A Bayesian Decision Model for Profit Maximizing and Environmentally Sound Lygus Control in Lentils

by

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ABSTRACT: A Bayesian decision model for Dimethoate applications to control Lygus bug damage in Pacific Northwest lentils was constructed. Results showed no treatment maximized net returns for a wide range of prior damage distributions and price discounts for damage. The decision model showed potential for both grower and environmental gains.

The public mandate for more environmentally sound farming methods places additional constraints on farmers. Production decisions must explicitly consider profitability and environmental effects within guidelines set by the 1995 Farm Bill, EPA regulations, and consumers who have expressed environmental concerns.

This paper evaluates one production process, the use of Dimethoate-based insecticides to control Lygus bugs (*Lygus Hesperus*) and related Chalky Spot damage to lentils grown in the Palouse region of Washington and Idaho (O'Keeffe 1984). This region is known as the lentil capital of the U.S. with over 90% of the nation's lentil production. Soil and climatic conditions permit lentil yields averaging 10 cwt per acre. In some years the Chalky Spot damage to lentils is devastating. In 1983, 51% of the lentil fields in the area produced inferior "sample grade" lentils. Commodity merchandisers discount prices offered for low quality lentils based on quality grades established by the Federal Grain Inspection Service (FGIS) of the USDA.

Some of the potential effects of Dimethoate include: toxicity to birds, aquatic organisms, and beneficial insects, and observed oncogenic, mutagenic, and fetotoxic effects in laboratory animals (USEPA 1983). Non-target organisms can be exposed to the pesticide via residues from direct application, spray drift, and runoff from treated areas.

The intent of this paper is to examine the private economics of the treatment decision using Bayesian analysis. Sensitivity analysis will examine the robustness of the model's solutions with respect to changes in price discount levels and grower's prior expectations of damage.

Bayesian Methodology and Data: Carlson (1969, 1970) provides the framework for a Bayesian model to evaluate pesticide decisions. The subjective grower prior expectations about lentil quality grades based on their experience and knowledge, are combined with predictions of damage from remote researchers to form posterior probability distributions for a grower's per acre income. His approach uses multiple iterations of Bayes' Theorem to combine the information from the grower and the researcher.

Growers' prior expectations of damage for treatment and no treatment were represented by several probability vectors to reflect differing degrees of optimism with respect to expected damage at harvest (see Table 1). The more pessimistic probability vectors assumed greater gains from treatment. This assumption seems reasonable since there was much greater scope for improvement in lentil quality with treatment under the pessimistic untreated scenarios.

Table 1. Subjective Prior Probability Distributions of Expected Grades at Harvest for No Treatment (NT) and Treatment (T)

Prior Distribution	Action	Lentil Grades (% Damage Range)			
		#1 (0-2)	#2 (2-3.5)	#3 (3.5-5)	Sample (>5)
1	NT	.900	.033	.033	.033
	T	.930	.023	.023	.023
2	NT	.670	.110	.110	.110
	T	.730	.090	.090	.090
3	NT	.450	.450	.050	.050
	T	.480	.480	.020	.020
4	NT	.210	.210	.210	.370
	T	.300	.300	.300	.100
5	NT	.100	.100	.100	.700
	T	.200	.200	.200	.400

Objective likelihoods from the remote researcher were derived from an estimated damage prediction model. This model was estimated using linear regression. The data used were field samples of Chalky Spot damage and Lygus populations in commercial lentil fields in the Palouse region of Washington and Idaho. In addition, aggregate environmental variables, gathered from weather records of the National Oceanic and Atmospheric Administration, were used to help predict damage. Equation (1) presents the estimated damage prediction model:

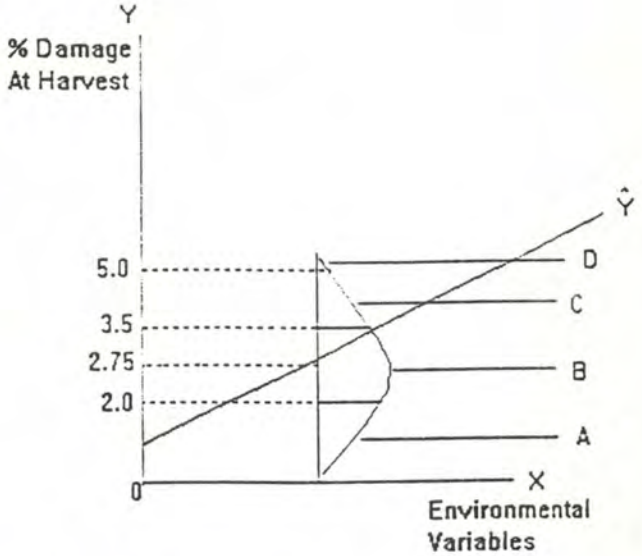
$$(1)\quad \text{Pct. Damage} = \underset{(.88)}{-.025} + \underset{(.36)}{1.23K} - \underset{(.34)}{.62DI} + \underset{(.04)}{.12R} - \underset{(.005)}{.016LR} + \underset{(.005)}{.010LA} - \underset{(.05)}{.12M} + \underset{(.004)}{.015\,LM}$$

$R^2 = .43$, MSE = 2.008, n = 75

Standard errors are in parentheses. L represents number of Lygus caught per hectare in standard sweep net samples. R, A, and M represent inches precipitation in March, April, and May. K is a binary variable identifying fields near Kendrick, Idaho, where damage was usually greater. DI is a binary variable identifying fields treated with Dimethoate. These variables were chosen to model the environmental conditions affecting the reproduction of Lygus (Strong, et al. 1970).

Objective likelihoods were generated by computing the relative areas under a standard normal curve truncated at 0%. The truncated normal was used as a close approximation to the appropriate truncated Student's t distribution. Such curves (Figure 1) portray the range of possible quality grade predictions given that actual damage corresponds to the level of predicted damage on the regression line. The indicator variable for treatment was used to create treatment and non-treatment regression models under similar conditions. The areas under standard normal curves at a specified level of predicted damage were compared for these cases. Figure 1 details this area measurement for a single regression model, and specified level of damage.

FIGURE 1. DERIVATION OF OBJECTIVE LIKELIHOODS



Assuming no treatment, Area D under the standard normal curve is the likelihood $P(Z_k|A_i)$ of prediction of sample grade lentils (Z_k), given that the midpoint estimate of 2.75% damage (A_i) is actually correct. Likelihoods for other point estimates of damage (A_i's) are made similarly by integrating the standard normal curves which are centered on the regression line at the appropriate damage level midpoints. The analysis for the treatment scenario is similar except that the regression line and associated normal curves are shifted downward consistent with the negative coefficient on the DI term in equation (1).

The likelihood probabilities for predicting quality grades for four subjective modal damage levels derived from this damage model are shown in Table 2.

Table 2. Objective Likelihoods ($P(Z_k|A_i)$) of Predicting Lentil Quality Grades for No Treatment (NT) and Treatment (T) Conditions

Predicted Lentil Grade (Z_k)	Point Estimate of Damage (A_i)							
	1%		2.75%		4.25%		5.25%	
	NT	T	NT	T	NT	T	NT	T
#1	.6346	.7315	.2919	.4122	.0831	.1480	.0211	.0505
#2	.2826	.2222	.3706	.3662	.2369	.3133	.1163	.1898
#3	.0737	.0426	.2530	.1791	.3559	.3356	.3027	.3498
Sample	.0081	.0037	.0845	.0425	.3241	.2030	.5600	.4098

The posterior probabilities for lentil grades used to compute treatment and no treatment expected returns for a given prior and prediction were derived using Bayes formula:

$$(2) \qquad P(A_i|Z_k) = \frac{P(A_i)P(Z_k|A_i)}{\Sigma P(A_i)P(Z_k|A_i)} = \frac{P(A_i)P(Z_k|A_i)}{P(Z_k)}$$

Lygus Control Economics:

Chalky Spot damage from Lygus threatens lentil crop expected returns: yield usually is not affected but quality and price are downgraded according to percent of damaged lentils. Current prices reflect a 3.8% price discount from #1 to sample grade. For sensitivity analysis other price discounts for sample grade of 4.8%, 15%, 20%, and 50% were considered with intermediate grade discounts computed proportionally (Table 3).

Table 3. Lentil Grades and Price Discounts ($/cwt)

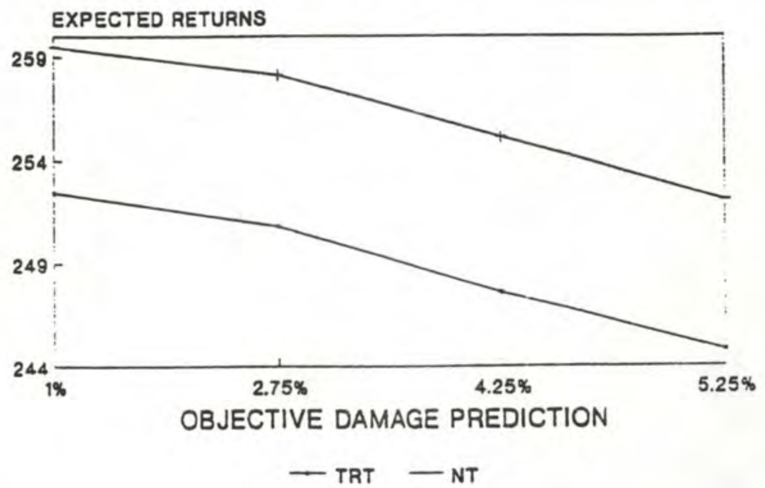
Grade	Percent Damage	Price Discount Scenarios				
		Current (3.8%)	4.8%	15%	20%	50%
#1	0.0-2.0	26.00	26.00	26.00	26.00	26.00
#2	2.1-3.5	25.50	25.35	24.70	24.18	23.40
#3	3.6-5.0	25.35	25.00	23.40	22.88	19.50
Sample	5.1+	25.00	24.75	22.10	20.80	13.00

The prescribed treatment for Lygus control is spraying with Dimethoate at a cost of about $7.00 per acre applied. Serious environmental hazards from this chemical caution against indiscriminate application to farm fields.

Results The posterior probabilities were used to estimate expected returns with and without treatment. For current prices, level two priors (Table 1) and a moderate damage prediction of 2.75%, no treatment provides higher expected returns. No treatment provided higher expected returns for 1%, 4.25%, and 5.25% objective damage predictions as well (Figure 2). This result was not expected given the fairly routine and widespread application of Dimethoate to infected fields by area farmers.

Sensitivity analysis for other prior distributions, price discounts for grade, and treatment costs was conducted to determine under what conditions treatment would be justified by expected returns. Sensitivity analysis was explored with the other prior expectations for 2.75% damage prediction under current prices and under a severe 20% price discount for grade. Based on expected returns, treatment was not justified for current prices and all priors including the extremely pessimistic level 5 scenario (Figure 3). Even with the severe 20% price discount, treatment offered higher expected returns only for the most pessimistic prior expectation (Figure 4). Sensitivity to price discounts for grade was explored for level 1 and level 4 prior expectations with 2.75% damage prediction. Treatment did not pay in terms of expected returns for even the 50% price discount under the most optimistic scenario, level 1 (Figure 5). For the more pessimistic scenario, treatment barely became economical at the 50% price discount (Figure 6). Results were not sensitive to treatment costs either. Even for treatment costs reduced by 50% or more, no treatment still offered

FIGURE 2. PREDICTED DAMAGE AND RETURNS
Current Prices, Prior 2



higher expected returns in most cases as before. As expected treatment compared more favorably relative to no treatment for greater damage predictions, higher price discounts, and more pessimistic priors and lower treatment costs. However, in nearly all cases no treatment offered higher expected returns.

<u>Summary and Conclusions</u> This research examined the expected returns when comparing treatment and no treatment for Chalky Spot damage of lentils. Lygus bug infestations are considered to be the major cause of such damage with spraying of Dimethoate as the common treatment. Based on the prior probabilities in this analysis and the damage equation, use of the potentially environmental damaging chemical was shown to be a noneconomic practice using Bayesian techniques to calculate expected returns. These results were robust, holding for a wide range of expected damage levels and lentil price discounts. Treatment had an expected return advantage only in the most pessimistic scenarios with the largest price discounts.

These results demonstrate that producers might benefit from discontinuing the standardized practice of spraying Dimethoate. This appears to be a relatively rare instance where both individual producers and the environment would benefit from reduced chemical use. These results, however, may apply only for current average levels of Lygus bug infestation. Discontinued use of spraying on a regional basis might result in increased average infestation rates over the region and increased marginal benefits of spraying to individual producers. These temporal and spatial aspects merit additional research before a final statement concerning the need for the treatment can be made.

FIGURE 3. RETURNS AS FN OF PRIORS
Current Prices

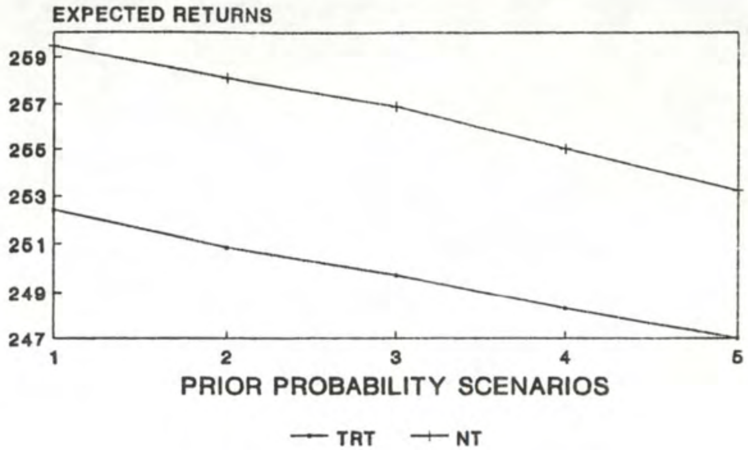


FIGURE 4. RETURNS AS FN OF PRIORS
20% Price Discount

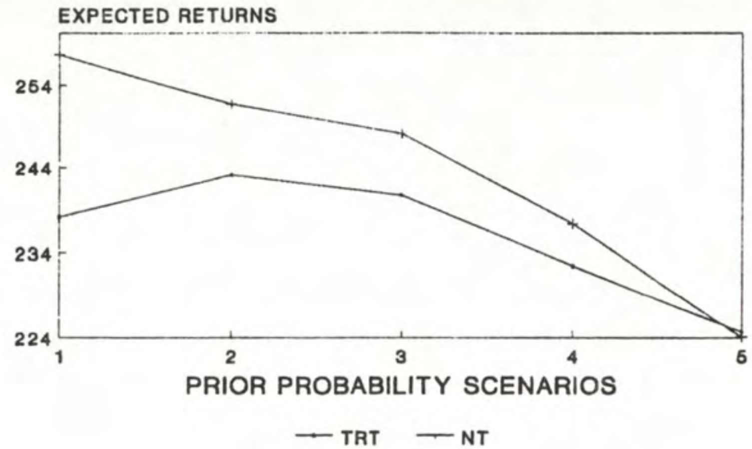


FIGURE 5. RETURNS AS FN OF PRICES
Prior 1

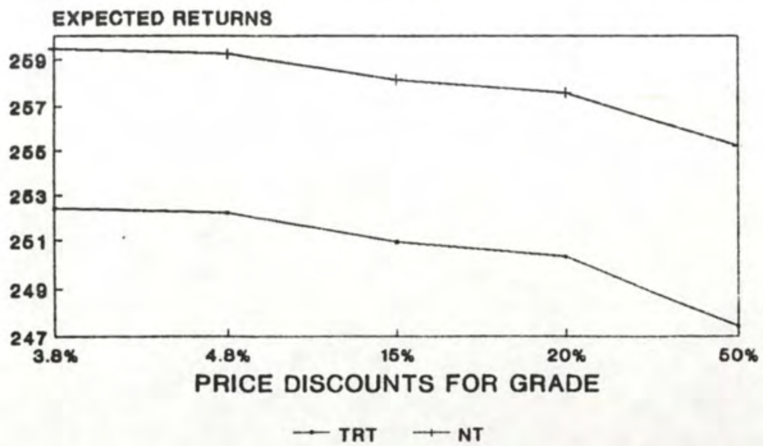
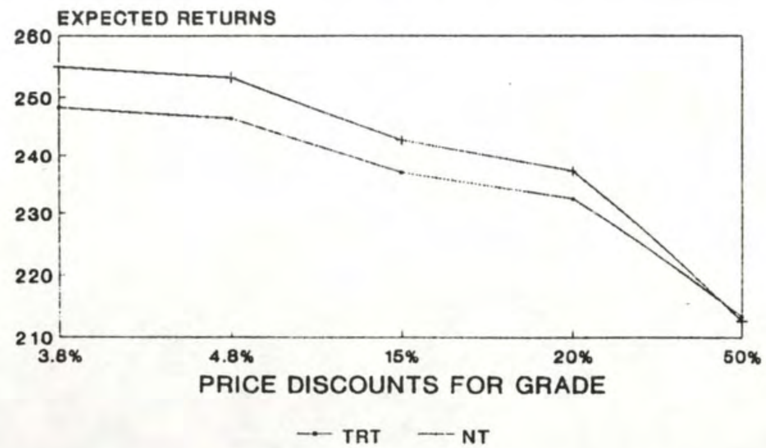


FIGURE 6. RETURNS AS FN OF PRICES
Prior 4



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