Hierarchical Modeling for Economic Analysis of Biological Systems: Value and Risk of Insecticide Applications for **Corn Borer Control in Sweet Corn Economics and Risk** of Sweet Corn IPM Paul D. Mitchell **Agricultural and Applied Economics** University of Wisconsin-Madison University of Minnesota Department of Entomology Seminar April 11, 2006

Goal Today

 Explain and illustrate Hierarchical Modeling
 Provide economic intuition of findings concerning the economic value of IPM for sweet corn

 Overview work in progress with Bill Hutchison and Terry Hurley on sweet corn IPM as part of a NC-IPM grant
 All work in progress

Problem/Issue

Use existing insecticide field trial data to estimate the value and risk of IPM for insecticide based control of European corn borer (ECB) in processing and fresh market sweet corn Operationally: Do I need another spray? Estimate the expected value of an additional insecticide application for ECB control Use hierarchical modeling to incorporate risk into the analysis

Conceptual Model

Keep key variables random to capture the risk (uncertainty) in pest control Develop a hierarchical model = linked conditional probability densities Estimate pdf of a variable with parameters that depend (are conditional) on variables from another pdf, with parameters that are conditional on variables from another pdf, etc.



Observe ECB Apply Insecticide?

Random % Survival gives Random Remaining ECB

Random % Marketable (Random Pest-Free Yield)

Net Returns



Net Returns = $P \times Y \times %Mkt - P_i \times AI_i - #Sprys \times CostApp - COP$

Random Initial ECB

- Mitchell et al. (2002): 2nd generation ECB larval population density per plant collected by state agencies in MN, WI, IL
- Empirically support lognormal density with no autocorrelation (new draw each year)

 Sweet corn has more ECB pressure, so use MN & WI insecticide trial data for mean and st. dev., pooling over years 1990-2003
 Lognormal density: mean = 1.28, CV = 78%

Insecticide Efficacy Data

Efficacy data from pyrethroid trials (~ 50)
Capture, Warrior, Baythroid, Mustang, Pounce
Most data from: MN, WI, IN and ESA's AMT
Data include:

Mean ECB larvae/ear for treated and untreated (control) plots of sweet corn
Percentage yield marketable for processing and for fresh market
Number of sprays and application rate

Random ECB after Sprays • Model: $ECB = ECB_0 \times (\% \text{ Survival})^{\text{sprays}}$ • Example: $ECB_0 = 4$, 50% survival per spray, 2 sprays, then $ECB = 4(\frac{1}{2})^2 = 1$ • Rearrange: % Survival = $(ECB/ECB_0)^{1/sprays}$ Geometric mean of % Survival per spray ■ Use observed ECB, ECB₀, and number of sprays to construct dependent variable: "Average % survival per spray"

Random % Survival

- Dependent variable: Average % Survival per spray
 Regressors
 - ECB₀ (density dependence)
 - Number sprays (decreasing returns)
 - Chemical specific effect
- Beta density (0 to 1) with separate equations for mean and st. dev. (Mitchell et al. 2004)
 Mean = exp(β₀ + β₁ECB₀ + β₂Sprays + α_iRate_i)
 St. Dev. = exp(σ₀ + σ₁Sprays)

Parameter	Estimate	Error	t-statistic	P-value
σ_0	-1.603	0.187	-8.587	[.000]
σ_1	-0.101	0.0474	-2.126	[.033]
β ₀	-0.902	0.195	-4.632	[.000]
β_1	-0.0800	0.0289	-2.771	[.006]
β ₂	0.115	0.0169	6.821	[.000]
α Pounce	-2.535	1.141	-2.221	[.026]
α Mustang	-4.967	4.768	-1.042	[.298]
α Baythroid	-10.101	5.156	-1.959	[.050]
α Capture	-12.609	5.456	-2.311	[.021]
α Warrior	-17.423	8.221	-2.119	[.034]
$R^2 = 0.192$	<u>RMSE = 0.137</u>			<u>N = 191</u>

Model Implications

• Mean = $\exp(\beta_0 + \beta_1 ECB_0 + \beta_2 Sprays + \alpha_i Rate_i)$ ECB₀ increase: Mean %S decreases since $\beta_1 < 0$ Density dependence: more ECB, lower survival rate Rate_i increase: Mean %S decreases since $\alpha_i < 0$ More insecticide, lower survival rate • Use α 's to compare across insecticides Warrior>Capture>Baythroid>Mustang>Pounce Spray increase: Mean %S increases since $\beta_2 > 0$ <u>Average</u> survival rate per spray increases with sprays Total survival rate = %Surivial^{sprays} decreases







Illustration of average %S per spray and total %S with Capture at a rate of 0.04 AI/ac with ECB_0 of 2



Effect of ECB_0 on conditional pdf of avg %Survival per spray RED: $ECB_0 = 1$ GREEN: $ECB_0 = 3$ BLUE: $ECB_0 = 5$ Randomly drawn ECB_0 affects % Survival pdf



Hierarchical Model Series of Linked Conditional pdf's 1) Draw Random ECB₀ from lognormal 2) Draw Average % Survival per spray from beta with mean and st. dev. depending on ECB_{0} , number of sprays, chemical, and rate 3) Calculate ECB = $ECB_0 \times (\% \text{ Survival})^{\text{sprays}}$ Draw % Marketable depending on ECB 4) Draw yield and price, calculate net returns 5) Unconditional pdf for ECB or net returns = ??? Must Monte Carlo simulate and use histograms and characterize pdf with mean, st. dev., etc.

lognormal density Random Initial ECB

Observe ECB Apply Insecticide?

Random % Survival gives Random Remaining ECB

transformed beta times lognormal

beta densities

Random % Marketable Random Pest-Free Yield

Net Returns

Random Price

lognormal density

Net Returns = $P \times Y \times %Mkt - P_i \times AI_i - #Sprys \times CostApp - COP$

Rest of the Model: Quick Summary Marketable for Processing or Fresh Market has beta density (0 to 1) - mean = $\exp(k_0 + k_1 ECB)$, constant st. dev. More ECB, on average lower percentage marketable (exponential decrease) Pest Free yield has beta density (common) Minimum: 0 tons/ac Maximum: 9.9 tons/ac (mean + 2 st. dev.) Mean: 6.6 tons/ac (WI NASS 3-yr avg.) CV: 25% (increase WI NASS state CV)

Prices and Costs Sweet Corn: \$67.60/ton Insecticides (\$/ac-treatment) Capture Warrior Baythroid \$6.09/ac \$2.82/ac \$3.49/ac Mustang Pounce \$2.80/ac \$3.76/ac Aerial Application: \$4.85/ac-treatment Other Costs of Production: \$200/ac No Cost for ECB Scouting, Farmer Management Time, or Land



maximizes farmer returns

Mean Returns (\$/ac)



Economic Thresholds (ECB larvae/ear) 2nd spray: 0.15 3rd spray: 0.20 4^t

4th spray: 0.25

Standard Deviation of Returns (\$/ac)



IPM has lower risk (lower standard deviation) than scheduled sprays

Value of IPM/Change in Mean Returns (\$/ac)



BaythroidCaptureWarrior•Source of IPM value is preventing unneeded sprays•IPM more value for Baythroid and Warrior, since cost more•IPM more value after more sprays, since need fewer sprays

IPM Risk Effect/Standard Deviation Change (\$/ac)



With proportional yield loss from pest, pests usually <u>reduce</u> st. dev. of returns, so pest control increases st. dev. of returns
IPM decreases st. dev. of returns since more pests
More sprays increases st. dev. of returns since fewer pests

Caveats

Can't do "Sequential" IPM: observe and decide multiple times during season

- Data only allow estimation of average % survival per spay for many sprays
- Need different data for "true" IPM
- Current data readily available easy to collect while required data are expensive to obtain

Canning companies control sprays and they are not necessarily maximizing farmer returns

Processing versus Fresh Market

IPM for Processing sweet corn

- I scheduled spray and use of IPM for the 2nd spray maximizes farmer returns
- First scheduled spray worth \$115-\$125/ac
- IPM increases mean returns \$5-\$10/ac (~ one spray), not including scouting costs
- IPM decreases st. dev. of returns slightly
- Similar analysis for Fresh Market sweet corn
 - IPM <u>decreases</u> mean returns
 - IPM decreases st. dev. of returns

Fresh Market Sweet Corn

Same basic model structure with updates Pest free yield: 1100 doz/ac with 25% CV Price: \$2.75/doz with st. dev of \$0.60/doz % marketable for fresh market - mean = $\exp(k_0 + k_1 ECB)$, constant st. dev. Six scheduled sprays maximize returns Optimal IPM threshold = zero

Benefit vs. Cost of IPM

Benefit of IPM: Preventing unneeded sprays Cost of IPM: Missing needed sprays, plus cost of information collection More valuable crop makes missing needed sprays too costly relative to low cost insecticides Few will risk \$1000/ac to try saving \$10/ac "Penny Wise-Pound Foolish"

Economic Injury Level • Pedigo's Classic EIL = $C/(V \times I \times D \times K)$ EIL = pest density that causes damage that it would be economical to control \Box C = cost of control \lor V = value of crop I x D = injury per pest x damage per injury K = % Kill of pest by control As V becomes large relative to C, the EIL goes to zero

Fresh Market Sweet Corn IPM Insecticide too cheap relative to value of fresh market sweet corn to make IPM valuable Insect pests vs insect terrorists (IPM or ITM?) Insecticide cost must increase so IPM creates more value by preventing unneeded sprays Market prices increase Environmental costs of insecticide use Alternatively: more competitive market for pesticide-free or organic sweet corn

Conclusion

Illustrated hierarchical modeling Capture effect of production practices on risk Generally requires Monte Carlo simulations Applied to ECB in sweet corn Also for ECB and corn rootworm in field corn IPM for commodity vs. high value crops If crop becomes too valuable relative to the cost of insecticide, IPM not economical Processing versus Fresh Market Sweet Corn