Risk and the Value of Additional Insecticide Applications for European Corn Borer Control in Processing Sweet Corn

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Abstract

This analysis uses data from field evaluations of pyrethroid insecticides to estimate the uncertainty (risk) and expected value of additional insecticide applications and IPM to control European corn borer larvae in processing sweet corn. Preliminary empirical results indicate that IPM can increase expected returns around $5-$9/ac and reduce the risk (variability) of net returns.

Introduction

Over 700,000 acres of sweet corn (*Zea mays* L.) are grown in the United States (US) each year, consisting of both fresh market (242,000 acres) and processing (467,000 acres) sweet corn. The north central region of the US annually produces about half of the processed sweet corn in the US, mostly in Minnesota and Wisconsin. Sweet corn is an important table vegetable. The total annual value of sweet corn grown in the US exceeds $800 million, while US consumers eat about 30 pounds of sweet corn per person each year (canned, fresh and frozen).

Insect pest control is important for both fresh market and processing sweet corn, as consumers generally have low tolerance for insect damage or presence. Conventional insecticides remain an important pest control tool, partly due to slow consumer acceptance of Bt sweet corn. Though not the only economically important insect pest of sweet corn, the European corn borer, *Ostrinia nubilalis* (Hubner), is probably the most important sweet corn pest in the north central region.

Typically, the reported performance of conventional insecticides is limited to the average percent control or marketability of the product at one or a few locations in a limited geographic area. However, even with data from multiple years and locations, little analysis exists concerning the uncertainty (risk) associated with pest control and the implied management implications. Pest control with conventional insecticides is risky because of uncertainty as to when the pest will appear and at what density, as well as from variability in the timing of insecticide applications and the effectiveness of insecticide treatments.

Profit margins for most sweet corn tend to remain quite low, being typically tied to grain corn prices. With marginal returns, growers are looking for opportunities to reduce the costs and risks while maintaining their economic viability. As a result of these tight margins, after making the one or two insecticide applications that are typically needed, a risky decision growers face is whether or not to apply one more spray. Because the actual damage is still uncertain, the cost of the extra spray may exceed the value of the damage prevented, thus reducing the farmer's margin even further. However, not using the extra spray may result in excessive damage that would have been economical to control with the extra spray. The goal of this analysis is to use data from field evaluations of insecticides to estimate the uncertainty (risk) and expected value of one more insecticide application to control European corn borer in processing sweet corn.

Data

The primary data for this study are from published insecticide efficacy trials, the most common sort of data available concerning insecticides. The data consist of the mean number of ECB larvae per ear in a control plot and in a treated plot. In addition, the data for the treated plot include the number of sprays applied, the application rate, and the compound and its formulation, plus the mean number of ECB larvae per ear remaining after these sprays. Finally, the data for both the control and treated plots include the mean percentage of the sweet corn marketable for processing and for the fresh market. The final data includes observations from 49 studies conducted between 1990 to 2003.

Most were from Minnesota (19) and Wisconsin and Indiana (8 each). The remainder are from several states, including Georgia, Illinois, Michigan, New Jersey, New York, Pennsylvania, and Virginia. Most (36) were from *Arthropod Management Tests*, but 8 are from other publications and 5 are from insecticide efficacy trials conducted by a processing company in Minnesota. Data are for 5 pyrethroid insecticides (Capture, Warrior, Baythroid, Pounce, and Mustang), though not all studies included each insecticide. Finally, depending on the specific variables used, the observations available for each estimation differ. These data constitute the meta-data used for this analysis.

Estimation

All estimation was done using TSP 4.5, an econometric software package. For each estimated function, several models were examined and the model chosen as indicated by standard model selection criteria, including t-tests of parameter significance, plus R-squared, Likelihood Dominance Criterion, and Akaike Information Criterion.

The general statistical model used for the relationship between key variables was conditional distribution in which the parameters of the dependent variable were estimated as functions of the independent variable(s). This method has been used to estimate the relationship between pest densities and crop damage, yield loss, and net returns (e.g., Mitchell, Gray, and Steffey 2004; Hurley, Mitchell, and Rice 2004). Once conditional distributions are estimated, the final statistical model links all the conditional distributions into a hierarchical model of net returns per acre for processing sweet corn as a function of the distribution of the ECB pest density.

A hierarchal model is a convenient statistical method of specifying such linkages by reducing a complex process to a relatively simple specification of linked conditional and unconditional distributions. The parameters of one conditional distribution depend on another random variable with its own parameters, and these parameters also depend on another random variable, and so on, until reaching a final unconditional distribution (Casella and Berger 2002, pp. 162-168). As commonly occurs with hierarchal models, closed form expressions for the unconditional distribution of the first conditional distribution in the hierarchy and its moments are impossible to obtain, so that simulation (Monte Carlo) methods are needed (Gelfand and Smith 1990).

Specific conditional distributions estimated for this analysis include (1) the distribution of the ECB larvae per ear conditional on the untreated ECB per plant and the amount of active ingredient (AI) applied for each insecticide and (2) the distribution of the percentage of harvested sweet corn marketable for processing conditional on the ECB larvae per ear and the amount of AI applied for each insecticide. Unconditional distributions needed included (1) the distribution of ECB larvae per ear without an insecticide treatment and (2) the distribution of sweet corn yield without any ECB pest pressure. Results for this estimation process are summarized below.

Estimation Results

Conditional Distribution of Treated ECB

The final model for the number of ECB larvae per ear was a conditional lognormal density with a mean and variance depending on the number of larvae without an insecticide treatment and the amount of AI applied. The model was estimated as a double-log model assuming a homoscedastic normal density using maximum likelihood:

$$\ln(ecb) = \beta_0 + \beta_1 \ln(ecb_0) + (\textstyle\sum_i \alpha_i D_i)\ln(AI) + \sigma\varepsilon ,$$

where *ecb* is the treated ECB population density (larvae per ear), ecb_0 is the ECB larval population density without insecticide treatment, D_i is an indicator (dummy) variable that equals one for insecticide *i*, and zero otherwise, *AI* is the amount of active ingredient applied (lbs/ac), and $\varepsilon \sim N(0,1)$. Parameters to estimate include β_0, β_1, and α_i, and σ, where *i* = {Pounce, Mustang, Baythroid, Capture, Warrior} indexes the insecticide. Table 1 reports the estimated coefficients and statistical properties. Because the natural logarithm of zero is undefined, all observations with *ecb* = 0 were dropped (32 of 191).

Given this model, the random ECB larval population density per ear is:

$$ecb = \exp(\beta_0) ecb_0^{\beta_1} AI^{\sum_i \alpha_i D_i} \exp(\sigma\varepsilon) , \tag{1}$$

which is a lognormal density with respective expected value (mean) and variance of:

$$\mathrm{E}[ecb] = \exp(\beta_0) AI^{\sum_i \alpha_i D_i} ecb_0^{\beta_1} \exp(0.5\sigma^2) \tag{2}$$

$$\mathrm{var}[ecb] = \left(\exp(\beta_0) AI^{\sum_i \alpha_i D_i} ecb_0^{\beta_1}\right)^2 \exp(\sigma^2)\left(\exp(\sigma^2) - 1\right) . \tag{3}$$

Using equation (2) for the mean as the predicted value, the model provides a fit for all 191 observations (not just the 159 with *ecb* > 0) with an R-squared of 0.30.

The positive β_1 coefficient in Table 1 implies that the larger the initial ECB larval population, the larger the ECB population will be after insecticide applications. The negative α_i coefficients for each insecticide imply that each insecticide reduces the ECB larval population. The magnitude of these coefficients, however, indicates the relative ranking of these insecticides, namely that Warrior is the most effective, with Capture essentially the same, then Baythroid is quite close, then Mustang, and finally Pounce is the least effective.

Conditional Distribution of Percentage Marketable for Processing

The final model for the percentage of harvested sweet corn marketable for processing as a function of the ECB larvae per ear was a conditional beta density estimated using maximum likelihood in a manner similar to Mitchell, Gray and Steffey (2004). The conditional mean is

$$\mathrm{E}[\%MktProc] = \exp(\alpha_m - \beta_m ecb), \tag{4}$$

while the standard deviation σ_m was constant (homoscedastic). All 83 observations were used, but those with 100% percent marketable for processing were changed to 0.999 so the likelihood function was defined. Models including other variables (e.g., AI, number of sprays) for the mean and heteroscedastic models were estimated, but none provided a significantly better fit and/or had insignificant parameters. Table 2 reports the estimated coefficients and statistical properties. Using equation (4) for the mean as the predicted value, the model provides a fit for all 83 observations with an R-squared of 0.35.

The interpretation of the coefficients is fairly intuitive. Namely, α_m determines the base level of the percentage of harvested sweet corn marketable for processing even if no ECB larvae are present (this is not 100% due to the presence of other pests and other random effects). The positive β_m determines how rapidly this percentage marketable for processing decreases as the ECB larval population decreases. Finally, σ_m determines the level of uncertainty in the percentage marketable for processing that arise from sources other than the ECB larval population.

Unconditional Distribution of ECB

The Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) annually collects 2nd generation ECB larvae population densities (larvae per plant) from several fields of field corn throughout the state, then summarizes these data by USDA-NASS crop reporting district. Mitchell (2005) has used these data to estimate the statistical distribution of ECB larvae per plant as an unconditional lognormal distribution for each crop reporting district. For the analysis reported here, the ECB population distribution for south central Wisconsin is used, which is a lognormal distribution with a mean $\mu_0 = 0.699$ larvae per plant and a standard deviation $\sigma_0 = 0.917$ larvae per plant.

These DATACP data for field corn ECB per plant are problematic. First, ECB larvae per plant is likely greater than ECB per ear of corn, since ECB larvae also feed on the corn stalk. However, the ECB larvae per ear of sweet corn is likely greater than ECB larvae per field corn plant, since ECB generally prefer sweet corn to field corn. Therefore, the ECB larvae per ear data reported for the untreated control plots in Minnesota and Wisconsin are also used to estimate the unconditional ECB larval population. The result is a lognormal distribution with a mean of 1.280 and standard deviation of 0.998. However, these data are also problematic since they are only from a few years (1990 to 2003) and from only a few locations. However, the simulations to generate economic results using these ECB population parameters have not been completed, but will be for the oral presentation.

Yield Distribution and Price Data

For the distribution of pest-free sweet corn yield, USDA-NASS yield data for Minnesota and Wisconsin for 1992-2004 were used in a manner similar to other studies (Mitchell Gray, and Steffey 2004; Hurley, Mitchell, and Rice 2004). For the mean, the 3-year (2002-2004) average for Wisconsin is used (6.60 tons/ac). To determine the yield variability, first a linear trend yield was estimated using USDA-NASS data for Minnesota and Wisconsin. Then, using the fit trend as the mean, the implied coefficient of variation

(CV) was calculated as the standard error of the regression over the estimated trend. These CV's ranged 10% to 12% for Minnesota and 8% to 10% for Wisconsin. For comparison, the process was repeated using USDA-NASS state average field corn yield data. The implied CV ranged 11% to 16% for Minnesota and 9% to 12% for Wisconsin. Since the yield CV for field corn is around 30% (Babcock, Hennessy, and Hayes 2002; Coble, Hiefner and Zuniga 2000), the assumed field level yield variability for sweet corn was set at 25%, slightly more than twice that implied by the USDA-NASS yield data. Thus, the standard deviation of yield is 1.65 tons/ac. A beta density is used for the distribution of the harvested sweet corn yield, a common distributional assumption for crop yields (Goodwin and Ker 2002). Thus the mean of the beta density is 6.60, the standard deviation is 1.65. Following Babcock, Hart, and Hayes (2002), the minimum yield is set at 0.0 tons/ac and the maximum at the mean plus two standard deviations, or 9.9 tons/ac.

For the sweet corn price, the 4-year (2001-2004) average of USDA-NASS prices for Minnesota was used ($67.20/ton). Typical insecticide costs per application ($/ac) were obtained for each insecticide and formulation from an informal survey of input suppliers and processing companies. These are summarized in Table 3.

As equations (1) and (2) indicate, the distribution of the ECB larval population per ear depends on the total AI of the insecticide applied, not the formulation or the application rate. Hence, the reported costs ($/ac) for each insecticide-formulation combination must be converted to a cost as $/AI for each insecticide. The ratio of the reported cost for material ($/ac) and the reported rate (AI/ac) for each application is the cost of the material as $/AI used for the analysis. Since this ratio varies slightly for the different formulations for each insecticide, Table 3 also reports the cost ($/AI) used for this analysis. Finally, the cost of aerial application from this informal survey was $4.85/ac per application.

Net Returns

For this analysis, the net returns ($/ac) for processing sweet corn production are:

$$\pi = P \times Y \times \%MktProc - P_i \times AI_i - NumSpry \times AppCost - COP, \quad (5)$$

where P is the non-random sweet corn price, Y is the realized yield, $\%MktProc$ is the percent of harvested yield marketable for processing, P_i is the price ($/AI) for the applied insecticide i, AI_i is the total AI applied for insecticide i, $NumSpry$ is the number of spray applications, $AppCost$ of the application cost per spray application ($4.85/ac), and COP is the cost of production for other costs such as tillage, herbicide, fertilizer, etc. As explained below, for this analysis, the COP will not affect the variability (risk) of net returns nor the value of an additional spray application, but merely serves a shift parameter to indicate the overall level of net returns for the grower. This analysis uses COP of $200/ac, but changing this value will not affect the results reported below.

Risk and the Value of an Additional Insecticide Application

Monte Carlo Based Economic Analysis

A common result when using hierarchical models is that the unconditional distribution for the variable if interest and its moments do not have closed solutions, so that numerical methods are required (Gelfand and Smith 1990). This problem occurs here, and so Monte Carlo integration (Greene 1997, p. 192-195) is used to determine the mean and variance of net returns for each scenario analyzed.

For this analysis, Monte Carlo integration involves drawing pseudo-random variables from the required distributions, then calculating net returns for each realization of the random variables. The key is to draw a sufficiently large number of random variables to fully characterize the distribution. For the analysis here, 20,000 pseudo-random numbers were drawn in Microsoft Excel using algorithms described by Cheng (1998). The average of net returns is a Monte Carlo estimate of the mean of the net returns distribution and the sample standard deviation is a Monte Carlo estimate of the standard deviation of the net returns distribution.

The general Monte Carlo process to obtain one pseudo-random draw of net returns using the hierarchical model is summarized as follows. Step 1: The untreated (unconditional) ECB larval population density is drawn from a lognormal density with the assumed mean μ_0 and standard deviation σ_0. Step 2: The ECB larval population is drawn using equation (1) for each insecticide assuming 1, 2, 3 and 4 applications at the maximum application rate reported for each insecticide in Table 3. These two steps generate 21 ECB larval population densities (5 insecticides by 4 different spray application assumptions, plus the original untreated ECB population density). Step 3: For each of these 21 ECB larval population densities, the percentage marketable for processing is drawn from a beta density with a mean calculated using equation (4) and the constant standard deviation σ_m. Step 4: The unconditional pest free yield is drawn as a beta density with the assumed mean, standard deviation, minimum and maximum. Step 5: Net returns are calculated for each of these 21 cases. These steps are repeated 20,000 times, then the average and standard deviation of the net retunes for each of these 21 cases is calculated as a Monte Carlo estimate of expected net returns and the risk associated with these returns.

Using these results, the value of an additional spray is calculated as the increase in expected net returns when using one more spray application, while the effect of an additional spray on risk is calculated as the increase in the standard deviation of net returns. Results for each of these scenarios represents the value and risk assuming scheduled insecticide applications, that is, insecticide applications are not chosen using the observed ECB larval population as part of integrated pest management (IPM).

Risk and the Value of IPM

For IPM, the ECB larval population density resulting after the initial scheduled insecticide application(s) is observed, and then an additional insecticide application is used only if this population density exceeds the economic threshold. The economic threshold for each insecticide is calculated as the ECB larval population density at which the increase in the expected net returns of an additional insecticide application equals the cost of an additional insecticide application. In terms of the steps in the Monte Carlo analysis previously described, the analysis of net returns using IPM is a Step 6. Step 6: If the ECB larval population for this iteration from Step 2 is less than the economic threshold, then use the net returns from Step 5 for this iteration; otherwise, use the net returns from Step 5 for the same insecticide for this iteration, but for one more application. Thus, the net returns for IPM are a combination of the net returns for two different scenarios, where the contribution from each scenario depends on the ECB larval population density after the initial spray application(s). Again, the average of net returns from IPM is the expected net returns with IPM, while the sample standard deviation measures the risk associated with IPM.

Preliminary Empirical Results

Table 4 reports the expected net returns for each insecticide under the different insecticide use strategies analyzed, while Table 5 reports the standard deviation of net returns for each. Table 6 reports the economic thresholds used for the IPM analysis.

Table 4 indicates that expected net returns for Pounce and Mustang are lower than for Baythroid, Capture, and Warrior. This occurs because these two insecticides are relatively less efficacious and so require more applications to yield good control. More applications imply higher applications costs, since Table 3 indicates that the cost ($/ac) of these insecticides is low relative to the cost of aerial application ($4.85/ac). The highest returns occur with Capture, with warrior a close second. Baythroid is somewhat below these, but clearly out performs (in terms of expected net returns) Mustang and Pounce. The remaining discussion focuses primarily on these three insecticides.

The insecticide use strategy maximizing net returns is one scheduled spray, then to use IPM to determine whether to apply a second spray. Figure 1 reports the value of IPM ($/ac) calculated as the difference in expected net returns relative to using the additional spray on a schedule as opposed to using IPM (i.e., 1 scheduled spray with IPM used to determine the need for a second sprays is compared to using 2 scheduled sprays). In general, value of IPM ranges $5-$9/ac depending on the number of initially scheduled sprays and the insecticide. Note, however, that the expected net returns in Table 4 and illustrated in Figure 1 do not include any additional cost for scouting to determine the ECB larval population. Since these costs are often part of more general scouting activities, removing the portion of these costs for just ECB larval scouting seemed difficult, and so they were not accounted for in this analysis.

Table 5 indicates that the standard deviation (risk) of net returns is fairly similar for all insecticides, and that it increases as more insecticides applications are used. This occurs because insecticides are generally what economists call “risk increasing inputs.” Hurley, Mitchell and Rice (2004) show the same effect for Bt corn for ECB control in field corn and cite several other empirical and theoretical studies of the same result.

Figures 2 and 3 illustrate the results from Tables 4 and 5 to show that IPM has a noticeable higher net returns and lower risk (standard deviation of net returns) than the comparable insecticide program relying on scheduled sprays.

Conclusion

The empirical results were prepared for inclusion in the written report for the 2005 Midwest Food Processors Association annual meetings in St. Paul, MN. These results are preliminary and have yet to be fully analyzed by the authors or submitted for peer review. However, they suggest that IPM for ECB larval control in processing sweet corn has the possibility to modestly increase net returns for growers while also reducing risk. Additional research continues to create more conclusive results concerning risk and the value additional insecticide applications and IPM for control of ECB larvae in processing sweet corn.

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Table 1. Estimated coefficients and statistical properties for the conditional distribution of treated ECB larvae per ear.

Parameter	Estimate	Standard Error	t-statistic	p-value
β_0	–4.042	0.2731	–14.80	< 0.001
β_1	0.4497	0.0874	5.146	< 0.001
α_{pounce}	–1.761	0.5158	–3.413	0.001
$\alpha_{mustang}$	–0.6943	0.1572	–4.417	< 0.001
$\alpha_{baythroid}$	–0.4150	0.1740	–2.386	0.017
$\alpha_{capture}$	–0.3090	0.1487	–2.078	0.038
$\alpha_{warrior}$	–0.2806	0.1171	–2.395	0.017
σ	0.8520	0.04778	17.83	< 0.001

Table 2. Estimated coefficients and statistical properties for the conditional distribution of the percentage of harvested sweet corn marketable for processing.

Parameter	Estimate	Standard Error	t-statistic	p-value
α_m	0.02644	0.003761	7.030	< 0.001
β_m	0.8054	0.09933	8.108	< 0.001
σ_m	0.03688	0.003855	9.566	< 0.001

Table 3. Cost of insecticide treatments for processing sweet corn production.

Insecticide-Formulation	Application Rate (AI/ac)	Reported Cost ($/ac)	Calculated Cost ($/AI)	Insecticide Cost ($/AI)
Pounce 3.2EC	0.10	1.88	18.80	18.80
	0.15	2.82	18.80	
	0.20	3.76	18.80	
Mustang Max	0.021	2.35	111.90	112.00
	0.025	2.80	112.00	
Baythroid 2EC	0.0375	5.21	138.93	138.50
	0.044	6.08	138.18	
Capture 2EC	0.033	2.30	69.70	70.50
	0.04	2.85	71.25	
Warrior 1CS	0.02	2.79	139.50	139.50
	0.025	3.49	139.60	

Table 4. Expected net returns ($/ac) for each insecticide use strategy.

	Insecticide				
Insecticide Use	Pounce	Mustang	Baythroid	Capture	Warrior
No Sprays	83.16	83.16	83.16	83.16	83.16
Schedule 1 Spray	137.68	176.65	199.86	208.78	207.45
Schedule 1 Spray, IPM for 2nd Spray	181.41	183.71	200.60	209.11	207.69
Schedule 2 Sprays	185.80	182.53	194.33	204.28	202.12
Schedule 2 Sprays, IPM for 3rd Spray	189.99	183.74	194.40	204.32	202.13
Schedule 3 Sprays	192.11	179.01	185.97	198.20	195.31
Schedule 3 Sprays, IPM for 4thSpray	192.56	179.30	185.96	198.20	195.30
Schedule 4 Sprays	189.54	172.54	176.62	191.55	187.96

Table 5. Standard deviation of net returns ($/ac) for each insecticide use strategy.

	Insecticide				
Insecticide Use	Pounce	Mustang	Baythroid	Capture	Warrior
No Sprays	128.50	128.50	128.50	128.50	128.50
Schedule 1 Spray	116.00	109.34	107.71	107.86	107.83
Schedule 1 Spray, IPM for 2nd Spray	105.52	106.92	107.51	107.78	107.79
Schedule 2 Sprays	107.90	107.88	107.85	108.07	108.00
Schedule 2 Sprays, IPM for 3rd Spray	106.16	107.29	107.85	108.07	108.02
Schedule 3 Sprays	107.94	107.71	108.00	108.21	108.13
Schedule 3 Sprays, IPM for 4th Spray	107.72	107.55	108.02	108.21	108.14
Schedule 4 Sprays	108.52	107.77	108.13	108.31	108.22

Table 6. Economic thresholds for IPM use of insecticides for ECB larval control in processing sweet corn.

Strategy	Economic Threshold (ECB larvae/ear)
To choose 2nd spray after 1 scheduled spray	0.15
To choose 3rd spray after 2 scheduled sprays	0.20
To choose 4th spray after 3 scheduled sprays	0.25

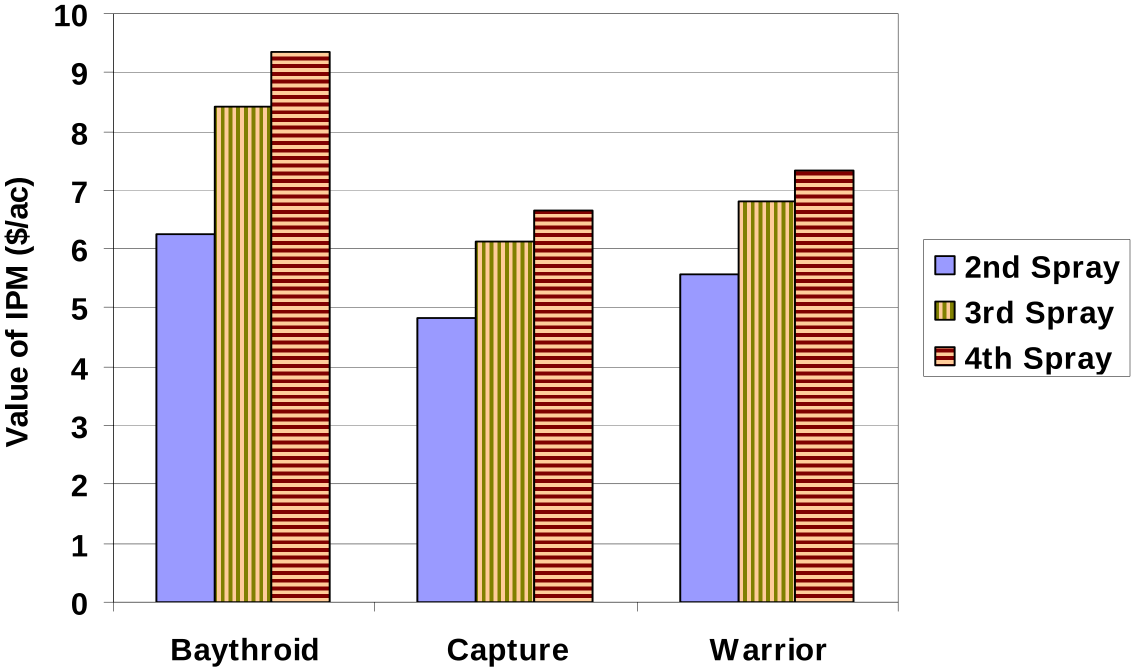

Figure 1. Value of IPM for use of an additional spray relative to using a scheduled additional spray.

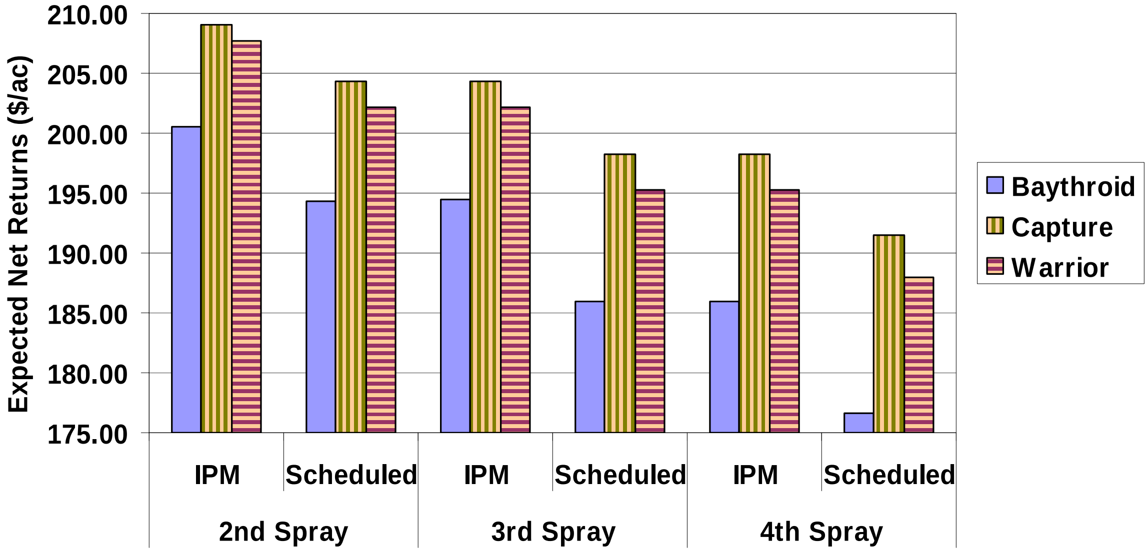

Figure 2. Expected net returns for different insecticide use strategies.

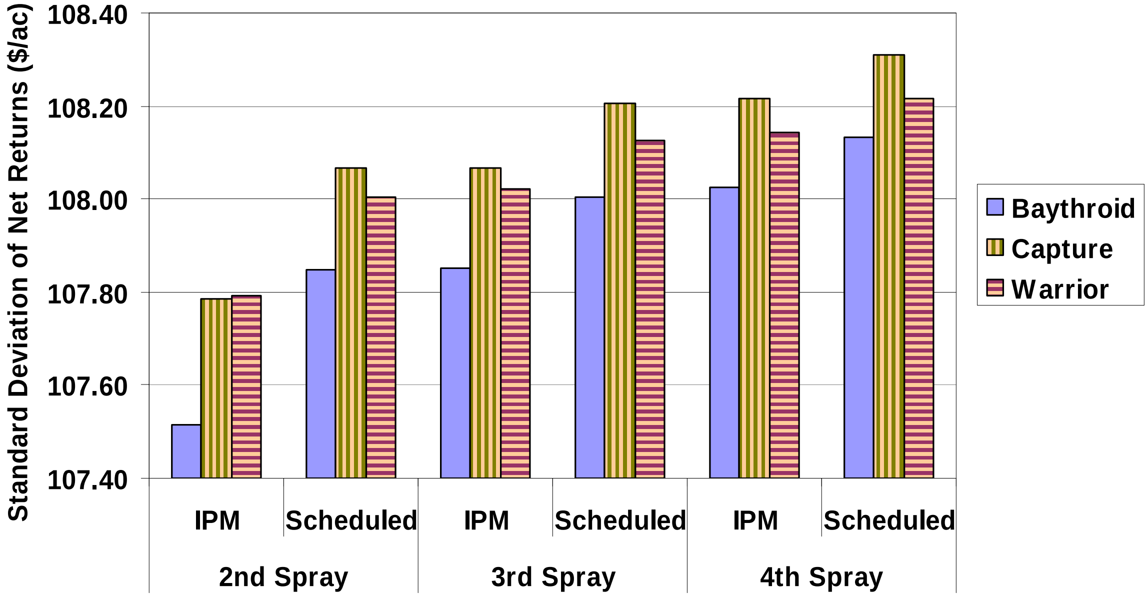

Figure 3. Standard deviation of net returns for different insecticide use strategies.