THE UNIVERSITY OF MANITOBA

THE ECONOMICS OF PESTICIDE USE: THE RELATIVE EFFECTIVENESS OF INSECTICIDE STRATEGIES RECOMMENDED TO CONTROL FLEA BEETLES IN RAPESEED

By

Donald Merle Boyle

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ECONOMICS

AND FARM MANAGEMENT

WINNIPEG, MANITOBA

October 1981

THE ECONOMICS OF PESTICIDE USE: THE RELATIVE EFFECTIVENESS OF INSECTICIDE STRATEGIES RECOMMENDED TO CONTROL FLEA BEETLES IN RAPESEED

BY

DONALD MERLE BOYLE

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

The Economics of Pesticide Use: The Relative Effectiveness of Insecticide Strategies Recommended To Control Flea Beetles in Rapeseed

by

Donald Merle Boyle

Major Advisor: Dr. David Freshwater

This study is an application of the economic theories of pesticide use to the problem of control of flea beetles in rapeseed crops of Manitoba. Flea beetles are the major insect pest affecting rapeseed. Spring infestations, if undetected, may cause damage severe enough that the rape plants cannot fully recover and yields are reduced. Several insecticides are recommended to control early season flea beetle infestations. Potential for large monetary benefits relative to small costs of chemical application seem to exist when an insecticide is applied, however, the benefits differ among the various control strategies. As presented in this thesis, a framework is developed by which these benefits may be calculated and compared.

The general objectives of this thesis are to present the relevant theories of pesticide use. From the theory of production under conditions of certainty interpolations of the available biological test plot data were made. Dosage response functions, or curves illustrating the crop yield resulting from various application rates of an insecticide, were estimated from the experimental data. The theory of production under uncertainty was useful to evaluate the alternative flea beetle pest management strategies in private cost and profit terms. Decision theory was used to identify and compare the possible levels of crop loss, alternative control actions, and the expected outcomes. A sensitivity analysis of the results was provided in terms of product prices, probability of damage estimates and rapeseed yields.

With the probabilities of damage and rapeseed prices used, the analyses indicated that the Furadan granular insecticide performed better than all other control alternatives. in terms of revenues net of chemical costs. The lindane and spray options, as well as the insecticide combinations, although they increase yields, do not provide revenues as great as the Furadan strategy. The do nothing option was the least preferred strategy.

As indicated by the Manitoba survey of rapeseed producers, a low acceptance of the optimal profit maximizing control strategy exists. With increased information of the potential benefits this low acceptance would perhaps be overcome.

ACKNOWLEDGEMENTS

Several individuals played a fundamental role assisting completion of this thesis. It is these people that I wish to express recognition.

First and foremost, I would like to thank my major advisor Dr. David Freshwater. I am sincerely appreciative of the valuable advice and guidance provided in the preparation of this thesis.

I express special thanks to my other committee members. The information provided by Dr. Robert J. Lamb was instrumental in the development of several components of this thesis. In addition, the practical insights provided by Rea M. Josephson were greatly appreciated.

I am grateful for the Manitoba Department of Agriculture funds and the Canadian Department of Agriculture operating grant which helped to finance research toward this thesis.

Special thanks are due to Laverne Coulson for typing the first draft of this thesis, and to Valerie Fields for making life with the computer seem less terminal.

Finally, I would like to acknowledge my family and friends for encouraging me to make this thesis a reality. Also, thanks to the 'annex animals' for not making this solely an academic experience.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

PROBLEM STATEMENT AND OBJECTIVES

1.1 INTRODUCTION

In western Canada, agricultural production has been affected substantially by rapid technological advances. Rapid change has required producers to adapt to new production techniques in order to remain competitive. The production of the oilseed crop, rapeseed, in western Canada is an example of how technological innovations have been introduced and accepted. Within the past 20 years, rapeseed has become an increasingly valuable crop. In terms of total area planted and monetary value, rapeseed is now the third most important crop in western Canada, preceeded only by wheat and barley. This current importance results from dramatic global increases in the demand for oilseed products, and the adaptations of rapeseed to meet those increases.

Production of rapeseed within Manitoba, 546 300 hectares in 1979, comprises about 15 percent of the province's total planted acreage.[1] Manitoba supplies about 16 percent of the total Canadian rapeseed production.[2] This level of production requires a knowledge of effective production techniques which will maximize producer returns. There is an incentive to optimize output because of the high value of rapeseed

---

[1] Manitoba Department of Agriculture, Manitoba Agriculture Yearbook (Winnipeg, Manitoba: 1979), p. 69.

[2] Canada Grains Council, Canadian Grains Industry: Statistical Handbook '80 (Winnipeg, Manitoba: 1980), p. 5.

relative to other crops. This goal of output optimization necessitates the utilization of proper pest management control strategies. Failure to control pests such as flea beetles results in the reduction of yields and degradation of crop quality.

The flea beetle is the major insect pest affecting rapeseed crops in western Canada. There are five main species of flea beetles, the most common being Phyllotreta cruciferae.[3] The major damage occurs to newly emerged rapeseed seedlings by overwintering adult flea beetles. Flea beetles occasionally overwinter in previous season's crop fields, but usually in leaf litter found in and around surrounding shelterbelts.[4] Severity of the damage depends largely on the climatic conditions. Under favourable conditions flea beetle densities increase rapidly and fields become infested in a few hours. The infestations, if undetected, may cause damage severe enough that the rape plants cannot fully recover and yields are reduced. It is the control of these spring flea beetle infestations which will be analyzed in this thesis. Damage may also occur due to mid-summer larval root feeding and pre-harvest new generation adult infestations. However, larval damage is considered to be inconsequential.[5] Also, the rapeseed crop has usually matured to the state that second generation damage in the fall is seldom serious.[6]

---

[3] C.E. Osgood, "Damage Assessment as Part of Flea Beetle Management on Rape," Proceedings of the Twenty-Second Annual Meeting: Agricultural Pesticide Society (Brandon, Manitoba: June 23-25, 1975), p. 54.

[4] L. Burgess, et al., Insect Pests and Diseases of Rape and Mustard (Vancouver, British Columbia: Rapeseed Association of Canada, No. 48, November 1977), p. 4.

[5] Osgood, op. cit.

[6] Burgess, et al., op. cit., p. 5.

Several insecticides are recommended to control early season flea beetle infestations. These insecticides fall into the following three categories:

1. in-furrow treatment,
2. seed treatment, and
3. post emergence foliar spray.

These treatments may be utilized individually or in any combination. Integrated pest management is not an option available to the producer at present, although research in this area is being undertaken. The feasibility and effectiveness of various biological and cultural insect controls have been investigated. Limited benefits may result from the release of a European beetle parasite.[7] It is not known to what extent this parasite has established itself in the wild population. A native parasite exists; however, it is ineffective in reducing beetle numbers. As well, plant breeding for insect resistance and innovations to cultural techniques are presently at the research stage of development.

In 1979, a survey of Manitoba producers indicated that about 74 percent of the rapeseed growers used insecticides to control flea beetle infestations.[8] The private cost of this control, in current 1981 terms, may range from a low of \$4.55 per hectare for a single application of a seed treatment to a high of \$18.21 per hectare for single applications of a combination of treatments.[9] Producers apply these insecticides

---

7 R.J. Lamb, "Biological Considerations for an Economic Analysis of Insect Pest Management in Rape," Winnipeg: Canada Department of Agriculture, December 1979 (mimeographed).

8 See Appendix A for survey questionnaire and results.

9 See Appendix B for a complete breakdown of chemical prices and application costs.

under uncertain conditions of flea beetle densities. Due to the lack of information concerning the populations, the insecticides are applied as a form of self-insurance. The producer may feel that the risks relating to possible yield reductions from beetle damage are lowered by applying insecticides in case flea beetles are present.

Potential for large monetary benefits relative to chemical costs seem to exist when an insecticide is applied. However, the benefits differ among the various control strategies. A framework by which these benefits may be calculated and compared will be developed. The relevant components of this decision framework will be detailed in the review of related literature.

Costs and returns associated with the chosen control strategy, will be presented in private terms. Possible social implications may arise because of the potency of the studied insecticides, resulting in potential health hazards and possible negative environmental effects. However, research supporting the notion of these negative externalities is lacking.

1.2 OBJECTIVES OF THE STUDY

The main objectives of this study are to:

1. review and summarize the relevant applied economic theories of insecticide use, insurance and information services as they relate to the problem of control of the flea beetle in rapeseed crops of Manitoba;
2. interpolate the available biological test plot data into economic terms which relate yield responses resulting from a chemical application for various damage conditions; and

3. evaluate in economic terms alternative flea beetle pest management strategies in relation to private costs and profit maximization.

1.3 ORGANIZATION OF THE THESIS

Chapter II is a summary of the related literature and the theoretical construct of the economics of pesticide use. On a theoretical basis, the motivation of insecticidal control, dosage levels, and timing of applications are discussed. Crop insurance and information services as they relate to insecticide use are also discussed.

Chapter III is the description of the methodological considerations used to apply the theories of insecticide use to the problem of flea beetle infestations in rapeseed crops in Manitoba. Experimental test plot results are used to calculate chemical yield responses. A sensitivity anlysis of possible rapeseed price estimates and flea beetle density probabilities is performed for the 1981 crop year. The game theory analytical approach is used as a method of evaluating, in monetary terms, the decision to use insecticides given expectations for the future.

Chapter IV is a summary of the results on the sensitivity of the possible outcomes of the pay-off matrices. The results are provided in private cost and profit terms which result from various combinations of damage conditions and price expectations.

Chapter V is a discussion of the implications of the results, limitations and conclusions of the study.

Chapter II

REVIEW OF RELATED LITERATURE

2.1 INTRODUCTION

The agricultural use of pesticides, in particular insecticides, has increased dramatically in Canada over the past 30 years. This study concentrates on the economic rationale for the use of insecticides to control agricultural insect pests. The 'pests' in this instance are defined as insects detrimental to the activities of man. The following is a chronolgical review of selected articles which discuss and develop the economic principles of pesticide use and agricultural pest management. The review contains economic concepts and analytical methodology which may be applied to the problem of flea beetle infestations in rapeseed.

2.2 CLASSICAL ECONOMICS: EFFICIENT INPUT USE UNDER PERFECT KNOWLEDGE

Classical production economics provides the theoretical basis for analyzing the use of insecticides at the farm level. Insecticides are an input into the crop production process. In economic terms, insecticides are the result of technical innovation which augments total production by increasing crop yields and product quality, and reduces possible year-to-year yield fluctuations due to insect damage. Under the assumption of perfect knowledge, the decision made by each producer is to choose among the available inputs of production, depending on their marginal products and input prices, to attain the goal of profit maximization.

The optimal use of a pesticide may be illustrated, as in Figure 2.1, with the use of a production function. The amount of a pesticide used, with all other inputs held constant, is represented on the horizontal axis. For a given level of pest population, the output attributable to the rate of application of the pesticide is shown on the vertical axis. In an insecticide example, the total physical product (TPP) function likely would not start at zero because some output would result from the factors of production held constant. For example, if some insect were present and no effort at control was made, at least some quantity of crop yield would be attained. In simplistic terms, the additional yield or output resulting from a particular rate of insecticide application is a function of the number of insects killed. This relationship becomes more complex if timing and frequency of the applications as well as the characteristics of the insect being controlled are accounted for.

The form of the classical TPP function, as in Figure 2.1, increases at an increasing rate at low pesticide levels; beyond some point, the function increases but at a decreasing rate, and the function is maximized before total output begins to decrease at an increasing rate. The three rates of increase are termed the stages of production. At stage I, successive additions of the pesticide result in an increasing quantity of total output. Given that other inputs are held constant and a goal of profit maximization, there is an incentive to continue adding units of the pesticide. Stage II of the TPP function is where successive additional units of the pesticide add to total output, but do so at a decreasing rate. Stage III occurs at the point where an additional unit of the pesticide fails to increase output. A point of saturation

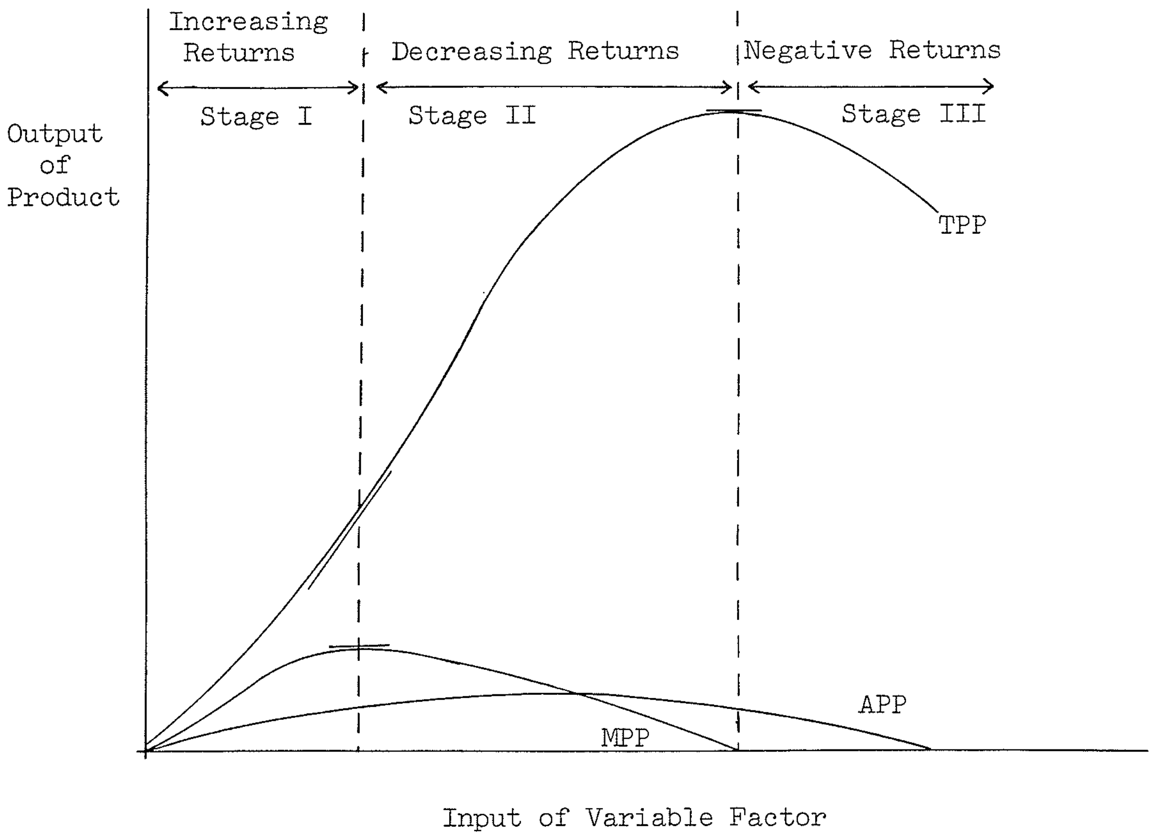

Figure 2.1

Relationship of Factor Input to Total, Marginal, and Average Physical Products

---

Source: E.O. Heady, Economics of Agricultural Production and Resource Use (Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1965), p. 43.

for the input is attained and additional incremental units begin to reduce yields at an increasing rate. In the instance of an insect population, the TPP function would perhaps be asymptotic to complete pest eradication at high application rates, unless the insecticide applied was phytotoxic to the crop.

> The average physical product (APP) function is defined as the total amount of output divided by the total level of the variable input used to produce that quantity of output.[10]

In geometric terms, the APP function is the slope of a line drawn from the origin to the TPP function, for any unit of the input applied. This function increases to the point where it intersects the marginal physical product (MPP) function. At this point, the average product per unit of input is maximized, or the slope of the line from the origin to the TPP function is greatest. Beyond this maximum point, the APP function decreases.

The MPP is the slope of the TPP or the yield increases that would result from each additional increment of an input added to the production process. The MPP function increases from the origin and is maximized at the inflection point on the TPP function. The inflection being the point at which the total output begins to increase at a decreasing rate when a further increment of input is used. Beyond this point the MPP function is decreasing and equals zero where the TPP is maximized. Within this area of decreasing marginal returns is the area of efficient production which corresponds to stage II of the production function. Along this decreasing portion of the TPP function there occurs an

---

[10] Ruben C. Buse and Daniel W. Bromley, Applied Economics: Resource Allocation in Rural America (Ames: Iowa State University Press, 1975), p. 109.

optimal input-output relationship in physical terms. This physical maximum occurs where MPP equals zero, the TPP is maximized, and further units of input result in negative yield increases.

When the prices of total output and costs of the input are included, an economic optimal level of input usage may be found. Figure 2.2 is the illustration of the points at which economic optimal input usage occurs. The value of marginal product (VMP) is the MPP for the particular input-output relationship multiplied by the price of the output. This is the necessary condition for profit maximization. The input prices are known and are illustrated on the vertical axis as P1 and P2. There is a revenue incentive to use additional units of input to the point at which the revenue received just covers the cost of the input.

> A specific decision rule is: use a variable input up to where the last unit employed creates just enough additional output to pay for its utilization in the production process.[11]

In algebraic terms, the optimum level of input usage occurs at the point where the VMP for the particular input-output relationship equals the price of the input.

Figure 2.2 illustrates two VMP functions and two input price conditions. As the price of the output increases, the VMP1 shifts out to VMP2. This is an economic justification for increasing the input usage from Q1 to Q2 given the input price conditions of P1. If the input price is increased from P1 to P2, the optimal quantities used on VMP1 or VMP2 decrease from Q1 to Q1′ and Q2 to Q2′, respectively. The sufficient conditions are fulfilled at these profit maximizing levels.

---

[11] Buse and Bromley, op. cit., p. 116

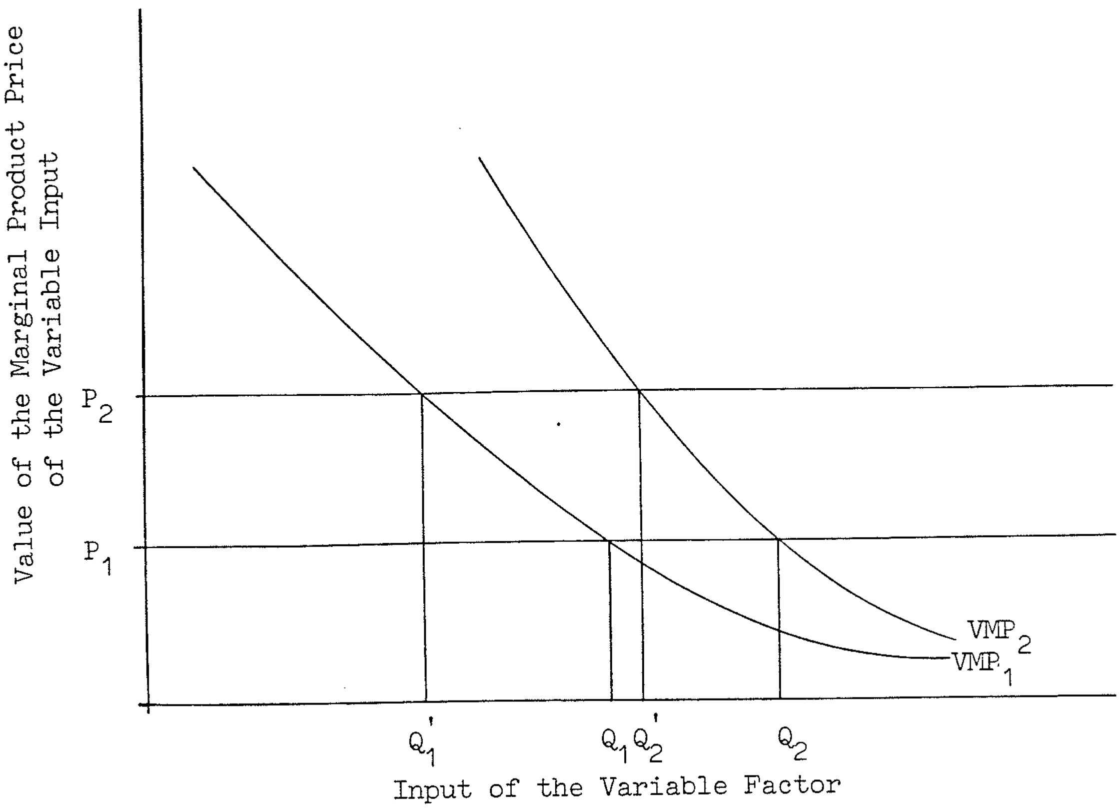

Figure 2.2

Relationship of Value of Marginal Product, Price of
the Variable Input, and Quantity of
Factor Input Used

The profit maximizing quantity of the pesticide input applied depends upon the fluctations in the level of chemical prices and the value of the marginal product. Chemical prices are determined by market supply and demand forces and are not subject to the individual producer's power to control. The value of the marginal product is dependent on the level of crop prices, also determined by market forces outside the producer's control. In addition, the marginal physical product is very dependent on the prevailing environmental conditions.

2.2.1 Hillebrandt, 1960

The two part article completed in 1960 by Hillebrandt is considered to be the first work in the area of economics of pest control. Part I deals with the following subjects: the estimation of a dosage response curve; the selection of an optimal pesticide application rate incorporating crop prices and chemical costs; and the factors affecting the profitability of treating an area of a crop.[12] Part II delves into the areas of risk and uncertainty with respect to the optimal application of pesticides.[13]

A dosage response curve was estimated illustrating the crop yield resulting from various rates of a pesticide application. The physical crop-pest-pesticide interactions influencing the shape of the curve were incorporated into the estimation. Dosage response curves are

---

[12] Patricia M. Hillebrandt, "The Economic Theory of the Use of Pesticides, Part I," Journal of Agricultural Economics, Vol. 13 (1960), pp. 464-472.

[13] Idem, "The Economic Theory of the Use of Persticides, Part II, Uncertainty," Journal of Agricultural Economics, Vol. 14 (1960), pp. 52-61.

illusrtrated in Figure 2.3 for three theoretical levels of pest infestation. The line AB and the corresponding parallels explain the relationship of output price and pesticide input costs. The point of intersection of these price lines and dosage response functions signifies optimal pesticide usage. This optimum corresponds to the equality of the value of marginal product and the input price or the sufficient profit maximizing condition. As illustrated, the optimal dosage or rate of pesticide application increases with pest infestation increments, but is also dependent on the slope of the output price-input cost relationship as well as the shape of the dosage response function.

Hillebrandt investigated the possibilities of returns to scale for a pesticide application. Depending on the situation, the input costs could either increase or decrease per unit applied as the area treated increases. For example, the cost of chemicals may be reduced because of volume purchasing; also the fixed cost per unit area would decrease because they are being utilized over a larger acreage. However, the labour costs involved in the application process may increase with larger acreages. The profitability of the pesticide application on an area of crop depends on two factors. The first factor being the chemical input: total cost of application per unit area increasing or decreasing as the area to be treated increases. The second factor is the slope of the marginal dosage function at the particular rate of application under consideration.

Figure 2.4 is the illustration of the profit or loss resulting from the single application of a pesticide over different acreages and pest densities when application costs and crop prices are known. For

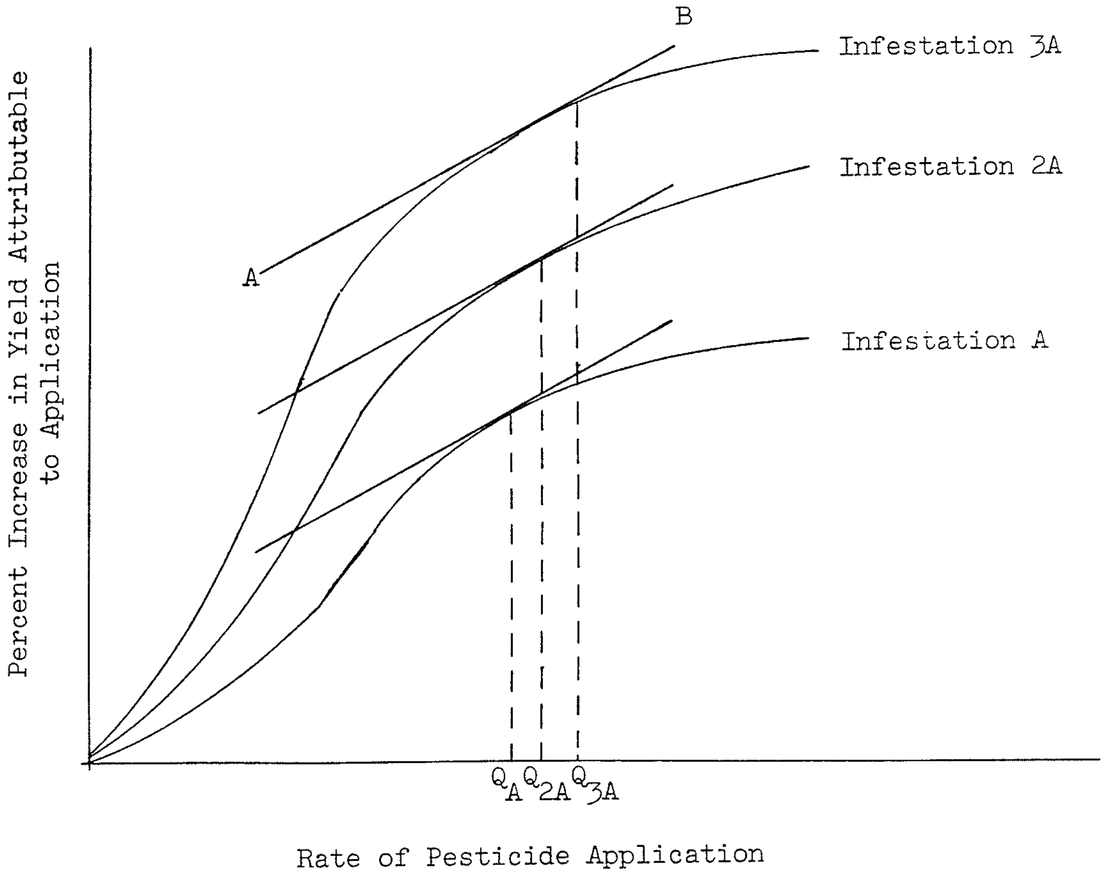

Figure 2.3

Relationship of Pesticide Application, Level of Infestation, Percent Increase in Yield, Chemical Cost, and Crop Price

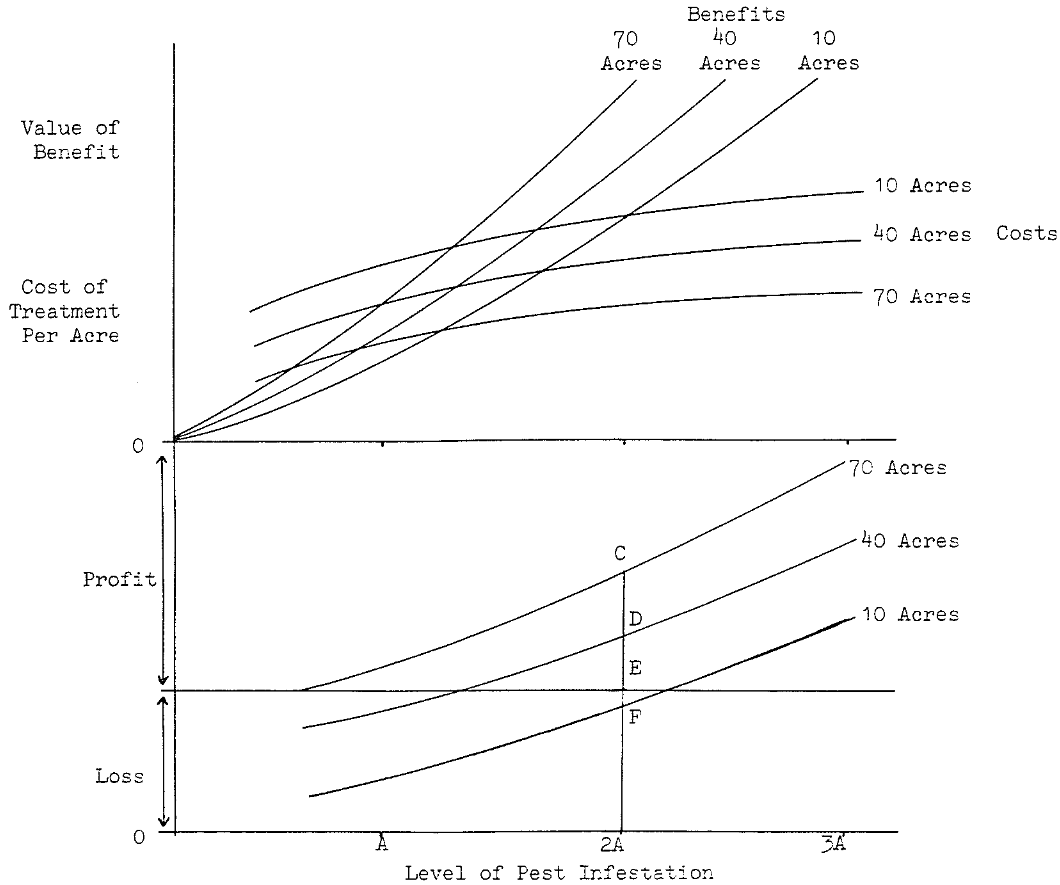

Figure 2.4

Relationship of Level of Infestation, Area to be Treated, Revenues Resulting, and Costs of Treatment illustrative purposes, it was assumed that the application costs decrease per unit area and the benefits per unit area increase as the total area treated increases. The upper half of the figure shows these increasing benefits and decreasing costs for three acreages as the level of pest infestation increases. The costs may be subtracted from the benefits at each acreage level to form the net revenue functions shown on the bottom half of the figure. Given the shape of the curves, it may be shown that under the conditions of a 2A level of infestation, the profit per acre received from treating a large field (70 acres) equalled the distance CE. For the medium acreage, the profit per acre received would be DE. The pesticide treatment on a small field would result in a loss per acre of EF.

Part II of the article by Hillebrandt relaxes the assumption of the producer's perfect knowledge in production decisions. The lack of information was dividied into the two categories of: risk which follows some known probability density function and is therefore insurable, and uncertainty which has unascertainable probabilities of occurrence and is not insurable. The main area of imperfect information centers on future crop prices. Research may determine the crop-pest-pesticide interactions or the dosage response functions for a given level of infestation, but the information may be subject to large fluctuations. The chemical and application costs are generally known. Lack of information about future crop prices falls into the uncertainty category while the form of the dosage response functions relating to specific levels of pest information may be risky, but plausible in statistical terms. Hillebrandt used Shackle's concept of "degree of potential surprise" at various profit levels and incorporated the producer's subjective estimate of the uncertain situation as well as indifference curves to determine the optimal pesticide application rate. The problem with this form of analysis is the lack of practicality and difficulty in estimating indifference curves, degrees of potential surprise and the determination of the subjective assessments.

2.2.2 Headley, 1968

With the three primary classes of inputs into the production process being land, labour, and capital; pesticides affect a substitution of capital investment for land and labour to increase productivity. Technical innovation in the production process provides the profitable encouragement for this substitution. The substitution of capital for other production inputs was analyzed in research done by Headley in 1968.[14] The major objective of Headley's study was to determine whether the use of pesticides in agricultural production differed from the theoretical economic optimum. To accomplish this goal, the benefits and costs of pesticide use were calculated from production function estimations on cross sectional data for 1963. The relationship as estimated by ordinary least squares regression techniques was as follows:

Total Output = f(total labour, land and buildings, machinery, fertilizer, pesticides, and other)

---

[14] J.C. Headley, "Estimating the Productivity of Agricultural Pesticides," American Journal of Agricultural Economics, Vol. 50 (February 1968), pp. 13-23.

Four equations were estimated to express this relationship. Interpretation problems occurred because of data aggregation and variable intercorrelations. The assumptions of uniform technology for the 48 studied states, and equivalent productivity from chemicals also hampered interpretations of the regression results. Increases in productivity resulting from the application of chemicals, particularly pesticides, vary widely depending on the crop grown, the pest being controlled, and the timing and rates of application.

The estimated marginal productivities for the variable inputs are shown in Table 2.1. Note that a marginal value product of over four dollars results on average from a one dollar outlay for the pesticide input. This marginal contribution to total output was approximately equal to that of the fertilizer input, and much greater than the contribution of the other variable inputs. As a result, in 1963, United States farmers received estimated benefits totalling $1.8 billion from the $436 million spent on the pesticides used.

Although Headley's results are now somewhat dated, the implications for present pesticide usage are still relevant. The large imbalance in the market for pesticide inputs is the reasoning for past and future trends in the use of pesticides. Because of the large margin between returns and costs, the use of pesticides has increased rapidly in the past and probably will continue to do so in the future. In theoretical terms, the level of input useage will increase until the VMP is equivalent to the MC for that input.

Table 2.1

Marginal Products of Farm Inputs in United States Agriculture, 1963

Variables	Regression Equations 1	2	3	4
Total Labour	$2.16/day	$1.40/day	$3.84/day	$4.21/day
Land and Buildings	0.06/$1.00	0.08/$1.00	0.06/$1.00	0.08/$1.00
Machinery	2.40/$1.00	-	2.43/$1.00	0.26/$1.00
"Other"	0.97/$1.00	-	0.97/$1.00	1.07/$1.00
Fertilizer	4.91/$1.00	4.20/$1.00	4.50/$1.00	3.95/$1.00
Pesticides	5.66/$1.00	4.23/$1.00	4.16/$1.00	3.90/$1.00
Machinery plus other	-	1.16/$1.00	-	-

Source: J.C.Headley, "Estimating the Productivity of Agricultural Pesticides," American Journal of Agricultural Economics, Vol.50, (February 1968), p.19.

2.2.3 Headley, 1972

The focus of the previous literature had been mainly the economically optimal use of pesticides. At this point, crop yields are optimized and returns are maximized. However, this optimum occurs under certain assumptions about the pest population. When pest densities are specified they are generally assumed to cause yield damage greater than the cost of control. This suggests a critical level of pest density at which cost of control equals the yield benefits. In the article by Headley in 1972, this concept of a threshold pest population was formalized in economic terms.[15]

Headley conceived the threshold population as a function of three variables: value of damage, pest population, and time. The model which was estimated had four basic components. The first component was the pest density damage function which relates the level of damage to the pest population and the ability of the crop to withstand damage. The equation of the damage function is:

$$D_t = b\,P_t^2 - A$$

where:

D_t = damage in time t,

P_t = pest population in time t,

A = a constant defining the crop's tolerance to pest damage, and

---

[15] J.C. Headley, "Defining the Economic Threshold" in Pest Control Strategies for the Future (Washington, D.C.: National Academy of Sciences, 1972), pp. 100-108.

b = a constant defining the incremental damage resulting from P_t.

The second element of the model is a pest population growth equation. As shown in the following equation, the population in time t is a function of the time t-n population multiplied by a biological growth factor.

$$P_t = P_{t-n}(1 + r)^n$$

where:

P_{t-n} = the pest population N periods prior to time t,

r = net growth rate of the pest population, and

$(1 + r)^n$ = a compound growth factor.

The effect of the pest on crop yield is the third element of the model. The crop yield is a direct result of the potential yield less the pest damage incurred. This is shown as follows:

$$y = N - cD_t$$

where:

y = the product yield,

c = a parameter measuring incremental yield effects, and

N = the potential crop yield under conditions of no pest infestations.

The first three equations were combined to form:

$$y = N - c\{b[P_{t-n}(1 + r)^n]^2 - A\}$$

This shows the effect that the pest population has on the crop. Figure 2.5 illustrates this further. The crop yield resulting at each level of pest population may be multiplied by a constant price to form the total revenue from production. From points A to B, crop yields have attained their potential under conditions of none to very low pest densities. Beyond point B, as pest densities increase, the revenue from production decreases at an increasing rate.

The cost of control for various pest populations is also graphed. Headley assumed that as the desired level of pest population was set at higher densities, the cost of control decreases. The final element in Headley's model is the following continuous cost function:

$$O = \frac{L}{P_{t-n}}$$

where:

O = the total cost of control, and

L = a constant parameter influencing incremental costs as pest population is reduced.

On the bottom half of Figure 2.5, the marginal revenue and cost curves are shown. The economic optimum occurs at the intersection of these two curves where the rate of change of the revenue from production and cost of pest control curves are equal. Point C corresponds to this intersection and is translated back to the top half of the figure. The distance DE is the profit gained from optimal pest control. The level of pest population F corresponds to the profit maximizing state and is

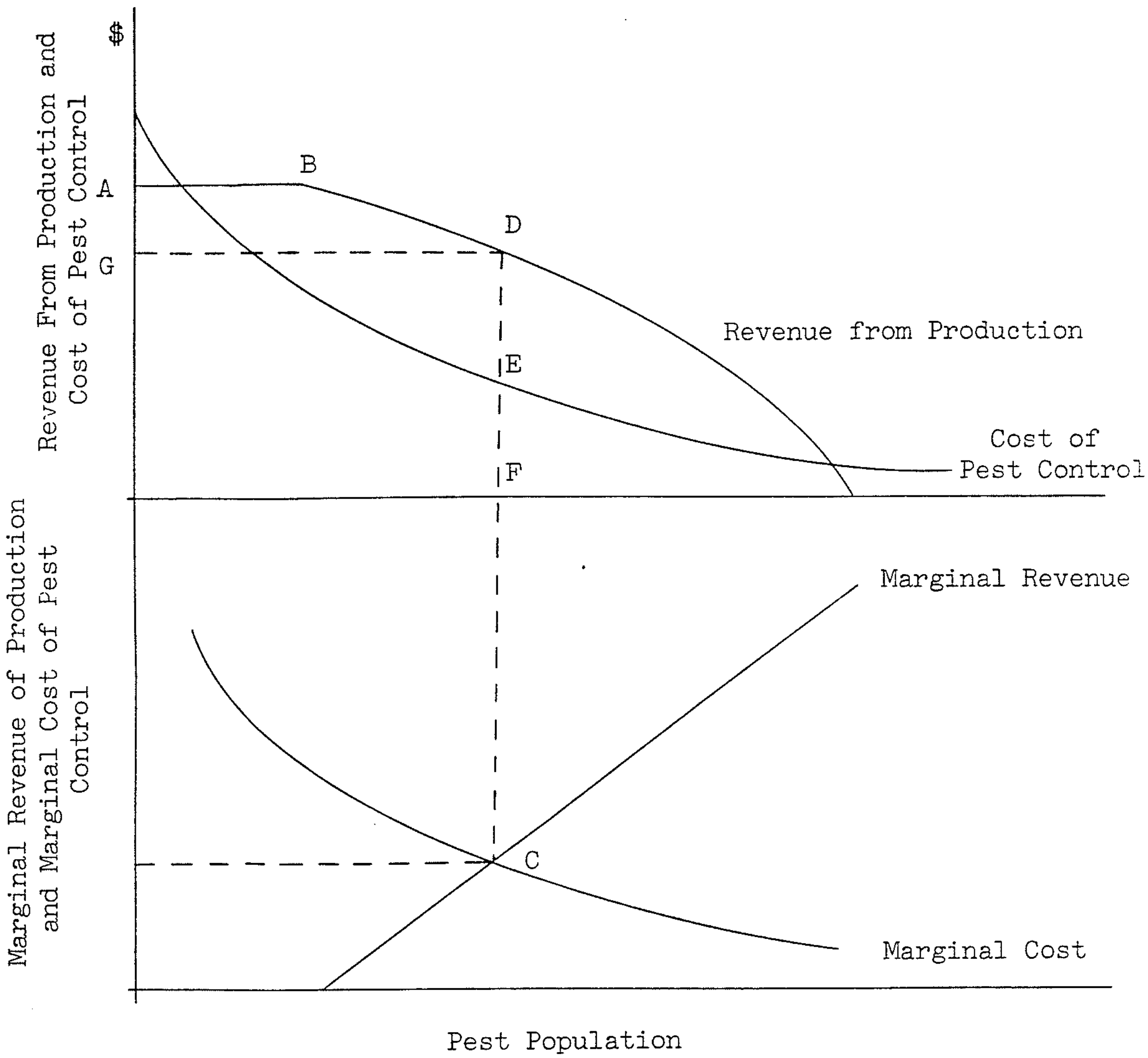

Figure 2.5

Relationship of Pest Populations, Value of Production, and Cost of Control

---

Source: J.C.Headley, "Defining the Economic Threshold" in Pest Control Strategies for the Future (Washington, D.C.: National Academy of Sciences, 1972),p.103.

defined to be the economic threshold or optimal pest population. It would be undesirable to allow pest densities to vary from this optimum. At higher levels of population, the cost of control is less but the yield loss outweighs the cost savings. Similarly, control to lower population levels involves a cost greater than the returns received from increased crop yields.

2.2.4 Hall and Norgaard, 1973

A redefinition of Headley's economic threshold was proposed by Hall and Norgaard in 1973.[16] The timing of application and quantity of pesticides applied were introduced as determinants, in addition to the variables utilized by Headley, in a model for effective profit maximizing pest control. The theoretical model included the following five elements:

1. The pest population growth function was similar to Headley's with the exception of a factor which included the reduction in the pest population due to a pesticide application. The following is the pest population growth function from the time of planting through to the time of pesticide application:

$$P(t) = P_o e^{rt} \quad \text{for } t_o \leq t \leq t_i$$

where:

$P(t)$ = the pest population,

---

[16] Darwin C. Hall and Richard B. Norgaard, "On the Timing and Application of Pesticides," American Journal of Agricultural Economics, Vol. 55 (1973), pp. 198-201.

P_o = the initial pest population,

e^{rt} = the pest population growth rate,

t_o = the time of planting, and

t_i = the time of pesticide application.

An addition to this function was made to include the reduction of the pest population due to the pesticide application. The resulting growth function was in the form of:

$$P(t) = (P_o e^{rt_i} - K)e^{r(t-t_i)} \quad \text{for } t_i < t \leq t_h$$

where:

K = the number of pests killed by the pesticide application, and

t_h = the time of crop harvest.

2. The second element is the pest population kill function which is simplified to be a function of the level of pesticide applied and the timing of the application.

$$K = K(X, t_i)$$

where:

X = the number of units of pesticide.

3. The third component of the Hall and Norgaard model is a function which relates the crop damage to pest populations. The following two equations describe this damage. The first equation is a continuous

function from the time of planting to harvest of the crop damage resulting per pest.

$$d(t) = b\ P(t)$$

where:

$d(t)$ = the instantaneous rate of crop damage in physical units due to pest population, and

b = rate of crop damage per pest.

The second equation includes the application of an insecticide:

$$D(t_h - t_o) = D1 + D2$$

where:

$D(t_h - t_o)$ = cumulative crop damage incurred between the time of planting and harvest,

$D1$ = the damage incurred prior to insecticide application, and

$D2$ = the damage incurred post insecticide application.

4. The fourth element of the model is the product yield function shown as follows:

$$Y = N - D(t_h)$$

where:

Y = the physical crop yield at harvest, and

N = the potential crop yield under conditions of no pests.

5. The final component of the model is the cost function of the form:

$C = a X$

where:

C = the total cost of pesticides, and

a = the cost of purchasing and application of a single unit of pesticide.

The result of differentiating the profit equation, which is crop revenues net of pesticide costs, with respect to application time ti and quantitiy of pesticide applied X, the following equations arise:

$$Kx(X, t_i) = \frac{a\ r}{Bb[e^{r(t_h - t_i)} - 1]}$$

$$Kt_i(X, t_i) = \frac{rK(X, t_i)e^{r(t_h - t_i)}}{e^{r(t_h - t_i)} - 1}$$

where:

B = the price of the crop.

The implications of the preceeding model are illustrated in Figure 2.6. The total cost of pesticide application is drawn as a constant marginal increase per unit applied. Total revenue curves are drawn for different application times. The curve, labeled TRt $\pm$ n, results from a time of application closer to an entomologically specified desirable time. The increase in profit to the producer is the distance AB at the optimal rate of pesticide application C. Dending on the slope of the

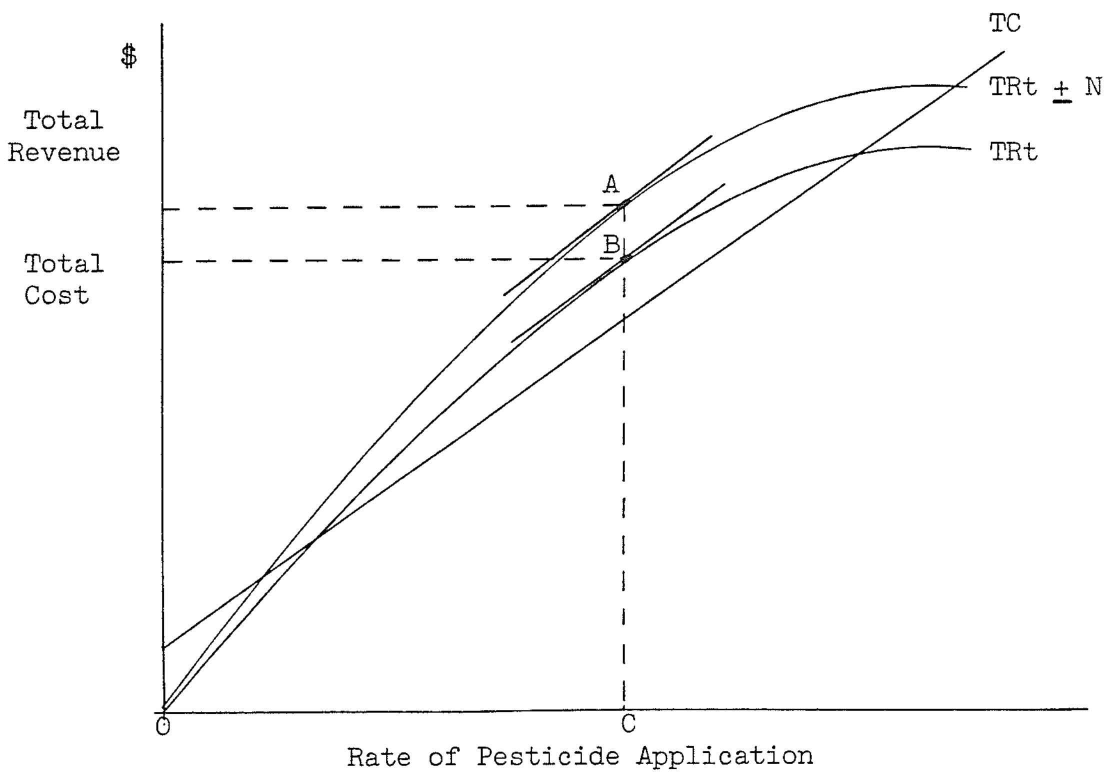

Figure 2.6

Relationship of Timing of Pesticide Application, Rate of Pesticide Application, Total Revenue, and Total Cost total revenue curve, this rate of application could increase or decrease as the timing becomes more precise.

The conclusions of the Hall and Norgaard model state that cost of pesticides and crop prices affect the rate of pesticide application. However, the optimal timing of pesticide application is determined independently of the pesticide and crop prices. The only variables affecting timing of application are the response of the pest population to the pesticide and the biological growth rate of the pest population.

2.3 UNCERTAINTY: PEST MANAGEMENT UNDER IMPERFECT KNOWLEDGE

To this point, the articles reviewed have regarded the use of pesticides under the assumption of perfect knowledge. However, pest densities, pesticide effectiveness, pest population dynamics, crop prices, and environmental conditions are subject to a large amount of variability. When variation occurs in the determinants of agricultural production, producers become uncertain about future outcomes. The producer must rely on past experience and expectations for the future to decide among the available inputs of production to maximize net returns. The following is a review which incorporates risk and uncertainty into a framework for optimal pest management.

2.3.1 Carlson, 1970

In the study completed in 1970, Carlson utilized Bayesian decision theory to include the uncertainties of crop disease and determine an optimal pest control strategy.[17] Carlson applied this theory to the example of brown-rot control in the California peach industry. The decision theory was used to determine which pesticide spraying strategy would maximize expected profits. The strategy was adjusted to account for disease forecasts.

Bayesian decision theory in a pest management context involves a process by which a decision-maker can identify all possibilities of crop loss, alternative control actions, and the resulting outcomes to form probabilistic subjective expectations for the future which may be updated given a forecast for the particular event. Subjective probabilities are used because in agricultural pest control few recorded series of events are accurate enough that objective or historical probabilities may be calculated with confidence. The determination of subjective probabilities in practice is often inaccurate but they are often more representative of the particular pest density situation than are historical probabilities.

As shown in algebraic form in Table 2.2, the possible control strategies or actions available to the producer are represented by: a1, a2, a3,..., am. The level of pest densities are defined as states of nature and are depicted as: s1, s2, s3,..., sn. All possible combinations of these "action-state of nature" pairs are shown in the resulting pay-off matrix. A net income value or a utility of that net income value for each pay-off is selected.

---

[17] Gerald A. Carlson, "A Decision Theoretic Approach to Crop Disease Prediction and Control," American Journal of Agricultural Economics, Vol. 52 (May 1970), pp. 216-223.

Table 2.2

Decision Theory Pay-Off Matrix

States of Nature	Actions				
	a1	a2	a3	...	am
s1	U(s1, a1)	U(s1, a2)	U(s1, a3)	...	U(s1, am)
s2	U(s2, a1)	U(s2, a2)	U(s2, a3)	...	U(s2, am)
.	.	.	.		.
.	.	.	.		.
.	.	.	.		.
sn	U(sn, a1)	U(sn, a2)	U(sn, a3)	...	U(sn, am)

This process may be shown as follows:

$$E(U) = \max_{a} \left[\sum_{s} U(a,s) \cdot P(s) \right]$$

where:

E(U) = expected utility,

U(a, s) = pay-off (utility) derived from each "action-state of nature" pair, and

P(s) = the decision-maker's subjective probability distribution for the random variable (s).

The producer's subjective probability distribution may be considered to be a prior probability distribution which may be updated with the incorporation of forecast information. The damage probabilities derived from the forecast information may be used to form a probability distribution conditional on a given state of nature. This conditional distribution may be used to formulate a posterior probability distribution of damage for each action. The following is Bayes's theorem which combines the prior and conditional probabilities:

$$P(s/z) = P(s) \cdot P(z/s)/P(z)$$

where:

$P(s|z)$ = posterior probability,

$P(s)$ = prior probability,

$P(z|s)$ = conditional probability, and

P(z) = marginal probability of forecasts.

The process of selection of the particular action which maximizes the pay-off for the given forecast takes the form of:

$$E(U) = \max_{h} \left[\sum_{s} U(h(z),s) \cdot P(s/z) \right]$$

where:

h(z) = the highest pay-off given the forecast (z).

To use the Bayesian decision-making process, Carlson elicited subjective damage probabilities from 76 California peach growers. There were five control actions considered on seven percentage of crop lost by disease states of nature. Chemical costs were determined from the particular action chosen. One crop price was assumed because of prior knowledge due to producer cooperative actions. The crop yields were determined from historical data for the varieties concerned. Because of the nature of the disease, rainfall forecasts were incorporated into the analysis. Ordinary least squares regression was used to estimate the crop loss due to disease.

The optimal pest management strategies were calculated by joining the prior and posterior probability distributions using Bayes's theorem. Optimal strategies or actions were determined in two manners. The first equated maximum expected net returns with maximum expected utility. The second method utilized producer utility functions in a mean-variance context to account for risk aversion or the willingness to forego an amount of profit to use more pesticides in order to reduce the standard deviation of the losses.

It was determined that the 44 percent of the California peach growers who did not intend using pesticides for brown-rot control could increase income \$25 to \$40 per acre if an optimal pesticide management strategy were followed. Also, under conditions of low pest density forecasts, revenue could be saved by using no pesticides. The social, environmental and health costs of pesticide use were not quantified in this analysis. However, it was suggested that these costs could be reduced if forecast information were incorporated into the farmer's decision process. Carlson concluded that where the probability of crop damage due to pests was variable from season to season, and the pest densities could be accurately forecasted, decision theory procedures are applicable, especially when the control costs are high, relative to crop prices.

2.4 INSURANCE AND INFORMATION: REDUCTION OF UNCERTAINTY IN PEST MANAGEMENT

In general, sub-optimal use of pesticides results from producer uncertainty or lack of information about the future and the pest being controlled. Sub-optimal refers particularly to over use of pesticides and the poor timing of applications. Poor timing occurs due to the lack of information concerning the crop-pest-pesticide relationship. Over use of pesticides stems from the risk averse nature of producers. Producers are willing to increase their expenditures on pest control to assure themselves that in the event of a pest infestation, adequate control measures have been taken. Pesticide over use is not good in the private sense because of the reduction in net revenues due to increased costs. Also, negative externalities may arise, such as health and environmental hazards which are of increasing concern and should be included in the control decision framework.

The following portion of the literature review discusses the concepts of insurance and information services to alleviate the uncertainties surrounding pesticide use. This reduction of uncertainty may reduce the over-applications of pesticides described above. Information services could promote optimal pest control strategies by disseminating knowledge about the particular crop-pest-pesticide relationship.

2.4.1 Miranowski, Ernst and Cummings, 1974

An analysis of pest management information services and insurance alternatives was performed in the study completed in 1974 by Miranowski, Ernst and Cummings.[18] It was thought that these options could be used within a public policy context to provide mechanisms to promote more efficient pest control. From the standpoint of social and private optima, both options were investigated. The pest management information service was thought to increase the individual producer's level of awareness of the crop-pest-pesticide relationship. The knowledge of the benefits of proper timing and rates of chemical application would perhaps reduce wasteful applications.

---

[18] John A. Miranowski, Ulhrich F.W. Ernst and Francis H. Cummings, "Crop Insurance and Information Services to Control Use of Pesticides" (Washington, D.C.: Environmental Protection Agency, EPA-600/5-74-018, September 1974).

The insurance option was thought to be justifiable on the grounds that a reduction in the programmed pesticide applications would occur. Programmed applications refer to the use of pesticides by risk-averse producers as a form of insurance. In previous seasons, the producers utilized pesticides and will continue to do so even though the probability of infestation may be low. Since the cost of pest control to the producer is usually low, compared with the price of the crop, a low cost insurance program covered by both producer and public interests could reduce unnecessary pesticide applications.

This study was confined to insecticides. The greatest concern in public policy dealing with pesticides is the use of insecticides because of toxicity and persistence in the environment. Although herbicides to date have been the most heavily demanded type of pesticide, insurance and information services are not likely to significantly reduce use because of the nature of the pests. Alternatives to chemical weed control would tend more toward cultural practices rather than insurance. Fungicides make up only 10 percent of the active ingredients applied. The insecticides studied were restricted to the crop cotton in the southern United States where chemical applications are the most intensive and the possibilities for insurance and information services are most plausible.

The information services are designed to provide three types of assistance to producers. Current information dealing with pest densities will be provided on a regular basis. Advice on pesticide use will be provided given the pest population counts. Chemical applications will be recommended when pest populations have attained an economic threshold level. The threshold was defined as:

> the infestation level at which the economic cost of reduced crop sales is predicted to exceed the cost of applying corrective pesticides or taking some other pest control measure.[19]

The third type of assistance will provide the producer with better crop production information. This information would include the latest production and pest management innovations, such as integrated control methods.

The crop insurance services to be provided would be unlike the current all-risk crop insurance. Current programs require producers to utilize good crop production techniques including preventative chemical applications to control insect populations. Specific-risk insurance with the value equal to the full value of the crop loss would reduce insecticide use. The cost of the premium would be subsidized by the public, and claims would be paid to the producers based on the portion of the crop lost to insect damage.

The basis for the analysis is the maximization of utility. Although the producer is concerned with net income from crop production, a trade-off occurs between the expected loss due to insect damage and risk. Producers, because of their risk-averse nature, would forego some expected revenue to reduce the risk of pest damage. This is illustrated in Figure 2.7. As the level of pesticide applied increases, crop losses are reduced and expected net income increases. The net income expectations are maximized at point Q. As crop losses are reduced by increasing insecticide applications, the risk associated with the losses are also reduced. Applications at rates greater than Q reduce risk, however, expected net income is declining. The decision criterion may be

---

[19] Miranowski, et al., op. cit., p. 17.

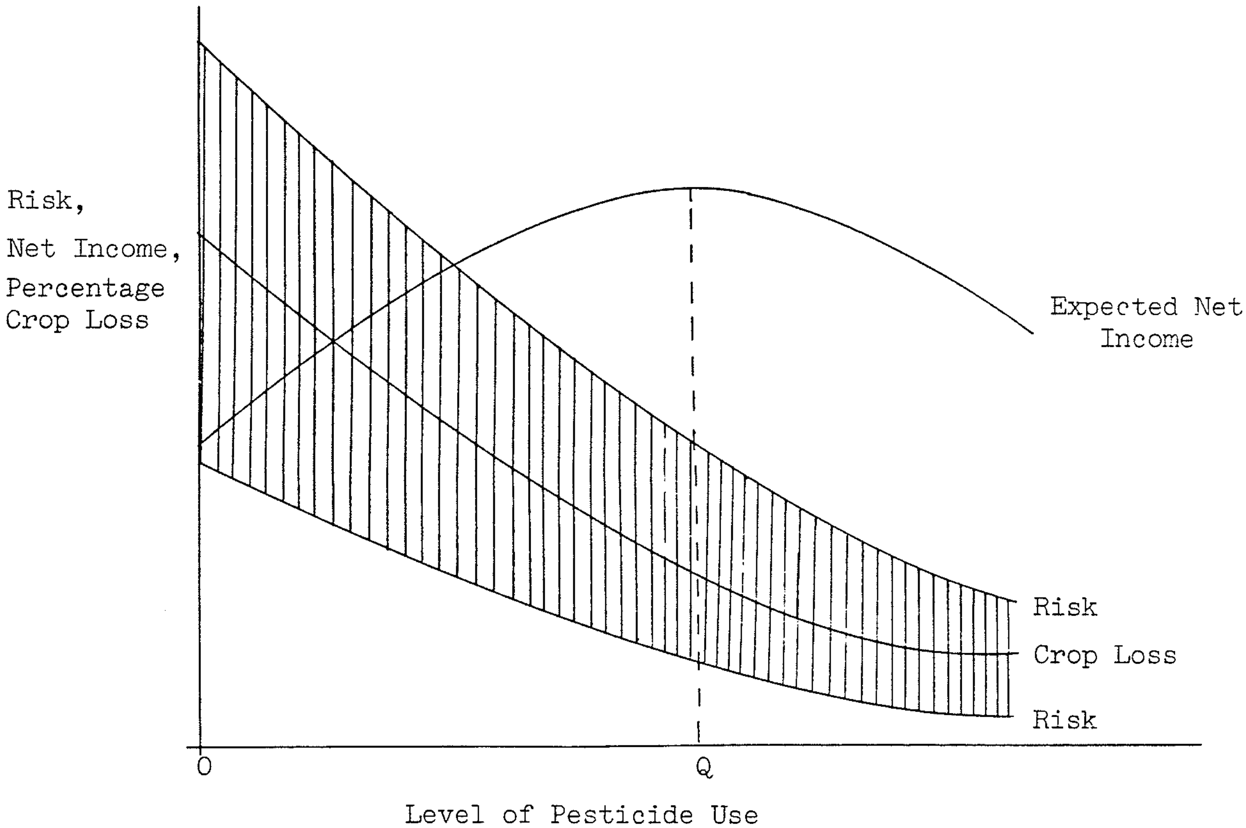

Figure 2.7
Relationship Between Pesticide Use, Expected Net Income and Crop Loss with a Risk Band

Source: John A. Miranowski, Ulhrich F.W. Ernst and Francis H. Cummings, "Crop Insurance and Information Services to Control Use of Pesticides" (Washington, D.C.: Environmental Protection Agency, EPA-600/5-74-018, September 1974), pp.27 and 29.

summarized as the trade-off between net income and risk to maximize producer utility.

To simulate the crop loss and net income relationship, the following function was used:

$$Y = Py(1 - S)Y^* - TC - Px\ X$$

where:

Y = net income per acre,

Py = price per unit of the crop,

S = fraction of the crop lost due to insect damage,

Y* = maximum possible yield per acre,

TC = total cost of production (except insecticide cost) per acre, assumed to be constant,

Px = price per pound of insecticides used, and

X = pounds of insecticides applied per acre.

The price of cotton was set at a single value representative of the current market value. The specification of the utility function corresponded to the risk-averse nature of the producers. The risk factor was defined to be the variance of the expected crop loss for a given control strategy. Nine control actions or chemical rates (0 to 40 pounds per acre) were used to determine the expected net income figures. Also, two types of cotton producers were defined. Producers were grouped as either informed or uninformed. The informed group would apply insecticides only when the pest density approached an economic threshold. The uninformed group sprayed automatically at regular intervals which amounted to 24 to 26 applications per season.

The simulation results indicated that with pest management services, the informed producers had increased net incomes and utilities. Both the expected net revenue and utility were maximized at an insecticide application rate of 25 pounds per acre. These results may be compared with those of the uninformed producers which would maximize expected net revenues at 30 pounds, but because of risk the maximum utility was attained when 35 pounds per acre was applied. For the informed producers, the risk of crop loss was reduced to the extent that insecticide use decreased by as much as 30 percent. This would lessen the need for insurance to decrease risk. The cost to the participating producer was $3 per acre which was more than neutralized by the increased efficiency in cotton production. Producers would not participate in the information services for the single reason that they lack information about the gains that would be provided. Producer participation in the information service would increase efficiency in cotton production and reduce insecticide use.

To simulate the crop insurance option, seven alternative policies were provided to the two groups of producers at five subsidy levels. The alternatives are listed as follows:

1. 50 percent co-insurance where the producer and the insurer each incur one-half of the loss incurred due to insect damage;
2. full loss coverage beyond a deductible of 0 percent;
3. full loss coverage beyond a deductible of 10 percent;
4. full loss coverage beyond a deductible of 20 percent;

5. full loss coverage beyond a deductible of 30 percent;
6. full loss coverage beyond a 40 percent deductible, which is what the Federal Crop Insurance now provides; and
7. no insurance.

In addition, the public sector subsidies were simulated as 0, 10, 25, 50 or 100 percent reduction of the insurance premiums.

The simulation results demonstrated that the insurance alternatives were not effectual for the uninformed producer. For the 50 percent co-insurance and the Federal Crop Insurance options, the producers would slightly reduce insecticide use only if the insurance premiums were subsidized 100 percent. This slight reduction in insecticide use is not likely to offset the large public subsidy. The only full loss coverage insurance alternative to be accepted under the conditions of less than a 50 percent premium subsidy was the zero deductibility option. It was concluded that for uninformed producers, the insurance options would be accepted only under heavy public subsidies, however, this would provide in several of the options an incentive to completely discontinue insecticide application.

The simulation results show the informed producer to be more flexible. If the public subsidy on insurance premiums was less than 50 percent, the informed producer would choose the no insurance option. At the 100 percent subsidy level, all insurance alternatives would be preferred, however, the co-insurance and Federal Crop Insurance systems probably would not reduce insecticide use. For the full loss coverage alternatives with the deductibilities of 0 and 10 percent, no insecticides would be used. At the 20 and 25 percent deductible levels, the applications would be significantly reduced but with a great cost to the public.

2.5 SUMMARY

The theoretical aspects of pesticide use, insurance and information services were summarized in the preceeding chapter. A selection of literature which developed and presented these concepts was reviewed. The review was constrained to the literature which contained economic concepts and methodology which may be applied to the problem of insecticidal control of flea beetles in rapeseed. The review was separated into three sections, each of which developed an economic aspect of pest control. The first section included the review of articles which dealt with the use of insecticides within the context of applied classical production economics. The second section focused on the problem of production under the uncertain conditions of pest attacks. Game theory was utilized to incorporate risk and uncertainty surrounding pest control decisions to maximize producer profits or utility. The final section of the review provides an insight into the possibilities for insurance and information services to reduce the uncertainties of pest control and thereby reduce insecticide use.

Classical economic theory under perfect knowledge provided the basis for the studies done by Hillebrandt, Headley, and Hall and Norgaard. Hillebrandt in 1960 formalized the concept of a dosage response function relating optimum pesticide applications to the cost of the chemical, the price of the crop, as well as the intensity of the attack. The optimal quantity of insecticide applied occurs where the marginal value product is equivalent to the price of the chemical for a given level of pest information. Headley in 1968 determined that about $4 worth of marginal value product resulted from the application of $1 worth of pesticide. This apparent sub-optimal level of pesticide application gives justification for the trend of rapid increases in the demand for agricultural pesticides.

Headley in 1972 formalized the concept of an economic threshold pest population. This threshold population occurs where the cost of control is equivalent to the yield benefits in marginal terms. Control of pest populations greater or less than this threshold would be sub-optimal in terms of profitability to the producer. Hall and Norgaard in 1973 added the concept of timing of the pesticide applications to the conditions for optimal pest control. Timing as a variable of the production process was determined to be independent of crop prices, control costs and rate of application. The optimal timing of chemical pest control is a function of the biological growth pattern of the pest.

The main restriction with the articles summarized to this point is the assumption of perfect knowledge in the production process. Cost of chemical applications are known and government regulations dictating proper use practices as well as application rate recommendations provide a sense of certainty in these areas. However, to a large extent, imperfect knowledge exists in the areas of future crop prices, pest population dynamics, and the chemical dosage response functions. The article by Carlson in 1970 included the uncertainties in a decision-theoretic pest control example to maximize expected profits. The possible control strategies are named actions while the probable levels of pest populations are states of nature. From each possible action-state of nature combination results a particular crop yield which may be analyzed in monetary or utility terms. Carlson utilized Bayes's theorem to incorporate forecast information dealing with the states of nature to update the producer's probabilistic expectations of the pest population. The control strategy chosen maximizes profit or an utility transformation.

The final portion of the literature review focuses on two concepts which are thought to alleviate the uncertainties surrounding pest control. The most complete study in the areas of specific-risk insurance and information services options was done by Miranowski, Ernst and Cummings in 1974. The conclusions reached by this study indicated that the insurance alternatives which reduced uncertainty and thereby decreased insecticide use would do so only at a high cost to society. The information services option showed the most promise in reducing insecticide use by improving the producer's knowledge about the crop-pest-pesticide relationship. Producers are willing to accept the program of information services if the benefit potentials are publicized.

The articles reviewed in this chapter contain analytical procedures which pertain to the problem of control of flea beetles on rapeseed. Dosage response functions as theorized by Hillebrandt are estimated for the insecticides recommended for the control of flea beetle infestations. The yield response calculated for each insecticide, at the recommended application rate, is incorporated with crop price expectations and flea beetle damage probability distributions into pay-off matrices as defined by Carlson. The profit motive is the choice criterion for the selection of the appropriate control strategy.

Chapter III

METHODOLOGICAL CONSIDERATIONS

3.1 INTRODUCTION

The decision model used in this analysis simulates possible outcomes of returns in relation to the subjective future assessment that a producer may have toward expected flea beetle damage and rapeseed prices. This analysis evaluates the effect that chemical treatments have on the yield of rapeseed by controlling flea beetle infestations. Flea beetle damage reduces rapeseed yield while chemical insecticides may reduce this damage. The various control measures are analyzed solely in terms of private cost effectiveness. Insecticide dosage response functions were developed from experimental plot data and are used as a method of relating the levels of chemical application to increases in yield. Increases in yield over a strategy of no treatment were calculated for six insecticide treatments for selected levels of flea beetle density.

3.2 THE CONCEPTUAL MODEL

The conceptual model is the logical process of producer decision-making. It is hypothesized that these decisions are made on the basis of expectations for the future. In this case, the expectations for the future are in the areas of: rapeseed prices, and crop damage or flea beetle densities. Future expectations consider both present conditions and past experiences. Figure 3.1 is the schematic representation of a

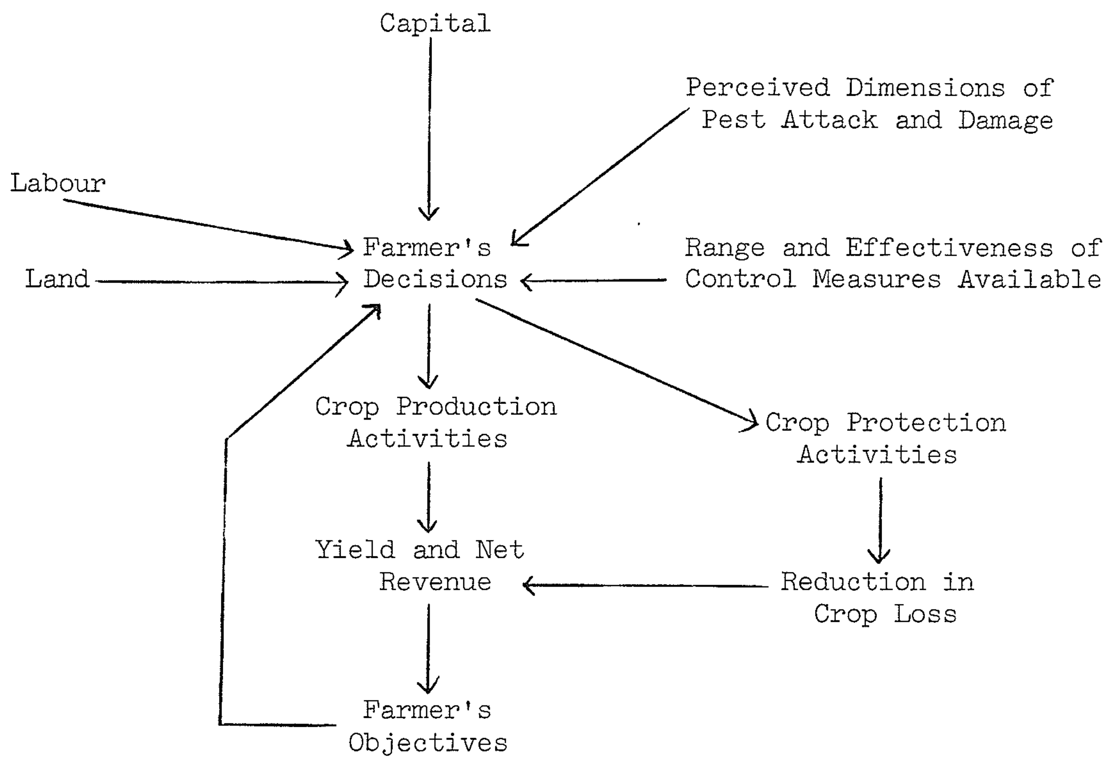

Figure 3.1

Factors Affecting Crop Protection Decision-Making

Source: G.A. Norton, "Analysis of Decision-Making in Crop Protection," Agro-Ecosystems, Vol. 3 (1976), p. 28.

producer's decision-making model. The producer utilizes the available inputs of production to optimally produce a crop. Given the producer's objectives and perception of possible pest damage, the decision is made to choose among the available control strategies to reduce crop loss.

3.2.1 Chemical Control of Flea Beetles on Rapeseed

Three types of chemical insecticides are used, either individually or in combination, to control flea beetle infestations in Manitoba. The three studied chemicals and their formulations are: carbofuran 5 percent granular, lindane-based seed treatments, and carbofuran 48 percent flowable. Supracide 25 percent emulsifiable concentrate is also used in this analysis where insufficient experimental data restricted the examination of the carbofuran 48 percent flowable.

Furadan 5 G (carbofuran) is an in-furrow granular systemic insecticide. This chemical is applied using a seed drill and is most effective when mixed with the seed prior to seeding. This granular Furadan is not an effective treatment if the crop is seeded with a discer.[20] When moisture is available the insecticide is absorbed into the plant and kills the flea beetles as they feed on the seedlings. Under ideal conditions, three weeks of protection are given to the rapeseed crop.

Lindane is the basic active ingredient of several commercially manufactured rapeseed seed treatments. Some of these chemicals include:

---

[20] Manitoba Department of Agriculture, Entomology Section, Technical Services Branch, 1981 Manitoba Insect Control Guide (Winnipeg, Manitoba), p. 32.

Lindasan, Gammasan, Thiralin, Benolin, and Vitavax.[21] The main difference among these chemicals is the one or more fungicides that are included to control plant disease. All of these chemicals are in powder formulations with the exception of flowable Vitavax. The rapeseed may be treated with lindane either commercially or by the producer prior to seeding. Under ideal conditions, lindane protects against flea beetle infestations for one week to 10 days. It is recommended that this form of treatment, in practice, should be followed up with a post emergence foliar spray.[22] This combination of treatments provides about three weeks of protection, which is similar to the singular application of Furadan granular.

The foliar sprays: Furadan 4.8 flowable (carbofuran), Supracide 25 percent emulsifiable concentrate (methidathion), Malathion 25 percent emulsifiable concentrate, and Guthion spray concentrate (azinphos-methyl) are all recommended insecticides to control flea beetles after plant emergence. These sprays can be used by themselves but the crop protection provided is limited. "Several spray applications would be necessary to provide adequate protection, particularly since the crop may emerge over a period of several days."[23] The sprays may also be used to enhance the effectiveness of the carbofuran and lindane treatments.

---

21 Saskatchewan Department of Agriculture, Plant Industry Branch, "List of Seed Treatment Products for Use on Cereal and Oilseeds" (Regina, Saskatchewan, 1980).

22 P.H. Westdal and W. Romanow, "Reduce Losses in Rapeseed," Manitoba Cooperator: Manitoba Crop Management Issue 1981 (March 5, 1981), p. 44.

23 Ibid.

The seven treatment possibilities studied in this analysis are listed below:

1. No insecticide treatment;
2. Furadan granular;
3. Furadan granular plus lindane seed treatment;
4. Furadan granular plus Supracide foliar spray;
5. Lindane seed treatment;
6. Lindane seed treatment plus Supracide foliar spray; and
7. Furadan foliar spray.

These options were studied because they are recommended strategies for the control of flea beetles on rapeseed. The research data developed to test the relative effectiveness of the chemicals are used as the basis of the analyses. Each of the control strategies, their recommended rates of application, and 1981 cost of application are listed in Table 3.1.

3.2.2 Insecticide Dosage Response Functions

To develop dosage response functions, experimental plot data were analyzed for both single and combined insecticide treatments. The term 'dose' refers to the rate of active ingredient per unit applied for a particular control strategy. Hillebrandt defined the dosage response curve as: "a curve showing, for various doses of pesticide, the yield of crop which is attributable to the application of the pesticide."[24] The following analysis contains the three types of insecticides utilized

---

[24] Hillebrandt, op. cit., p. 464.

Table 3.1

Control Strategies for Flea Beetle Infestations on Rapeseed

Control Strategy and Rate of Active Ingredient Application	Timing of Application	1981 Cost Per Hectare*
1. No insecticide	-	-
2. Furadan granular 0.280 kg.ai./ha.	at planting	$13.664
3. Furadan granular 0.280 kg.ai./ha.	at planting	
plus Lindane seed treatment 18 gm.ai./kg. of seed	at planting	$18.210
4. Furadan granular 0.280 kg.ai./ha.	at planting	
plus Supracide foliar spray 140 gm.ai./ha.	7 to 10 days after crop emergence	$18.057
5. Lindane seed treatment 18 gm.ai./kg. of seed	at planting	$4.546
6. Lindane seed treatment 18 gm.ai./kg. of seed	at planting	
plus Supracide foliar spray 140 gm.ai./ha.	7 to 10 days after crop emergence	$8.939
7. Furadam foliar spray 110 gm.ai./ha.	7 to 10 days after crop emergence	$4.095

*Prices of insecticides and application costs are explained in Appendix B.

on two species of rapeseed to control flea beetle infestations. The chemicals which are assessed include: carbofuran granules, lindane-based seed treatments, and carbofuran post-emergence sprays.[25]

Initially, the chemicals were to be studied on the basis of the particular type of rapeseed. However, this analysis shows that the insecticide dosage responses are equal between the two species of rapeseed. In statistical terms, based on the number of available observations, the mean yield responses resulting from insecticide treatments of equal dosage were found to be equivalent between the various licensed varieties of the two species: Brassica campestris and Brassica napus.

3.2.2.1 Carbofuran 5 Percent Granular

Carbofuran observations were obtained from experimental plot data and were ranked according to the chemical active ingredient application rates. In some instances, certain experimental results were deleted from the data set. Experiments, or sample observations within experiments, were discarded where seeding rates were inconsistent with proper management practices.[26] Experiments were also discarded if they were inordinately different from results in general. Inordinately different results would be negative or very extreme positive percentage yield net gains as compared with the average. Negative yields would indicate a phytotoxic effect on the plant when few flea beetles are present, or

---

[25] For a detailed description of the estimation procedures, data listings and averaging, chemical aggregation procedures, function alternatives, as well as the statistical comparison between the responses on the two types of rapeseed, see Appendix C.

[26] For the pertinent recommended agronomic practices for rapeseed production, see Appendix D.

something inconsistent occurring to the system of plots as the growing season progresses. Very extreme positive net gains result from the control or untreated plot being destroyed so any small yield increase resulting from an insecticide application would be exaggerated when put into percentage terms.

On a theoretical basis, it was decided that the estimated dosage response curves should be fitted through the origin. The reasoning for this is that if no insecticide were applied to a particular plot, there should be no difference in the resulting yield from the yield obtained on a check plot. In other words, it is assumed that the chemical application is the only factor which could affect a yield change. All other factors are assumed to be constant. The curve could intersect along the horizontal (chemical rate) axis to the right of the origin, but no data has been produced which might give some insight as to what that threshold might be. Using the SHAZAM computer program for econometric methods and the chosen log-linear equation estimation, the estimated line could not be forced through the origin.[27] A dummy point (0.001, 0.001) was added to the data so the line would approximately be fitted through the origin.

The chosen form of the dosage response function is of the form:

$$y = a + b \ln x$$

where:

y = the percent increase in yield over a control plot attributable to the insecticide,

---

27 Kenneth J. White, "A General Computer Program for Econometric Methods - SHAZAM," Econometrica, 1978.

x = the rate of the insecticide application, and

a, b = the parameters of the estimated equation.

The result is as follows:

$$y = 58.665 + 8.6248 \ln x$$

This is the estimated equation relating the percentage increase in yield of rapeseed resulting from various carbofuran 5 percent granular application rates. This average damage in any given year, although assumed to result from a flea beetle infestation, is in reality caused by a combination of factors such as soil and climatic conditions as well as cultural practices. For example, in a dry spring flea beetle damage would be exaggerated because chemical treatments are not as effective under low soil moisture conditions. In addition to the average curve, curves relating to high and low flea beetle infestations were also estimated. Because of the combination of causal factors the curves are referred to as insecticide dosage response functions under high, average and low damage conditions. The high and low damage curves were estimated to provide a range of insecticide effectiveness. The estimation was done by taking the same slope of the curve as estimated for the average damage and plotting the lines through the averaged high and low observations at the most widely used application rate of 0.280 kg.ai. per hectare. Table 3.2 presents the resulting carbofuran dosage response functions. Although the recommended rate ranges from 0.224 to 0.280 kg.ai. per hectare, the higher rate was used because about one-third of the carbofuran experiments were performed at this rate. The increases in rapeseed yield resulting from the carbofuran granular application over

Table 3.2

Furadan 5G Dosage Response Functions and the Percent Increases in Yield at the Recommended Application Rate of 0.280 kg.ai./ha.

Damage Level	Equations and Coefficients	Percent Increase in Yield Over Control Plots
High	YH = 118.74907 + 8.6248 ln x	107.8
Average	YA = 58.665 + 8.6248 ln x (*) (**)	47.7 (R^2 = 0.8513)
Low	YL = 30.896574 + 8.6248 ln x	19.9

*, **Significance of the parameters at the 1 and 2 percent levels, respectively.

application over an untreated plot are 107.8, 47.7, and 19.9 percent for the high, average, and low damage levels, respectively. This analysis was constrained to use the same slope for all three dosage response functions because of a low number of sample observations at chemical application rates other than rates that are recommended. The dosage response functions relating to the three levels of damage are plotted in Figure 3.2.

3.2.2.2 Lindane Seed Treatments

The process of deriving the lindane seed treatment dosage response functions was similar to that of the carbofuran granular. The observations were obtained from the same data source and as stated earlier, certain experiments and results were discarded for similar reasons. The curve estimation for the lindane chemicals, as with carbofuran, uses a dummy observation (0.001, 0.001) in the data source, so the estimated curve will be fitted approximately through the origin. The high and low damage curves were estimated about the average curve in a method similar to carbofuran. At the experimental application rate of 15.50 gm.ai. per kilogram of seed, the high and low yield observations were averaged. About one-half of the lindane experiments were performed at this rate, therefore, low and high yields could be estimated. At the recommended application rate of 18.0 gm.ai. per kilogram of seed no plot experiments were performed, however, yield increases as estimated from the response functions were reported at this recommended rate. The slope of the curve estimated for the average level of damage was held constant because of data limitations, and curves were plotted through the averaged

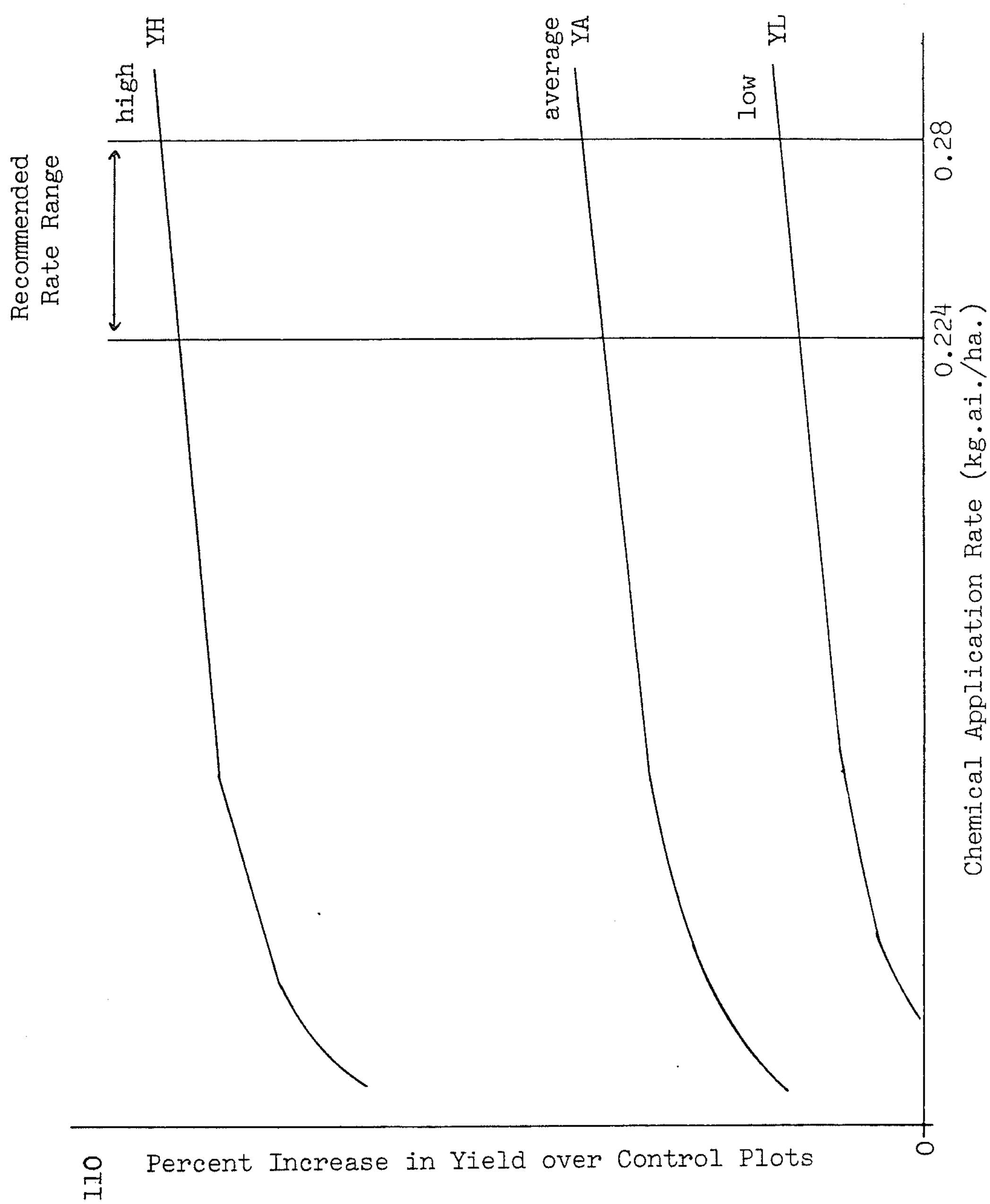

Figure 3.2

Carbofuran Dosage Response Functions

high and low observations. The three estimated lindane seed treatment dosage response functions are listed in Table 3.3. The percentage increase in yield of the lindane treated plots over the untreated plots was determined to be 60.18, 22.22, and 10.93 percent for the high, average and low damage levels, respectively. The lindane seed treatment dosage response functions at the three damage levels are plotted in Figure 3.3.

3.2.2.3 Carbofuran Foliar Spray

The derivation of the carbofuran spray dosage response functions follow the same process as the lindane seed treatments and the carbofuran granular. With one-third of the plot experiments performed at each of 70 and 150 gm.ai. per hectare recommended application rates, yield increases were taken at the averaged 110 gm.ai. per hectare application rate. The estimated functions are listed in Table 3.4. The percentage increase in yield resulting from the spray application, over the control plots, was 40.59, 25.44, and 14.90 percent for high, average and low damage conditions, respectively. The estimated curves are graphed in Figure 3.4.

3.2.2.4 Insecticide Combinations

When the chemical control of flea beetles is practiced on rapeseed, the utilization of combinations of two insecticides is possible. The chemical combinations analyzed in this thesis are as follow:

1. Furadan granular plus lindane seed treatments;
2. Furadan granular plus a post-emergence spray; and

Table 3.3

Lindane Seed Treatment Dosage Response Functions and the Percent Increases in Yield at the Recommended Application Rate of 18 gm.ai./kg of seed

Damage Level	Equations and Coefficients	Percent Increase in Yield Over Control Plots
High	YH = 53.82286 + 2.1981 ln x	60.18
Average	YA = 15.868 + 2.1981 ln x (*) (**)	22.22 (R^2 = 0.3629)
Low	YL = 4.5766738 + 2.1981 ln x	10.93

*, **Significance of the parameters at the 2 and 10 percent levels, respectively.

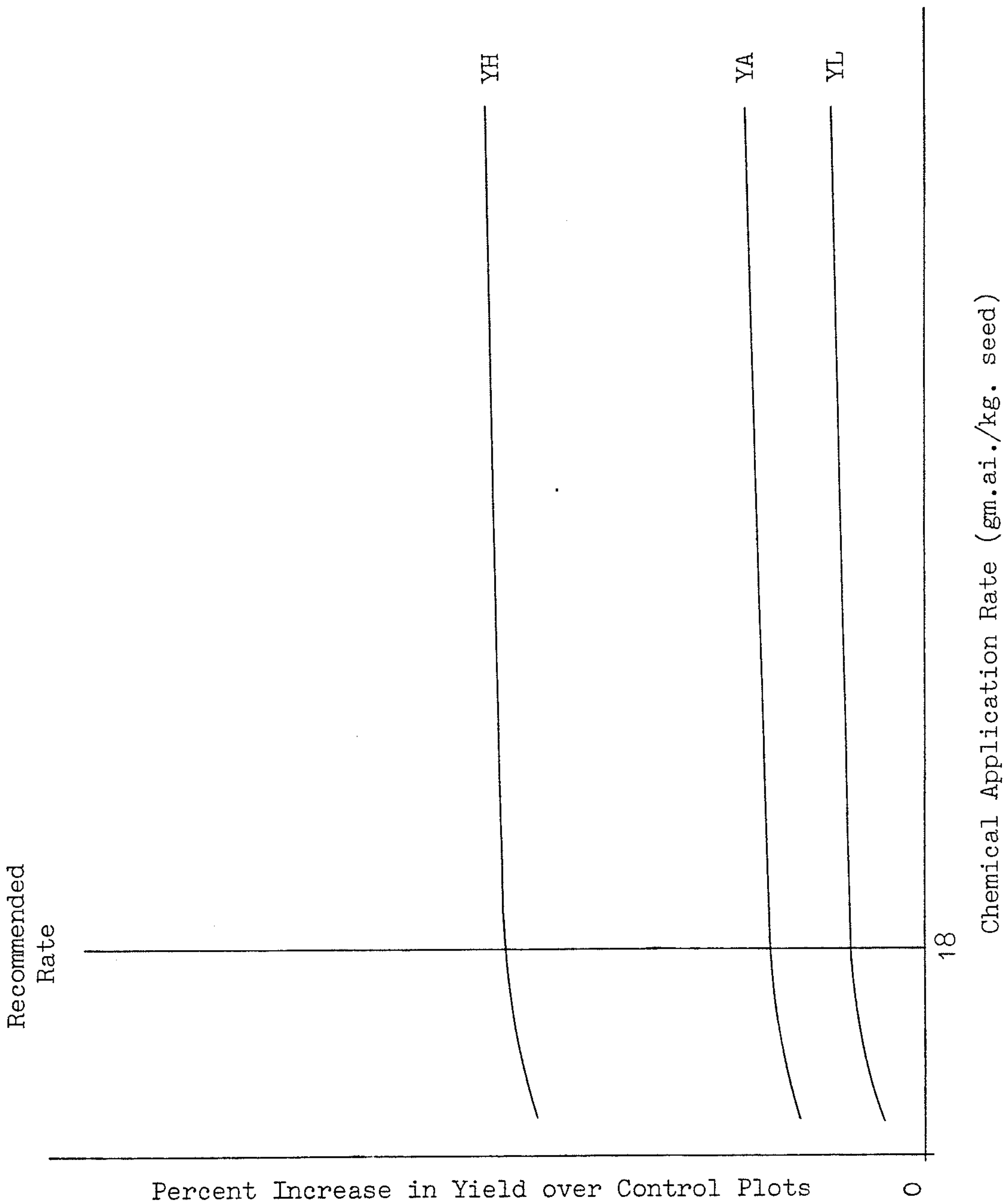

Figure 3.3

Lindane Seed Treatment Dosage Response Functions

Table 3.4

Carbofuran Foliar Spray Dosage Response Functions and the Percentage Increases in Yield at the Recommended Application Rate of 110 gm.ai./ha.

Damage Level	Equations and Coefficients	Percent Increase in Yield Over Control Plots
High	YH = 30.3314 + 2.1814 ln x	40.59
Average	YA = 15.190 + 2.1814 ln x (*) (*)	25.44 (R^2 = 0.9884)
Low	YL = 4.6414 + 2.1814 ln x	14.90

*Significance of the parameters at the 1 percent level.

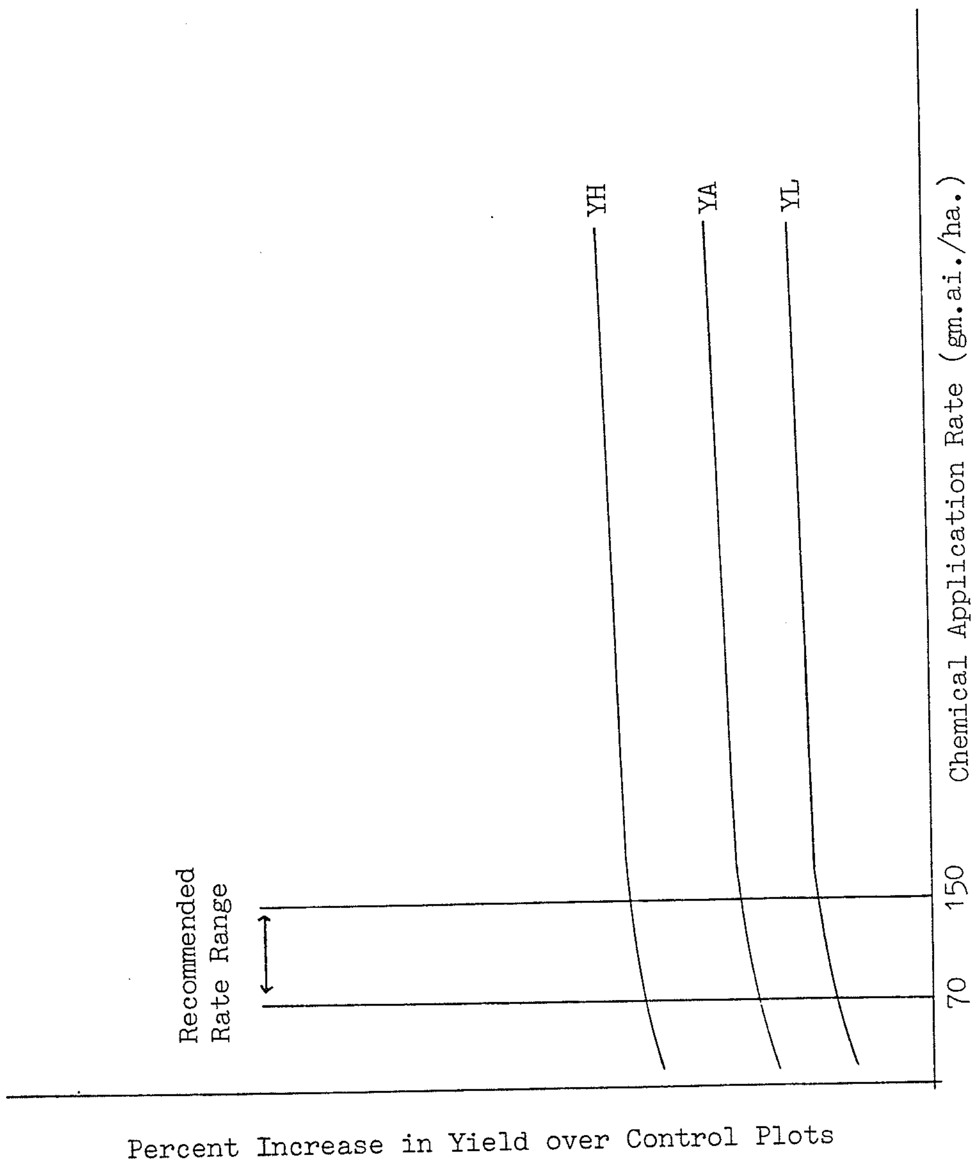

Figure 3.4

Carbofuran Sprays Dosage Response Functions

3. Lindane seed treatment plus a post-emergence spray.

The analysis of response functions for insecticide combinations is constrained because of data limitations. The experimental observations that did exist analyzing the combination of insecticides were not performed under similar conditions. As well, the scarcity of observations made the curve estimation impossible. The additions to rapeseed yield caused by the three alternative insecticide combinations were taken from one experiment performed in 1977 on B. napus rapeseed.[28] The foliar post-emergence spray utilized was Supracide 25 percent emulsifiable concentrate (methidathion) which may be substituted for the carbofuran 4.8 flowable foliar spray at a higher application rate.[29] Methidathion has a moderate toxicity while carbofuran 4.8 flowable is highly toxic.[30] Although the entire dosage response functions could not be estimated, the percent additions to yield over the single insecticide treatments were calculated from this particular experiment. The percent yield additions from the chemical combinations were added to the percent increase in yields estimated, at the recommended application rates, for the single treatment dosage response functions.[31]

---

[28] P.H. Westdal, W. Romanow and W.L. Askew, "Comparison of the Effects of Different Insecticides, Applied for the Control of the Crucifer Flea Beetle on Rape, on Beetle Numbers, Plant Injury, Development and Yield," in Pesticide Research Report, compiled annually by the Expert Committee on Pesticide Use in Agriculture (1977), pp. 153-154.

[29] Manitoba Department of Agriculture, Entomology Section, Technical Services Branch, 1981 Manitoba Insect Control Guide (Winnipeg, Manitoba), p. 32.

[30] Manitoba Department of Agriculture, Entomology Section, Insecticide Handbook: for Manitoba Pesticide Dealers and Applicators (Winnipeg, Manitoba, 1980), pp. 23 and 28.

[31] See Appendix C for the procedures of Insecticide Dosage Response estimates.

The assumption is made that the percentage yield additions estimated for the insecticide combinations would hold constant for each level of dosage. This assumption was made because of insufficient test results to indicate either an increasing or decreasing increment in yield to the primary insecticide treatment as the level of damage increases. For example, using carbofuran granular plus a foliar spray at any given level of damage, the spray augments the carbofuran response by 0.8307 percent. A comparable value was calculated for the carbofuran granular plus lindane seed treatment and the lindane seed treatment plus a foliar spray options.

The percentage increases in yield for the insecticide combinations over untreated plots are listed in Table 3.5 for the low, average and high dosage levels. The carbofuran granular in combination with the lindane seed treatment is estimated to be approximately equivalent to the combination of carbofuran and a foliar spray. The equivalence is in terms of dosage response, not necessarily cost effectiveness. For example, the yield increases may be almost equal for the control strategies, however, the cost to the producer varies and must be accounted for in the decision framework.

3.2.2.5 Summary and Application of the Insecticide Response Functions

The estimated log-linear dosage response functions for the three damage levels for each insecticide strategy take the form as graphically illustrated in Figure 3.5. The curves at the recommended application

Table 3.5

Percentage Yield Increases of Treated Plots Over Control Plots for the Insecticide Combinations Applied at Recommended Rates

Damage Level	Furadan Plus Lindane	Furadan Plus Foliar Spray	Lindane Plus Foliar Spray
Low	20.73	20.72	23.93
Average	48.53	48.52	35.22
High	108.63	108.62	73.18

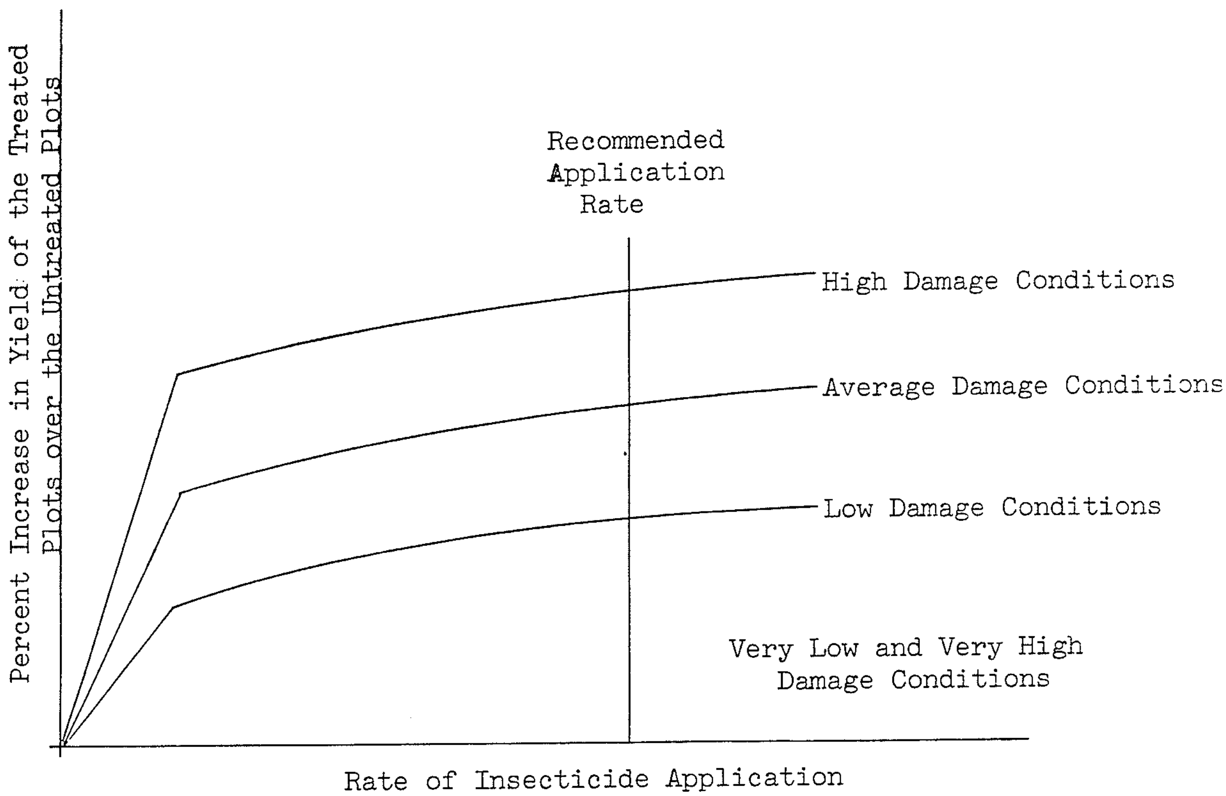

Figure 3.5

Relationship of Insecticide Application Rate, Percentage Increase in Yield and Level of Damages rate show, for each level of damage, the percentage increase in yield of the treated plots over the control plots. The damage conditions refer to the combination of cultural, climatic and agronomic conditions which may exaggerate the true extent of the flea beetle densities. This package of damage conditions may be referred to as the state of nature.

For the purpose of this analysis it has been assumed that the percentage increases in yield for any insecticide treatment is equal to zero at very low or very high damage states of nature. For example, under very low damage conditions, or state of nature, the chemical has nothing to react upon to effect an increase in yield. Similarly, at a very high damage state of nature the density of the pest population is so great that no amount of insecticide could counteract the destruction of the entire rapeseed crop.

When the rate of insecticide application is held constant, as a recommended rate, the percent yield responses increase as the intensity of the damage conditions increase. For example, the change in yield resulting from a chemical treatment under average damage conditions is less than the change in yield that results under high damage conditions. Thus, insecticides are most effective under high damage conditions. However, at some level of damage greater than the assumed high level the effectiveness of the insecticides decrease. The density of insects per plant is so great that crop destruction occurs with any control strategy.

From each of the dosage response curves a percent increase in yield of treated plots over untreated may be obtained for each insecticide applied at the recommended rate. The three chemical combination yield increases were extrapolated from a single experiment, as mentioned previously. Table 3.6 presents a summary of the effects of various flea beetle insecticide treatment possibilities for five damage states of nature. Development of these five damage states of nature is discussed in the next section of this chapter. The zero entries in the first and last rows of the table indicate no increases in yield over an untreated plot for the very low and very high damage conditions. At the very low damage level, the flea beetle populations are not a problem and the application of any insecticide does not enhance yield. Under very high damage conditions, both the treated and untreated plots are destroyed because of the severity of the infestation. The table indicates that the highest overall percentage increases in yield result from Furadan applications, which are enhanced by a combination of lindane or a spray. Under low damage conditions, the combination of a lindane seed treatment and a spray is most effective. Under medium and high damage conditions, single applications of lindane or a spray produce yield increases but generally at lower percentages than other treatments.

3.2.3 Flea Beetle Population Densities

The assessment of the damage resulting from flea beetle population densities has fluctuated widely over the past number of years. It appears that the level of rapeseed damage is caused by a number of factors, with flea beetle population densities being only one of these factors. Other factors which may affect damage levels are: soil temperature and moisture, winter severity, flea beetle densities in the previous fall, climatic conditions at the time of planting, and cultural

Table 3.6

Percent Increase in Yield of the Treated Plots Over Control Plots for the Seven Treatment Possibilities Applied at Recommended Rates

States of Nature Damage Levels	Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Spray
Very low	0	0	0	0	0	0	0
Low	0	19.9	20.73	20.72	10.93	23.93	14.90
Average	0	47.7	48.53	48.52	22.22	35.22	25.44
High	0	107.8	108.63	108.62	60.18	73.18	40.59
Very high	0	0	0	0	0	0	0

practices of the rapeseed producer. Besides having a great effect on the stand of rapeseed, these factors also greatly influence the flea beetle population. It is the adult flea beetle population which is dormant over the winter and attacks the newly emerged rapeseed plants in the spring. The winter severity and fall population determines the number of flea beetles in the spring. For the purpose of this analysis, it is not only the producer's expectations of flea beetle densities that matters but the entire spectrum of variables which may intensify the effects of the flea beetle damage. Therefore, the population density probabilities are in reality the producer's subjective assessment of the damage probabilities.

The probabilistic assessment of flea beetle densities is independent of the chemical treatments. The insecticides do affect the level of damage resulting from the flea beetle densities but not the probabilistic expectations of the densities prior to the damage occurring. This is because the population of flea beetles is regarded as being relatively constant and the numbers that attack rapeseed are a small portion of the total. The actual flea beetle densities or damage probabilities in a historical sense are unquantified. It is thought that Manitoba rapeseed producers consistently face average to high flea beetle densities.

> Although quantitative surveys are lacking, populations of flea beetles appear to have remained consistently high in the southern part of the growing area for at least 10 years and similar levels of abundance are now being reached in more northerly areas.[32]

----

32 W.J. Turnock and D.J. Samborski, "Management of Plant Pests," a paper prepared for the Prairie Production Symposium (Saskatoon, Saskatchewan, October 29-31, 1980), p. 19.

In this study, a range of flea beetle populations or damage states of nature is assumed with five graduations from very low to very high. Three probability distributions were postulated to provide a sensitivity analysis with the actual distribution being unknown. The postulated distributions are shown in Figures 3.6, 3.7 and 3.8.

The distributions approximate a triangular distribution which would measure low, average and high damage expectations. Each of the distributions has its high probability value set at 40 percent. For the sensitivity analysis this high probability is set at each of the low, average and high levels thereby providing a range of distribution skewness.

3.2.4 Rapeseed Yields

Rapeseed yields vary considerably from year-to-year for reasons other than flea beetle densities. The producer has to consider in his future expectations the less than optimal crop yields which may result due to an undesirable damage state of nature. Since it is unknown exactly what particular yield would result under specified damage conditions or states of nature, two ranges of possible yields have been considered for each of the two rapeseed species, the two rapeseed species being *Brassica napus* and *Brassica campestris*. The two yield ranges, a lower and higher, are used because of the differences in yield that result due to geographic location and cultural practices.

The yields within the *B. napus* species of rapeseed were calculated by assuming five equivalent graduations between zero and the postulated high yields of 30 and 35 bushels per acre to formulate the two yield ranges. It has been shown that *B. campestris* rapeseed yields one-third

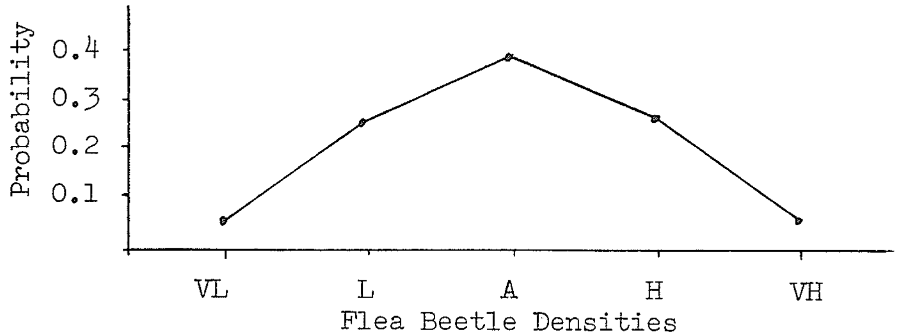

Figure 3.6

Average Flea Beetle Damage Distribution

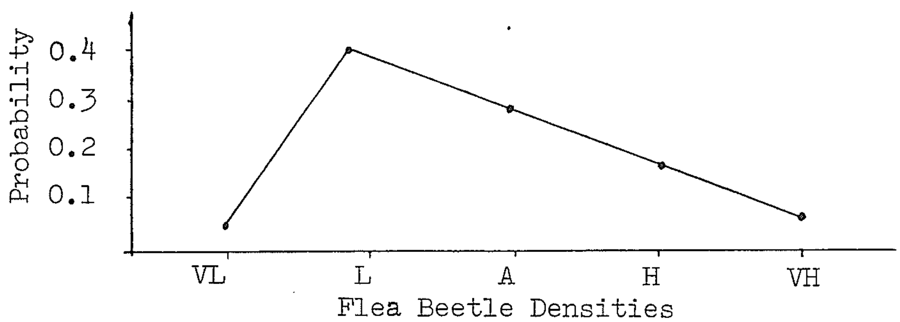

Figure 3.7

Low Flea Beetle Damage Distribution

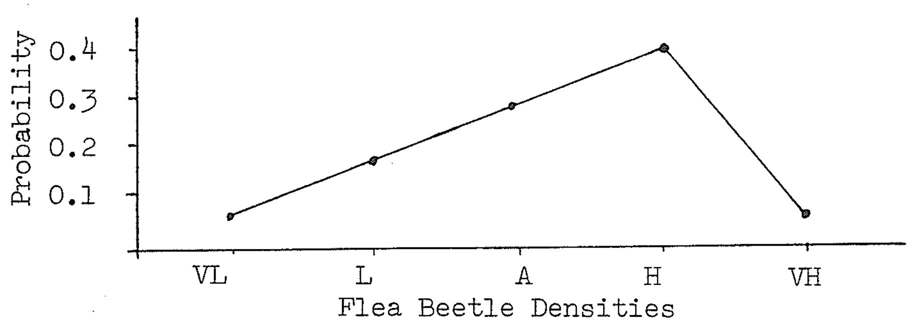

Figure 3.8

High Flea Beetle Damage Distribution

to one-quarter less than the B. napus species. The Manitoba Co-operative Tests arrive at the conclusion that the difference is 33.125 percent based on a three year average.[33] From the respective lower and higher yield ranges postulated for B. napus yield ranges were calculated for B. campestris using the above percentage difference as a conversion factor. The yield ranges are listed for the two rapeseed species in Table 3.7.

The yields ranging from very high to very low result from very low to very high damage states of nature, respectively. For example, the very low yield of zero results from a very high damage state of nature. These yields are assumed to occur under conditions where no insecticide treatment was used. In other words, if this were an experimental plot system under consideration, these yields would occur on the untreated control plots at the various damage states of nature.

Percentage increase in yields resulting from a chemical application were estimated for each insecticide and combination of insecticides at the recommended application rates from the dosage response functions. It was assumed that under very low damage conditions, very high rapeseed yields result and any amount of insecticide applied would not further increase the yields. At very high damage conditions the resulting yield would approach zero and any insecticide applied could do nothing to change this because of the extremely high population densities. Tables 3.8 through 3.11 show the rapeseed yields resulting from insecticide treatments at different levels of damage. The yields are listed for both species of rapeseed at two possible yield ranges.

---

[33] See Appendix E for the Manitoba rapeseed yield comparative tests.

Table 3.7

Rapeseed Yields With No Insecticide Treatment

Yield Level	B. napus		B. campestris	
	Low Yield Range	High Yield Range	Low Yield Range	High Yield Range
	..................tonnes per hectare..................			
Very high	1.681	1.962	1.124	1.312
High	1.261	1.471	0.843	0.984
Medium	0.840	0.981	0.562	0.656
Low	0.420	0.490	0.282	0.328
Very low	0.0	0.0	0.0	0.0

Table 3.8

Brassica napus Rapeseed Yields Under Various Insecticide Control Strategies (Low Yield Range)

State of Nature Damage Level	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Spray
	......tonnes per hectare......						
Very low	1.681	1.681	1.681	1.681	1.681	1.681	1.681
Low	1.261	1.512	1.522	1.522	1.399	1.562	1.449
Average	0.841	1.242	1.249	1.249	1.027	1.137	1.055
High	0.420	0.873	0.877	0.877	0.673	0.728	0.591
Very high	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3.9

Brassica napus Rapeseed Yields Under Various Insecticide Control Strategies (High Yield Range)

State of Nature Damage Level	Treatments						
	Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Spray
	...tonnes per hectare...						
Very low	1.962	1.962	1.962	1.962	1.962	1.962	1.962
Low	1.471	1.764	1.776	1.776	1.632	1.823	1.690
Average	0.981	1.449	1.457	1.457	1.199	1.326	1.230
High	0.490	1.019	1.023	1.023	0.786	0.849	0.689
Very high	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3.10

Brassica campestris Rapeseed Yields Under Various
Insecticide Control Strategies
(Low Yield Range)

State of Nature Damage Level	Treatments						
	Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Spray
	...tonnes per hectare...						
Very low	1.124	1.124	1.124	1.124	1.124	1.124	1.124
Low	0.843	1.011	1.018	1.018	0.935	1.045	0.969
Average	0.562	0.830	0.835	0.835	0.687	0.760	0.705
High	0.282	0.586	0.588	0.588	0.452	0.488	0.396
Very high	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3.11

Brassica campestris Rapeseed Yields Under Various Insecticide Control Strategies (High Yield Range)

State of Nature Damage Level	Treatments						
	Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Spray
	tonnes per hectare						
Very low	1.312	1.312	1.312	1.312	1.312	1.312	1.312
Low	0.984	1.180	1.188	1.188	1.092	1.219	1.131
Average	0.656	0.969	0.974	0.974	0.802	0.887	0.823
High	0.328	0.682	0.684	0.684	0.525	0.568	0.461
Very high	0.0	0.0	0.0	0.0	0.0	0.0	0.0

From the previous tables, several generalizations result. At very low and very high damage levels, insecticide treatments do no better than the untreated strategy. At the low damage level, the highest yielding strategy is the lindane seed treatment plus a foliar spray. Without taking chemical costs into account the Furadan plus lindane and Furadan plus a foliar spray combinations appear to be the highest yielding strategy under average and high damage conditions. These Furadan combinations yield only slightly better than Furadan as a singular treatment.

3.2.5 Rapeseed Prices

To estimate what rapeseed prices would be in 1981 a linear ordinary least squares extrapolation was done on annual price data for the years 1960 through 1979.[34] This linear estimate was assumed to be an average level for producer expectations. High and low expectations were derived by taking a one standard deviation interval on either side of the estimated average line. The high, average and low price expectations provide a means of analyzing price sensitivity of the expected value results. The estimated price equations, coefficients and estimates are listed in Table 3.12.

---

[34] See Appendix F for the rapeseed price data summary and the estimation procedures.

Table 3.12

Rapeseed Price Equations

Price Level	Equations and Coefficients	1979	1980	1981
		.........$ per tonne.........		
High	Y = -23 325.472 + 11.948 x	319.610	331.568	343.516
Medium	Y = -23 373 + 11.948 x	272.092	284.040	295.988
Low	Y = -23 420.528 + 11.948 x	224.564	236.512	248.460

3.3 MODEL SUMMARY

The conceptual model formalized in the first section of this chapter sets out the relevant components of the rapeseed flea beetle decision-making model which are analyzed in this thesis. The producer bases the pest control decision on the available inputs of production, the expected level of pest damage and the effectiveness of the available control strategies. Given the producer's subjective evaluation of the pest population and the firm's operating objectives, pest control measures are utilized to optimally reduce crop losses. The control measures tested are the seven insecticide pest control strategies including the option of no control. The effectiveness of these strategies to reduce flea beetle damage is calculated by way of the insecticide dosage response functions. The rapeseed yields resulting from the various flea beetle damage states of nature are estimated for the two species of rapeseed grown in Manitoba.

With probabilities for flea beetle damage states of nature given, as well as the particular control strategy utilized, the cost of insecticide control and rapeseed prices, and the type of rapeseed grown, a decision theoretic pay-off matrix may be used to calculate the producer's expected monetary returns. Given the farm firm's operating objective of profit maximization, a pest control strategy may be chosen to accomplish this. For the purpose of evaluating the sensitivity of the different components of the flea beetle control decision, a range of flea beetle population probability distributions, rapeseed prices, and rapeseed yields resulting from the various insecticide strategies were incorporated into the analysis.

Chapter IV

PRESENTATION AND DISCUSSION OF EMPIRICAL RESULTS

4.1 INTRODUCTION

This chapter presents a summary of the empirical results estimated for the decision model specified in Chapter III. The chapter is divided into three sections. The first section summarizes and illustrates in a decision tree format the components which make up this insecticide decision-making model. The second section is a presentation and discussion of a pay-off table for each of the two species of rapeseed, under comparable price and damage conditions, typifying the results calculated in the analysis. The final section is a summary of the expected net returns computed from the pay-off tables. These expected net return figures represent the results of the sensitivity analyses performed on the various components of the decision model.

4.2 INSECTICIDE DECISION-MAKING MODEL

The components of the insecticide decision-making model are illustrated in a logical decision tree format in Figure 4.1. This decision tree describes, in sequence, the process by which the profit maximizing objective may be attained. Given that rapeseed is to be grown, the primary production decision is the choice between the two species. The decision hinges mainly on the date of seeding.[35] Although experimental

---

[35] See Appendix D for recommended cultural practices of rapeseed.

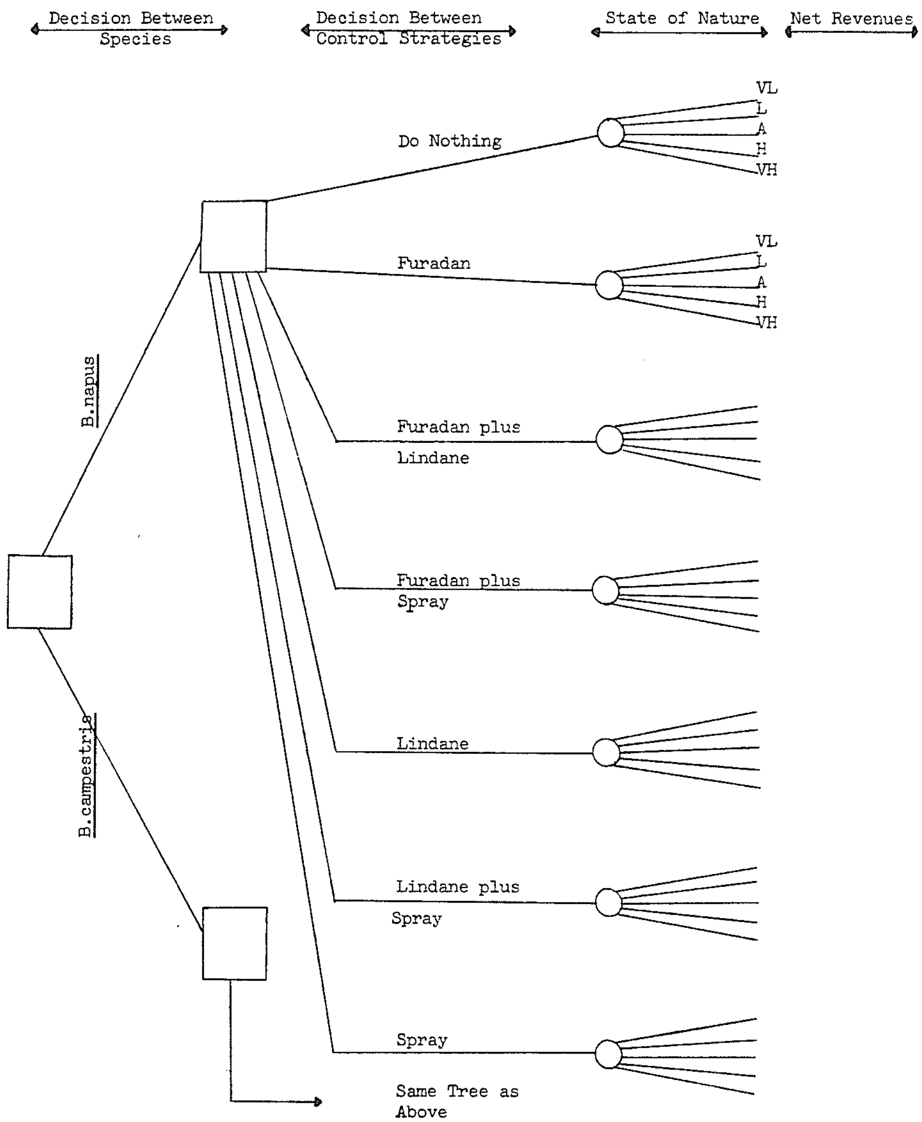

Figure 4.1

Rapeseed Production Decision Tree

results suggest that flea beetles are indifferent between species, the resulting yields are different. For example, the percentage reduction in yield is equivalent for both species under comparable conditions, however, the *B. campestris* varieties yield about one-third less than the *B. napus* varieties. The advantage of *B. campestris* is the fact that it requires fewer days to mature.

The second decision that the producer faces is the choice among the seven alternative flea beetle control strategies. The optimal choice is determined by analyzing the expected returns resulting from the probabilistic states of nature at a given price level. The selection of the optimal control strategy is based on the maximization of expected monetary net returns. There are five main components of this decision process which could affect the final outcome. The factors which may change the choice of the control strategy are: the type of rapeseed grown, chemical prices and application costs, effectiveness of the chemicals used, price of the final product, and the state of nature or damage level present in the system.

The type of rapeseed grown, as discussed earlier, is decided solely on the basis of the number of frost-free growing days remaining at the date of seeding. However, the *B. napus* species of rapeseed has greater yields than the *B. campestris* species, therefore the monetary returns resulting are greater. Although the percentage of the crop lost between rapeseed species is equal for a given state of nature, the monetary returns lost would be proportionately greater for the *B. napus* species. The possibility exists that a different optimal control strategy may be selected for *B. napus* because the expected monetary losses under no control are much greater than the losses suffered by the *B. campestris* species.

Chemical prices and application costs are an important factor in the determination of the optimal control strategy. If costs of a particular strategy increase relative to another equally effective strategy, the optimal profit maximizing strategy would be to select the insecticide which costs the least.

The effectiveness of the insecticide strategies were determined from the respective insecticide dosage response functions at the recommended application rates. Each insecticide's effectiveness was measured in terms of a percentage increase in yield over an untreated plot under comparable damage conditions. Five levels of damage conditions were assumed and rapeseed yields resulting from each insecticide strategy were calculated. Because the calculations were performed as a percentage increase in yield, a starting point was needed for yields obtained from an untreated plot for the assumed states of nature. Since actual yields could not be accurately determined from the available data, two yield ranges were taken for comparative purposes. From these untreated yield ranges, the yields resulting from the various insecticide control strategies were calculated.

Rapeseed yields are important in the decision process because they may be multiplied by a probability of occurrence and the price of the final product to formulate an expected return for each strategy. For example, the application of an insecticide was assumed to result in a particular yield for each of the five possible states of nature. These yields, when multiplied by the probability for the states of nature, result in an expected yield. This figure may then be multiplied by the price of the product less the costs of the chemical and application to give the expected net revenue. This is done for each control strategy and the optimal chosen maximizes the expected net revenue.

The price of the final product was estimated by ordinary least squares regression. Since the price of the product is an important factor in the decision process in terms of the producer's expectations for the future, three price possibilities were given to provide a sensitivity analysis. The optimal control strategies are determined from the expected net revenues resulting from each of the high, medium and low price conditions.

The state of nature probabilities were the most difficult factor to quantify and are the most important component in the formulation of expected net revenues. The entire decision-making process depends upon representative probabilities for an optimal strategy to be selected. If the damage states of nature were known with certainty there would be no need for this type of decision analysis. For example, if the probability of a very low damage state of nature were 100 percent, no insecticide should be used because the flea beetle densities are insufficient to cause a yield reduction. Similarly, a 100 percent probability of a very high damage state of nature indicates that no insecticide should be used because the flea beetle densities are so intense that the crop would be lost at any application rate.

The three states of nature more in line with actual damage conditions are the low, average and high levels of damage. Each state of nature utilizes an insecticide strategy to reduce damage, however, the prediction of a 100 percent probability for a particular state of nature to exist is not plausible. A wide range of cultural, climatic, and environmental conditions affects the flea beetle population dynamics, thus three probability distributions were utilized to provide a sensitivity to the results. Based on historical and subjective information about the probabilities, the three distributions were skewed to the low, average and high damage states of nature, respectively, with the very low and very high levels of damage limited to 5 percent probability of occurrence.

4.3 INSECTICIDE PAY-OFF TABLES

The following is a discussion of the results contained within the insecticide pay-off tables. Representative pay-off tables, one for each species of rapeseed under similar product price and flea beetle damage conditions, are presented.[36] Tables 4.1 and 4.2 contain the revenues per hectare net only, of the flea beetle control costs per hectare attained for *B. napus* and *B. campestris* species of rapeseed under medium price conditions and an average damage distribution.

From these tables, several characteristics exist which are common to the 18 combinations of sensitivity analyses performed on each of the rapeseed species. The 18 combinations were comprised of two yield ranges for each species of rapeseed, three damage state of nature probability distributions, and three price levels. The most significant outcome of the analysis is the ranking of importance of the insecticide control strategies within each table. Under any given price condition, with the

---

[36] See Appendix G for a complete listing of the pay-off table results.

Table 4.1

Pay-Off Table for B. napus with Medium (1981) Price Expectations*
(High Yield Range - Average Damage Skewness)

State of Nature X	Probability of Occurrence P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	580.728	567.064	562.518	562.671	576.182	571.789	576.633
Low	0.25	435.398	508.459	507.465	507.618	478.506	530.647	496.125
Average	0.40	290.364	415.223	413.045	413.198	350.344	383.541	359.970
High	0.25	145.034	287.948	284.586	284.739	228.101	242.355	199.841
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		290.290	392.861	390.446	390.599	345.371	374.809	346.606

*Corresponds to Appendix G, Table G.14.

Table 4.2

Pay-Off Table for B. campestris with Medium (1981) Price Expectations*
(High Yield Range - Average Damage Skewness)

State of Nature X	Probability of Occurrence P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	388.336	374.672	370.126	370.279	383.790	379.397	384.241
Low	0.25	291.252	335.602	333.424	333.577	318.673	351.870	330.667
Average	0.40	194.168	273.148	270.082	270.235	232.836	253.602	239.503
High	0.25	97.084	188.200	184.246	184.399	150.848	159.182	132.355
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		194.168	258.260	255.046	255.199	229.477	247.727	230.564

*Corresponds to Appendix G, Table G.32.

state of nature probability distribution skewed toward low, average or high levels of damage, and both species of rapeseed for two yield ranges there exists no change in the ranking of the pay-offs resulting from the various control strategies. At the very low damage state of nature, the preferred strategy is the do nothing approach with the remaining strategies being ranked lower as costs of application increase. For a low damage state of nature, the lindane plus foliar spray strategy provides the highest return, with the singular application of Furadan granular second, and Furadan in combination with either lindane or a spray resulting in the third highest net return. In both the average and high damage states of nature, the single application of Furadan granular is the preferred strategy, followed secondly by the Furadan in combination with lindane or a foliar spray. The do nothing strategy is again preferred for the very high damage state of nature with the other strategies ranked according to the lower costs of application.

4.4 SUMMARY OF EXPECTED NET RETURN RESULTS

Each pay-off table indicates expected returns net of chemical and application costs for the seven flea beetle control strategies. The expected net returns are summarized from the sensitivity analyses performed on: rapeseed yields, prices and probability of damage distributions. Tables 4.3 and 4.4 refer to the *B. napus* species of rapeseed low and high yield ranges, respectively, while Tables 4.5 and 4.6 correspond to the *B. campestris* species low and high yield ranges, respectively.

Table 4.3

Summary of Expected Revenues Net of Chemical Costs
*B. napus**
(Low Yield Range)

Damage Density Skewness	Price Level	Do Nothing	Furadan	Furadan plus Lindane	Furadan plus Spray	Lindane	Lindane plus Spray	Spray
		Treatments						
		................Returns Net of Chemical Costs: $ per hectare................						
Low Damage Skewness	Low	229.763	293.445	290.614	290.767	265.369	288.108	268.801
	Medium	273.715	352.192	349.688	349.841	317.001	344.929	321.004
	High	317.667	410.939	408.763	408.916	368.633	401.752	373.206
Average Damage Skewness	Low	208.880	278.798	275.818	275.971	247.107	267.188	248.353
	Medium	248.837	334.744	332.062	332.215	295.246	320.007	296.644
	High	288.794	390.689	388.307	388.460	343.384	372.828	344.934
High Damage Skewness	Low	187.972	261.692	258.562	258.715	229.292	246.665	226.165
	Medium	223.930	314.365	311.506	311.659	274.023	295.558	270.212
	High	259.887	367.037	364.450	364.603	318.754	344.453	314.258

*For complete pay-off tables, see Appendix G, Tables G.1-G.9, inclusive.

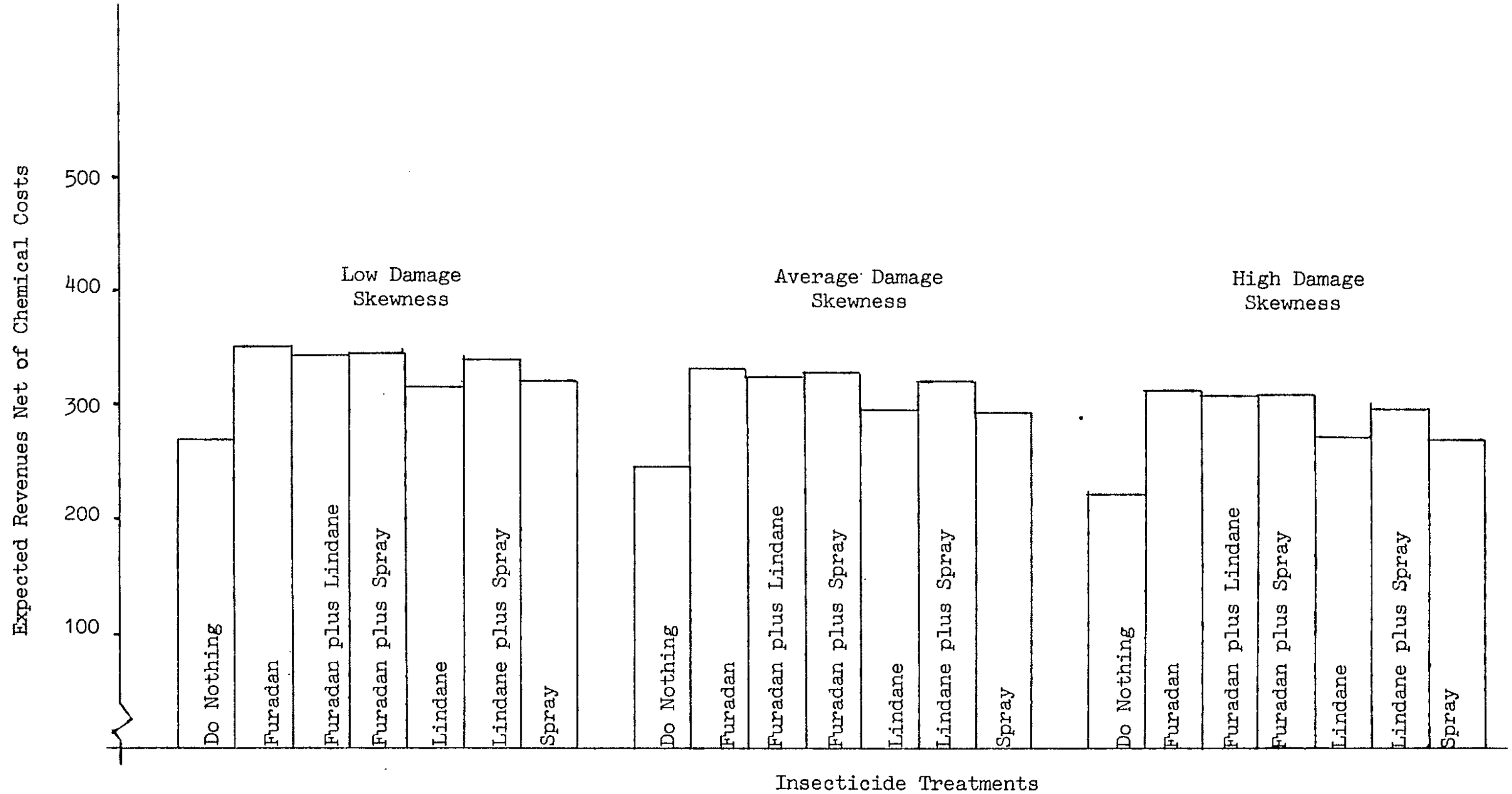

Figure 4.2

B. napus

(Low Yield Range - Medium Price Expectations)

Table 4.4

Summary of Expected Revenues Net of Chemical Costs
B. napus*
(High Yield Range)

Damage Density Skewness	Price Level	Treatments: Do Nothing	Furadan	Furadan plus Lindane	Furadan plus Spray	Lindane	Lindane plus Spray	Spray
		................Returns Net of Chemical Costs: $ per hectare................						
Low	Low	268.039	344.665	342.107	342.260	310.452	337.638	314.157
Damage	Medium	319.312	413.210	411.032	411.185	370.708	403.935	375.036
Skewness	High	370.585	481.755	479.957	480.110	430.964	470.232	435.915
Average	Low	243.677	327.584	324.826	324.979	289.184	313.190	290.293
Damage	Medium	290.290	392.861	390.446	390.599	345.371	374.809	346.606
Skewness	High	336.903	458.138	456.065	456.218	401.559	436.429	402.920
High	Low	219.291	307.645	304.689	304.842	268.413	289.238	264.416
Damage	Medium	261.239	369.108	366.456	366.609	320.627	346.276	315.779
Skewness	High	303.187	430.571	428.223	428.376	372.841	403.315	367.143

*For complete pay-off tables, see Appendix G, Tables G.10–G.18, inclusive.

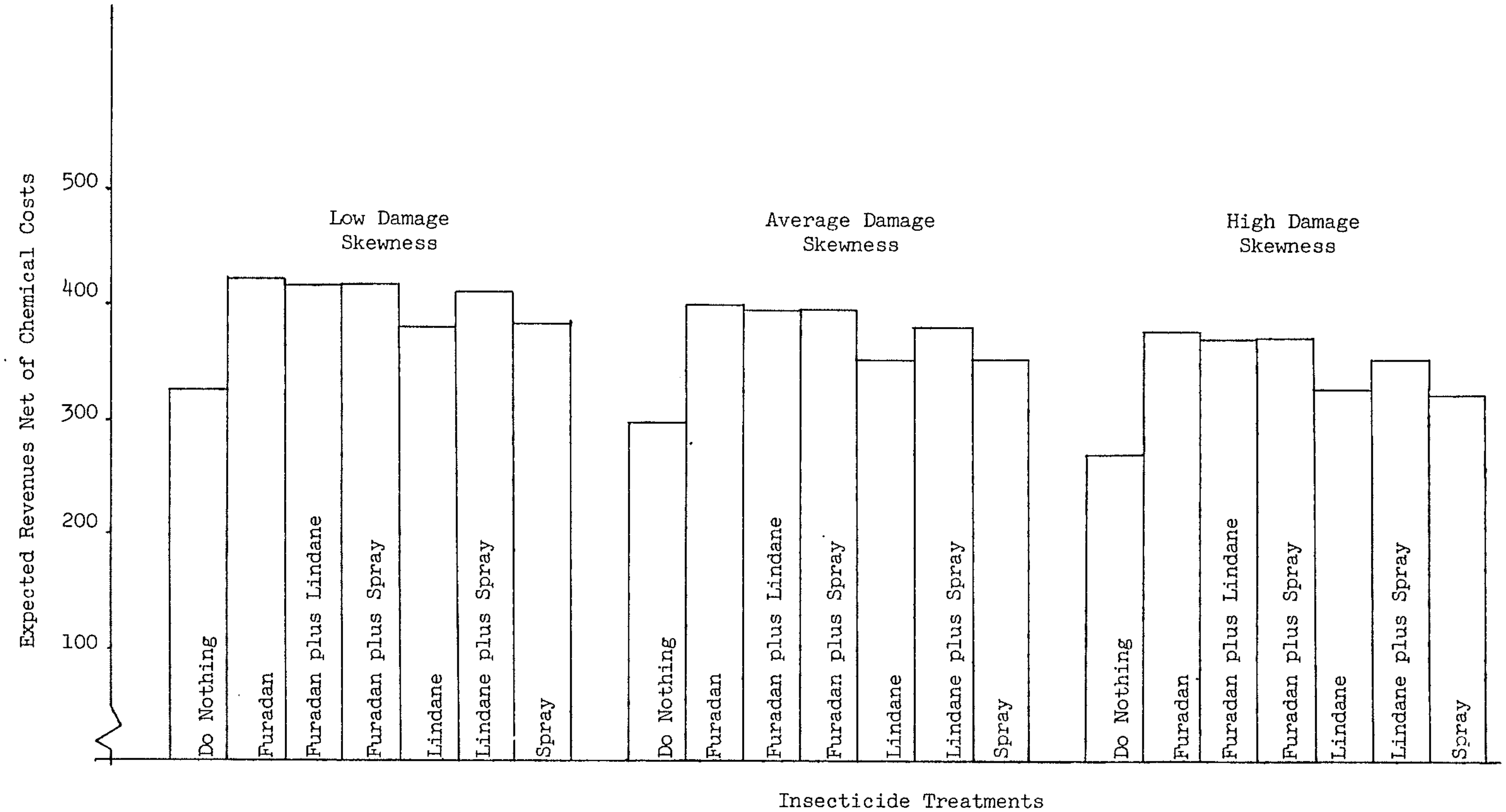

Figure 4.3

B. napus

(High Yield Range - Medium Price Expectations)

Table 4.5

Summary of Expected Revenues Net of Chemical Costs
*B. campestris**
(Low Yield Range)

Damage Density Skewness	Price Level	Treatments: Do Nothing	Furadan	Furadan plus Lindane	Furadan plus Spray	Lindane	Lindane plus Spray	Spray
		................Returns Net of Chemical Costs: $ per hectare................						
Low Damage Skewness	Low	153.648	191.763	188.384	188.537	176.010	189.779	178.399
	Medium	183.039	231.059	227.904	228.057	210.549	227.792	213.308
	High	212.430	270.355	267.423	267.576	245.087	265.805	248.218
Average Damage Skewness	Low	139.697	181.986	178.496	178.649	163.848	175.779	164.721
	Medium	166.419	219.412	216.124	216.277	196.060	211.113	197.014
	High	193.142	256.838	253.752	253.905	228.272	246.448	229.307
High Damage Skewness	Low	125.771	170.644	167.017	167.170	152.009	162.101	149.925
	Medium	149.829	205.900	202.449	202.602	181.956	194.819	179.388
	High	173.888	241.156	237.881	238.034	211.903	227.537	208.851

*For complete pay-off tables, see Appendix G, Tables G.19-G.27, inclusive.

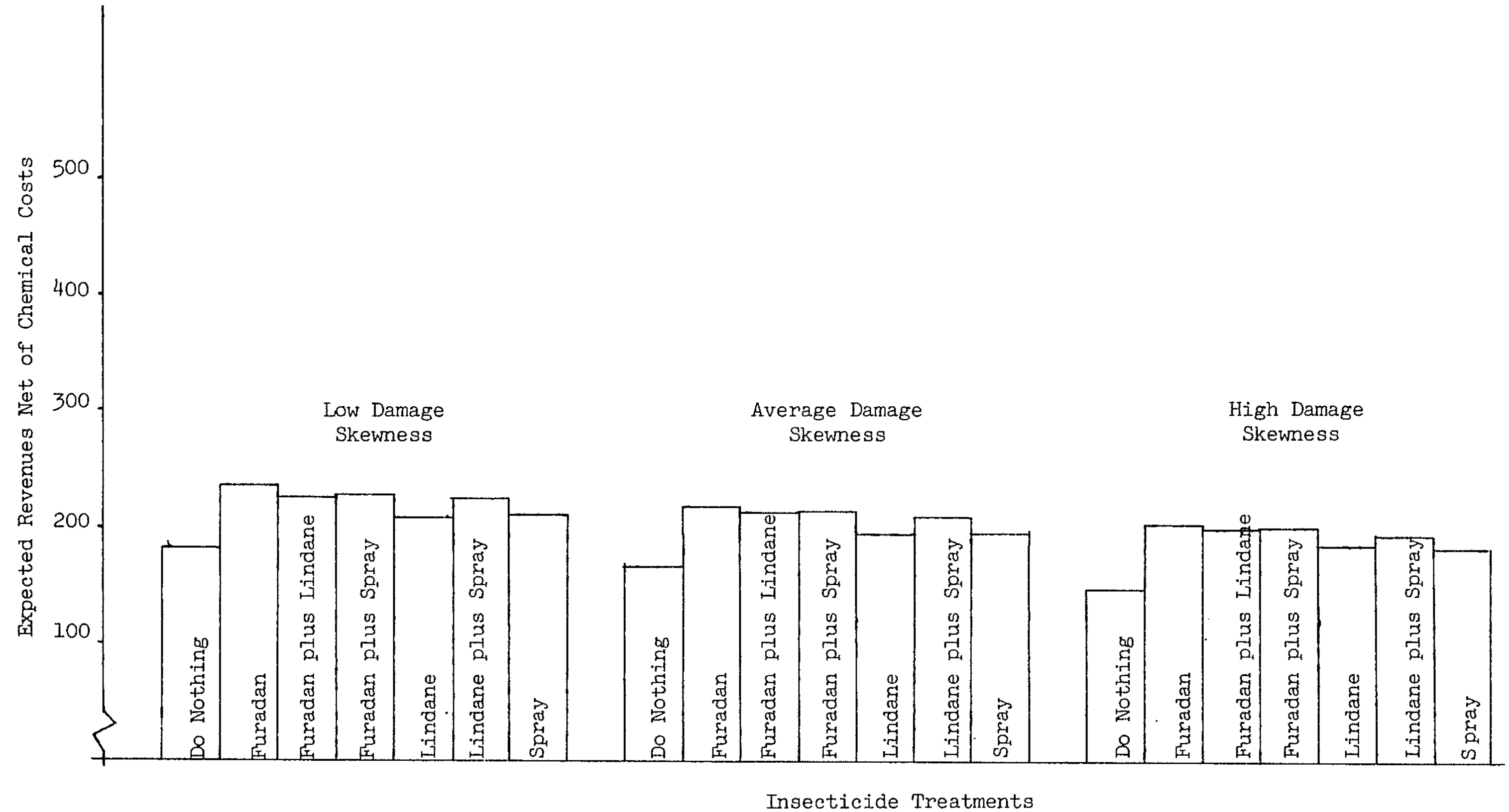

Figure 4.4

B. campestris

(Low Yield Range - Medium Price Expectations)

Table 4.6

Summary of Expected Revenues Net of Chemical Costs
*B. campestris**
(High Yield Range)

Damage Density Skewness	Price Level	Treatments: Do Nothing	Furadan	Furadan plus Lindane	Furadan plus Spray	Lindane	Lindane plus Spray	Spray
		................Returns Net of Chemical Costs: $ per hectare................						
Low Damage Skewness	Low	179.289	226.026	222.746	222.899	206.148	222.849	208.860
	Medium	213.585	271.876	268.839	268.992	246.452	267.188	249.596
	High	247.881	317.726	314.932	315.085	286.755	311.527	290.333
Average Damage Skewness	Low	162.990	214.596	211.168	211.321	191.899	206.513	192.884
	Medium	194.168	258.260	255.046	255.199	229.477	247.727	230.564
	High	225.347	301.924	298.924	299.077	267.055	288.941	268.245
High Damage Skewness	Low	146.691	201.279	197.702	197.855	177.973	190.500	175.567
	Medium	174.751	242.395	239.004	239.157	212.887	228.650	209.934
	High	202.812	283.512	280.306	280.459	247.801	266.801	244.302

*For complete pay-off tables, see Appendix G, Tables G.28–G.36, inclusive.

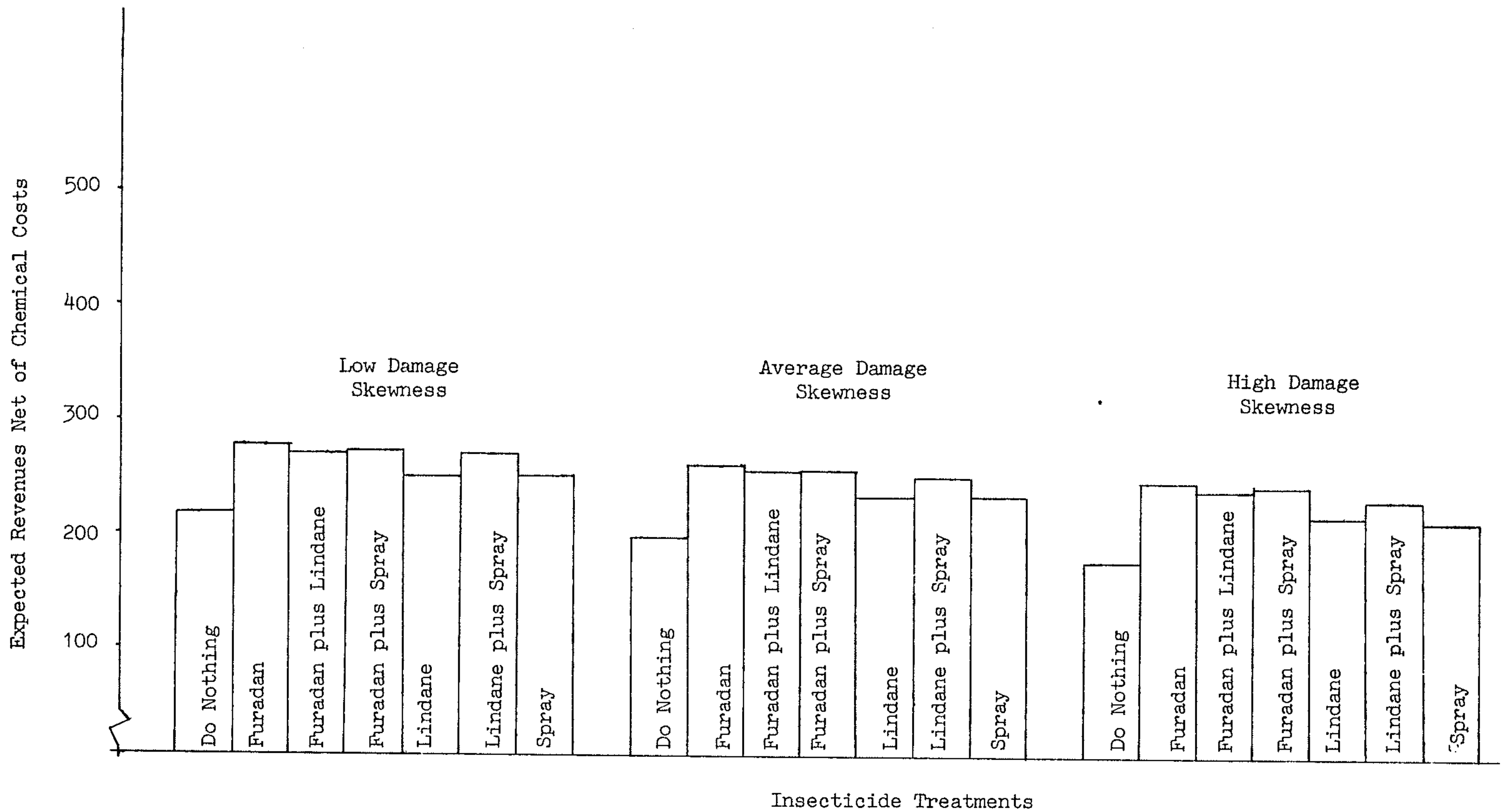

Figure 4.5

B. campestris

(High Yield Range - Medium Price Expectations)

For illustrative purposes there corresponds to each tabled summary of expected net revenue results a set of bar graphs showing for the three levels of damage distribution skewness the expected net revenues resulting at the medium price level. Figures 4.2 and 4.3 refer to the *B. napus* species of rapeseed low and high yield ranges, respectively, while Figures 4.4 and 4.5 refer to the *B. campestris* species of rapeseed low and high yield ranges, respectively.

The major characteristic common to each pay-off table calculated is the ranking of the optimal insecticide strategies. Optimal refers to the strategy which provides the greatest expected net returns. These returns are net only of the insecticide and application costs, ignoring the other costs of production, since these are constant for all control strategies. The optimal strategy for every pay-off table was the Furadan 5 percent in-furrow granular treatment. The remaining strategies are ranked according to the greatest net return. Rapeseed yields were higher with the second ranked Furadan granular in combination with a post-emergence spray, however the additional cost of the spray application was greater than the resulting benefits. A similar outcome was observed for the third ranked Furadan granular and lindane seed treatment combination. The lindane and post-emergence foliar spray combination ranked fourth. The spray by itself ranked fifth with the lindane seed treatment sixth. However, when the probability of damages distribution is skewed toward high damages at any price level, the rankings of the lindane seed treatment and the spray alternatives are reversed. The least desirable, or the strategy which provided the lowest return net of insecticide and application costs, was the do nothing flea beetle control strategy.

Expected net returns resulting from the seven flea beetle control strategies are analyzed for the B. napus varieties of rapeseed are presented in Table 4.3. The sensitivity of the results presented in this table are from the low yield range for the three proposed probability distributions and three rapeseed price levels. For the damage probability distribution skewed toward low damage, under low rapeseed price conditions, the highest expected net return resulted from the single application of Furadan. The expected net return was calculated to be \$293.445 per hectare, which represented a net increase of \$63.682 over the receipts received from the do nothing control strategy for a \$13.664 per hectare insecticide application. This expected net increase in income resulting from the optimal Furadan granular application, as compared with the least desirable do nothing strategy, rose by \$78.477 and \$93.272 per hectare under medium and high price conditions, respectively.

Under conditions where the probability distribution was skewed toward average damage, the expected net returns were less than the returns received under low damage skewness. However, when compared with the do nothing strategy, the benefits received from the optimal application of the Furadan granular insecticide increased. For example, moving from low to medium damage skewness under low price conditions, the expected net return is reduced by \$14.647 to \$278.798 per hectare for the Furadan granular application, but the expected net benefit over the do nothing strategy increased by \$6.236 per hectare. A further reduction in net returns results for the Furadan application under high damage skewness, but the net benefits of the insecticide application increase when compared with the greater losses incurred by the do nothing strategy. The expected net benefits of the Furadan application over the do nothing strategy for high damage skewness, and low, medium and high prices were $73.720, $90.435 and $107.150 per hectare, respectively.

Table 4.4 provides a listing of the expected net return results for the *B. napus* varieties of rapeseed for the high yield range. The expected net returns for Furadan under low, average and high damage skewness are $51.220, $48.786 and $45.953 per hectare greater than at the low yield range and low price conditions. Under medium price conditions, the expected net returns are $61.018, $58.117 and $54.743 per hectare greater for the Furadan strategy for the high yield range. At the high price level, these figures are again increased to $70.816, $67.449 and $63.534 per hectare for the low, average and high damage skewness, respectively.

Furadan, at the low damage skewness and low price level, had an expected net return of $344.665 per hectare which was $76.626 per hectare greater than the do nothing strategy. As the damage probability distribution shifts to the average and high skewness, the expected net returns decrease to $327.584 and $307.645 per hectare, respectively, at the low price level. However, the benefits of the Furadan strategy increase when in comparison to the do nothing strategy. The expected per hectare benefits are $76.626, $83.907 and $88.354 under low price conditions, low, average and high damage distribution skewness, respectively. These benefits increase under medium and high price conditions. For medium prices, the net benefits are $93.898, $102.571 and $107.869 per hectare. Under high price conditions, the net benefits of the Furadan compared with the do nothing strategy increase to $111.170, $121.235 and $127.384 per hectare for low, average and high damage skewness, respectively.

Table 4.5 includes the expected net return summary of the analyses performed on the low yield range of the B. campestris species of rapeseed. For the low, average and high damage skewness and low price conditions, the Furadan expected net returns are $191.763, $181.986 and $170.644 per hectare, respectively. These returns increase to $231.059, $219.412 and $205.900 per hectare for the low, average and high damage skewness, respectively, under medium price conditions. Under high rapeseed prices for the three damage distributions the Furadan expected net returns are $270.355, $256.838 and $241.156 per hectare. The expected net benefits of the Furadan strategy as compared with the do nothing strategy are $38.115, $42.289 and $44.873 per hectare for low, average and high damage skewness at the low price level. These expected net benefits increase to $48.020, $52.993 and $56.071 per hectare for the medium price level. At the high price level, the expected net benefits are $57.925, $63.696 and $67.268 per hectare.

Table 4.6 is the listing of the results calculated from the high yield range of the B. campestris species of rapeseed. The optimal Furadan expected net returns are $226.026, $214.596 and $201.279 per hectare for the low, average and high damage skewness, respectively, for the low price level. These returns increase to $271.876, $258.260 and $242.395 per hectare under the medium price conditions. The highest net returns within each damage distribution skewness was at the high price level. These expected net returns are $317.726, $301.924 and $283.512 per hectare. The expected benefits of the Furadan strategy, as compared with the do nothing strategy, are greater for the high yield range. The benefits increase as the rapeseed price level increases and as the damage level becomes skewed toward high damage. The expected net benefits of the Furadan application for the low price level are \$46.737, \$51.606 and \$54.588 per hectare at the low, average and high damage skewness, respectively. At the medium price level, the expected net benefits are \$58.291, \$64.092 and \$67.644 per hectare. These benefits increase to \$69.845, \$76.577 and \$80.700 per hectare at the high price level.

4.5 SUMMARY AND IMPLICATIONS

The empirical results presented in this chapter resulted from the insecticide decision problem, the components of which were specified in Chapter III. The flea beetle control decision process that the producer faces is illustrated in a decision tree format. The results presented in this chapter are grouped into two sections. The first section is an example of the pay-off tables estimated for each of the two species of rapeseed. These tables are representative of the pay-off tables used to calculate the expected net return results summarized in the second section.

An attempt was made to provide a measure of the cost effectiveness of the various insecticide strategies in terms of a benefit/cost ratio comparison. Although the calculation of the ratio was made for each strategy, the comparisons between strategies were not valid. The limitation which affected the validity was the use of the insecticides at the provincially recommended application rates. These recommended rates were set as a function of the biological responsiveness of the insecticides.

The limitation invalidated the premise that the strategy that maximized the benefit/cost ratio, or the net returns per dollar invested, also maximized net returns possible for the same area of land. For example, the benefit/cost ratio for one strategy may be greatest for the strategy that has a less than optimal expected net return, because the insecticide may not be applied at rates greater than recommended. Therefore, an upper limit is set for the return expected. It is not known if the benefit/cost ratio holds true for multiple applications of the insecticide. It would perhaps be useful to consider insecticide strategies at which equal costs may be incurred, so comparison of the benefit/cost ratios between strategies would not be impaired by the recommended rate. However, the recommended rates were set for other than economic considerations, and social and environmental costs may be more important at greater than recommended rates. It is in the producer's best interest to maximize his net return per area planted rather than per dollar invested as measured by a benefit/cost ratio, because of the upper limit of the number of dollars that may be invested per area on certain insecticides.

The implications of this analysis suggest that based on the plot data, rapeseed prices and flea beetle probability of damage distributions utilized, the optimization of producer returns occurs when the Furadan 5 percent in-furrow granular insecticide is used. However, with better information concerning the nature of the flea beetle population, it is plausible that the probability of damage distributions could be revised. For instance, as the probability of a population approaches 100 percent, different control strategies would be implemented to maximize expected net returns. Under very low and very high damage conditions, no insecticide would be advised. At low damage conditions, lindane in combination with foliar spray would maximize returns. Furadan granular would be recommended for the average and high damage conditions.

Chapter V

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The problem studied in this thesis is the economic evaluation of the effectiveness of available flea beetle control strategies. Three main objectives were defined in stating the problem. The objectives were: to review the pertinent theories of insecticide use, to estimate rapeseed yield responses resulting from particular insecticide strategies by analyzing the available experimental plot data, and finally, to incorporate the above information into a form by which an insecticide strategy may be optimally chosen under various price and damage condition estimates to maximize expected net returns. The following chapter is a summary of the theoretical basis for optimal insecticide use and the methodology which was utilized to estimate the expected net returns. Limitations of the analysis and results, as well as implications for further research are also discussed.

To fulfill the objective of reviewing the theories of insecticide use which apply to evaluating the effectiveness of control of flea beetles on rapeseed, a wide variety of articles were examined. The literature review covered the theories of insecticide use from three perspectives. The first regarded the classical economic optimality conditions for efficient resource use as the basis of analysis. Imperfect knowledge surrounding the use of insecticides was recognized in the second perspective as an important consideration, and was included in analyzing producer planning decisions. Given the uncertainties of pest control, the final perspective is the presentation of the possibilities that insurance and information services would perhaps reduce unnecessary insecticide applications to attain a socially preferred level of insecticide use while maintaining the private optima. The private optimality considerations are that a producer would likely reduce insecticide use given a certainty alternative which would make him no worse off.

Classical production theory describes the conditions for optimal insecticide use under conditions of certainty. When considering additional successive increments of an input to the production process, holding all other inputs constant, optimal input usage occurs at the point where the value of the marginal product for the last unit of input added is equivalent to the price or marginal cost of that input. The applications to optimal pesticide use were investigated by several people. Hillebrandt defined the concept of a dosage response function which illustrates the crop yield that results from various rates of a pesticide application. Dosage response functions could be estimated for a particular level of pest infestation with the optimal dosage determined by the slope of the dosage response function tangent to the slope of an output price-input cost relationship. This price-cost relationship is determined by a number of factors. Hillebrandt investigated the possibilities of increasing and decreasing cost functions, and their effect on optimal pesticide rates.

Headley utilized cross sectional data to determine if the use of pesticides in agricultural production differed from the theoretical economic optimum. The conclusion was reached that, on average, a $4 marginal value product results from a $1 outlay for the pesticide inputs. Although the results of the analysis are in 1963 terms, Headley's explanation for the imbalance in the pesticide market is still relevant. The imbalance is suggested to be the primary cause of the large increases in demand for effective chemicals for agricultural pest control. The demand stems from producers who are adopting technological innovations to maximize net returns.

Headley, in later research, defined in economic terms the concept of a threshold pest population. It is this pest population at which the cost of control is equivalent to the benefits. The threshold is dependent upon three variables: value of crop damage, level of pest population, and time. These variables are in turn functions of: the ability of the crop to withstand damage, the growth of the pest population, and the effect that the pest has on the crop. The pest population defined in economic threshold is also the desired level of pest population. Control of pest densities to levels less than the desired level requires a cost marginally greater than the marginal revenue received from the crop saved. Also, if pest densities are controlled to levels greater than optimal, the revenue lost is greater than the cost savings.

The economic threshold pest population was redefined by Hall and Norgaard and included the concept of timing of the pesticide application as a determinant in optimal pest management. The timing of application is described as being independent of crop prices and chemical costs. The price-cost relationship affects only the rate of pesticide application. The timing of application is defined from the biological interaction of the crop-pest-pesticide relationship. The major variables affecting this relationship are the response of the pesticide on the pest population and the growth rate of the population.

In the second perspective, as utilized by Carlson, the assumption of perfect knowledge in the production process is relaxed. A decision theoretic approach to pest management was utilized to incorporate the uncertainties of production to attain the goal of profit or utility maximization. With decision theory, each of the relevant components of the problem is identified. All possible actions or pest control alternatives are listed as are the outcomes that result for each state of nature or unknown level of pest damage. The states of nature when put into probabilistic terms are utilized to formulate expected net revenue or utility figures for each pest control strategy. The probabilities are subjective and are often historically inaccurate, but are representative of the particular pest density situation. The subjective probability distribution may be updated with the use of Bayes's theorem and current forecast information to formulate a posterior probability distribution. The strategy chosen maximizes either expected returns net of chemical and application costs or some utility measure of the returns. The utility measure may be used to account for producer's level of risk aversion in the pest control decision process.

The third perspective taken in the literature review was the use of insurance alternatives and information services to reduce the uncertainties surrounding the pest control decision process. The premise made by Miranowski, et al., was that by reducing uncertainty, the level of insecticides used would decrease. Two possibilities were presented for reducing the uncertainties of pest control. Insurance alternatives and information services were analyzed in terms of effectiveness, cost to the public, and the level of acceptance by the target group of producers. In this study, it was suggested that low cost specific-risk insurance would cause a reduction in the number of unnecessary applications which were previously used for self-insurance purposes. Information services were also suggested to reduce unnecessary pesticide applications by providing an increased level of awareness about the actual damage conditions. Simulations were performed to analyze the effect of accepting a pest control alternative. Producers were categorized as either informed or uninformed, defining whether or not insecticide applications were carried out at economic threshold levels. Seven insurance alternatives were presented to producers at varying premium subsidy levels. It was concluded that the insurance policy alternatives would reduce insecticide use, but only under very high subsidy levels. The level of reduction of insecticide use differed widely depending on the type of producer, the particular policy, and the level of subsidy. The informed producer would be willing to utilize insurance at subsidy levels over 50 percent, however, some policies resulted in no reduction of insecticide use. The uninformed producers were inflexible and slight reductions in insecticide use occur only at 100 percent subsidy levels. The conclusion was reached by Miranowski, et al., that information services were superior to the insurance alternatives in terms of public cost effectiveness in reducing insecticide use. For a $3 per acre cost, the potential for a 30 percent reduction in insecticide use occurred for the informed producer. The information services would be readily accepted if the potential benefits were communicated to the producers.

The methodology used in this thesis to evaluate the effectiveness of the various flea beetle control strategies was directly related to the first two perspectives of the literature reviewed. Within a certainty context, the fulfillment of the objective of interpolating the available test plot data into economic terms, the concept for dosage response functions as defined by Hillebrandt, was used. The second perspective of the economics of pest control, as employed by Carlson, provided a framework by which expected returns could be maximized under conditions of uncertainty in the production process. The third perspective was considered in this analysis in the sense that through improved information about the crop-pest-pesticide relationship, an optimal pest management strategy may be attained. This need for improved information is indicated in the suggestions for further research.

Dosage response functions that were estimated for the various beetle control strategies relate to the crop yield resulting from an insecticide application. The dosage response functions, similar to a standard production function, were estimated by varying the rate of insecticide application holding all other inputs constant using experimental plot data. Functions were estimated under three different damage conditions with two others being assumed. For example, a curve was estimated for each insecticide using combined cross sectional and time series plot data. This curve was defined as the insecticide dosage response function relating to average damage conditions. The term damage condition refers to a particular combination of insect damage, climatic, environmental and cultural conditions, defined in this analysis as the prevailing damage state of nature. The state of nature varies from year to year, therefore dosage response functions were also estimated for high and low states of nature. The two assumed dosage response functions relate to very low and very high damage states of nature. Very low damage conditions refer to an insignificant population of flea beetles which would not affect rapeseed yields, while at very high damage conditions, no amount of insecticide applied could offset the total destruction of the crop.

Percentage increases in yield resulting from an insecticide treatment over an untreated plot were taken from the dosage response functions at the most widely used application rate for each insecticide. The rates, in most instances, correspond to the recommended application rate. For insecticide combinations, the percent increase in yield calculations utilized yield responses from inferred dosage response functions. The functions were inferred in the sense that the results from one plot experiment were used to determine the percent additions to yield over the single insecticide treatment.

As the level of pest infestation increases from low to high damage states of nature, the percent change in yield over a control plot resulting from an insecticide treatment also increases. These percentage increases in yield were determined for low, average and high damage conditions for each control strategy, holding the application rates constant. For the very low and very high damage conditions, it was assumed that no change in yield would result from an insecticide treatment.

The performance of the control strategies, in terms of yield responses, differed slightly as the level of damage increased. Under low conditions, the lindane and spray combination provided the greatest percentage increase in yield over an untreated plot. Furadan in combination with either a lindane seed treatment or a post-emergence foliar spray was estimated to provide the highest percentage increases in yield for average and high damage conditions. However, the Furadan as a single treatment increased yields almost to the levels provided by the lindane or spray combinations.

Three probability distributions for damage conditions were postulated to provide a sensitivity of flea beetle density expectations. The distributions are subjective in nature because the historical flea beetle population surveys are not readily amenable to objective probabilistic assessment. Also, the rapeseed damage caused by flea beetles may be accentuated or reduced by a combination of cultural and environmental factors. In this study, a range of flea beetle damage states of nature, or the populations of flea beetles in combination with other influential factors is assumed with five graduations from very low to very high damage. The estimated distributions are also assumed to be representative of the producer's subjective assessment of the damage conditions, independent of the control strategy utilized.

Since the actual flea beetle densities are ambiguous, in terms of the damage caused, the resulting yields of the two species of rapeseed were assumed to be given by the prevailing state of nature. For completeness, two ranges of rapeseed yields were used for each species. Each range had five graduations from very low to very high yields resulting from very high to very low levels of damage, respectively. These yields were assumed to be representative of the yields obtained under no flea beetle control. Given a particular control strategy, the yields were adjusted by the percentage increase in yield calculated by the respective dosage response function and damage state of nature.

The rapeseed prices and chemical costs used were in 1981 terms. The rapeseed prices were determined by linear regression on annual data for the past 20 years. Sensitivity analysis of the price results was provided by estimating high and low prices. These prices were derived by taking a one standard deviation interval on either side of the estimated average price line.

The components of the decision problem outlined above are combined in a decision-theoretic framework as in the second perspective of the literature review. To fulfill the final objective of evaluating in economic terms, the alternative flea beetle control strategies, private costs and returns of treatments were incorporated in pay-off tables. Five damage states of nature were assumed for the seven control strategies studied. Percentage increase in yields over the untreated strategy were determined from the estimated insecticide dosage response functions. For completeness and comparative purposes, two possible yield ranges were taken for both species of rapeseed. The net returns were calculated for three rapeseed price levels less only the insecticide and application costs. To calculate net return expectations for each insecticide strategy, a damage probability distribution was used. The basis for the selection of the optimal insecticide strategy was the maximization of expected net returns.

5.2 CONCLUSIONS AND LIMITATIONS

The results of the sensitivity analyses performed on the pay-off tables, in terms of the assumed probability of damage distributions and rapeseed price levels, indicate that the Furadan 5 percent granular in-furrow strategy provided the highest expected net returns. Higher yields or a greater level of insecticide effectiveness results from the Furadan in combination with a post-emergence spray or a lindane seed treatment. However, the additional cost associated with the spray and lindane application ranked these strategies second and third, respectively. The lindane and spray combination would be the preferred strategy given a certainty expectation of low flea beetle damage, however given the probabilities used in this analysis, the strategy is ranked fourth. The spray by itself ranked fifth with the lindane seed treatment sixth. However, when the probability of damages distribution is skewed toward high damages, the lindane seed treatment provides a slightly better return than the spray. The least desirable strategy, in terms of expected net returns, was the do nothing strategy, however it would be preferred given the certainty expectation of very low or very high damage conditions.

The results calculated based on plot data coincide with the control strategy rankings determined from the survey, as presented in Appendix A. The average provincial rapeseed yield as determined from the survey results was 20.2 bushels per acre. Furadan granular yielded 24.4 bushels per acre while the lindane seed treatments yielded 21.0 bushels per acre. The do nothing control strategy with ten sample observations yielded only 10.6 bushels per acre.

Within the range and scope of this analysis, the price of rapeseed component of the decision model was found to be an insignificant factor in influencing the insecticide use patterns on rapeseed. The analysis performed on the three 1981 rapeseed price estimates showed that the ranking of the expected net returns resulting from the various control strategies remained unchanged. Also, the three probability of damage distributions utilized failed to change the optimal strategy. Although the expected net return values decreased as the damage probability distribution was skewed toward higher damage, the reduction had no effect on the optimal choice.

To fulfill the objectives set out in Chapter I, several assumptions were made which may impose some limitations on the interpretation of the results. From the primary plot data that was used to estimate the dosage response functions, yield inferences were made to the less controlled conditions present in a producer's field. To provide enough of a range of insecticide application rates for curve estimation, cross sectional and time series data were pooled and aggregated. A large variation in the yields occur within each insecticide studied for reasons other than flea beetle damage. The damage inflicted upon the rapeseed crop by flea beetles may be exaggerated by environmental and cultural conditions. Because these external factors could not be excluded even on a plot basis, the concept of damage conditions was assumed to incorporate the variation in yields. Five levels of damage conditions were assumed from very low to very high and were referred to as states of nature. From the damage state of nature, of which flea beetle densities are a part, a particular yield of rapeseed results. The yields differed because of the characteristics of the species grown and the areas that they are grown in. A range of rapeseed yields was assumed under conditions of no insecticide control. The percentage increases in yield as determined by the dosage response functions for the various control strategies under the different damage states of nature were added to the assumed yield range.

The calculation of expected net returns required the estimation of a probability of damage distribution. The distribution was constructed by combining historical and subjective evaluations of the pest situation. A choice of three levels of skewness for the probability distribution enabled a sensitivity analysis of the results. The estimated damage distributions may be found unrepresentative, given further research into the quantification of the probabilistic flea beetle damage expectations. However, although it would be useful to calculate the actual distribution, the change would have to be drastic before any variation in the ranking of the optimal strategies occurred.

5.3 SUGGESTIONS FOR FURTHER RESEARCH

It would be useful to have updated information dealing with actual flea beetle conditions. Information, as concluded by Miranowski, et al., reduced unnecessary insecticide applications due to the uncertainties concerning pest control. Information could also promote the use of an optmal pest management strategy. With the cost of insecticide treatments being low relative to the potential benefits, and the variation in those returns among the alternative control strategies, an increased level of awareness would be beneficial to the producers. The survey indicated indicated that 74 percent of the Manitoba producers used insecticides to control for flea beetles. Of these producers only 45 percent used the strategy ranked first by this analysis. This low acceptance by producers could perhaps be overcome if the potential benefits were publicized. Information updates would be useful in formulating posterior damage distributions, as done by Carlson using Bayes's theorem. A model for forecasting flea beetle densities based on past populations, cultural and environmental conditions would be useful for incorporation into producer planning decisions.

In this analysis, the dosage response functions for each insecticide were estimated utilizing experimental plot data at application rates near to the recommended rates. The accuracy of the curves outside the range of the data is questionable and it would be useful to see what happens to yields at application rates greatly different than recommended. Experiments performed at these rates would test the accuracy of the estimated functions. In this thesis, recommendations were made for actual fields from data calculated from experimental plots. Measurement of insecticide effectiveness on commercial fields would enable us to determine whether the economic analyses performed are sufficiently realistic.

Because of the toxicity and persistence of the insecticides used, further research into the potential health hazards and negative environmental effects would give more meaning to the costs of application reported in this thesis. The costs reported in this thesis were in private terms, but for completeness, negative externality effects should be included in the determination of an optimal pest control strategy.

BIBLIOGRAPHY

Agrawal, R.C. and E.O. Headley. "Applications of Game Theory in Agriculture," Journal of Agricultural Economics. Vol. 19, No. 2, May 1968.

Agricultural Institute of Canada. "Pesticides, Agriculture and the Environment," Agronews. January 1981.

Anderson, Jock R. "Risk Efficiency in the Interpretation of Agricultural Production Research," Review of Marketing and Agricultural Economics. Vol. 42, No. 3, September 1974.

________, John L. Dillion and Brian Hardaker. Agricultural Decision Analysis. Ames, Iowa: The Iowa State University Press, 1977.

Bauer, L. "Risk and Uncertainty: How to Handle in Planning and Practice." Paper presented to the Farm Management and Agricultural Appraisal 1978 Proceedings, in cooperation with the Agricultural Institute of Canada Annual Conference, Regina, Saskatchewan, July 1978.

Bullen, F.T. "Benefit/Cost Analysis of Various Degrees of Crop Protection," Proceedings of the Ecology Society of Australia. Vol. 5, 1970.

Burgess, L., J. Dueck, G.A. Petrie and L.G. Putnam. Insect Pests and Diseases of Rape and Mustard. Vancouver, British Columbia: Rapeseed Association of Canada, No. 48, November 1977.

________. "Flea Beetles (Coleoptera: Chrysomelidae) Attacking Rape Crops in the Canadian Prairie Provinces," Canadian Entomologist. Vol. 109, No.1, January 1977.

Buse, Rueben C. and Daniel W. Bromeley. Applied Economics: Resource Allocation in Rural America. Ames, Iowa: Iowa State University Press, 1975.

Cammell, M.E. and M.J. Way. "Economics of Forecasting for Chemical Control of the Black Bean Aphid, Aphis Fabae, on the Field Bean, Vicia Faba," Annals of Applied Biology. Vol. 85, No. 3, April 1977.

Campbell, Harry F. "Estimating the Marginal Productivity of Agricultural Pesticides: The Case of the Tree-Fruit Farms in the Okanagan Valley," Canadian Journal of Agricultural Economics. Vol. 24, No. 2, July 1976.

Canada Department of Agriculture. Pesticide Research Report. Compiled annually by the Expert Committee on Pesticide Use in Agriculture, 1967-1979, inclusive.

Canada Grains Council. Canadian Grains Industry: Statistical Handbook 80. Winnipeg, Manitoba, 1980.

Carlson, Gerald A. "A Decision Theoretic Approach to Crop Disease Prediction and Control," American Journal of Agricultural Economics. Vol. 52, No. 2, May 1970.

________. "Insurance, Information, and Organizational Options in Pest Management," Annual Review of Phytopathology. Vol. 17, 1979.

________. "Economic and Biological Variables Affecting Demand for Publicly and Privately Provided Pest Information." Paper presented at the American Agricultural Economics Association Annual Meeting, University of Illinois, Urbana-Champaign, Illinois, July 27-30, 1980.

________ and C.E. Main. "Economics of Disease-Loss Management," Annual Review of Phytopathology. Vol. 14, 1976.

Cochran, Mark. "Selection of Optimal Pest Management Strategies Under Uncertainties: A Study in Apple Production." An unpublished mimeo, 1980.

Croft, Brian A. "Potentials for Research and Implementation of Integrated Pest Management on Deciduous Tree-Fruits" in Pest Control Strategies. Edward H. Smith and David Pimental (editors), New York: Academic Press, 1978.

Daniel, Wayne W. Applied Nonparametric Statistics. Boston: Houghton Mifflin Company, 1978.

Dillion, John L. and R.R. Officer. "Economic vs. Statistical Significance in Agricultural Research and Extension: A Pro-Bayesian View," Farm Economist. Vol. 12, No. 1, 1971.

Ehrlich, Isaac and Gary S. Becker. "Market Insurance, Self-Insurance and Self-Protection," Journal of Political Economy. Vol. 80, No. 4, July/August 1972.

The Faculty of Agriculture. Principles and Practices of Commercial Farming. Fourth and Fifth Editions, Winnipeg, Manitoba: The University of Manitoba, 1974 and 1977.

Feder, Gershon. "Pesticides, Information, and Pest Management Under Uncertainty," American Journal of Agricultural Economics. Vol. 61, No. 1, February 1979.

Fischer, Lewis A. "Some Economics of Pest Control in Agriculture," Canadian Journal of Agricultural Economics. Vol. 16, No. 2, June 1968.

Framingham, C.F. and Associates. "1980 Cost of Soybean Production Study for Manitoba." University of Manitoba, Department of Agricultural Economics and Farm Management, Winnipeg, Manitoba, 1980.

Hall, Darwin C. "The Profitability of Integrated Pest Management: Case Studies for Cotton and Citrus in the San Joaquin Valley," Bulletin of the Entomological Society of America. Vol. 23, No. 4, December 1977.

________ and Richard B. Norgaard. "On the Timing and Application of Pesticides," American Journal of Agricultural Economics. Vol. 55, No. 2, May 1973.

Hanemann, W. Michael and Richard L. Farnsworth. "Risk Preference and Perceptions in the Use of I.P.M." Working Paper No. 81, California Agricultural Experiment Station, Giannini Foundation of Agricultural Economics, March 1980.

Halter, Albert N. and Gerald W. Dean. Decisions Under Uncertainty: With Research Applications. Cincinnati: South-Western Publishing Co., 1971.

Headley, J.C. "Estimating the Productivity of Agricultural Pesticides," American Journal of Agricultural Economics. Vol. 50, No. 1, February 1968.

________. "Defining the Economic Threshold" in Pest Control Strategies for the Future. Washington, D.C.: National Academy of Sciences, 1972.

________. "The Economics of Pest Management" in Introduction to Insect Pest Management. R.L. Metcalfe and W.H. Luckman (editors), New York: John Wiley, 1975.

________. "The Economics of Pest Management by Individual Growers," Iowa State Journal of Research. Vol. 49, No. 4, May 1975.

________. "Economics of Pest Control: Have Priorities Changed?" Farm Chemicals. Vol. 142, No. 2, April 1979.

Heady, Earl O. Economics of Agricultural Production and Resource Use. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965.

Hillebrandt, Patricia M. "The Economic Theory of the Use of Pesticides, Part I," Journal of Agricultural Economics. Vol. 13, No. 4, January 1960.

________. "The Economic Theory of the Use of Pesticides, Part II, Uncertainty," Journal of Agricultural Economics. Vol. 14, No. 1, June 1960.

Johnston, S.J. Econometric Methods. Second Edition, New York: McGraw-Hill Book Company, 1972.

Kennedy, J.S. "The Motivation of Integrated Control," The Journal of Applied Ecology. Vol. 5, 1968.

Koutsoyiannis, A. Theory of Econometrics. Second Edition, London: The MacMillan Press Ltd., 1978.

Lamb, R.J. "Biological Considerations for an Economic Analysis of Insect Pest Management in Rape." Winnipeg, Manitoba: Canada Department of Agriculture, December 1979 (mimeographed).

________. "Hairs Protect Pods of Mustard (Brassica Hirta 'Gisilba') From Flea Beetle Feeding Damage," Canadian Journal of Plant Science. Vol. 60, No. 4, October 1980.

Layard, P.R.G. and A.A. Walters. Micro-Economic Theory. New York: McGraw-Hill Book Company, 1978.

Longworth, J.W. and D. Rudd. "Plant Pesticide Economics and Special Reference to Cotton Insecticides," Australian Journal of Agricultural Economics. Vol. 19, No. 3, December 1975.

Manitoba Department of Agriculture. Manitoba Agriculture Yearbook. Winnipeg, Manitoba, 1978 and 1979.

________. Rapeseed '80. An eight lesson course adapted by the Manitoba Department of Agriculture, produced by the Alberta Department of Agriculture, and presented to western Canadian rapeseed producers, Winnipeg, Manitoba, 1980.

________, Entomology Section. Insecticide Handbook: For Manitoba Pesticide Dealers and Applicators. Winnipeg, Manitoba, 1980.

________, Technical Services Branch. 1980 and 1981 Manitoba Insect Control Guide. Winnipeg, Manitoba.

Martin, Marshall A., Christopher A. Cashman and Bruce A. McCarl. "Economic Impacts of Restrictions on Selected Soybean Insecticides: An Analysis of a Typical Indiana Farm." A paper submitted for consideration as a selected paper for the 1980 American Agricultural Economics Association meetings, University of Illinois, Urbana-Champaign, Illinois, July 27-30, 1980.

Miranowski, John A., Ulrich F.W. Ernst and Francis H. Cummings. "Crop Insurance and Information Services to Control Use of Pesticides." Washington, D.C.: Environmental Protection Agency, EPA-600/5-74-018, September 1974.

National Research Council Committee on Plant and Animal Pests. Principles of Plant and Animal Pest Control, Volume 3: Insect-Pest Management and Control. Washington, D.C.: National Academy of Sciences, Publication 1965, 1969.

Newton, Carlton M. and William A. Leuschner. "Recognition of Risk and Utility in Pest Management Decisions," Entomological Society of America Bulletin. Vol. 21, No. 3, 1975.

Norgaard, Richard B. "Integrating Economics and Pest Management" in Integrated Pest Management. J.L. Apple and R.F. Smith (editors), New York: Plenum Press, 1976.

Norton, G.A. "Analysis of Decision-Making in Crop Protection," Agro-Ecosystems. Vol. 3, No. 1, August 1976.

Osgood, C.E. "Damage Assessment as Part of Flea Beetle Management on Rape," Proceedings of the Twenty-Second Annual Meeting: Agricultural Pesticide Society. Brandon, Manitoba, June 23-25, 1975.

Pimental, David and John H. Perkins (editors). Pest Control: Cultural and Environmental Aspects. Boulder, Colorado: Westview Press, 1980.

Putnam, L.G. "Insect Pests of Brassica Seed Crops and Flax: Economics and Control" in Oilseed and Pulse Crops in Western Canada - A Symposium. J.T. Harapiak (editor), Calgary, Alberta: Western Cooperative Fertilizers Ltd., 1975.

________. "Response of Four Brassica Seed Crop Species to Attack by the Crucifer Flea Beetle, Phyllotreta Cruciferae," Canadian Journal of Plant Science. Vol. 57, No. 3, July 1977.

Raiffa, Howard. Decision Analysis: Introductory Lectures on Choices Under Uncertainty. Reading, Massachusetts: Addison-Wesley Publishing Company, 1970.

Reichelderfer, Katherine H. "A Simulative Approach to the Comparison of Alternative Methods for the Control of Mexican Bean Beetles on Soybeans." Unpublished doctoral dissertation, College Park: University of Maryland, 1977.

________. "Economics of Integrated Pest Management: Discussion," American Journal of Agricultural Economics. Vol. 63, No. 5, December 1980.

________ and Filmore E. Bender. A Simulative Approach to Controlling Mexican Bean Beetle on Soybeans in Maryland. College Park, Maryland: Maryland Agricultural Experiment Station, No. 935, October 1978.

________. "Application of a Simulative Approach to Evaluating Alternative Methods for the Control of Agricultural Pests," American Journal of Agricultural Economics. Vol. 61, No. 2, May 1979.

Ruesink, William G. "Economics of Integrated Pest Management: Discussion - An Entomologist's View of I.P.M. Research Needs," American Journal of Agricultural Economics. Vol. 62, No. 5, December 1980.

Saskatchewan Department of Agriculture, Plant Industry Branch. "List of Seed Treatment Products for Use on Cereal and Oilseeds." Regina, Saskatchewan, 1980.

Schlaiffer, Robert. *Analysis of Decisions Under Uncertainty*. New York: McGraw-Hill Book Company, 1969.

Shoemaker, Christine A. "Pest Management Models of Crop Ecosystems" in *Ecosystem Modeling in Theory and Practice: An Introduction with Case Histories*. Charles A.S. Hall and John W. Day, Jr. (editors), New York: John Wiley and Sons, 1977.

Slovic, Paul, Howard Kunreuther and Gilbert F. White. "Decision Processes, Rationality, and Adjustment to Natural Hazards" in *Natural Hazards: Local, National, Global*. G.F. White (editor), London: Oxford University Press, 1974.

Smith, Ray F. "Economic Aspects of Pest Control," *Proceedings of the Tall Timbers Conference on Ecological Animal Control by Habitat Management*. No. 3, 1971.

________. "Pesticides: Their Use and Limitations in Pest Management" in *Insect Pest Management: Readings*. Merle Shepard (editor), New York: MSS Information Corporation, 1973.

Southwood, T.R.E. and G.A. Norton. "Economic Aspects of Pest Management Strategies and Decisions" in *Insects: Studies in Population Management*. P.W. Geier, L.R. Clark, D.J. Anderson and H.A. Nix (editors), Canberra: Ecological Society of Australia, 1973.

Spur, William A. and Charles P. Bonini. *Statistical Analysis for Business Decisions*. Homewood, Illinois: Richard D. Irwin, Inc., 1973.

Steel, Robert G.D. and James H. Torrie. *Principles and Procedures of Statistics*. New York: McGraw-Hill Book Company, 1960.

Talpaz, Hovav and Itshak Borosh. "Strategy for Pesticide Use: Frequency and Applications," *American Journal of Agricultural Economics*. Vol. 56, No. 4, November 1974.

________, G.L. Curry, P.J. Sharpe, D.W. De Michele and R.E. Frisbie. "Optimal Pesticide Application for Controlling the Boll Weevil on Cotton," *American Journal of Agricultural Economics*. Vol. 60, No. 3, August 1978.

Taylor, C.R. "The Nature of Benefits and Costs Associated with the Use of Pest Control Methods." Paper presented at the American Agricultural Economics Association Annual Meeting, University of Illinois, Urbana-Champaign, Illinois, July 27-30, 1980.

________, Ronald D. Lacewell and Hovav Talpaz. "Use of Extraneous Information with an Econometric Model to Evaluate Impacts of Pesticide Withdrawals," Western Journal of Agricultural Economics. Vol. 4, No. 1, July 1979.

Thomson, W.T. Agricultural Chemicals: Book I Insecticides. 1977 Revision, Fresno, California: Thomson Publications, 1977.

Tummala, V.M. Rao and Richard C. Henshaw (editors). Concepts and Applications of Modern Decision Models. East Lansing, Michigan: MSU Business Studies, 1976.

Turnock, W.J. "Adaptability and Stability of Insect Pest Populations in Prairie Ecosystems" in Insect Ecology - Papers Presented in the A.C. Hodson Lectures. H.M. Kulman and H.C. Chiang (editors), University of Minnesota Agriculture Experiment Station Technical Bulletin 310, 1977.

________, R.J. Lamb and R.J. Bilodeau. "Report on: 1978 Trial of the Trap-Crop Method of Flea Beetle Control in Rape." Unpublished mimeo, 1980.

Turnock, W.J. and D.J. Samborski. "Management of Plant Pests." Paper prepared for the Prairie Production Symposium, Saskatoon, Saskatchewan, October 29-31, 1980.

van den Bosch, Robert. "The Cost of Poisons," Environment. Vol. 14, No. 7, September 1972.

Webster, J.P.G. "The Analysis of Risky Farm Decisions: Advising Farmers About the Use of Pesticides," Journal of Agricultural Economics. Vol. 28, No. 1, January 1977.

Westdal, P.H. and W. Romanow. "Observations on the Biology of the Flea Beetle, Phyllotreta Cruciferae (Coleoptera: Chrysomelidae)," Manitoba Entomologist. Vol. 6, 1972.

________. "Reduce Losses in Rapeseed," Manitoba Co-operator: Manitoba Crop Management Issue 1981. March 5.

Williams, D.B. "Price Expectations and Reaction to Uncertainty by Farmers in Illinois," Journal of Farm Economics. Vol. 33, No. 1, February 1951.

Young, Douglas L. "Estimation of Objectives and Synthetic Probability Measures." A paper presented at the Western Agricultural Economics Association Annual Conference, New Mexico State University, Las Cruces, July 20-22, 1980.

APPENDIX A

SURVEY QUESTIONNAIRE AND RESULTS

APPENDIX A

SURVEY QUESTIONNAIRE AND RESULTS

Within this appendix are included the applicable insecticide section of the 1979 Weed Survey questionnaire and relevant Manitoba results as compiled by Agriculture Canada in Saskatoon, Saskatchewan. This weed survey had included an additional question dealing with flea beetle damage and insecticide control on rapeseed. The pertinent questions of the survey are listed below. Although the survey was not designed for the purpose of economic analysis, especially the formulation of damage probabilities, insight into producer practices is useful.

The Manitoba portion of the survey had a total of 45 respondents who grew rapeseed. Of these, three observations were discarded because of failing to disclose full information. Rapeseed species proportions were determined from the varietal results. It was calculated that about 80 percent of the rapeseed varieties grown in 1979 were of the higher yielding _B. napus_ species and the remainder of the _B. campestris_ species. These figures are representative of the species proportions grown in Manitoba over the past five years. Table A.1 is a listing of the relevant Manitoba survey results. Observations 17, 18 and 24 were deleted because of incomplete information.

From the survey, it was determined that about 74 percent of the Manitoba rapeseed producers use insecticides to control for flea beetle damage. Of these producers, 45 percent used an in-furrow treatment, 39 percent a seed treatment, 10 percent a post-emergence foliar spray, and about 6 percent used a combination of two insecticides. This suggests that the surveyed producers preferred the higher priced in-furrow Furadan treatment.

Although the producer's assessment of flea beetle damage is given, the results are not readily amenable to economic analysis. There was no clear set of guidelines by which the flea beetle damage could be accurately calculated by the producer. The damage ratings between surveyed producers are not comparable because there were no standards set for ranking the level of damage. Also, for economic analysis, the benefits from insecticide control could only be determined if it were known what yield would be obtained under conditions of no treatment under the same conditions. For example, a control plot within the treated field would be useful as a standard for calculation of insecticide benefits.

1979 Weed Survey Questionnaire - Selected Field

Location of Selected Field

Municipality: ____________________

Questions

1. Present crop in field: ____________________

   Variety: ____________________

2. Number of acres in field: ____________________

   Yield of crop (bushels/acre): ____________________

11. If the present crop in this field is rapeseed, please answer the following questions.

   (a) Indicate, with a check, the level of flea beetle damage on the crop this year:

      no problem ______
      light ______
      medium ______
      heavy ______

   (b) Did you use chemicals for the control of flea beetles in this field this year?

      yes ______
      no ______

   (c) If you used chemical control, please indicate the specific product applied:

	Specific Product
seed treatment	______
in-furrow treatment	______
post-emergence foliar spray	______

Table A.1

Manitoba Survey Results

No.	Municipality	Variety	No. of Acres	Yield bu./ac.	Level of Damage	Control yes/no	Seed Treatment	In-Furrow	Spray
1	Stanley	Regent	20	30	light	yes		Furadan	
2	Roblin	Tower	48	27	light	yes		Furadan	
3	Winchester	Regent	60	33	no problem	yes		Furadan	
4	Turtle Mt.	Tower	120	25	no problem	yes		Furadan	
5	Turtle Mt.	Regent	70	25	no problem	no			
6	Morris	Regent	35	30	light	yes	Thiralin		Furadan
7	Morris	Regent	100	27	light	yes			Furadan
8	De Salaberry	Torch	320	25	light	yes			Furadan
9	Argyle	Torch	63	22	no problem	yes		Furadan	
10	Morris	Tower	120	33	no problem	yes		Furadan	
11	Whitewater	Regent	60	8	light	no			
12	Whitewater	Regent	160	2	no problem	yes		Furadan	
13	Oakland	Regent	130	20	light	yes		Furadan	
14	Glenwood	Regent	110	30	light	yes		Furadan	
15	Grey	Tower	95	20	no problem	yes		Furadan	
16	Pipestone	Tower	70	3	light	yes	Vitavax		
17	Whitehead		56	22	no problem	yes		Furadan	
18	Rosser		170	25					
19	Odanah	Regent	35	27	no problem	yes	Gammasan		
20	Miniota	Tower	57	18	medium	yes			Furadan
21	St. Andrews	Regent	200	37	no problem	yes		Furadan	
22	Blanshard	Torch	44	25	light	yes	Gammasan		
23	Minto	Regent	40	35	no problem	yes	Gammasan		
24	Saskatchewan		155	20	light	yes		Furadan	
25	Blanshard	Tower	65	15	light	yes	Benolin R.		

Table A.1 - Continued

Manitoba Survey Results

No.	Municipality	Variety	No. of Acres	Yield bu./ac.	Level of Damage	Control yes/no	Seed Treatment	In-Furrow	Spray
26	Minto	Regent	150	20	light	no			
27	Strathclair	Regent	138	20	heavy	yes	Gammasan		
28	Strathclair	Regent	48	17	light	no			
29	Ellie	Regent	95	7	no problem	no			
30	Gimli	Torch	15	0	no problem	no			
31	Rossburn	Regent	65	17	no problem	yes	Vitavax		
32	Birtle	Torch	141	14	light	yes		Furadan	
33	Russell	Regent	35	4	no problem	no			
34	Armstrong	Torch	150	28	no problem	yes	Benolin		
35	Dauphin	Midas	34	22	no problem	yes	Gammasan		
36	Grandview	Regent	52	32	no problem	yes	Vitavax		
37	Siglunes	Torch	32	30	no problem	yes		Furadan	
38	Gilbert Plains	Midas	72	25	medium	yes		Furadan	Furadan
39	Dauphin	Midas	70	18	light	yes		Furadan	
40	Grandview	Tower	78	20	no problem	yes	Gammasan		
41	Dauphin	Midas	48	14	medium	yes	Gammasan		
42	Park	Torch	90	15	no problem	no			
43	Mossey River	Torch	30	10	heavy	no			
44	Swan River	Midas	50	0	no problem	no			
45	Swan River	Regent	150	20	light	no			

Source: Canada Department of Agriculture, "1979 Weed Survey - Selected Fields" (Saskatoon, Saskatchewan).

APPENDIX B

INSECTICIDE PRICES AND APPLICATION COSTS

APPENDIX B

INSECTICIDE PRICES AND APPLICATION COSTS

This appendix is a listing of all of the prices of the insecticides used in this analysis. Table B.1 is a listing for the years 1980 and 1981 of the manufacturers suggested retail prices. The prices were converted into price per active ingredient (ai.) to determine the cost of the insecticide application from the recommended rates which were in active ingredients per unit. Table B.2 is a listing of the rate recommendations, the cost per unit of active ingredient, and also the cost per hectare and per acre of the singular insecticide applications. Table B.3 is the listing of the cost of the seven flea beetle control strategies including the insecticide combinations used in this analysis.

The cost of running a sprayer, in addition to the cost of the post-emergence foliar insecticides, was determined from 1980 cost data.[37] These variable costs were adjusted to 1981 levels by adding 10 percent to allow for inflationary increases in costs. The costs taken into account were fuel, lubrication and maintenance. The variable costs calculated were $0.224 per acre or $0.554 per hectare for 1980. The 1981 costs were $0.609 per hectare.

---

[37] C.F. Framingham and Associates, "1980 Cost of Soybean Production Study for Manitoba" (University of Manitoba, Department of Agricultural Economics and Farm Management, Winnipeg, Manitoba, 1980).

Table B.1

Insecticides Used and Suggested Retail Prices

Chemical Trade Name	Marketing Agency	Manufacturer Suggested Retail Prices*	
		1980	1981
Furadan 5 G.	Chemagro	$0.96/lb. x 50 lb.bag	$1.11/lb. x 40 lb.bag
Furadan 4.8 Fl.	Chemagro	$46.00/U.S. gal. = 3.785 litres	$60.85/4 litres
Gammasan+ 50 S.T.**	Chipman	$20.35/kg.***	$22.55/kg.***
Supracide 25 E.C.	Green Cross	$30.725/gal.	$30.725/gal.****

*These prices were obtained from the respective chemical company distributors. The prices for 1980 Furadan 5 G. and 1980 Furadan 4.8 Fl. were obtained from Cargill Grain Company. The prices are suggested retail prices and may vary from dealer to dealer.

**The price of Gammasan+ was taken to represent all of the lindane-based seed treatments.

***Average value for the 1.5 kg. and 4 kg. sizes.

****Averaged value for the 4 gal. and 5 gal. sizes. The 1981 price for Supracide was the same as in 1980 at the date the analysis was done.

Table B.2

Prices of Insecticides Per Unit Area

Chemical Trade Name	Recommended Application Rate*	Price/gm.ai. 1980 1981	Price/ac. 1980 1981	Price/ha. 1980 1981
Furadan 5 G.	280 gm.ai./ha.**	$0.04233	$4.796	$11.852
		0.0488	5.530	13.664
Furadan 4.8 Fl.	110 gm.ai./ha.***	0.02532	1.127	2.785
		0.03169	1.411	3.486
Gammasan 50 S.T.	18 gm.ai./kg. of seed ****	0.0407	1.660	4.103
		0.0451	1.8398	4.546
Supracide 25 E.C.	140 gm.ai./ha.*****	0.02703	1.531	3.784
		0.02703	1.531	3.784

*Manitoba Department of Agriculture, Entomology Section, Technical Services Branch, 1980 Manitoba Insect Control Guide (Winnipeg, Manitoba, 1980), pp. 14-15.

**The most commonly used rate for the Pesticide Research Reports, 1967-1979.

***Averaged value of 70 to 150 gm./ha. (recommended rate range).

****The seeding rate for *B. napus* was set at 5.6 kg./ha.

*****The rate which was used in the Pesticide Research Report, 1977, pp. 153-154.

Table B.3

Insecticide Treatment Costs Per Unit Area*

Insecticide Treatment	Cost Per Acre 1980 1981	Cost Per Hectare 1980 1981
Do Nothing	- -	- -
Furadan 5 G.	$4.796 5.5298	$11.852 13.664
Furadan 5 G. plus plus Gammasan 50 S.T. (lindane)	6.456 7.3698	15.955 18.210
Furadan 5 G. plus Supracide 25 E.C.	6.551 7.307	16.190 18.057
Gammasan 50 S.T. (lindane)	1.660 1.8398	4.103 4.546
Gammasan 50 S.T. (lindane) plus Supracide 25 E.C.	3.145 3.617	8.441 8.939
Furadan 4.8 Fl.	1.351 1.657	3.339 4.059

*The costs included the variable costs of using a sprayer for the post-emergence foliar sprays.

APPENDIX C

INSECTICIDE DOSAGE RESPONSE FUNCTIONS

APPENDIX C

INSECTICIDE DOSAGE RESPONSE FUNCTIONS[38]

Introduction

This appendix summarizes all of the relevant insecticide experimental plot results obtained from the published Pesticide Research Reports.[39] Certain experiments were discarded and data was aggregated and averaged for various reasons which will be discussed. From the remaining experimental plot results, dosage response functions were formulated for each chemical insecticide. The process of curve estimation relating rates of chemical application to percent changes in yield is discussed, with an explanation of why the particular equational form was chosen.

Carbofuran 5 Percent Granular

Table C.1 is a listing of the carbofuran observations which were used in the process of curve estimation. All of the observations were from the *B. napus* species of rapeseed. As explained earlier, experiments or sample observations within experiments were deleted because of cultural

---

[38] Dosage response refers to the percentage yield increases resulting from an insecticide application. The percentage increase being derived from the formula:

$$\% \text{ Change in Yield} = \frac{\text{Treated Plot Yield} - \text{Untreated Yield}}{\text{Untreated Yield}} \times 100$$

[39] Canada Department of Agriculture, Pesticide Research Report, compiled annually by the Expert Committee on Pesticide Use in Agriculture, 1967-1979.

Table C.1

Carbofuran Sample Observations
B. napus

No.	Rate of Application	Date of Seeding	% Increase in Yield
	....kg.ai./ha......		
1	0.125	1979 May 28	59.63
2	0.125	1979 May 28	16.77
3	0.135	1977 May 31	19.52
4	0.135	1977 May 31	25.26
5	0.140	1976 June 2-3	49.50
6	0.210	1976 June 3-4	85.42
7	0.210	1976 June 3-4	60.42
8	0.210	1976 May 26	39.12
9	0.216	1977 May 31	22.84
10	0.224	1979 May 31	20.01
11	0.224	1979 June 5	81.19
12	0.224	1979 May 31	59.96
13	0.224	1979 June 5	18.23
14	0.224	1979 May 31	18.23
15	0.224	1979 June 5	19.58
16	0.250	1979 May 28	71.56
17	0.250	1979 May 28	13.55
18	0.280	1977 May 11-12	16.10
19	0.280	1976 June 2-3	50.00
20	0.280	1976 June 3-4	77.08
21	0.280	1979 June 11	11.24
22	0.280	1979 May 31	75.02
23	0.280	1979 June 5	115.42
24	0.280	1979 May 31	100.12
25	0.280	1979 June 5	25.01
26	0.280	1979 May 31	27.32
27	0.280	1979 June 5	53.31

practices and yield gains incompatible with normal agronomic results. The 27 observations ranged in application rates from 0.125 through 0.280 kg.ai./ha. The percentage increase in yields resulting from these carbofuran application rates ranged from a low of 11.24 percent to a high of 115.42 percent. The recorded dates of seeding were utilized as a method by which the particular observation could be traced back to the original experiment.

Figure C.1 is the graphical illustration of the carbofuran treatment observations used. These observations were aggregated into four groups. Two of the groups were at each of the upper and lower bounds of the carbofuran application rate recommendations.[40] Within each of these groups, the yield results were averaged to avoid biases due to differences in the number of observations at each application rate. Table C.2 is a listing of the aggregated and dummy data points which were used for the carbofuran dosage response curve estimation. As explained earlier, the dummy point (0.001, 0.001) was added to the data so the estimated line would approximately be fitted through the origin.

The process of curve estimation was done with ordinary least squares regression using a number of alternative functional forms. The equational forms that were tested are listed as follows:

1. $Y1 = a + b\,x$ linear transformation
2. $\ln Y2 = a + b\,x$ log-linear transformation
3. $\ln Y3 = a + b \ln x$ double log-linear transformation

---

[40] Manitoba Department of Agriculture, Entomology Section, Technical Services Branch, _1980 Manitoba Insect Control Guide_ (Winnipeg, Manitoba, 1980), pp. 14-15.

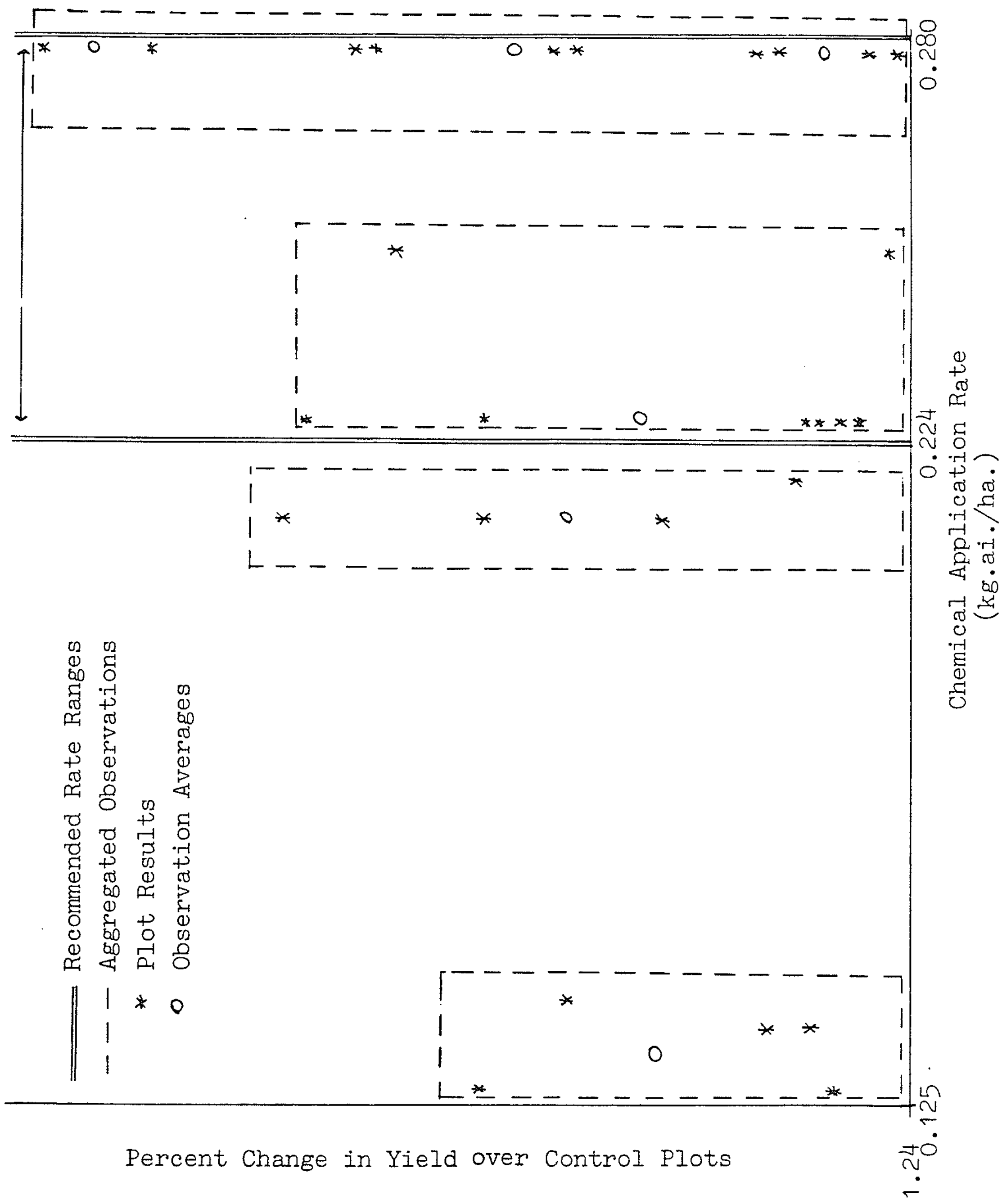

Figure C.1

Carbofuran Sample Observations and Aggregates
B. Napus

Table C.2

Carbofuran Aggregated Sample Observations

No.	Insecticide Application Rate	Percentage Change in Yield Over Untreated Plots
	.........kg.ai./ha..........	
1	0.001	0.001
2	0.132	34.14
3	0.210	51.95
4	0.224	37.79
5	0.280	55.06

4. $Y4 = a + b/x$ reciprocal transformation

5. $Y5 = a + b \ln x$ log-linear transformation

Each of these equations was graphed and compared, to determine the best fit to the data. This was accomplished by taking the original experimental plot data at the recommended rates and comparing with the predicted values on each equation. Figure C.2 depicts the equation comparisons. Equations number 2 and 3 were discarded because of their highly positive slopes within the recommended rate ranges. Equation number 1 proved to be a good fit within the recommended rate range, but implied a constant linear increase in yield resulting from equal increments of the insecticide. Equation number 4, because of its maximal asymtotic properties, was thought to be the best form under theoretical considerations. For example, no matter how much of the insecticide is applied, only some maximal limit increase in yield could be attained. However, with equation number 4, this maximum yield was almost fully attained at a relatively low level of insecticide application.

The chosen functional form of the estimated equation was:

$$Y = a + b \ln x$$

where:

Y = percent change in yield over an untreated plot,

x = rate of the insecticide application, and

a, b = coefficients of the equation.

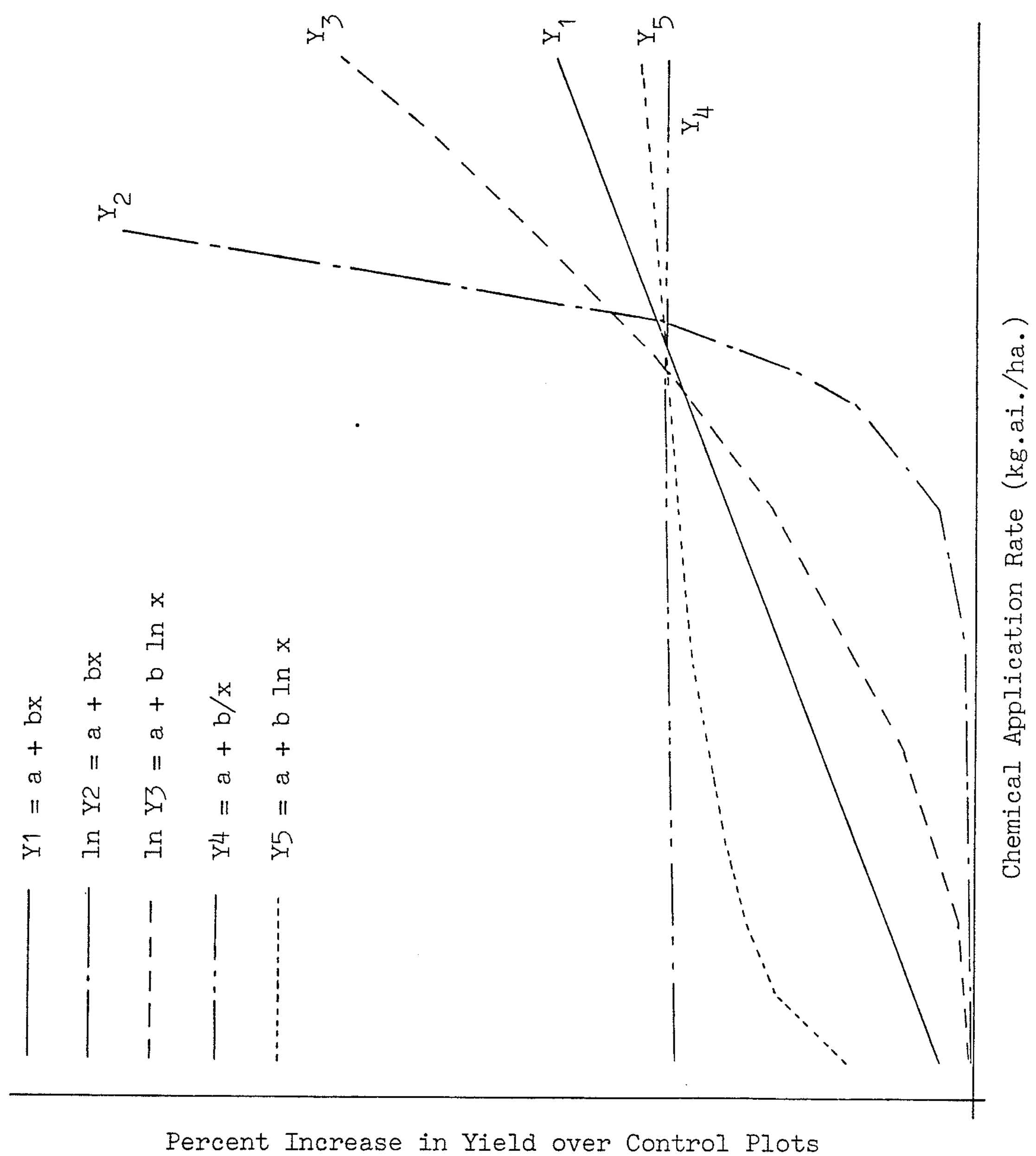

Figure C.2

Alternative Carbofuran Dosage Response Functions

B. napus

Lindane Seed Treatments

The observations for the estimation of the lindane seed treatment dosage response function came from experiments performed on *B. napus* rapeseed as did the carbofuran granular observations. The resulting sample size is less than carbofuran at 16 observations. These observations encompass application rates over a wide range, from 5.71 to 93.75 gm.ai./kg. of seed. The increases in yield resulting from a lindane application over an untreated plot ranged from a low of 5.62 percent to a high of 72.71 percent. Table C.3 is the listing of all of the observations which were used in the dosage response function estimation.

The lindane seed treatment observations were plotted, in Figure C.3, to illustrate how they were aggregated into six groups. The observations were averaged within the groups so a single point represented each group. The resulting aggregated and averaged data is listed in Table C.4.

Carbofuran Foliar Sprays

The experimental observations utilized are listed in Table C.5. All of the observations were obtained from experiments performed on the *B. campestris* species of rapeseed. The tests done on *B. napus* rapeseed were confined to a total of two observations at a single application rate. The experimental plot observations are plotted and aggregated into three groups in Figure C.4. Two of these groups being within the recommended application rate range of 70 to 150 gm.ai./ha., and one group is at a rate much greater than what is recommended.[41]

---

[41] Ibid.

Table C.3

Lindane Seed Treatment Sample Observations

No.	Rate of Application	Date of Seeding		% Increase in Yield
	.gm.ai./kg. of seed.			
1	5.71	1978	Mid-May	9.79
2	7.68	1976	June 2-3	27.86
3	15.42	1976	June 3-4	23.96
4	15.42	1976	June 3-4	12.50
5	15.42	1976	June 3-4	62.09
6	15.50	1978	Mid-May	55.96
7	15.50	1978	Mid-May	72.71
8	15.50	1978	Mid-May	48.63
9	15.64	1979	June 11	5.62
10	25.00	1976	May 26	11.24
11	25.00	1977	May 31	14.35
12	30.84	1977	May 11-12	6.78
13	30.84	1976	June 3-4	33.33
14	31.28	1979	June 11	5.62
15	46.88	1975	May 28-29	25.04
16	93.75	1975	May 28-29	27.03

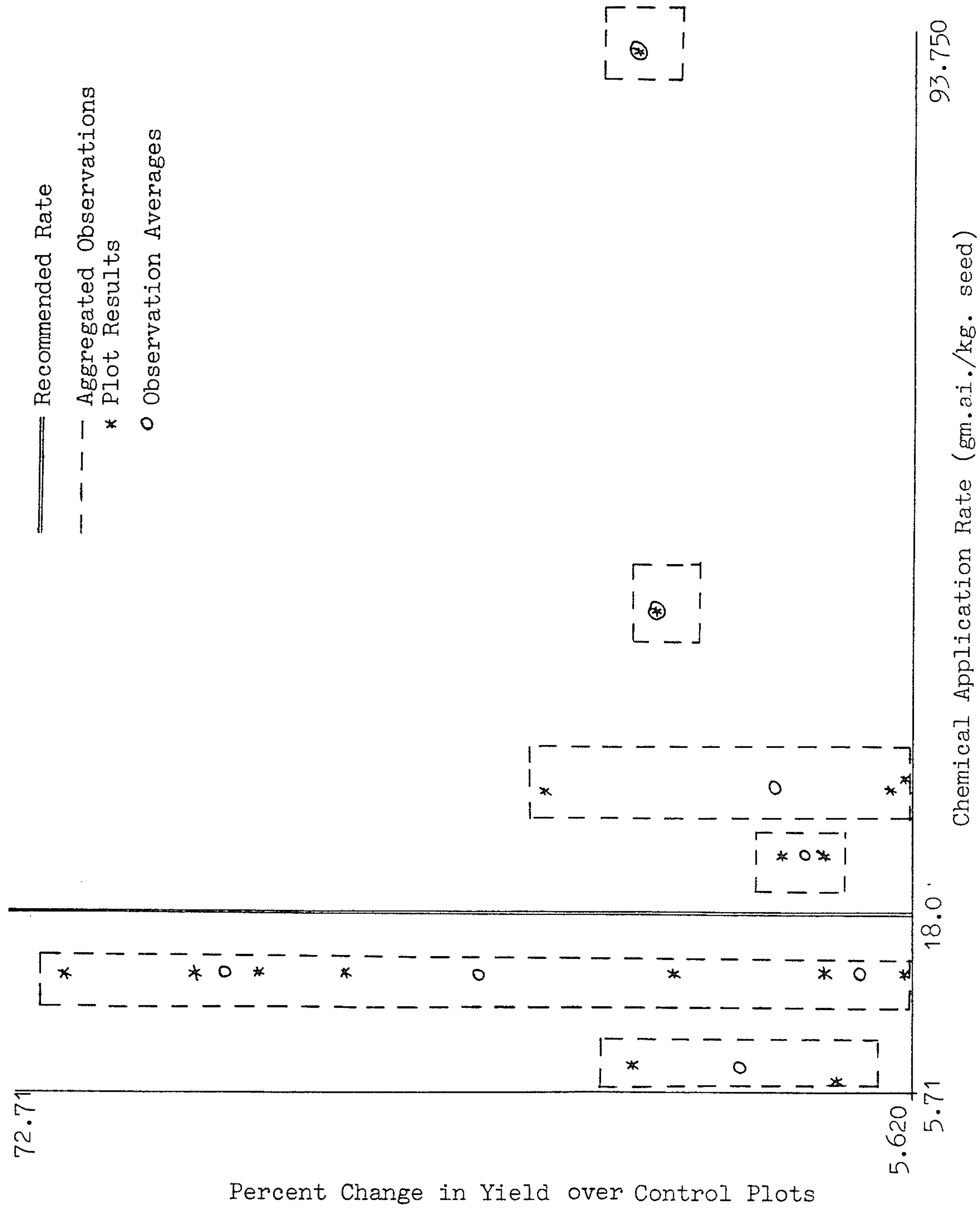

Figure C.3

Lindane Seed Treatment Sample Observations
and Aggregates
<u>B. Napus</u>

Table C.4

Lindane Seed Treatment Aggregated
Sample Observations

No.	Insecticide Application Rate	Percentage Change in Yield Over Untreated Plots
	.....gm.ai./kg. of seed.....	
1	0.001	0.001
2	6.96	18.83
3	15.49	40.21
4	25.00	12.80
5	30.99	15.24
6	46.88	25.04
7	93.75	27.03

Table C.5

Carbofuran Sprays Sample Observations

No.	Rate of Application	Date of Seeding	% Increase in Yield
	....gm.ai./ha......		
1	70.00	1974 June 5	46.50
2	70.00	1974 May 6	19.56
3	70.00	1971 May 12	12.09
4	140.00	1973 May 24	17.70
5	140.00	1972 May 16	34.67
6	140.00	1971 May 12	21.72
7	700.00	1971 May 12	24.39
8	700.00	1970 May 21	34.17

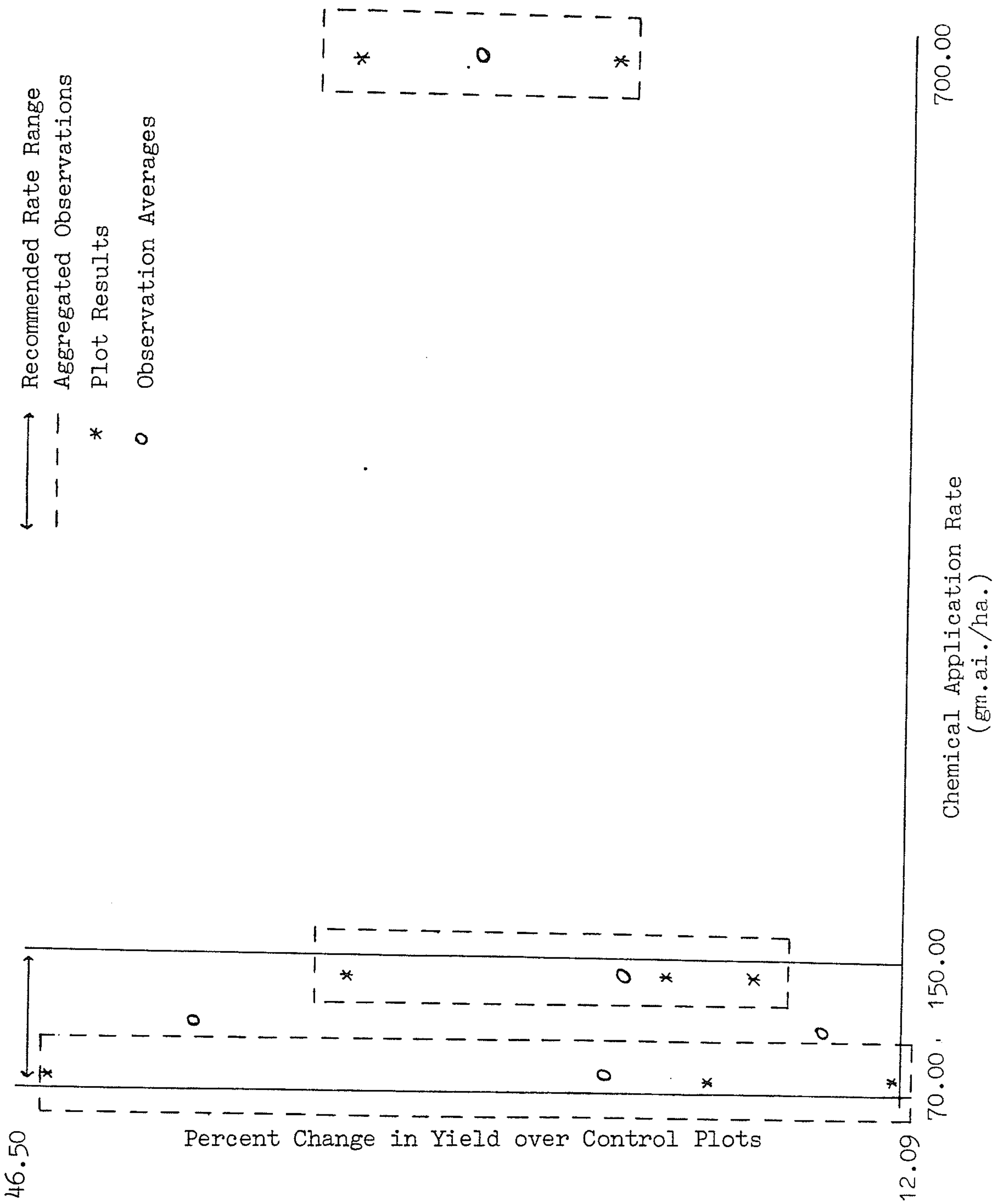

Figure C.4

Carbofuran Spray Observations and Aggregates
B. Campestris

The observations were averaged to a single point within each group and these averages are listed in Table C.6. Also, within this table, the dummy observation (0.001, 0.001) is listed and is used for dosage response function estimation to approximate the origin.

Insecticide Combinations

As explained earlier, the data limitations required the calculation of dosage response functions for insecticide combinations be calculated from a single experiment. Table C.7 is a listing of the average yields resulting from each single and combinations of insecticide applications for that experiment. The rapeseed was seeded at 5.6 kg./ha. on May 11 and 12, 1977 at Oakville, Manitoba on a 20 acre field. The plots within the field were replicated nine times for each insecticide treatment. The spraying of Supracide occurred one week after crop emergence. The Gammasan 50 percent and Lindasan 75 percent insecticides are the lindane based seed treatments.

The chemical combinations analyzed in this thesis are:

1. Furadan granular plus lindane seed treatments,
2. Furadan granular plus a post-emergence spray, and
3. Lindane seed treatment plus a post-emergence spray.

For these combinations, the increases in yield over a single application were determined and added to the dosage response of that single insecticide. For example, the Furadan plus a lindane seed treatment yielded 0.830 percent better than Furadan alone. This percentage increase in yield was added to the dosage responses for Furadan, calculated earlier at each damage level, to formulate the corresponding yield responses for the insecticide combination.

Table C.6

Carbofuran Sprays Aggregated Sample Observations

No.	Insecticide Application Rate	Percentage Change in Yield Over Untreated Plots
	.........gm.ai./ha..........	
1	0.001	0.001
2	70.00	26.05
3	140.00	24.70
4	700.00	29.28

Table C.7

1977 Insecticide Trial Yield Results*

Treatments	Seed Yield
	...kg.....
0.280 kg.ai./ha. Furadan 5 G.	15.65
0.280 kg.ai./ha. Furadan 5 G. plus 14 gm.ai./kg. seed Gammasan 50 Percent	15.78
0.280 kg.ai./ha. Furadan 5 G. plus 140 gm.ai./ha. Supracide 25 E.C.	15.70
14 gm.ai./kg. seed Gammasan 50 Percent	13.74
14 gm.ai./kg. seed Gammasan 50 Percent plus 140 gm.ai./ha. Supracide 25 E.C.	15.32
14 gm.ai./kg. seed Lindasan 75 Percent	14.34
14 gm.ai./kg. seed Lindasan 75 Percent plus 140 gm.ai./ha. Supracide 25 E.C.	16.41
140 gm.ai./ha. Supracide 25 E.C.	14.34
Check	13.48

*P.H. Westdal, W. Romanow and W.C. Askew, "Comparison of the Effects of Different Insecticides, Applied for the Control of the Crucifer Flea Beetle on Rape, on Beetle Numbers, Plant Injury, Development and Yield," in Pesticide Research Report, compiled annually by the Expert Committee on Pesticide Use in Agriculture,(1977), pp. 153-154.

Reaction of Insecticide to Type of Rapeseed

This section provides the statistical proof that the reaction of insecticides on *B. napus* and *B. campestris* species of rape are equal for the data available. The two insecticide treatments which are tested are the carbofuran 4.8 flowable foliar spray and the lindane seed treatments. The dosage response functions for the sprays were estimated using experimental observations from *B. campestris* rapeseed, while the functions for the seed treatments were from *B. napus* rapeseed. Limited numbers of yield results were the most serious constraint to the analysis, but also a range of application rates was needed for curve estimation. The estimation was confined to the experiments done on the particular species of rapeseed that provided this rate range as well as degrees of freedom.

For the lindane seed treatments, the 16 observations from the *B. napus* experimental plots had application rates ranging from 5.71 to 93.75 gm.ai./kg. of seed. The number of observations obtained from *B. campestris* were limited to five points at the single application rate of about 15.5 gm.ai./kg. of seed. At this application rate, the *B. napus* species experiments had seven observations. The observations are listed in Table C.8.

For the foliar spray experiments, eight observations were used from the *B. campestris* plots to formulate the dosage response functions. The total number of observations in *B. napus* rapeseed were confined to two at the application rate of 70 gm.ai./ha. At this rate, three observations were obtained from *B. campestris* experiments. The data points for the foliar sprays are listed in Table C.9.

Table C.8

Comparison of Percentage Increases in Yield Resulting From Lindane Seed Treatment Applications Between Two Species of Rapeseed

B. napus		B. campestris	
Application Rate	Percentage Increase In Yield Over the Control Plots	Application Rate	Percentage Increase in Yield Over the Control Plots
.gm.ai./kg. seed.		.gm.ai./kg. seed.	
15.42	23.96	15.5	67.72
15.42	12.50	15.5	46.26
15.42	62.09	15.5	81.01
15.50	55.96	15.8	14.35
15.50	71.71	15.8	14.22
15.50	48.63		
15.64	5.62		

Table C.9

Comparison of Percentage Increases in Yield Resulting From Carbofuran Spray Applications Between Two Species of Rapeseed

B. napus		B. campestris	
Application Rate	Percentage Increase In Yield Over the Control Plots	Application Rate	Percentage Increase in Yield Over the Control Plots
.gm.ai./kg. seed.		.gm.ai./kg. seed.	
70.0	67.34	70.0	46.50
70.0	20.00	70.0	19.56
		70.0	12.09

A statistical test was used to determine if the samples of the two chemical treatments were significantly different within each of the two species of rapeseed. The Tukey's quick test was used to determine if the samples came from identical populations.[42] This test utilizes the actual sample observations, percentages in this case, to determine the amount of overlap between the groups of insecticide observations. The more overlap, the greater the likelihood the samples came from identical populations.

The hypothesis of identical populations was accepted for both the lindane seed treatments and the Furadan foliar sprays. Therefore, the insecticide dosage response functions for one species of rapeseed would be statistically identical for the other species, given the present results of the experimental plot data. It was also inferred for the insecticide combinations and the Furadan granular, which had no B. campestris experimental observations, the same would hold true. The percentage yield increases of the treated plots over the control plots for the seven treatment strategies, whether estimated by or inferred from the dosage response functions, would hold equal for both rapeseed species: B. napus and B. campestris.

---

[42] Wayne W. Daniel, Applied Nonparametric Statistics (Boston: Houghton Mifflin Company, 1978), pp. 71-73.

APPENDIX D

RECOMMENDED CULTURAL PRACTICES FOR RAPESEED

APPENDIX D

RECOMMENDED CULTURAL PRACTICES FOR RAPESEED

Introduction

This appendix contains a summary of dates of seeding and rates of seeding for rapeseed, which are recommended to western Canadian producers. The information presented includes recommendations for both the *Brassica napus* (Argentine) and the *Brassica campestris* (Polish) species of rapeseed. This information was used as a partial criterion to reject certain experimental plot results. The date of seeding data, and the resulting number of frost-free days, was the sole criterion for the decision between the species of rapeseed to be grown.

Date of Seeding

The date of seeding is an important constraint in western Canadian rapeseed production. The date of seeding, although largely dependent on the spring climatic and field conditions, is very important when considering the number of frost-free growing days that are available. The variation in the number of frost-free days within Manitoba is illustrated in Figure D.1. For the *B. napus* and *B. campestris* species of rapeseed, the number of days required for maturity are 92 to 102 and 73 to 83, respectively.[43]

---

[43] The Faculty of Agriculture, *Principles and Practices of Commercial Farming*, Fifith Edition (Winnipeg, Manitoba: The University of Manitoba, 1977), p. 108.

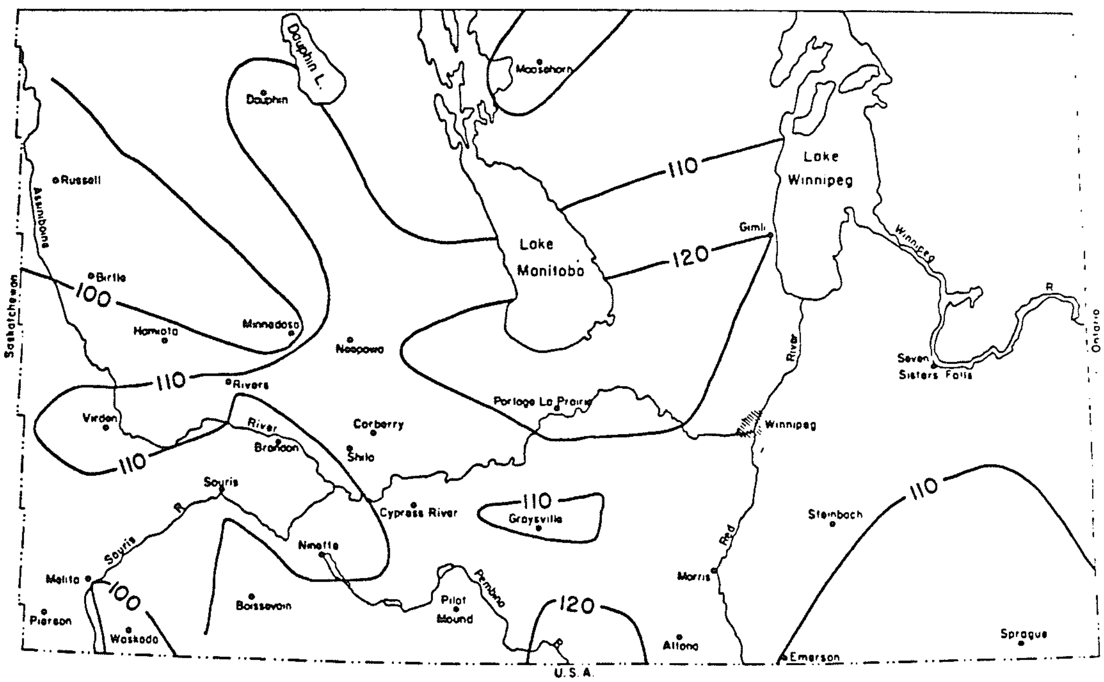

Figure D.1

Average Number of Frost-Free Days Above 0°C

Source: The Faculty of Agriculture, Principles and Practices of Commercial Farming, Fourth Edition (Winnipeg: The University of Manitoba, 1977), p. 19.

The following is a summary of the effects that date of seeding have on the rapeseed crop and the implications of these effects on this analysis. The seeding date affects seven characteristics of rapeseed production: emergence, stand establishment, time to first flower, plant height, days to maturity, seed yield, and seed quality.

The number of days from seeding to plant emergence as well as percent of seed germination is related to the seeding date. The later in the spring that planting occurs, the fewer the number of days to plant emergence. Also, as the soil warms up, later in the spring, the rate of seed germination increases. Table D.1 contains the effect of date of seeding on plant emergence and seed germination. The results indicate that the postponement of planting may be beneficial to plant yields. However, there is a trade-off between the postponement of planting and the danger of serious losses in the event of fall frosts.

As a result of date of seeding, the number of days to plant maturity is greatly affected. Although a later planting may result in the crop maturing in fewer days, the recommended planting dates are for as early as possible in the spring. The number of days lost by seeding later may not be entirely compensated for in plant maturity within the growing season. A later planting date still results in a fall harvest later than an earlier seeding date even though the number of days to maturity is reduced.

The date of seeding affects the seed yield to a significant extent. Although dependent on other factors, such as soil, climatic, cultural and locational conditions, the seed yield varies greatly if the planting date is postponed. It is, therefore, recommended that the *B. napus*

Table D.1

Effect of Date of Seeding on Plant Emergence and Seed Germination

Type of Rapeseed	Days to Plant Emergence		Percent Seed Germination Soil Temperature	
	Early May	Late May	Cool 5°C	Warm 15°C
B. campestris	8-11	5-7	30	> 92
B. napus	9-12.	6-8	60	> 92

Source: Manitoba Department of Agriculture, Rapeseed '80, an eight lesson course adapted by the Manitoba Department of Agriculture, produced by the Alberta Department of Agriculture and presented to Western Canadian Rapeseed Producers (Winnipeg, Manitoba, 1980), pp. 525-526.

varieties (Midas, Tower, Regent) be seeded between May 5 and May 30 and the B. campestris varieties (Torch, Candle, Span) be seeded before mid-June.[44] Figure D.2 illustrates the effects upon yield resulting from variations in planting dates. This figure indicates that, on average, the yields resulting from the two species of rapeseed are equivalent about the end of May. A farmer would be indifferent between planting either species at this date.

Rate of Seeding

Rates of seeding rapeseed vary in western Canada depending on the species seeded, soil conditions, and cultural practices. The recommended seeding rates for the B. napus (Argentine) and B. campestris (Polish) species are 4 to 7 kg./ha. and 5 to 8 kg./ha., respectively.[45] Figure D.3 is an illustration of the effect of seeding rate on yield, for two planting techniques. This test of seeding rates performed on the B. napus species concluded that at rates above the recommended range only marginal increases in yield result.[46] Also, as illustrated in the figure, only a small effect on yield results due to a variation of the seeding rate within the recommended range under comparable conditions.

---

[44] The Faculty of Agriculture, op. cit., p. 112.

[45] Ibid., p. 518.

[46] Ibid., p. 519.

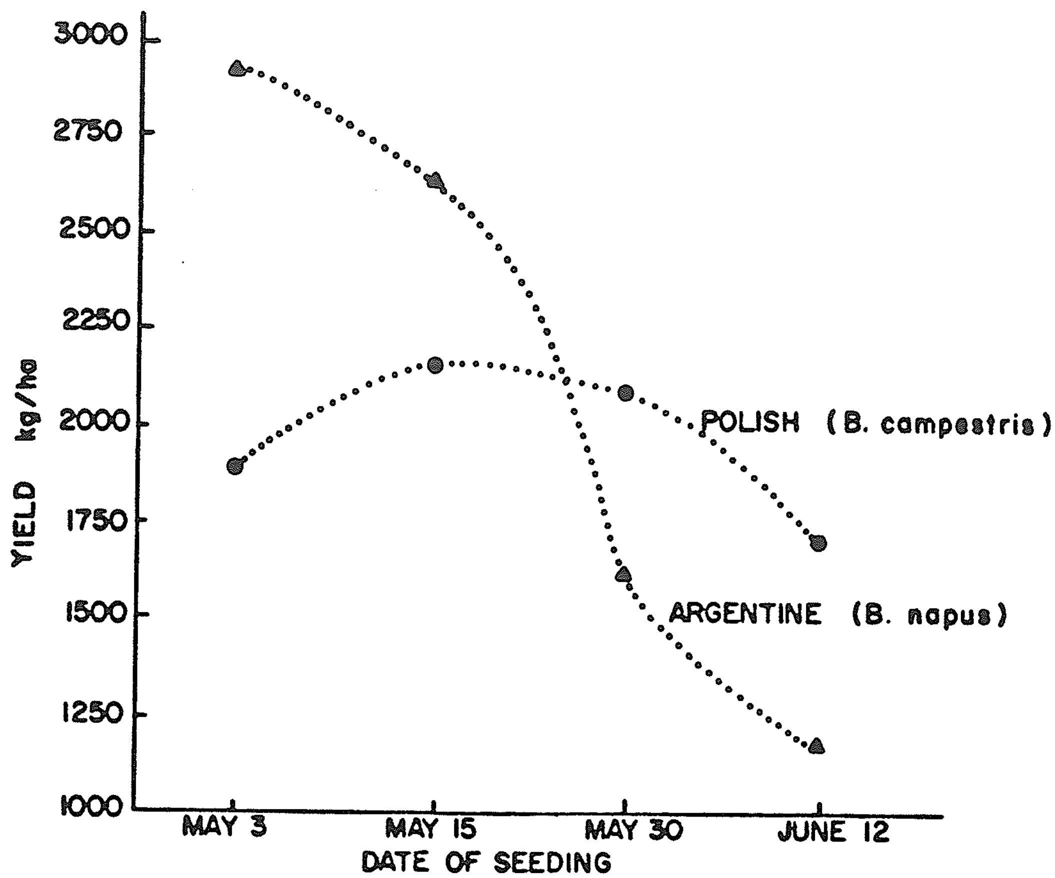

Figure D.2

Effect of Rate of Seeding on Rapeseed Yield

Source: Manitoba Department of Agriculture, Rapeseed '80, an eight lesson course adapted by the Manitoba Department of Agriculture, produced by the Alberta Department of Agriculture and presented to Western Canadian Rapeseed Producers (Winnipeg, Manitoba, 1980), p.529.

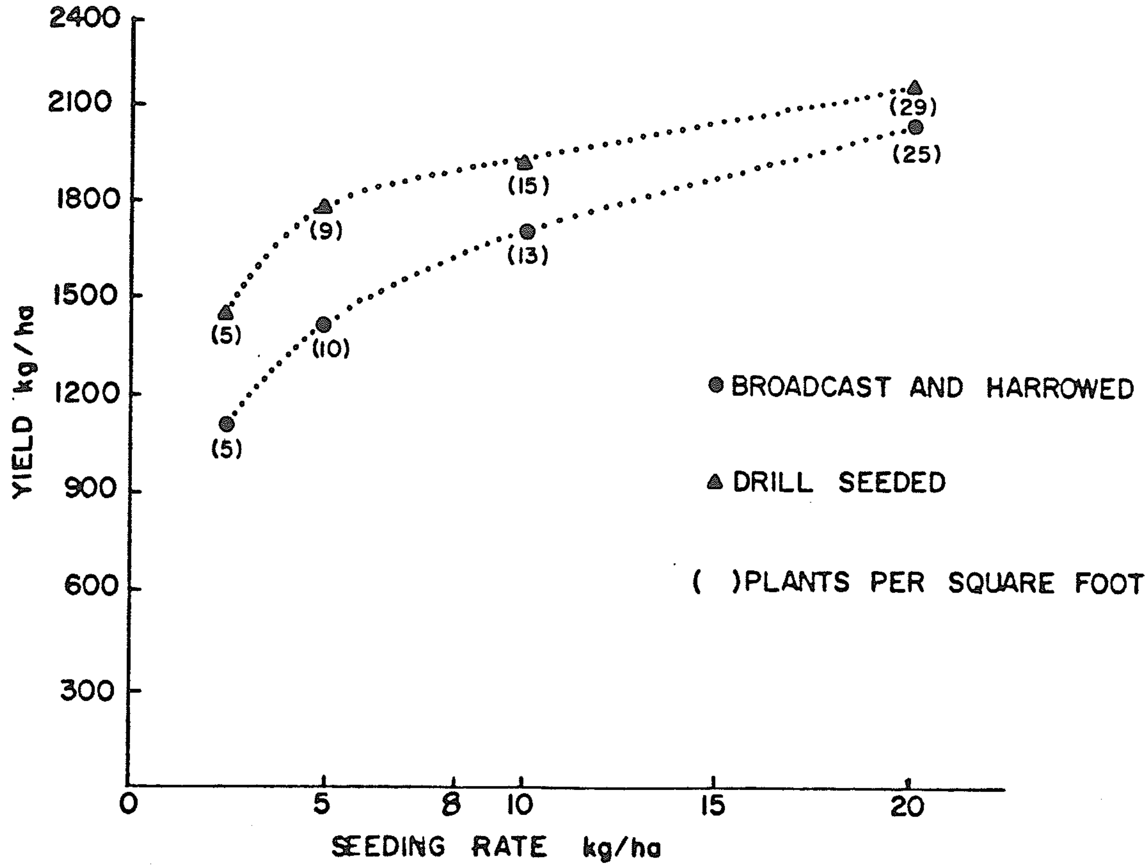

Figure D.3

Effect of Seeding Rate on Yield

Source: Manitoba Department of Agriculture, Rapeseed '80, an eight lesson course adapted by the Manitoba Department of Agriculture, produced by the Alberta Department of Agriculture and presented to Western Canadian Rapeseed Producers (Winnipeg, Manitoba, 1980), p.519.

APPENDIX E

MANITOBA YIELD COMPARISON OF THE *B. NAPUS* AND *B. CAMPESTRIS* SPECIES OF RAPESEED

APPENDIX E

MANITOBA YIELD COMPARISON OF THE *B. NAPUS* AND *B. CAMPESTRIS* SPECIES OF RAPESEED

This appendix is a listing of the rapeseed species and varietal yield performance in Manitoba. The data was collected from the 1977, 1978 and 1979 Manitoba Co-operative Rapeseed Tests which are a group of plot experiments conducted at five Manitoba locations and the yields are aggregated to form a provincial average. The provincial averages of these tests are listed in Table E.1. Also, for the purpose of this analysis, the yields of the varieties within each species were aggregated to determine the species yield average. From these species averages, it was calculated that the *B. campestris* species yielded on average one-third (33.125 percent) less than the *B. napus* species.

Table E.1

Yield of Rapeseed Varieties in Manitoba

Species and Variety	Yield 1977	1978	1979	Three-Year Average	Species Average
	........kg./ha.........				
B. napus					
Altex	2 280	1 868	1 755	1 968	
Regent	2·180	1 914	1 643	1 912	
Tower	2 263	1 798	1 548	1 870	
				-----	1 917
B. campestris					
Candle	1 460	1 310	1 383	1 384	
Torch	1 545	1 426	1 513	1 495	
				-----	1 440

Source: Manitoba Department of Agriculture, *Rapeseed '80*, an eight lesson course adapted by the Manitoba Department of Agriculture, produced by Alberta Department of Agriculture and presented to Western Canadian Rapeseed Producers, Winnipeg, Manitoba, 1980, p. 222.

APPENDIX F

MANITOBA RAPESEED PRICE TRENDS

APPENDIX F

MANITOBA RAPESEED PRICE TRENDS

The purpose of this appendix is to present a summary of the data and estimation procedures used to forecast 1981 rapeseed prices. The data was obtained for the 20 year period from 1960 to 1979. The results were estimated in a linear form by ordinary least squares regression. The historical data as well as the estimated line are presented in a graphical form in this appendix.

The regression was a simple linear extrapolation of price against time. The form of the estimated equation is as follows:

$$Y = a + b\,x$$

where:

Y = the price of rapeseed resulting at a particular year,

X = years, and

a, b = coefficients of the equation.

For the purpose of a sensitivity analysis, a line was also estimated one standard deviation on either side of the estimated line. The resulting 1981 extrapolated prices are assumed to be what a producer might expect as high, average and low prices. The price data utilized are listed in Table F.1. The actual as well as the estimated lines are graphed in Figures F.1 and F.2, respectively.

Table F.1

Rapeseed Metric and Imperial Historical Prices

Year	Prices: Per Bushel	Per Tonne
1960	$2.00	$ 88.09
1961	1.80	79.36
1962	1.75	77.16
1963	2.50	110.23
1964	2.70	119.05
1965	2.45	108.02
1966	2.45	108.02
1967	1.80	79.48
1968	1.88	82.89
1969	2.40	105.82
1970	2.35	103.62
1971	2.15	94.80
1972	3.10	136.68
1973	5.84	257.50
1974	7.07	311.70
1975	5.11	225.31
1976	5.82	256.51
1977	6.50	286.60
1978	6.25	275.59
1979	5.75	253.53

Source: Manitoba Department of Agriculture, Manitoba Agriculture Yearbook (Winnipeg, Manitoba, 1979).

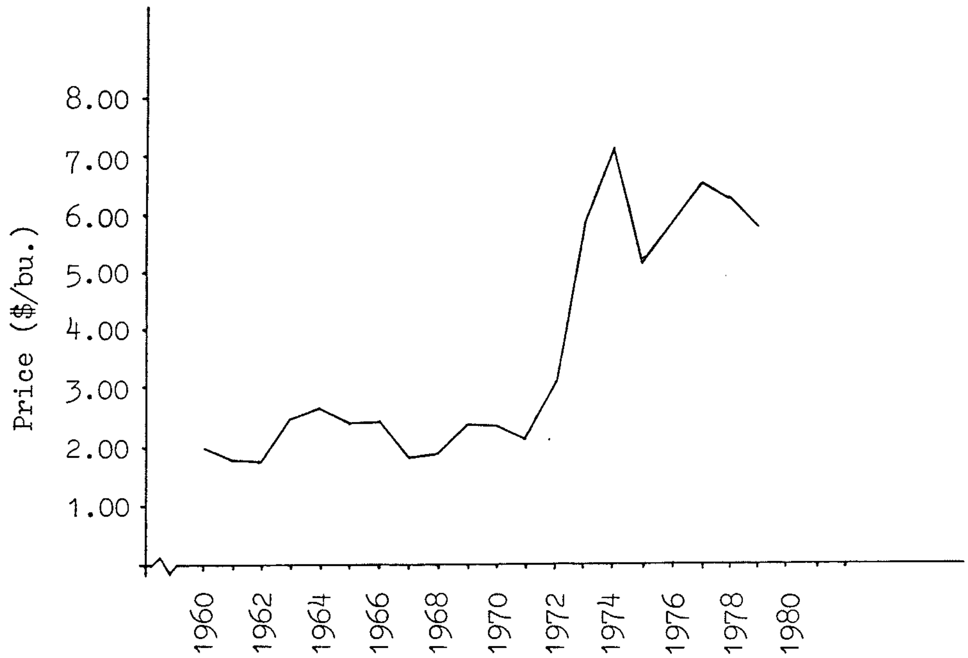

Figure F.1

Actual Prices, 1960 to 1979

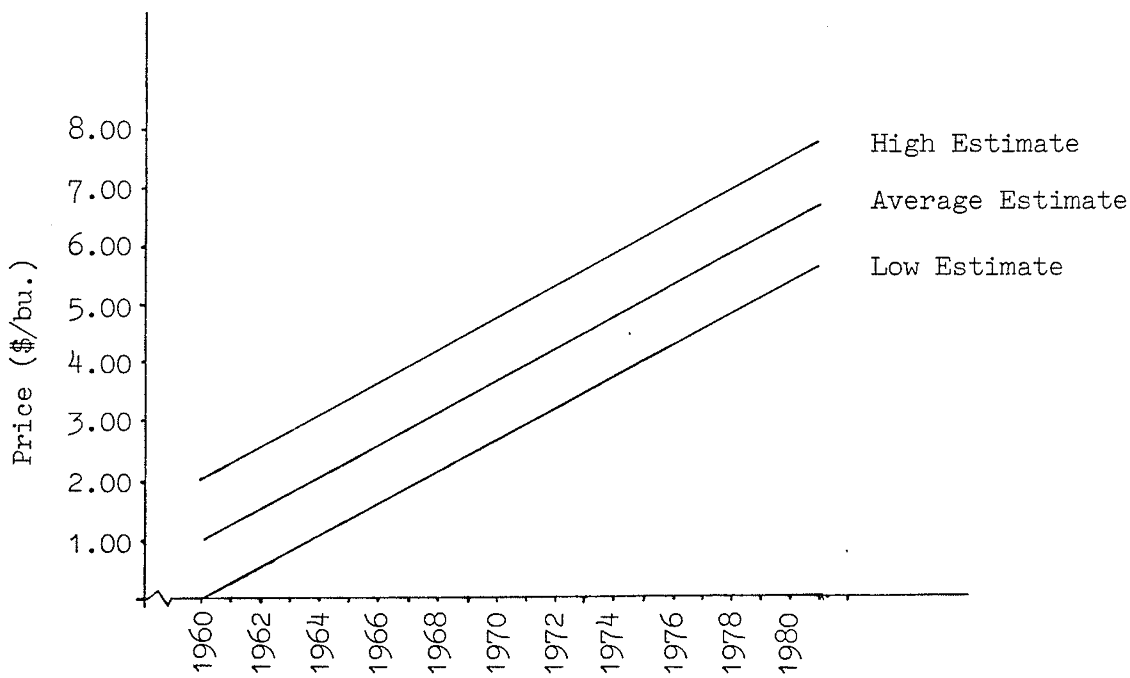

Figure F.2

Estimated and Inferred Price Trends

APPENDIX G

RESULTS

APPENDIX G

RESULTS

Contained within this appendix is a complete listing of the results calculated in this thesis. The results are presented in pay-off tables which are sets of columns of possible monetary returns associated with particular control strategy and state of nature combinations. Each state of nature has a probability of occurrence, therefore, an expected value for that column may be calculated by summing the products of the monetary net returns and the probability of the associated state of nature. This expected monetary value (EMV) resulting from each possible control strategy may be algebraically described in the following manner:

$$EMV = \Sigma [\pi \cdot P(X)]$$

where:

EMV = expected monetary value,

π = profit or return net of chemical and application costs for a particular control strategy-state of nature combination, and

P(X) = probability that the state of nature or damage level (X) will occur.

The profit (π) or returns net of chemical and application costs are calculated at each state of nature or damage level as follows:

$$\pi = [\text{Yield} \cdot \text{Price}] - \text{Cost}$$

where:

Yield = the tonnes per hectare that would be expected to result under certain damage conditions given the flea beetle control strategy utilized,

Price = the price level of rapeseed anticipated in $ per tonne, and

Cost = the cost of the control strategy utilized.

The following tables are divided into two sections, each of which has two sub-sections. The two sections being the pay-off tables for each of the two species of rapeseed. The two sub-sections are the yield ranges, lower and higher, for both species. Within each of these four sub-sections, nine tables, the sensitivity of the results, are listed. The sensitivity analysis is based on varying the crop prices and the skewness of the flea beetle damages probability distribution.

Table G.1

Payoff Table for *B. napus* with Low (1981) Price Expectations
(Low Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	417.661	403.997	399.451	399.604	413.115	408.722	413.566
Low	0.40	313.308	362.008	359.946	360.099	343.050	379.156	355.924
Average	0.30	208.955	294.923	292.117	292.270	250.622	273.561	258.030
High	0.20	104.353	203.242	199.690	199.843	162.668	171.940	142.745
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		229.763	293.445	290.614	290.767	265.369	288.108	268.801

Table G.2

Payoff Table for B. napus with Medium (1981) Price Expectations
(Low Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	497.556	483.892	479.346	479.499	493.010	488.617	493.461
Low	0.40	373.241	433.870	432.284	432.437	409.541	453.394	424.792
Average	0.30	248.926	353.953	351.479	351.632	299.434	327.599	308.172
High	0.20	124.315	244.734	241.371	241.524	194.654	206.540	170.834
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		273.715	352.192	349.688	349.841	317.001	344.929	321.004

Table G.3

Payoff Table for B. napus with High (1981) Price Expectations
(Low Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	577.450	563.786	559.240	559.393	572.904	568.511	573.355
Low	0.40	433.174	505.732	504.621	504.774	476.033	527.633	493.660
Average	0.30	288.897	412.983	410.841	410.994	348.245	381.639	358.314
High	0.20	144.277	286.225	283.054	283.207	226.640	241.141	198.923
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		317.667	410.939	408.763	408.916	368.633	401.752	373.206

Table G.4

Payoff Table for B. napus with Low (1981) Price Expectations
(Low Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	417.661	403.997	399.451	399.604	413.115	408.722	413.566
Low	0.25	313.308	362.008	359.946	360.099	343.050	379.156	355.924
Average	0.40	208.955	294.923	292.117	292.270	250.622	273.561	258.030
High	0.25	104.353	203.242	199.690	199.843	162.668	171.940	142.745
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		208.880	278.798	275.818	275.971	247.107	267.188	248.353

Table G.5

Payoff Table for B. napus with Medium (1981) Price Expectations
(Low Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	497.556	483.892	479.346	479.499	493.010	488.617	493.461
Low	0.25	373.241	433.870	432.284	432.437	409.541	453.394	424.792
Average	0.40	248.926	353.953	351.479	351.632	299.434	327.599	308.172
High	0.25	124.315	244.734	241.371	241.524	194.654	206.540	170.834
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		248.837	334.744	332.062	332.215	295.246	320.007	296.644

Table G.6

Payoff Table for *B. napus* with High (1981) Price Expectations
(Low Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	577.450	563.786	559.240	559.393	572.904	568.511	573.355
Low	0.25	433.174	505.732	504.621	504.774	476.033	527.633	493.660
Average	0.40	288.897	412.983	410.841	410.994	348.245	381.639	358.314
High	0.25	144.277	286.225	283.054	283.207	226.640	241.141	198.923
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		288.794	390.689	388.307	388.460	343.384	372.828	344.934

Table G.7

Payoff Table for B. napus with Low (1981) Price Expectations
(Low Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	417.661	403.997	399.451	399.604	413.115	408.722	413.566
Low	0.20	313.308	362.008	359.946	360.099	343.050	379.156	355.924
Average	0.30	208.955	294.923	292.117	292.270	250.622	273.561	258.030
High	0.40	104.353	203.242	199.690	199.843	162.668	171.940	142.745
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		187.972	261.692	258.562	258.715	229.292	246.665	226.165

Table G.8

Payoff Table for *B. napus* with Medium (1981) Price Expectations
(Low Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	497.556	483.892	479.346	479.499	493.010	488.617	493.461
Low	0.20	373.241	433.870	432.284	432.437	409.541	453.394	424.792
Average	0.30	248.926	353.953	351.479	351.632	299.434	327.599	308.172
High	0.40	124.315	244.734	241.371	241.524	194.654	206.540	170.834
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		223.930	314.365	311.506	311.659	274.023	295.558	270.212

Table G.9

Payoff Table for *B. napus* with High (1981) Price Expectations
(Low Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	577.450	563.786	559.240	559.393	572.904	568.511	573.355
Low	0.20	433.174	505.732	504.621	504.774	476.033	527.633	493.660
Average	0.30	288.897	412.983	410.841	410.994	348.245	381.639	358.314
High	0.40	144.277	286.225	283.054	283.207	226.640	241.141	198.923
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		259.887	367.037	364.450	364.603	318.754	344.453	314.258

Table G.10

Payoff Table for B. napus with Low (1981) Price Expectations
(High Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	487.479	473.815	469.269	469.422	482.933	478.540	483.384
Low	0.40	365.485	424.619	423.055	423.208	400.941	444.004	415.802
Average	0.30	243.739	346.355	343.796	343.949	293.358	320.519	301.511
High	0.20	121.745	239.517	235.965	236.118	190.744	202.004	167.094
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		268.039	344.665	342.107	342.260	310.452	337.638	314.157

Table G.11

Payoff Table for B. napus with Medium (1981) Price Expectations
(High Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	580.728	567.064	562.518	562.671	576.182	571.789	576.633
Low	0.40	435.398	508.459	507.465	507.618	478.506	530.647	496.125
Average	0.30	290.364	415.223	413.045	413.198	350.344	383.541	359.970
High	0.20	145.034	287.948	284.586	284.739	228.101	242.355	199.841
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		319.312	413.210	411.032	411.185	370.708	403.935	375.036

Table G.12

Payoff Table for B. napus with High (1981) Price Expectations
(High Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	673.978	660.314	655.768	655.921	669.432	665.039	669.883
Low	0.40	505.312	592.298	591.874	592.027	556.072	617.291	576.447
Average	0.30	336.989	484.091	482.293	482.446	407.330	446.563	418.430
High	0.20	168.323	336.379	333.207	333.360	265.458	282.706	232.588
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		370.585	481.755	479.957	480.110	430.964	470.232	435.915

Table G.13

Payoff Table for B. Napus with Low (1981) Price Expectations
(High Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	487.479	473.815	469.269	469.422	482.933	478.540	483.384
Low	0.25	365.485	424.619	423.055	423.208	400.941	444.004	415.802
Average	0.40	243.739	346.355	343.796	343.949	293.358	320.519	301.511
High	0.25	121.745	239.517	235.965	236.118	190.744	202.004	167.094
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		243.677	327.584	324.826	324.979	289.184	313.190	290.293

Table G.14

Payoff Table for *B. napus* with Medium (1981) Price Expectations
(High Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs:			$ per hectare...............			
Very low	0.05	580.728	567.064	562.518	562.671	576.182	571.789	576.633
Low	0.25	435.398	508.459	507.465	507.618	478.506	530.647	496.125
Average	0.40	290.364	415.223	413.045	413.198	350.344	383.541	359.970
High	0.25	145.034	287.948	284.586	284.739	228.101	242.355	199.841
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		290.290	392.861	390.446	390.599	345.371	374.809	346.606

Table G.15

Payoff Table for B. napus with High (1981) Price Expectations
(High Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	673.978	660.314	655.768	655.921	669.432	665.039	669.883
Low	0.25	505.312	592.298	591.874	592.027	556.072	617.291	576.447
Average	0.40	336.989	484.091	482.293	482.446	407.330	446.563	418.430
High	0.25	168.323	336.379	333.207	333.360	265.458	282.706	232.588
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		336.903	458.138	456.065	456.218	401.559	436.429	402.920

Table G.16

Payoff Table for *B. napus* with Low (1981) Price Expectations
(High Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	487.479	473.815	469.269	469.422	482.933	478.540	483.384
Low	0.20	365.485	424.619	423.055	423.208	400.941	444.004	415.802
Average	0.30	243.739	346.355	343.796	343.949	293.358	320.519	301.511
High	0.40	121.745	239.517	235.965	236.118	190.744	202.004	167.094
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		219.291	307.645	304.689	304.842	268.413	289.238	264.416

Table G.17

Payoff Table for *B. napus* with Medium (1981) Price Expectations
(High Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	580.728	567.064	562.518	562.671	576.182	571.789	576.633
Low	0.20	435.398	508.459	507.465	507.618	478.506	530.647	496.125
Average	0.30	290.364	415.223	413.045	413.198	350.344	383.541	359.970
High	0.40	145.034	287.948	284.586	284.739	228.101	242.355	199.841
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		261.239	369.108	366.456	366.609	320.627	346.276	315.779

Table G.18

Payoff Table for B. napus with High (1981) Price Expectations
(High Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	673.978	660.314	655.768	655.921	669.432	665.039	669.883
Low	0.20	505.312	592.298	591.874	592.027	556.072	617.291	576.447
Average	0.30	336.989	484.091	482.293	482.446	407.330	446.563	418.430
High	0.40	168.323	336.379	333.207	333.360	265.458	282.706	232.588
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		303.187	430.571	428.223	428.376	372.841	403.315	367.143

Table G.19

Payoff Table for *B. campestris* with Low (1981) Price Expectations
(Low Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	279.269	265.605	261.059	261.212	274.723	270.330	275.174
Low	0.40	209.452	237.529	234.722	234.875	227.764	250.702	236.663
Average	0.30	139.635	192.558	189.254	189.407	166.146	179.891	171.069
High	0.20	70.066	131.934	127.884	128.037	107.758	112.309	94.295
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		153.648	191.763	188.384	188.537	176.010	189.779	178.399

Table G.20

Payoff Table for _B. campestris_ with Medium (1981) Price Expectations
(Low Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	332.691	319.027	314.481	314.634	328.145	323.752	328.596
Low	0.40	249.518	285.580	283.106	283.259	272.203	300.368	282.717
Average	0.30	166.345	232.006	228.940	229.093	198.798	216.012	204.577
High	0.20	83.469	159.785	155.831	155.984	129.241	135.503	113.116
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		183.039	231.059	227.904	228.057	210.549	227.792	213.308

Table G.21

Payoff Table for B. campestris with High (1981) Price Expectations
(Low Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	386.112	372.448	367.902	368.055	381.566	377.173	382.017
Low	0.40	289.584	333.631	331.489	331.642	316.641	350.035	328.772
Average	0.30	193.056	271.454	268.626	268.779	231.449	252.133	238.084
High	0.20	96.872	187.636	183.777	183.930	150.723	158.697	131.937
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		212.430	270.355	267.423	267.576	245.087	265.805	248.218

Table G.22

Payoff Table for *B. campestris* with Low (1981) Price Expectations
(Low Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	279.269	265.605	261.059	261.212	274.723	270.330	275.174
Low	0.25	209.452	237.529	234.722	234.875	227.764	250.702	236.663
Average	0.40	139.635	192.558	189.254	189.407	166.146	179.891	171.069
High	0.25	70.066	131.934	127.884	128.037	107.758	112.309	94.295
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		139.697	181.986	178.496	178.649	163.848	175.779	164.721

Table G.23

Payoff Table for B. campestris with Medium (1981) Price Expectations
(Low Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	332.691	319.027	314.481	314.634	328.145	323.752	328.596
Low	0.25	249.518	285.580	283.106	283.259	272.203	300.368	282.717
Average	0.40	166.345	232.006	228.940	229.093	198.798	216.012	204.577
High	0.25	83.469	159.785	155.831	155.984	129.241	135.503	113.116
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		166.419	219.412	216.124	216.277	196.060	211.113	197.014

Table G.24

Payoff Table for B. campestris with High (1981) Price Expectations
(Low Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	386.112	372.448	367.902	368.055	381.566	377.173	382.017
Low	0.25	289.584	333.631	331.489	331.642	316.641	350.035	328.772
Average	0.40	193.056	271.454	268.626	268.779	231.449	252.133	238.084
High	0.25	96.872	187.636	183.777	183.930	150.723	158.697	131.937
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		193.142	256.838	253.752	253.905	228.272	246.448	229.307

Table G.25

Payoff Table for B. campestris with Low (1981) Price Expectations
(Low Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	279.269	265.605	261.059	261.212	274.723	270.330	275.174
Low	0.20	209.452	237.529	234.722	234.875	227.764	250.702	236.663
Average	0.30	139.635	192.558	189.254	189.407	166.146	179.891	171.069
High	0.40	70.066	131.934	127.884	128.037	107.758	112.309	94.295
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		125.771	170.644	167.017	167.170	152.009	162.101	149.925

Table G.26

Payoff Table for B. campestris with Medium (1981) Price Expectations
(Low Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	332.691	319.027	314.481	314.634	328.145	323.752	328.596
Low	0.20	249.518	285.580	283.106	283.259	272.203	300.368	282.717
Average	0.30	166.345	232.006	228.940	229.093	198.798	216.012	204.577
High	0.40	83.469	159.785	155.831	155.984	129.241	135.503	113.116
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		149.829	205.900	202.449	202.602	181.956	194.819	179.388

Table G.27

Payoff Table for B. campestris with High (1981) Price Expectations
(Low Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	386.112	372.448	367.902	368.055	381.566	377.173	382.017
Low	0.20	289.584	333.631	331.489	331.642	316.641	350.035	328.772
Average	0.30	193.056	271.454	268.626	268.779	231.449	252.133	238.084
High	0.40	96.872	187.636	183.777	183.930	150.723	158.697	131.937
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		173.888	241.156	237.881	238.034	211.903	227.537	208.851

Table G.28

Payoff Table for *B. campestris* with Low (1981) Price Expectations
(High Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	325.980	312.316	307.770	307.923	321.434	317.041	321.885
Low	0.40	244.485	279.519	276.960	277.113	266.772	293.934	276.913
Average	0.30	162.990	227.094	223.790	223.943	194.719	211.445	200.388
High	0.20	81.495	155.786	151.737	151.890	125.896	132.186	110.445
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		179.289	226.026	222.746	222.899	206.148	222.849	208.860

Table G.29

Payoff Table for *B. campestris* with Medium (1981) Price Expectations
(High Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	388.336	374.672	370.126	370.279	383.790	379.397	384.241
Low	0.40	291.252	335.602	333.424	333.577	318.673	351.870	330.667
Average	0.30	194.168	273.148	270.082	270.235	232.836	253.602	239.503
High	0.20	97.084	188.200	184.246	184.399	150.848	159.182	132.355
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		213.585	271.876	268.839	268.992	246.452	267.188	249.596

Table G.30

Payoff Table for B. campestris with High (1981) Price Expectations
(High Yield Range - Low Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	450.693	437.029	432.483	432.636	446.147	441.754	446.598
Low	0.40	338.020	391.685	389.887	390.040	370.573	409.807	384.422
Average	0.30	225.347	319.203	316.375	316.528	270.954	295.760	278.619
High	0.20	112.673	220.614	216.755	216.908	175.800	186.178	154.266
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		247.881	317.726	314.932	315.085	286.755	311.527	290.333

Table G.31

Payoff Table for B. campestris with Low (1981) Price Expectations
(High Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	325.980	312.316	307.770	307.923	321.434	317.041	321.885
Low	0.25	244.485	279.519	276.960	277.113	266.772	293.934	276.913
Average	0.40	162.990	227.094	223.790	223.943	194.719	211.445	200.388
High	0.25	81.495	155.786	151.737	151.890	125.896	132.186	110.445
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		162.990	214.596	211.168	211.321	191.899	206.513	192.884

Table G.32

Payoff Table for B. campestris with Medium (1981) Price Expectations
(High Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		...............Returns Net of Chemical Costs: $ per hectare...............						
Very low	0.05	388.336	374.672	370.126	370.279	383.790	379.397	384.241
Low	0.25	291.252	335.602	333.424	333.577	318.673	351.870	330.667
Average	0.40	194.168	273.148	270.082	270.235	232.836	253.602	239.503
High	0.25	97.084	188.200	184.246	184.399	150.848	159.182	132.355
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		194.168	258.260	255.046	255.199	229.477	247.727	230.564

Table G.33

Payoff Table for *B. campestris* with High (1981) Price Expectations
(High Yield Range - Average Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	450.693	437.029	432.483	432.636	446.147	441.754	446.598
Low	0.25	338.020	391.685	389.887	390.040	370.573	409.807	384.422
Average	0.40	225.347	319.203	316.375	316.528	270.954	295.760	278.619
High	0.25	112.673	220.614	216.755	216.908	175.800	186.178	154.266
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		225.347	301.924	298.924	299.077	267.055	288.941	268.245

Table G.34

Payoff Table for B. campestris with Low (1981) Price Expectations
(High Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments: Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	325.980	312.316	307.770	307.923	321.434	317.041	321.885
Low	0.20	244.485	279.519	276.960	277.113	266.772	293.934	276.913
Average	0.30	162.990	227.094	223.790	223.943	194.719	211.445	200.388
High	0.40	81.495	155.786	151.737	151.890	125.896	132.186	110.445
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		146.691	201.279	197.702	197.855	177.973	190.500	175.567

Table G.35

Payoff Table for B. campestris with Medium (1981) Price Expectations
(High Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	388.336	374.672	370.126	370.279	383.790	379.397	384.241
Low	0.20	291.252	335.602	333.424	333.577	318.673	351.870	330.667
Average	0.30	194.168	273.148	270.082	270.235	232.836	253.602	239.503
High	0.40	97.084	188.200	184.246	184.399	150.848	159.182	132.355
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		174.751	242.395	239.004	239.157	212.887	228.650	209.934

Table G.36

Payoff Table for B. campestris with High (1981) Price Expectations
(High Yield Range - High Damage Skewness)

State of Nature X	Probability P(X)	Treatments						
		Do Nothing	Furadan	Furadan Plus Lindane	Furadan Plus Spray	Lindane	Lindane Plus Spray	Furadan Spray
		..............Returns Net of Chemical Costs: $ per hectare..............						
Very low	0.05	450.693	437.029	432.483	432.636	446.147	441.754	446.598
Low	0.20	338.020	391.685	389.887	390.040	370.573	409.807	384.422
Average	0.30	225.347	319.203	316.375	316.528	270.954	295.760	278.619
High	0.40	112.673	220.614	216.755	216.908	175.800	186.178	154.266
Very high	0.05	0.0	(13.664)	(18.210)	(18.057)	(4.546)	(8.939)	(4.095)
Expected Revenue Net of Chemical Costs		202.812	283.512	280.306	280.459	247.801	266.801	244.302