WAP**
			Pest Management (P)			
Control	600.56 b	704.89 c	412.22 b	64.67 b	38.56 b	24.33 b
Insecticide	454.00 a	350.67 a	202.56 a	38.67 a	24.11 a	11.56 a
IPM	598.89 b	427.67 b	210.22 a	62.89 b	39.44 b	22.11 b
F	11.11	52.81	48.48	29.08	7.86	14.79
P value	0.001	0.00	0.00	0.00	0.00	0.00
			Soybean variety (V)			
Anjasmoro	551.11	491.22	274.11	57.56	36.22	19.44
Demas 1	558.00	501.33	272.89	53.33	32.44	19.78
Dering 1	544.33	490.67	278.00	55.33	33.44	18.78
F	0.07	0.05	0.09	0.62	0.41	0.08
P value	0.93	0.95	0.91	0.55	0.67	0.92
			Interaction			
P x V	ns	ns	ns	ns	ns	ns

Value followed by the same letter in the same column is not significantly different in DMRT at 5% of significant level.

Table 8. Effect of soybean variety and pest management on soybean production

Treatment	**Production (kg per m2)**
Pest Management (P)	
Control	13.10 a
Insecticide	20.03 b
IPM	20.04 b
F	77.11
P value	0.00
Soybean variety (V)	
Anjasmoro	16.33 a
Demas 1	17.16 ab
Dering 1	19.69 b
F	25.44
P value	0.00
Interaction	
P x V	ns

Value followed by the same letter is not significantly different in DMRT at 5% of significant level.

Overall, our results underline the complementary impact of different pest management systems in regulating pest population in soybean fields and its impact on soybean yield. Reducing pesticide use can increase the diversity and abundance of natural enemies. These organisms can control pest populations naturally so that the damage to leaves and pods in the IPM plot can be suppressed and does not show a significant difference compared to the chemical control plot. Although this study covered only one crop season, our results highlight the importance of contributions from natural enemy communities in increasing yields. Moreover, the ecosystem service provided by natural enemies can minimize negative effects on the environment, reduce the dependence on pesticide applications, and maintain high-yield sustainability (44,45,46). Therefore, combining several pest control technologies that make the application of insecticides the last alternative in pest control is a pest management system that can ensure the sustainability of soybean production.

4. Conclusion

The interaction between pest management systems and varieties significantly affected the leaf damage. The lowest leaf damage was found in the interaction between insecticide and *Demas 1* and between IPM and *Demas 1*, it was significantly different from other interactions. Pest management systems affected pest population, plant damage, abundance, and diversity of natural enemies and soybean production. The IPM treatment consists of several treatments, namely seed treatment (*Bacillus polymixa* and *Pseudomonas flourescens*; Rhizomax®, Wish Indonesia), corn plant (*Zea* mays) as a barrier plant, pheromone (Fero Grayak®, Rumah Bio Indonesia), pest population monitoring, application of botanical pesticide (azadirachtin 0.003 g-l, Agri Neem®, Rumah Bio Indonesia) and application of chemical pesticide (cypermethrin 2 ml-l, lambdacyhalothrin 2 ml-l) based on monitoring of pest population, can increase soybean production equivalent to soybean production in insecticide plot.

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