AN ECONOMIC EVALUATION OF SOYBEAN STINK BUG CONTROL ALTERNATIVES FOR THE SOUTHEASTERN UNITED STATES

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Abstract

Methyl parathion or Penncap M (an encapsulated methyl parathion) are used extensively throughout the United States for controlling stink bug pests in soybeans, *Glycine Max* (L.) Merrill. However, this insecticide is highly toxic to mammals, birds, and non-target arthropods, and thus is less environmentally sound than other insecticides. For environmental and human health considerations, investigating alternative insecticides for control is desired. For this investigation, research based on field experimental data from Florida, Georgia, and Louisiana during the 1988 and 1989 growing seasons were employed. Results indicate that alternative, currently available, and less toxic insecticides may reduce producer costs, increase yield, and improve soybean quality. These alternative insecticides include Scout (tralomethrin), Karate (lambda-cyhalothrin), Orthene (acephate), and Baythroid (cyfluthrin). In terms of improved profits these alternative insecticides may dominate methyl parathion or encapsulated methyl parathion.

Key words: pest management, risk efficiency, stochastic dominance, soybean, *Glycine max*, stink bug, *Nezara viridula*

In the southeastern United States, stink bugs, primarily *Nezara viridula* (L.), are major pests that contribute to serious quality damage and annual yield losses in soybean, *Glycine max* (L.) Merrill (McPherson et al.). Florida, Georgia, Louisiana, and South Carolina are the southeastern states most infested with stink bugs. In 1989, stink bug was the number one soybean insect pest in Georgia, and chemical control and crop losses cost over 13 million dollars (Adams et al.). Among the species in the stink bug complex associated with soybean, southern green stink bug (*N. viridula*) is the most common species (Turnipseed and Kogan).

Stink bugs damage both quantity and quality of the soybean crop (Todd). Seeds damaged by stink bugs will result in price reductions, with dockage based on percent damaged kernels. Some foreign buyers may even completely reject seeds with stink bug damage. Thus, stink bugs can lower a producer's yield, price, and profits.

An immediate response to combat the threat of pests is to apply pesticides. The Environmental Protection Agency (EPA) places pesticides into four toxicity categories (1-4) based on the results of acute toxicity studies on test animals, usually rats and rabbits (EPA). These four categories are: (1) highly toxic, (2) moderately toxic, (3) slightly toxic, (4) and low toxicity (Georgia Cooperative Extension Service). Toxicity is measured in LD_{50}, the dosage required to kill 50 percent of the test animals (Cohrssen and Covello, p.39). The lower the LD_{50}, the more toxic the chemical.

In the past decade, methyl parathion, used for soybean stink bug control, was one of the most widely adopted pesticides throughout the southern region. Application of methyl parathion mitigates the economic impact of stink bugs; however, as listed in Table 1, methyl parathion is a highly toxic chemical, a Category 1 insecticide. Even the other formulation of methyl parathion, Penncap M, which is also known as micro-encapsulated methyl parathion, is moderately toxic, a Category 2 insecticide. Both of these formulations provide good stink bug efficacy (Wier and Boethel). According to the 1991 Georgia Pest Control Handbook (Georgia Cooperative Extension Service), methyl parathion and micro-encapsulated methyl parathion are very toxic, compared with other insecticides, to beneficial insects and spiders, which help control insect pest infestations, and are insecticides considered hazardous to honeybees. Application of methyl parathion on soybeans is reserved for late season use when conservation of beneficial insects is not as critical as it is in the early season. In addition, methyl parathion is restricted to

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Table 1. Toxicity of Methyl Parathion and Alternative Insecticides

Insecticides	Toxicity Category[b]	Acute LD_{50} Values[a] Oral (mg./kg.) White Rats	Dermal (mg./kg.) Rabbits
Ambush (permethrin)	3	>4,000	>2,000
Asana (esfenvalerate)	2	458	2,000
Baythroid (cyfluthrin)	3	590	5,000 (Rat)
Cymbush (cypermethrin)	3	251 (Corn Oil)	1,600 (Rat)
Karate (lambda-cyhalothrin)	2	64	2,000
Methyl Parathion	1	9-25	300-400
Orthene (acephate)	3	866-945	>10,250
Penncap M (micro-encapusulated methly parathion)	2	>60	>1,200
Scout (tralomethrin)	3	1,070-1,250	>2,000

Source: EPA and Georgia Cooperative Extension Service

[a]Toxicity is measured in LD_{50}, the dosage of a substance where 50 percent of the exposed test animals are killed. The lower the LD_{50}, the greater the toxicity. The oral dosage for Cymbush was mixed with corn oil, and the dermal test for Baythroid and Cymbush was performed on white rats.
[b]Toxicity categories 1, 2, and 3 are associated with highly, moderately and slightly toxic insecticides, respectively.

applications 20 days prior to grazing or hay and/or bean harvest. Currently, methyl parathion is still labeled for use on soybeans, but its status is under EPA review. With environmental awareness increasing, resulting in possibly increased producer liability from pesticide applications, the substitution of less toxic chemicals is desirable both for producers and consumers (Segerson; Wetzstein and Centner).

Given that the patent for methyl parathion expired in the late 1980s, neither the past producer, Monsanto Agricultural Products Company, nor other U.S.-based companies have indicated an interest in continued manufacture of the product. In the future, as the insecticide becomes less readily available, its price may increase. This potential scarcity may partially account for the cost of five gallons of emulsifiable concentrate (4 lb./gal.) methyl parathion increasing from \$69.10 in 1987 to \$89.90 in 1989 (Georgia Crop Reporting Service). Though alternative insecticides have potential for controlling certain stink bug species, and, as indicated in Table 1, these insecticides may be less toxic, there exists limited research on their economic feasibility.

Highly toxic insecticides, including methyl parathion, may be effective in controlling stink bugs but environmentally hazardous, whereas less environmentally toxic insecticides may be ineffective for stink bug control. Furthermore, producers' attitudes toward risk associated with variability in profit, yield, and soybean damage may determine which chemicals could be feasible alternatives for methyl parathion. This choice under risk caused by interaction among economic, environmental, and technical considerations may be addressed from a risk analysis perspective.

OBJECTIVE

The objective of the research presented in this paper was to identify the risk-efficient set of stink bug insecticide controls in the southeastern United States. Data for this analysis were derived from 1988 and 1989 field experiments in Florida, Georgia, and Louisiana. Stochastic dominance and expected value analyses were used in determining risk efficient sets.

STINK BUG CONTROL FIELD EXPERIMENTS

In 1988 and 1989, similar field experiments were conducted at agricultural experiment stations in Florida, Georgia, and Louisiana. At each location, two soybean varieties were planted in mid-May with a conventional wide-row cropping system. One of the varieties was an early maturing Group V variety, Forrest, which was used to lure the stink bugs into the test area (McPherson and Newsom). The other variety was a later maturing Group VII variety, either Bragg or Braxton. The late-maturing variety was partitioned into a randomized block design with four replications. Stink bug controls were randomly arranged within each replication in plots that measured 30 by 50 feet (0.034 acre). Two separate test locations were used in Louisiana and Georgia in 1989 and also two in Louisiana in 1988. Lower dosage rates of methyl parathion were applied in the second test site. Insecticides evaluated included Ambush (permethrin), Asana (esfenvalerate), Baythroid (cyfluthrin), Cymbush (cypermethrin), Karate (lambda-cyhalothrin), methyl parathion or micro-encapsulated methyl parathion, Orthene (acephate), Scout (tralomethrin), and an untreated control.

All plots were sampled weekly using standard 15-inch diameter sweep nets (Kogan and Pitre), and treatments were applied whenever stink bug population densities reached the treatment threshold of six per 25 sweeps during soybean growth stages R_4 (pods developing) through R_6 (full green bean developed in the pod) (Adams and McPherson). Approximately 30 days separate R_4 from R_6. All insecticides were applied on the same date to control a uniform distribution of stink bug population densities that exceeded the treatment threshold in all plots. These single insecticide applications provided season-long stink bug control in all plots each year, except for Georgia in 1988. In the 1988 Georgia experiment, a second insecticide application was necessary for all plots two weeks after the first treatment to maintain stink bugs below the threshold level. For all other years and locations only one application was applied.

Although it was the objective of this study to wait for an economic threshold level, this never occurred in Florida in 1989, so applications were made at one-half the threshold. In practice, soybean producers often only partially adopt threshold recommendations. They may apply insecticides at a sub-economic threshold level, concerned that damage will occur if they wait too long. In soybean production, a discussion of the feasibility of partially adopting economic thresholds, under risk, is presented in Szmedra et al.

No distinction was made between the Bragg and Braxton soybean varieties in this study, because earlier reports documented no differences between cultivars in the same maturity group (Gilman et al.). All plots were harvested with a small plot combine with yield and seed quality evaluations conducted. Four 100-seed samples were randomly selected from each treatment. Using criteria reported by Jenson and Newsom, these seeds were manually categorized as having either light, moderate, heavy, or no stink bug damage according to their appearance. Light damage indicates seeds with little damage, moderate damage refers to shrivelled and discolored seeds, and heavy damage indicates severely shrivelled and deformed seeds.

Seed Quality Adjustment

Based on an elevator's usual practice of dockage, seeds with no damage or light damage are categorized as seeds without damage, and seeds with moderate or heavy damage are categorized as damaged seeds. No dockage is applied to seeds without damage. For damaged seeds, only one-fourth of actual damage is counted for dockage, because damage involving discoloration and wrinkled surface usually will not hurt the oil and protein content of the seeds. For damage below eight percent (equivalent to 32 percent of actual damage), each one percentage point damage is docked two cents per bushel. For damage beyond eight percent each additional 0.5 percentage point damage is docked three cents per bushel. Soybean price before dockage, \$5.96 per bushel, is the average October soybean price received by Georgia producers from 1983 to 1989 (Georgia Crop Reporting Service).

CONCEPTUAL MODEL

The stochastic economic state variable is annual per acre profit, π_{kj}, for field experiment k, across stations and years, and insecticide j.

$$(1)\quad \pi_{kj} = Y_{kj}P(1 - D_{kj}) - [A(r_j + v) + C](1 + i) - NC - L,$$

where Y_{kj} denotes stochastic yield in bushels per acre; P and D_{kj} are per-bushel soybean price and stochastic price reduction, dockage, for soybean damage, respectively. Total cost per acre is the sum of cash costs and noncash costs. Cash costs can be divided into cost of insecticides, $A(r_j + v)(1 + i)$, and all other cash costs, $C(1 + i)$. Cost per acre of insecticide, $A(r_j + v)(1 + i)$, is determined by the number of applications, A, times the sum of per acre cost for insecticide j, r_j, and per unit cost of application, v, multiplied by $(1 + i)$, where i is the biannual interest rate. A six-month loan is assumed. In all experiments $A = 1$, except for the Georgia experiments in 1988 where $A = 2$. Other cash costs include seed, fertilizer, herbicides, scouting, machinery, machinery taxes, land rent, and interest on operating capital. Noncash costs, NC, include depreciation, average investment, and housing of machinery, and L denotes cost of unpaid family labor.

Costs

Insecticide costs, for the alternative chemicals, were based on the unit prices of active ingredients from a representative southeastern agricultural chemical supply company. The costs of insecticides per acre before application, r_j, Table 2, were calculated based on the amount of active ingredient present. Application cost, v, by aerial spray was set at $3.25 per application, and an annual 13 percent interest rate was assumed. Other cash costs and noncash costs, listed in Table 3, were based on a 1989 Georgia soybean budget (Given and Mills).

Risk Efficiency Criteria

A risk efficient set of insecticides is determined by producers' aversion to risk. In situations with unknown producer preferences, this risk efficient set is based on various approximations of the probability distributions associated with profit, yield, and damage for each alternative insecticide. Numerous efficiency criteria specifying restrictions on preferences and probability distributions are prevalent in the literature. For a discussion of these alternative efficiency criteria refer to Wetzstein et al. One efficiency criteria popular in agricultural economics literature and employed for this study is stochastic dominance analysis. A necessary condition for one

Table 2. Cost of Alternative Chemicals used in Field Experiments

Chemical	Formulation[a]	Dosage (lb. AI/acre)[b]	Cost per lb. AI	Cost per acre
Ambush	2E	0.1	$45.50	$4.55
Asana XL	0.66E	0.03	150.00	4.5
Baythroid	2EC	0.015	125.33	1.88
Cymbush	3E	0.04	90.25	3.61
Karate	1EC	0.015	190.00	2.85
M. Parathion	4E	0.5	4.50	2.25
Orthene	75S	0.75	9.47	7.10
Penncap M	2FM	0.5	8.80	4.40
Scout Xtra	0.9EC	0.016	244.38	3.91

[a]EC, S, FM, and E denote emulsifiable concentrate, sprayable, flowable, and emulsifiable, respectively.
[b]AI denotes active ingredient.

Table 3. Per Acre Soybean Costs Excluding Insecticide Costs

Category	Unit	Price / Unit	No. of Units	Cost / Acre
Cash costs				
Seed (including inoculant and fungicide)	bu.	13.00	0.80	$10.40
Lime	ton	22.00	0.33	7.26
Fertilizer				
Phosphate (P_2O_3)	lb.	0.25	45.00	11.25
Potash (K_2O)	lb.	0.15	90.00	13.50
Herbicides	appl.	20.00	1.00	
Insect Control				
Scouting (for season)	acre	3.00	1.00	3.00
Machinery				
Fuel	gal.	0.75	10.00	7.50
Repair and maintenance	acre	20.00	1.00	20.00
Machinery tax and insurance	acre	3.00	1.00	3.00
Land rent	acre	20.00	1.00	20.00
Interest on operating capital[a]		0.13		
Noncash costs				
Machinery: Depreciation average investment, and housing	acre	35.00	1.00	35.00
Unpaid family labor	hr.	5.50	2.50	13.75

[a]Interest on operating capital is calculated based on the total of cash costs other than insecticides for a duration of six months.

distribution to dominate another, not only for stochastic dominance analysis but for all risk efficiency criteria, is expected value analysis, where a comparison of the first moment of the decision density functions is performed. Necessary and sufficient condition for stochastic dominance analysis involves the comparison of the cumulative probability distributions for alternative insecticides. Specifically, second degree stochastic dominance (SSD) requires that the area below the cumulative probability distribution of the dominant insecticide must be less than or equal to the area below the cumulative distribution of the insecticide it dominates.

RESULTS

Summary statistics for profit, yield, and damage, aggregated for years 1988 and 1989, are listed in Tables 4, 5, and 6, respectively. Disaggregated summary statistics by year and state are in Chyen. For years 1988 and 1989, profit per acre fluctuated between $-119.87 and $132.65. Generally, among the three states, Louisiana had the highest mean profits resulting from higher yields (Tables 4 and 5) and lower soybean stink bug damage (Table 6). Among the states, profits in Georgia fluctuated the most, because of high variations in both yield and damage. Georgia experienced dry spells in 1988, and 1989 was, overall, a dry year. Water was also a limiting factor in Florida. Compared with Florida, Louisiana, and Georgia soybean yields in the 1980s, as reported by the USDA, the field experiment average yield below 21 bu/acre in Florida is low, over 38

Table 4. Profit Summary Statistics for Florida, Georgia, and Louisiana, Years 1988 and 1989

Chemical	Number of Observations[a]	Mean	Variance	Minimum	Maximum
		dollars			
All Regions[b]					
Scout	40	-5.10	4,077.91	-102.50	88.20
Karate	36	-5.28	5,632.48	-117.33	132.65
Orthene	36	-11.22	4,971.04	-108.60	98.27
Penncap M	48	-13.16	5,260.69	-113.11	106.56
Baythroid	36	-3.91	5,498.78	-115.50	116.39
Control	36	-14.85	5,160.18	-119.87	111.34
Florida					
Scout	8	-72.75	560.46	-102.50	-18.03
Karate	8	-60.65	911.84	-103.77	-13.09
Orthene	8	-85.07	335.27	-108.60	-50.14
Penncap M	8	-74.19	220.17	-103.90	-48.38
Baythroid	8	-75.05	404.82	-100.59	-27.49
Ambush	8	-70.90	903.05	-113.05	-22.46
Control	8	-65.14	780.60	-115.27	-22.84
Georgia					
Scout	12	-52.72	1,250.55	-95.38	29.14
Karate	12	-53.12	4,496.62	-117.33	132.65
Orthene	12	-58.32	1,199.27	-100.72	21.69
Penncap M	16	-75.16	1,660.92	-113.11	55.71
Baythroid	12	-45.28	3,374.41	-115.50	106.55
Control	12	-77.33	1,166.19	-119.87	-13.54
Louisiana					
Scout	20	50.53	895.61	-18.63	88.20
Karate	16	58.30	1,553.24	-45.94	104.95
Orthene	16	61.03	507.34	19.57	98.27
Penncap M	24	48.53	1,730.82	-60.39	106.56
Baythroid	16	62.68	1,390.93	-11.37	116.39
Control	16	57.17	966.20	-8.23	111.34

[a]Two test sites were conducted in Louisiana and Georgia in 1989 and two in Louisiana in 1988. This accounts for different number of observations across states. At the second test sites, alternative rates of Penncap M and Scout were included. These alternative rates of were as effective as the standard rates and thus were included in the overall analysis.

[b]All regions denotes the three states Florida, Georgia, and Louisiana.

Table 5. Yield Summary Statistics for Florida, Georgia, and Louisiana, Years 1988 and 1989

Chemical	Mean	Variance	Minimum	Maximum
	-------bushels per acre-------			
All Regions[a]				
Scout	29.95	111.54	13.24	44.97
Karate	29.81	154.57	11.80	53.68
Orthene	29.63	136.26	12.69	47.23
Penncap M	28.67	143.90	11.47	48.30
Baythroid	29.70	152.33	11.30	49.67
Control	27.09	142.07	9.66	48.55
Florida				
Scout	18.38	15.06	13.24	27.33
Karate	20.62	25.49	13.19	28.85
Orthene	16.88	9.91	12.69	22.71
Penncap M	18.48	7.85	13.09	26.48
Baythroid	17.67	11.52	13.86	25.89
Ambush	18.94	25.84	11.55	26.97
Control	18.49	21.77	10.35	25.75
Georgia				
Scout	22.48	35.97	16.36	35.78
Karate	22.21	132.16	11.80	53.68
Orthene	22.47	40.59	13.89	36.46
Penncap M	18.61	49.84	11.47	40.42
Baythroid	23.14	99.01	11.30	49.00
Control	17.01	36.26	9.66	27.64
Louisiana				
Scout	39.07	25.31	27.32	44.97
Karate	40.12	44.04	22.50	47.59
Orthene	41.38	13.42	34.37	47.23
Penncap M	38.76	48.08	20.33	48.30
Baythroid	40.64	38.47	28.28	49.67
Control	38.95	27.65	27.79	48.55

[a]All regions denotes the three states Florida, Georgia, and Louisiana.

Table 6. Damage (Percent Kernels Damaged by Stink Bug Feeding)Summary Statistics for Florida, Georgia, and Louisiana, Years 1988 and 1989

Chemical	Mean	Variance	Minimum	Maximum
	---------percent---------			
All Regions[a]				
Scout	4.82	18.39	0.00	21.00
Karate	5.50	26.64	0.00	18.00
Orthene	5.11	19.21	0.00	18.00
Penncap M	5.02	20.35	0.00	20.00
Baythroid	4.83	15.53	0.00	18.00
Control	7.00	25.50	0.00	20.00
Florida				
Scout	6.13	7.36	2.00	11.00
Karate	8.38	16.48	4.00	15.00
Orthene	5.88	9.11	3.00	13.00
Penncap M	7.75	10.44	3.00	14.00
Baythroid	7.00	4.75	5.00	12.00
Ambush	7.50	5.25	4.00	11.00
Control	7.63	6.48	5.00	13.00
Georgia				
Scout	6.83	39.14	1.00	21.00
Karate	7.33	42.56	1.00	18.00
Orthene	7.67	30.39	1.00	18.00
Penncap M	7.06	31.56	1.00	20.00
Baythroid	6.58	26.91	0.00	18.00
Control	11.08	30.91	3.00	20.00
Louisiana				
Scout	3.10	4.29	0.00	9.00
Karate	2.69	5.21	0.00	7.00
Orthene	2.81	5.40	0.00	9.00
Penncap M	2.75	5.77	0.00	10.00
Baythroid	2.44	2.00	0.00	4.00
Control	3.63	6.86	0.00	8.00

[a]All regions denotes the three states Florida, Georgia, and Louisiana.

bu/acre in Louisiana is relatively high, and 20 bu/acre in Georgia is not unexpected. Stink bug density in Florida was light for both years, never reaching the economic threshold in 1989. For Georgia, stink bugs exceeded the economic threshold in 1988 and 1989, and in Louisiana the damage was relatively light in 1988 but increased in 1989. Either low yield, high damage, or a combination of these factors resulted in insufficient revenue to cover all expenses. In terms of expected value analysis for all regions, Baythroid is the efficient chemical when considering profit, although Scout dominated in yield and protection against stink bug damage. For individual states, considering profit, Baythroid remains dominant in both Georgia and Louisiana, whereas Karate is dominant in Florida. Baythroid is also dominant in yield and crop damage with the exception of Orthene for crop damage in Florida and crop yield in Louisiana. Methyl parathion (Penncap M) was not dominant in terms of expected value analysis, indicating that efficient alternatives to this toxic chemical may exist. The price increase of over 15 percent for methyl parathion from 1987 to 1989 may partially account for this.

Considering producers' possible aversion to risk, SSD efficient sets for combined years 1988 and 1989 are listed in Table 7. Assuming nothing about the probability distributions of either profit, yield, or damage, risk averse southeastern soybean producers may replace methyl parathion (Penncap M) with the risk efficient chemicals Scout and Baythroid and possibly reduce environmental and human health degradation. Both Scout and Baythroid are Category 3 toxic chemicals compared to Penncap M, a Category 2 chemical. Figure 1 illustrates the profit cumulative probability functions for this risk efficient set, Scout and Baythroid, compared with functions for Penncap M and the control. In terms of yield, less toxic Scout may also replace methyl parathion (Penncap M), and less toxic Scout or Baythroid may be used to lower damage. The cumulative probability functions for yield and damage associated with the risk efficient sets compared to Penncap M and the control are illustrated in Figures 2 and 3, respectively.

Penncap M is only risk efficient in terms of profit and yield for Florida stink bug control compared with Georgia and Louisiana when the years are combined, and in terms of controlling Florida stink bug damage Penncap M did not enter the risk efficient set. Risk-averse Florida producers might select Scout, Baythroid, or Karate as a replacement to Penncap M when considering profit or yield. They might also use Scout or Orthene for damage control.

Table 7. Second Degree Stochastic Dominant Efficient Sets

Year	Region	Profit	Yield	Damage
1988 and 1989	All Regions[a]	Scout Baythroid[b]	Scout[b]	Scout[b] Baythroid
	Florida	Scout Karate[b] Penncap M Baythroid	Scout Karate[b] Penncap M Baythroid	Scout Orthene[b]
	Georgia	Scout Baythroid[b]	Scout Orthene Baythroid[b]	Baythroid[b]
	Louisiana	Orthene Baythroid[b]	Orthene[b]	Baythroid[b]
1988				
	All Regions	Scout[b] Karate Penncap M	Scout[b] Karate Penncap M	Scout[b] Orthene Baythroid
	Florida	Karate[b] Penncap M	Karate[b] Penncap M	Scout Orthene[b] Baythroid
	Georgia	Scout Karate Baythroid[b]	Scout Baythroid[b]	Scoutb Karate[b]
	Louisiana	Karate Baythroid Cymbush[b]	Karate Orthene Cymbush[b]	Baythroid[b]
1989				
	All Regions	Scout Orthene Baythroid[b]	Scout Orthene[b]	Penncap M[b] Baythroid
	Florida	Control[b]	Karate[b] Baythroid Control	Scout[b]
	Georgia	Scout Baythroid[b]	Scout Orthene Baythroid[b]	Penncap M Baythroid[b]
	Louisiana	Orthene[b]	Orthene[b]	Karate[b]

[a]All regions denote the three states Florida, Georgia, and Louisiana.
[b]Efficient chemical based on maximum expected value criterion.

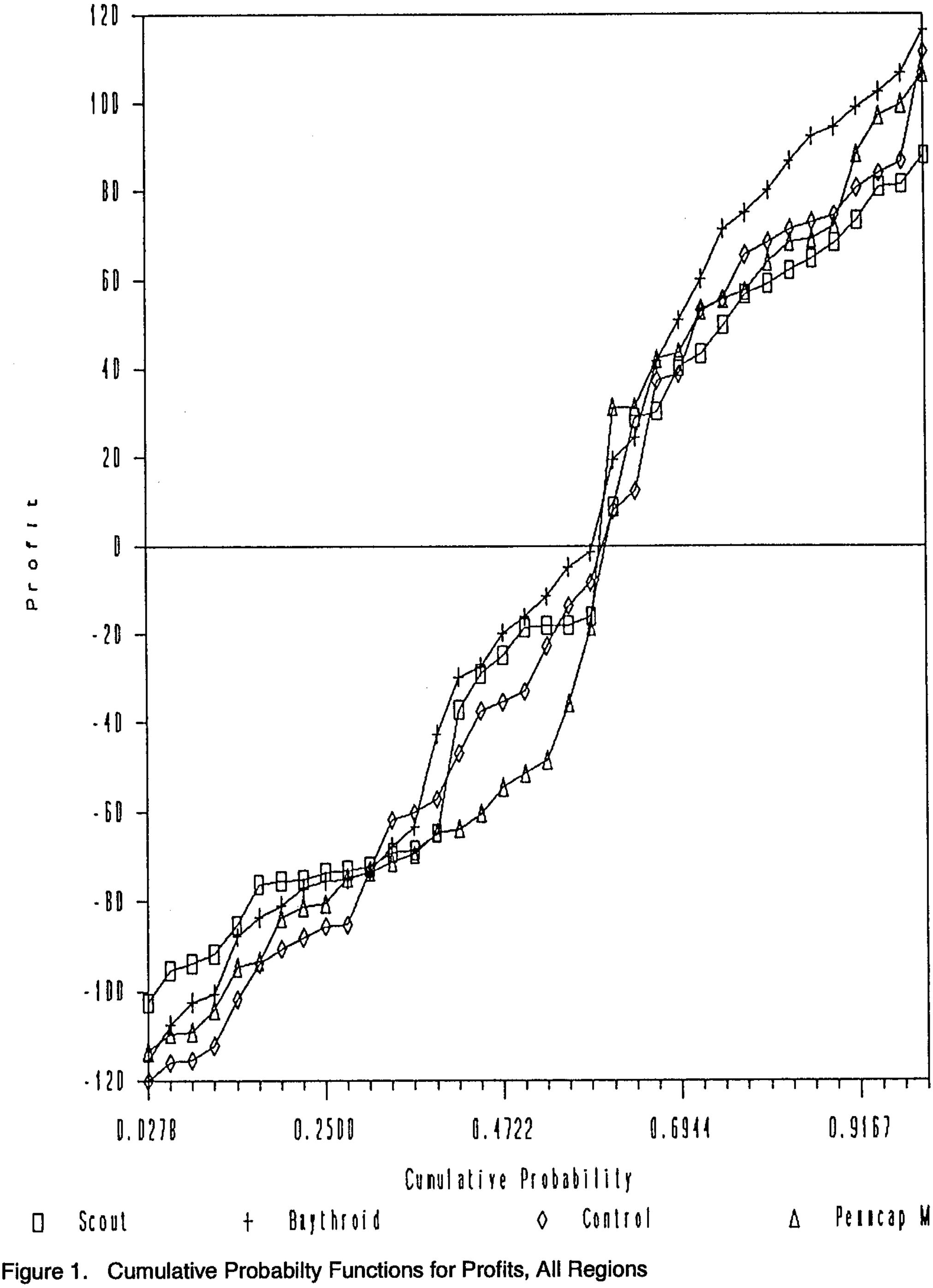

Figure 1. Cumulative Probabilty Functions for Profits, All Regions

Georgia farmers may apply Scout or Baythroid and potentially reduce environmental degradation in addition to selecting a risk efficient chemical based on profits. They may also select Scout, Orthene, or Baythroid for risk efficiency associated with yield and Baythroid for risk efficient damage control. Louisiana farmers may choose Orthene or Baythroid for risk efficiency associated with profit, Orthene for yield efficiency, and Baythroid for damage control.

Considering years 1988 and 1989 separately, with all regions combined, Penncap M enters the risk efficient sets for profit and yield in 1988, and for profit and damage in 1989. Scout still remains in the efficient set for profit, yield, and damage for each separate year, with the exception of the efficient set

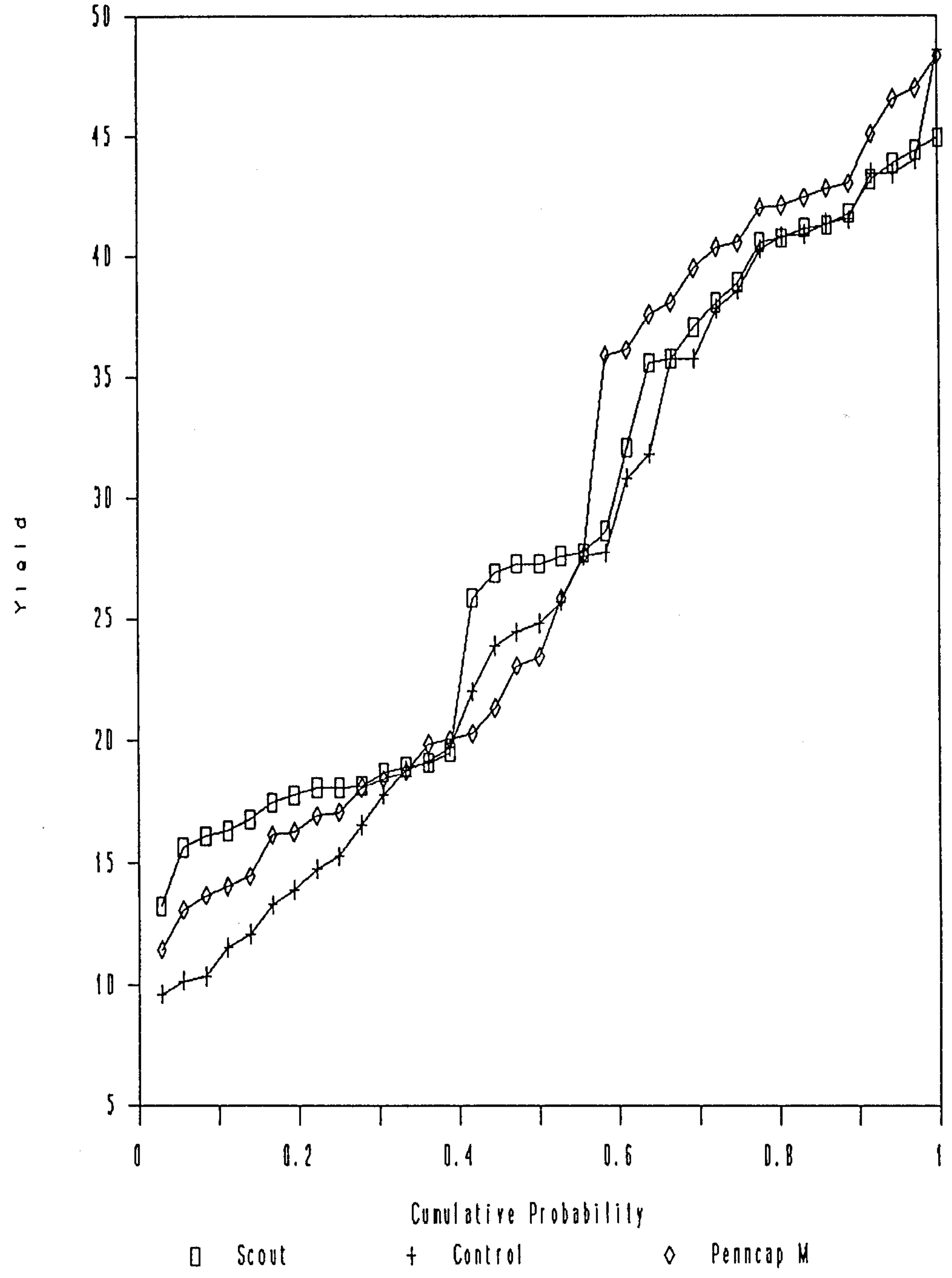

Figure 2. Cumulative Probabilty Functions for Yield, All Regions

for damage in 1989. A reason that Penncap M entered the efficient set for profit in the separate years and did not entered when the years are combined is the low minimum level of profits in 1988 for Scout and Karate, $-91.75 and $-87.82, respectively, compared to Penncap M, $-81.12. This prevents both Scout and Karate from dominating Penncap M in terms of SSD analysis; however, in 1988 both insecticides dominate Penncap M under EV analysis.[1] In 1989, of the three insecticides, Scout,

[1] A necessary condition for one distribution to SSD dominate another is that the smallest value of a dominant distribution cannot be less than the smallest value of a dominated distribution.

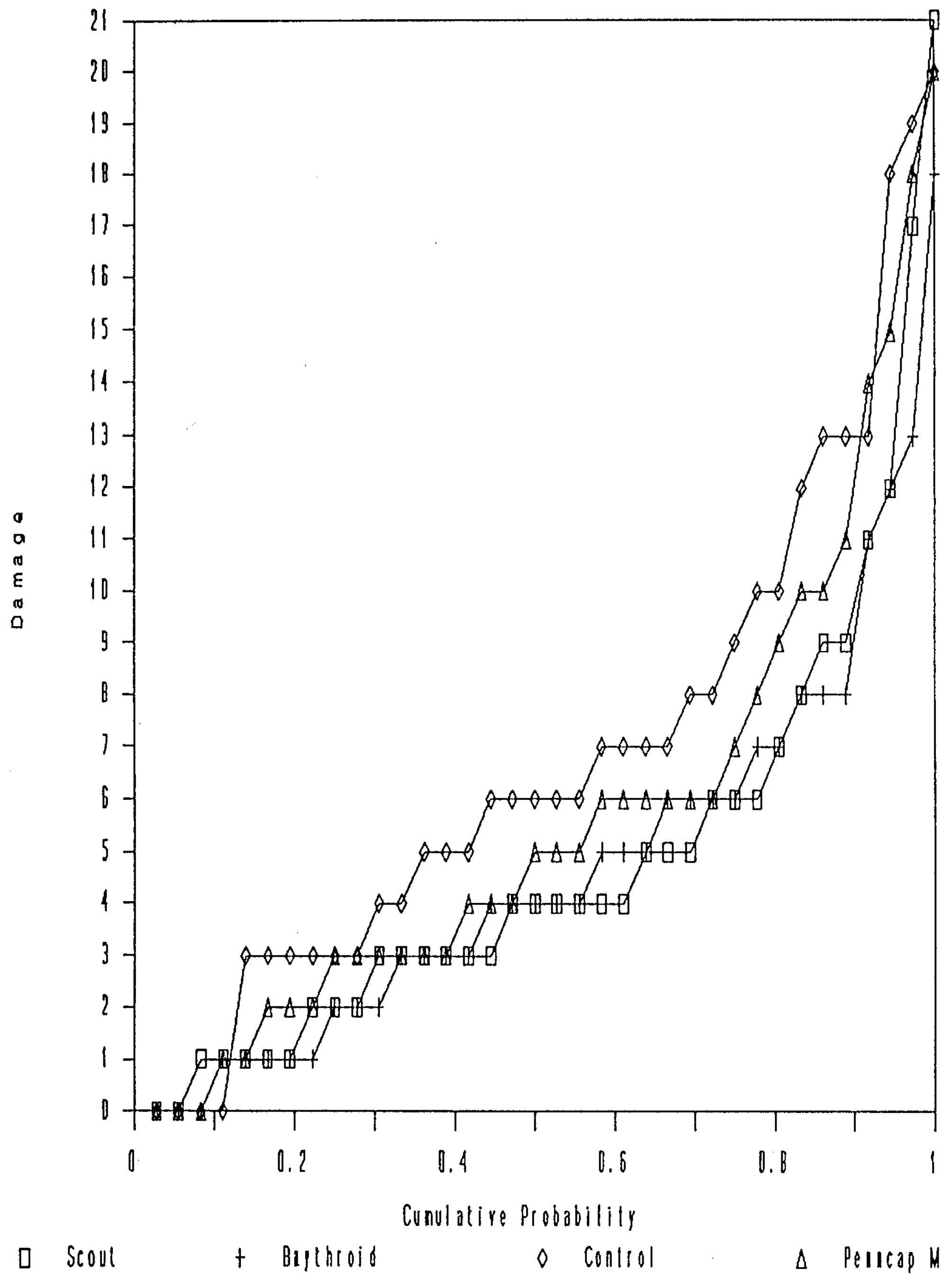

Figure 3. Cumulative Probabilty Functions for Damage, All Regions

Orthene, and Baythroid along with Penncap M that are in the SSD efficient set for all regions considering profit, only Baythroid dominates Penncap M in terms of EV analysis.

As indicated when discussing the field experiments, in Florida in 1989, a sub-threshold insecticide application was applied. This resulted in the control as the only SSD efficient insecticide for Florida profit in 1989 and the control along with Karate and Baythroid in the risk efficient set associated with yield. Applying insecticides at a sub-threshold level might have reduced the positive effects on yield of beneficial insects and spiders. However, not applying an insecticide to control for stink bugs, which feed directly on the soybean seed, resulted in a higher level of damage compared to applying an insecticide such as Scout.

CONCLUSIONS

As outlined by Dixit investment decisions, three characteristics underlie consideration of alternative insecticides. First, there exist both monetary and nonmonetary sunk costs associated with investigating and considering the alternatives. These costs cannot be recouped if the decision to replace an insecticide is reversed in the future. For example, as noted by a reviewer, many local pesticide dealers or applicators only sell a limited number of compounds, which limits a producer's options. Producer efforts to have dealers acquire alternative pesticides entails sunk costs. A second feature of the decision is the uncertain economic and physical environment, and information that may reduce this uncertainty is limited. Third, the consideration of alternative insecticides recurs and includes not only whether to select an alternative insecticide but when to switch. Given these three characteristics, waiting has positive value. This value of waiting should be compared to the loss of current profit. If information on alternative insecticides becomes sufficiently favorable, a decision to switch insecticides, according to current information, should be undertaken and not delayed into the future. This view of considering alternative insecticides is termed, by Dixit, a theory of optimal inertia.

As producers evaluate their production systems to select alternative insecticides, the quantity and caliber of information available underlie their decisions. Information based on results presented in this paper indicate that alternative, less-toxic chemicals may currently be available for risk-efficient control of soybean stink bug damage. This information supports a decision to not delay in switching insecticides. Considering the toxicity of methyl parathion, the possibility of currently available alternative stink bug control is encouraging. If the price of methyl parathion continues to increase relative to other less toxic chemicals, the risk efficiencies of these alternative insecticides will become even more pronounced. Thus, producers might not jeopardize returns, and environmental degradation may be reduced with further restrictions on the supply and use of methyl parathion.

Unfortunately, this conclusion is based on only two years of experimental field plot data, which does not result in a definitive conclusion. Without additional research results supporting these conclusions, producers will be unlikely, based on the theory of optimal inertia, to select less toxic chemical control of stink bugs. Farm management programs might provide suggestions in selection of these alternative chemicals. However, care is required in making such suggestions. Failure to consider all relevant elements of the production system may be the source of error leading to inappropriate suggestions.

REFERENCES

Adams, D.B., and R.M. McPherson. *Control Insects in Soybeans.* Georgia Cooperative Extension Service Circular 720, 1990.

Adams, D.B., R.M. McPherson, D.C. Jones, and D.L. Horton. "Soybean Insects" In *Summary of Losses from Insect Damage and Costs of Control in Georgia, 1989*, G.K. Douce and R.M. McPherson, eds. University of Georgia Agr. Exp. Sta. Spec. Pub. 70. Feb 1991.

Cohrssen, J.J., and V.T. Covello. *Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Risks.* The National Technical Information Service, U.S. Department of Commerce, 1989.

Chyen, D. "Evaluation of Soybean Stink Bug Control Alternatives for the Southeastern United States." M.S. thesis, University of Georgia, 1991.

Dixit, A. "Investment and Hysteresis." *J. Econ. Perspectives*, 6(1992):107-132.

Environmental Protection Agency. "Labeling Requirements for Pesticides and Devices." *Code of Federal Regulations*, Title 40, Part 156, 1991.

Georgia Cooperative Extension Service. *Georgia Pest Control Handbook.* University of Georgia, 1990 and 1991.

Georgia Crop Reporting Service. *Georgia Agricultural Facts.* 1983-90 issues.

Gilman, D.F., R.M. McPherson, L.D. Newsom, D.C. Herzog, and C. Williams. "Resistance in Soybeans to the Southern Green Stink Bug." *Crop Science*, 22(1982):573-576.

Given, W.D., and F. Mills. *Crop Enterprise Cost Analysis, South Georgia 1989.* Georgia Cooperative Extension Service, Mis. Publication 27-S, 1988.

Jenson, R.L., and L.D. Newsom. "Effect of Stink Bug-Damaged Soybean Seeds on Germination, Emergence, and Yield." *J. Econ. Entomology*, 65(1972):261-264.

Kogan, M., and H.N. Pitre, Jr. "General Sampling Methods for Above-ground Populations of Soybean Arthropods." *Sampling Methods in Soybean Entomology*, M. Kogan and D.C. Herzog, eds. New York: Springer-Verlog, 1980.

McPherson, R.M., L.D. Newsom, and B.F. Farthing. "Evaluation of Four Stink Bug Species from Three Genera Affecting Soybean Quality and Yield in Louisiana." *J. Econ. Entomology*, 72(1979):188-194.

McPherson, R.M., and L.D. Newsom. "Trap Crops for Control of Stink Bugs in Soybean." *J. Georgia Entomology Soc.* 19(1984):470-480.

Segerson, K. "Liability for Groundwater Contamination from Pesticides." *J. Environ. Econ. and Management*, 19(1990): 227-243.

Szmedra, P.I., M.E. Wetzstein, R.W. McClendon. "The Economic Threshold Under Risk: A Case Study of Soybean Production." *J. Econ. Entomology*, 83(1990):641-646.

Todd, J.W. "Effects of Stink Bug Damage on Soybean Quality" In *Soybean Seed Quality and Stand Establishment*, J.B. Sinclair and J.A. Jackobs, eds. INTSOY Series Number 22, College of Agriculture, University of Illinois at Urbana-Champaign, 1982.

Turnipseed, S.G., and M. Kogan. "Soybean Entomology." *Ann. Rev. of Entomology,* 21(1976):247-282.

U.S. Department of Agriculture. *Agricultural Statistics*. 1982, 1984, 1986, 1988.

Wetzstein, M.E., and T.J. Centner. "Regulating Agricultural Contamination of Groundwater Through Strict Liability and Negligence Legislation." *J. Environ. Econ. and Management*, 22(1992):1-11.

Wetzstein, M.E., P.I. Szmedra, R.W. McClendon, and D.M. Edwards. "Efficiency Criteria and Risk Aversion: An Empirical Evaluation." *So. J. Agr. Econ.* 20(1988): 171-178.

Wier, A.T., and D.J. Boethel. "Control of Southern Green Stink Bug on Soybean, 1989." *Insecticide and Acaricide Tests*, 15(1990):289-290.