

ESTIMATING THE MARGINAL PRODUCTIVITY OF PESTICIDES
ON IRRIGATED CORN AND GRAIN SORGHUM FARMS
IN WESTERN KANSAS

by

James R. Sleper

B. S., University of Missouri-Columbia, 1980

A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Economics

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1982

Approved by:


Major Professor

Spec.
Coll.
LD
2668
.T4
1982
564
C.2

11202 315698

TABLE OF CONTENTS

	Page
List of Tables	iii
List of Figures	v
Acknowledgments	vi
Chapter	
I. Introduction	1
Magnitude of Pest Damage	
Increasing Importance of Pesticides	
Policies and Laws Pertaining to Pesticides	
Objective of this Study	
Data Used for the Study	
II. Review of the Literature	12
III. Economic Production Function Theory	20
Response Curves	
Types of Production Functions	
Cause and Effect Functions	
Methods of Controlling Pests	
Altered Environment	
Planting Dates Altered	
Crop Rotation	
Cultivation	
Fallow	
IV. The Model	31
Regression Analysis	
Statistical Concepts	
Types of Regression Models	

Description of Farm Data	
The Sample	
Variables Examined	
Dependent Variable	
Independent Variables	
Dummy Variables	
Various Pesticide Equations	
V. Results	58
Irrigated Corn Analysis	
Yearly Differences-Corn	
Individual Year Models	
Irrigated Grain Sorghum Analysis	
Yearly Differences-Grain Sorghum	
VI. Conclusion and Implications	75
Findings	
Limitations and Assumptions of the Data	
References	78
Appendix	81
Abstract	82

LIST OF TABLES

Table	Page
1. Volume Of Pesticide Sales During 1966-1976 (Million Pounds Of Active Ingredient).	4
2. U.S. Fertilizer Use Per Acre During 1950-1980	5
3. Energy Breakdown Within Agriculture (BTU's)	6
4. Farm Output Changes During 1850-1970	8
5. Value Of The Marginal Products Computed By Headley	13
6. Marginal Rates Of Substitution And Elasticity Of Substitution Of Cropland And Insecticides, By Region, United States, 1964	15
7. Value Of The Marginal Products Computed By Janke	16
8. Total And Irrigated Acres, Gross And Net Income, And Capital Managed Per Farm For Irrigated Corn And Grain Sorghum Farms (1973-1979)	46
9. Total Number of Farms Irrigating Corn And Grain Sorghum And Number By Year In The Sample	47
10. Indices Used To Deflate Gross Income (1973- 1979)	49
11. Independent Variable Means Per Farm For The Irrigated Corn And Grain Sorghum Farms (1973-1979)	51
12. Independent Variable Means And Standard Deviations Per Acre For The Irrigated Corn And Grain Sorghum Farms (1973-1979)	52
13. Cost Indices Used To Deflate The Independent Variables (1973-1979)	53
14. Regression Variables Used In Study And Their Respective Codes	59
15. Corn VMP For All 6 Index Variables	65
16. Corn Correlation Matrix	66
17. Grain Sorghum VMP For All 6 Independent Variables	72

18. Grain Sorghum Correlation Matrix	73
--	----

LIST OF FIGURES

Figure	Page
1. The Classical Production Function	22
2. Hypothetical Regression Analysis Equation	33
3. General Non-Linear Function	35
4. General Quadratic Function Curve	40
5. General Cobb-Douglas Function Curve	42
6. Farm Management Associations For The State Of Kansas	44
7. General Stair-Step Curve For Pesticides	56
8. General Value Marginal Product Curve	61

Acknowledgments

I wish to express a sincere appreciation and thanks to my major professor Dr. Orlan H. Buller, Professor of Agricultural Economics, for his patience and valuable experience in helping me with this thesis. In addition, I wish to thank Dr. Larry N. Langemeir and Dr. Bryan Schurle for serving on my graduate committee. A special gratitude goes to Dr. Jeff Williams for his helpfulness during my graduate studies. Also, a very special thanks goes to my wife, Pam, for her patience and encouraging love.

Chapter I

Introduction

Agriculturalists and other professionals have become very concerned about the increase in the use of pesticides the last few decades. The concern relates to the safe use and profitability of pesticides. Careful management in the use, kind and time of purchase is required for a profitable return. Knowledge about the various pesticides available and their physical characteristics is an important concern for farm managers.

The story of the Irish Potato famine has become a legend in many parts of the world. Because of the potato blight, Ireland's population declined by 2 million people in 6 years from 1845-1851.

Even during biblical times "bugs" were a big problem for farmers. In folklore, the word "bug" represents a devil and in the English language the word "bug" until the seventeenth century meant an evil spirit.

Plant diseases, weeds, and various insects have been the "villain" for centuries. However, since World War II, progress in controlling these pests has been dramatic. Since WWII dramatic discoveries and developments of crop control agents have completely altered farming practices including: seed treatments, pre-post emergent weed control, brush control, defoliation, and fruit setting.

Before 1800 simple materials such as lye, lime, and soap were used to control pests. Then, in 1867 use of Paris

Green to control the Colorado beetle marked the beginning of the use of commercial pesticides.

The term pesticides has many definitions and includes many types. For instance, pesticides to an entomologist has a completely different context than to a chemist. This study concentrates on the broad class of pesticides representing herbicides, insecticides, and fungicides. However, pesticides also include nematocides, lanpreycides, gametocides, and antioxidants. Herbicides are those chemicals used to control or kill vegetation. Insecticides are those chemicals used to control or kill insects and, fungicides are chemicals used to control or kill fungi.

Magnitude of Pest Damage

Pests are a major cause in destroying agricultural products. The term pests in this context is referred to as viruses, bacteria, weeds, and insects, but the damage to agriculture caused by these pests is very difficult to assess. Insects cause an average loss of at least 10 percent of the value of every crop, every year. In the United States alone, insect damage is calculated to be about 3.5 billion dollars per year.(5) Plant diseases are calculated to be 2.9 billion dollars and weeds account for 3.7 billion dollars of damage per year in the U.S.

Worldwide, pests destroy a much larger share of agricultural production. For instance, it has been estimated that insects damage over 21 billion dollars in crops alone every year. The overall damage to worldwide

agricultural production has been estimated to be over 80 billion dollars (in terms of the U.S. dollar).(5)

Increasing Importance of Pesticides

The food system uses one-sixth of all energy used in the United States. The use of pesticides and fertilizers which account for more than a third of the energy used in actual agricultural production has trended upward, especially during the past few decades. For example, corn is the major crop on which herbicides are used. And in 1964, 43 percent of the total corn acres in the United States were treated with herbicides. In 1981, just seventeen years later, 98 percent of all corn acreage was treated with herbicides.

The use of fertilizer has increased more than pesticides. Fertilizer nutrient use per acre is 5 times the 1950 rate, and is the primary reason for increased crop yields. However, increasing energy costs tend to restrain the use of some pesticides and fertilizers. Tables 1, 2, and 3 show the importance that fertilizers and herbicides have played in agriculture.(25)

Agricultural production relies heavily on fossile fuels (petrochemicals) for producing, processing, and distributing food products in the United States. Extensive usage of fertilizers, herbicides, insecticides, and fuels has increased, and the production requires large amounts of energy. Therefore, it is very important for research to develop economical usage procedures for these inputs as well

TABLE 1. Volume Of Pesticide Sales During 1966-1976
(Million Pounds Of Active Ingredient)

Year	Herbicide	Insecticide	Fungicide
1966	110	155	30
1971	230	175	40
1976	390	180	50

Source: 1978 Handbook of Agricultural Charts, U.S.
Department of Agriculture, No. 551.

TABLE 2. U.S. Fertilizer Use Per Acre During 1950-1980

Year	Fertilizer Pounds per acre
1950	30
1960	44
1970	110
1980	130

Source: 1978 Handbook of Agricultural Charts, U.S.
Department of Agriculture, No. 551.

TABLE 3. Energy Breakdown Within Agriculture (BTU's)

Activity	Trillion BTU's
Crop Drying	75
Irrigation	260
Transportation	370
Machinery	469
Pesticides & Fertilizers	764
Miscellaneous	81

Total	2022

Source: 1978 Handbook of Agricultural Charts, U.S.
Department of Agriculture, No. 551.

as finding new substitutes.

Policies and Laws Pertaining to Pesticides

"The use of modern pesticides very often represents the difference between profitable crop production and no crop at all." (5)

The use of pesticides in the United States agriculture has resulted in intensifying production techniques. This has allowed pesticides to be used as substitutes for labor and equipment, and its use is trending up. Insecticide sales are expected to be up 10 to 15 percent in 1982 as compared to 1981 and 1980. The quantity of the active ingredient in herbicides is expected to increase by 5 percent this year, thus agricultural chemicals have and continue to play an important role in the revolution of modern farm production.

Another aspect in which pesticides have changed agriculture is through dramatic increases in farm output production. For example, farm output has increased by 250 percent from 1940 to 1960, a rate of change about twice that which occurred during the entire previous century. (5) Yields of many crops have doubled or even tripled since World War II. Table 4 illustrates the increase in output that agriculture has realized.

Agricultural chemicals are an essential part of modern farming practices. They have enabled new standards in food production and quality. However, even after all this optimism, some discretion is needed. Increased attention

TABLE 4. Farm Output Changes During 1850-1970

Year	
1850	one farmer produces food & fiber for 4.18 people
1900	one farmer produces food & fiber for 6.95 people
1940	one farmer produces food & fiber for 10.69 people
1950	one farmer produces food & fiber for 15.49 people
1960	one farmer produces food & fiber for 25.00 people
1970	one farmer produces food & fiber for 48.00 people

Source: Research in Pesticides, edited by C. O. Chichester, "Methods of Estimating Effects", by Robert L. Metcalf, pp. 17-29.

has focused on the controversy by government agencies and private companies on the risk and benefits of chemicals.

The controversy mentioned pertaining to the use of pesticides has been debated with respect to social and economic pressures. Even recently the problem of Viet Nam veteran and refugee exposure to "Agent Orange" has developed. Perhaps the strongest opposition to pesticides was during the 1960's when the Department of Agriculture was sued because of the use of DDT to control the gypsy moths.

The effects of pesticides has caused great concern about their use. New laws, policies, and agencies have been set up to try to control the use of various pesticides. The Food and Drug Administration, Delaney Amendment, and the Department of Agriculture share the responsibility of protecting our environment so it will not be adversely affected by these chemicals.

Today's farmer is subject to pressure from consumers to keep the so called "poisons" off the food. More research is needed to develop new pesticides that have less harmful effects without reducing control.

Objective of this Study

Past studies have indicated that chemical pesticides are a highly productive input compared to fertilizer and other inputs. The objective of this study was to estimate the marginal value product of pesticides on irrigated crops in southwest Kansas. The analysis used regression models to estimate production functions. The types of equations

estimated were linear, Cobb-Douglas, and quadratic. Using these equations, the marginal return from pesticides was calculated. In addition, the marginal returns were estimated for inputs machinery repair, interest paid, seed, fertilizer, and fuel expense.

Data Used for the Study

Data used in this study were taken from records of Farm Management Association 3 and 5 for the years 1973 to 1979. Farmers pay a fee to this association for assistance in keeping farm business records, production records, preparing taxes, and analyzing financial situations. Therefore, the averages of farms used in this study are believed to have higher gross and net incomes, and more expertise in management, than the average of all farms in the region. More discussion concerning the data can be found in Chapter IV.

Only irrigated corn and grain sorghum farms in western one-third of Kansas were examined. Irrigation farmers were selected because pesticides are a major input in production. Because of the limited amount of rainfall (usually less than 20 inches per year), many farmers irrigate so that weed, insect and disease control is needed for profitable production. The primary irrigated crops in this area include corn and grain sorghum. Because of limited irrigation water in this region and the recent increases in input costs, farmers in western Kansas need to know as much as possible about maximizing income with respect to the use

of various pesticides. Therefore, this study is to provide information to farmers in western Kansas and other similar areas so that profitable economic decisions can be made.

CHAPTER II

REVIEW OF THE LITERATURE

"The purpose of research on agricultural production functions is to provide a better understanding of input-output relationships and thus provide general guides and indications useful to farm managers".(7) The most common method used to evaluate the return from an added dollar spent on pesticides is the use of marginal analysis. Marginal analysis considers the added returns and added cost of the input being used.

"The most quoted study concerning the value of pesticides to agricultural production is that of Headley in 1968."(19) Headley estimated the marginal productivity of pesticides and other farm inputs including labor, land and buildings, machinery, fertilizer, and other expenses. The USDA farm income and expense data for 1963 was used. An average farm for each state comprised the sample. Using the Cobb-Douglas function, the value of marginal product (VMP) ranged from \$3.90 to \$5.66 for pesticide expense. Headley considered his best estimate of marginal productivity of pesticides to be \$4.16 in gross income for the marginal dollar spent on pesticides. Table 5 shows Headley's estimates of VMP for the various other farm inputs.

In addition, Headley estimated marginal rates of substitution of cropland for insecticides. The marginal rate of substitution is the reduction in ounces of insecticides per one acre increase in cropland without

TABLE 5. Value Of The Marginal Products Computed By Headley

Variables	Regression equations			
	1	2	3	4
Total labor	\$2.16/day	\$1.40/day	\$3.82/day	\$4.21/day
Land and buildings	.06/1.00	.08/1.00	.06/1.00	.08/1.00
Machinery	2.40/1.00	--	2.43/1.00	.26/1.00
Other	.97/1.00	--	.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	--

reducing output. He found that marginal rates of substitution of cropland for insecticides vary substantially among different areas of the United States. For example, marginal rates of substitution varied from -3.257 in the Southeast region to -.80 in the Lake States region. The negative sign indicates that pesticide use substitutes for land use. For example, increasing pesticide use decreases land use to produce a given amount of output. Furthermore, the elasticity of substitution between different areas were found. The elasticity of substitution is the percentage decrease in insecticide divided by one percent increase in cropland. A negative elasticity sign indicates substitutability between the inputs. The marginal rates of substitution and elasticity of substitution for the various regions are found in Table 6.(11)

Janke in 1978 estimated the value of pesticides on crop farms in northeast Kansas using three types of production functions. The production functions used consisted of: linear, Cobb-Douglas, and quadratic. He found the linear and quadratic forms appeared to have the best fit. The model used a combination of time series and cross sectional data for the years 1974 to 1978. The linear functional form indicated that on the average, northeastern Kansas farmers earned \$2.78 gross income per dollar expended on pesticides. The quadratic function revealed a return of \$3.26 per dollar spent on pesticides. Estimates of marginal benefits from expenditures on fertilizer, depreciation, and labor are

TABLE 6. Marginal Rates Of Substitution And Elasticity Of Substitution Of Cropland And Insecticides, By Region, United States, 1964

Region	Marginal rate of substitution of cropland for ₁ insecticides ¹	Elasticity of substitution cropland for ₂ insecticides ²
Appalachian	-33.19	-2.70
Corn Belt	-10.03	-4.33
Delta States	-256.47	-14.89
Lake States	-.80	-8.16
Pacific	-24.06	-6.49
Mountain	-.97	-7.77
Southeast	-3257.00	-326.67
Southern Plains	-537.17	-326.67
United States ³	-13.24	-6.49

¹ Ounces of insecticide reduced per 1-acre increase in cropland.

² Percentage decrease in insecticides per 1-percent increase in cropland.

³ Does not include Alaska and Hawaii.

TABLE 7. Value Of The Marginal Products Computed By Janke

Variable	Equations		
	Linear	Cobb-Douglas	Quadratic
Pesticide expense	\$2.78/1.00	\$2.00/1.00	\$3.25/1.00
Depreciation expense	\$1.67/1.00	\$2.89/1.00	\$1.71/1.00
Fertilizer expense	\$1.32/1.00	\$.75/1.00	\$1.82/1.00
Labor hired expense	\$1.51/1.00	\$3.22/1.00	\$4.01/1.00
R ²	.62	.45	.66

given in Table 7.

Heady and Auer (1966) estimated the portion of increased predicted yields due to weather and technology for several major U.S. crops. Time series production functions were used for the time period 1939 to 1960. An approximated first-term Taylor expansion was used to estimate the annual changes in expected state crop yields. The research showed that a 24.7 bushel increase in corn yield was due to weather, fertilizer, hybrid improvement, location and other nonspecified variables. Fertilizer application was estimated to increase corn yield by 9.7 bushels.

Hawkins et al in 1977, estimated the returns to range from \$3.30 to \$4.89 per dollar spent on herbicides. Ten years of experimental data treatment on different crop rotation systems was used.

Carlson (1977) computed marginal products for insecticides used on cotton in five regional cotton growing areas. Data was collected by personal interviews with cotton producers during the 1964 to 1969 period. Carlson found the expenditure for insecticides to be relatively constant for this time period. However, the marginal productivity fell each year. This was attributed to a declining kill function possibly due to insects becoming immune to insecticides. The marginal physical product of the insecticide varied from a low of 48.30 to a high of 1024 pounds of cotton per insecticide unit. The primary reasons for this wide range was due to the range of years used in the study and regional

locations.

In 1976, Cambell estimated the marginal productivity of pesticides on tree-fruit farms. Data used in the study included irrigation water, labor, fertilizers and pesticide sprays from a survey of 57 orchards in British Columbia. A Cobb-Douglas production function was used to estimate that the marginal value product was significant for these types of farms. The findings showed that every pesticide dollar used resulted in a \$12 return. Therefore, the marginal costs of reducing pesticide use are relatively high.

Schroder et al (19) 1981 computed the marginal private benefit/cost return to be \$2.30 per dollar of herbicide cost for additional land treated with herbicides. Pooled cross-sectional time series data was used to estimate the production function. The study identified contributions of technology and weather to soybean yield variation for the 1965 to 1979 period for the Corn Belt region. The technology variables used included: genetic improvement, herbicides, and row-width.

Schroder et al (20) 1981 estimated a regional cross-sectional production function for the period 1964 to 1979 for the Corn Belt region. The study used a Cobb-Douglas equation and a first degree polynominal equation. The research examined the technology and weather to corn yield variation. The technological variables included: genetic improvement, acres treated with herbicides and insecticides, fertilizers, and plant populations. A pooled cross-

sectional time series data base was used for the analysis. Results indicated that the marginal value of a one-dollar expenditure for chemical ranged from \$2.00 to \$4.00 depending on the equation used.

Cashman et al in 1980 estimated the farm level impact of selected soybean insecticides with respect to EPA laws. A mathematical programming model was used to simulate the operation of a 600 acre Indiana corn-soybean farm. The study found the benefit/cost ratio for each of the three soybean insecticides was greater than \$2.00 for every dollar spent on insecticides. The analysis used 1979 cost and price data. Using regression analysis on experimental plot data, gains of 2.5, 2.9, and 3.4 bushels per acre were found using the three insecticides studied. The three insecticides examined were carbaryl, methomyl, and malathion respectively.

CHAPTER III

ECONOMIC PRODUCTION FUNCTION THEORY

Response Curves

Every physical output that is being produced has at least two different forms of inputs. In the agricultural sector, crop production requires many different inputs such as seed, fertilizer, soil, fuel, labor, and management. These few mentioned inputs are a fraction of the total amount of inputs needed in agricultural output production.

Social scientists as well as physical scientists express the input/output relationship in terms of a production function, that is, a quantity of output is determined by a specified quantity of inputs. The following equation describes such a relationship.

$$(1) \quad Y = f(X_1, X_2, X_3, \dots, X_n)$$

The term "Y" is usually referred to as the yield, response, or product; more commonly stated as the output being produced. The terms $X_1, X_2, X_3, \dots, X_n$ represent the various inputs used to produce product "Y". Therefore, product "Y" depends on the inputs $X_1, X_2, X_3, \dots, X_n$.

An agricultural production function shows that every output produced requires some amount of resource input. However, crop and livestock production requires many different forms of inputs. It is impossible to list all the inputs involved in producing a particular commodity. Therefore, theory allows us to simplify the production

function by using only the most important inputs. This theory is concerned with quantity of output achieved in relation to varying input quantities.

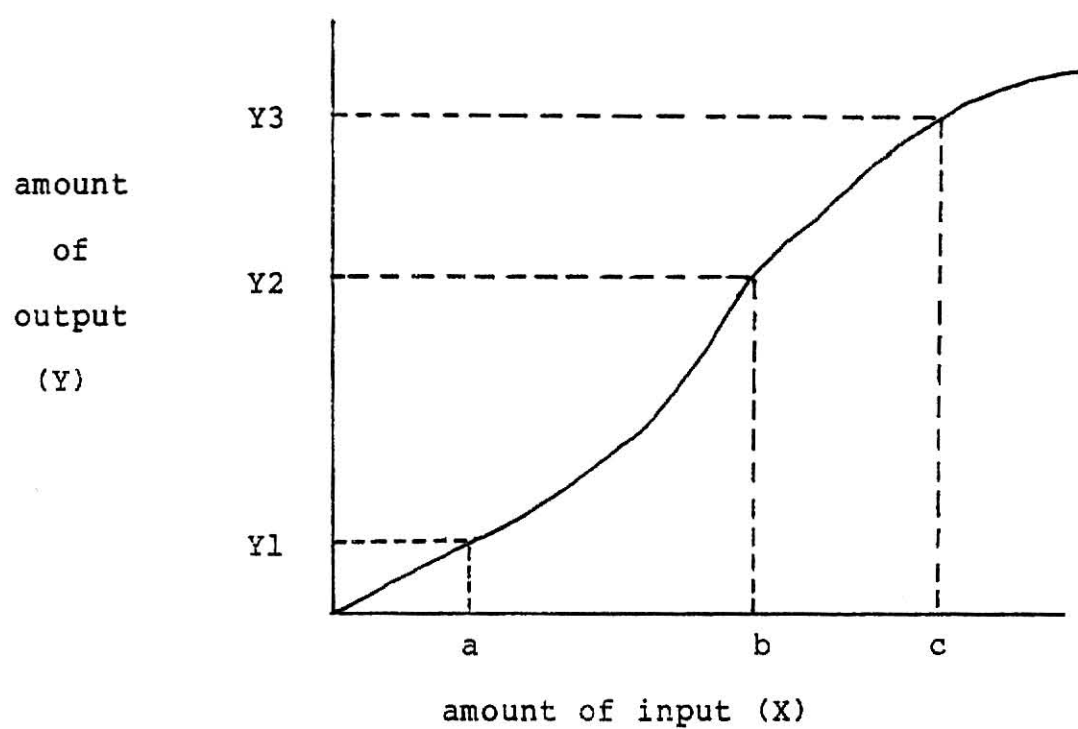
Production function theory states for livestock and crop production that:

- a) "there is a continuous smooth causal relation between the X's (inputs) and Y (output).
- b) diminishing returns prevail with respect to each input factor that the additional output from succeeding units of X becomes less and less; indeed, beyond some peak yield additional units of X may have an increasingly deleterious effect on yield.
- c) decreasing returns to scale prevail so that an equal proportionate increase in all inputs results in a less than proportionate increase in output."(6)

The second (b) criterion is the most important concept in understanding the nature of production functions, because usually there are "diminishing returns" associated with production. "The law of diminishing returns states that if increasing amounts of one input are added to a production process while all other inputs are held constant, the amount of output added per unit of variable input will eventually decrease".(7)

Figure 1 illustrates the law of diminishing returns of the classical type. Between input points a and b output

FIGURE 1. The Classical Production Function



where: all other factors (inputs) are assumed to be constant.

increases at an increasing rate as successive amounts of inputs are being used. This exemplifies increasing marginal returns. The term marginal, refers to the change in output as one unit of input is either increased or decreased. In this case, output increases at an increasing rate as successive units of input are being used (from a to b). Between points b and c, output increases at a decreasing rate as successive inputs are used. This input/output relationship is described as the law of diminishing marginal returns. Diminishing returns occurs because of the influence of the fixed factors. Biological conditions that limit crop and livestock growth result in this unique relationship between input and output.

The law of diminishing marginal returns infers that there is a "right amount" of input to be used in conjunction with the fixed inputs in producing product Y. Every manager should recognize that neither too little nor too much input should be used. With an understanding of the law of diminishing marginal returns, profitable decision making can be made concerning the correct amount of input used to produce a product.

In calculating this "right amount" of input that should be used, a few assumptions should be made. First of all, cost of the input and price of the product are assumed to be known. The production function is known from research or records.

The marginal physical product (MPP) concept is needed

to calculate the most profitable input used in production of output Y. The marginal physical product is the change in output resulting from an increment change in input. The marginal physical product measures the amount of output either being increased or decreased as the amount of input is being increased or decreased. The marginal physical product is computed by taking the first derivative of a known production function.

$$(2) \quad \text{MPP} = dY/dX \quad \text{or} \quad \Delta Y/\Delta X$$

where Δ = the change in output Y (eg. $Y_1 - Y_2 = \Delta Y$).

Equation 2 shows the algebraic formula for computing the marginal physical product. Multiplying the price of product Y by the MPP determines the marginal value product. Equating the marginal value product to the cost of the input is the most profitable amount of input use. For example, equation 3 shows this relationship.

$$(3) \quad P_Y * \text{MPP} = P_X$$

Value marginal product is referred to as the added benefit of producing one additional unit of product. Therefore, we can then reduce equation 3 to the following equation:

$$(4) \quad \text{VMP} = P_X$$

Equation 4 illustrates that when the value marginal product is equal to the cost of the input, that particular level of output is the most profitable. If the VMP is greater than the P_X (price of input X), it is profitable to increase the quantity of the input X to produce an additional unit of

product "Y". The idea of diminishing marginal returns suggests that MPP decreases, so, at some finite amount of input "X", the condition of $VMP = P_x$ will be satisfied.

Types of Production Functions

Defining crop and livestock production functions requires mathematics, statistics, economic theory, and most of all basic understanding of the relationship between inputs and outputs used.

One type of production function used in this study is linear. This type has a constant VMP because each additional unit of output produces a constant increase in output. This implies that when the VMP is greater than the price of the input, then an infinite amount of production would be profitable. Linear production functions do not adequately define the situation being studied. For example, the linear type suggests that there are constant returns to scale throughout the entire production process. This concept indicates that growth and biological limits do not exist.

Another type of production function used in this study is nonlinear. This production function describes data using a nonlinear type of an equation. In this case, the VMP can be either increasing, decreasing or both; thus, suggesting increasing or decreasing diminishing marginal returns respectively. During the former case where VMP is increasing, more input would increase returns at an increasing rate. However, when VMP is decreasing, added returns

decrease with each unit increase in input; therefore, at some point VMP is equal to the cost of the input and the profit maximizing, or loss minimizing, situation is determined. Nonlinear production functions are used whenever they describe biological and physical limits as in diminishing marginal returns. A few different types of nonlinear production functions will be described in the next chapter along with a more detailed description of linear production functions.

Cause and Effect Functions

The data used in this study used various variable expenses such as, labor, interest, seed, fertilizer, fuel, and herbicides. These variable expenses were then related to gross income. The linkages between each of these variable expenses to gross income is through a chain of cause and effect relationships. In this study, the use of pesticides was the primary variable expense being examined. The chain of functions on how pesticides affect gross income is as follows. Pesticides are used to eradicate weeds, kill insects, control diseases, etc. In the case of weed control the expression in equation form is:

$$(5) \quad WC = f(P)$$

where WC = weed control and

P = pesticide usage.

The reason for controlling weeds is to increase crop yield and so $Y = f(WC)$, where Y = crop yield. Income is a function of crop yield where $I = f(Y)$; therefore, by

substitution $I = f(P)$ or income is a function of pesticide usage. (15)

This study develops a production function of the following form:

$$(6) \quad \text{gross income} = f(P, S, F, I, L)$$

where P = pesticides,

S = seed,

F = fertilizer,

I = interest,

L = labor

Equation 6 specifies the various inputs (pesticides, seed, etc.) that are used to produce gross income. Data used report inputs in dollars spent and not physical quantities used. The production function developed is not a physical input-output relationship in the classical sense.

Methods of Controlling Pests

The most widely used method of reducing or controlling the various pests such as weeds, insects, and diseases is through the use of pesticides. Nevertheless, the way in which these pesticides work depends on a countless number of factors. The complexity of pesticides is illustrated with herbicides as an example. There are several different brands and kinds of herbicides and each controls specific types of weeds. In addition, many factors influence a herbicide's effectiveness such as soil type, organic matter content of soil, temperature, and moisture. The primary problem facing farmers and others who are using herbicides

is that some of these factors change greatly from year to year, thus the effectiveness of weed control is easily altered.

To illustrate, soil moisture is needed to convey the herbicide from the soil up into the weed via the plant's root system. If not enough soil moisture is present, then the chemical is not as effective thus fewer weeds are controlled. On the other hand, if excessive moisture is present then the chemical is either washed away, diluted, or simply leached too deep within the soil for adequate weed kill. There are other variables just as important as moisture in determining the effectiveness of the herbicide which behave independently of the effect of moisture also.

Controls and methods other than chemicals are used to reduce and control pests. Pesticide use by farmers became extensive after World War II. Various other methods of controlling pests exist and have been practiced by farmers for years.

Altered Environment:

Farmers at times attempt to "alter the environment" as a means of controlling weeds. Weed populations can be reduced by permitting the weeds to germinate followed by discing and planting. This reduces weed population for the planting year. The newly planted crop has a "head start" on any remaining weeds.

Planting Dates Altered:

For many years insects have been partially controlled by altering the normal planting dates. During certain times, various insects and diseases are either mature or are more capable of damaging crops. If by selecting the planting date so that the plant grows and matures during the time insects are least effective, plant damage is reduced. However, the problem in using this tactic is that the planting date with regard to pest management may not be the best planting date with regard to best crop yield.

Crop Rotation:

Crop rotation has been used for many years to control weeds. The major idea is to "starve out" the pest by using unsusceptible crops or to change the normal environment of the pests. Many farmers use a small grain such as wheat, rye, or oats and a legume such as alfalfa, dispersed in the normal corn or soybean routine.

Cultivation:

Probably the most well known practice for controlling pests especially weeds is cultivation. Farmers, long before the use of commercial chemicals, relied primarily on this method to control weeds. Rotary hoes and cultivators have been and continue to be used by farmers as a means of uprooting or covering weeds. In addition, the soil is being aerated which may help the interchange of gases in the soil.

Fallow:

Fallow is allowing land to be idle for a year. The fallow years allow farmers time to destroy seeds. In semi-arid regions where fallow is commonly practiced, fallowing for weed control also conserves moisture.

CHAPTER IV

THE MODEL

Regression Analysis

Regression analysis was used to determine the marginal productivity of pesticides on irrigated corn and grain sorghum production in western Kansas. Regression analysis estimates the relationship between two types of variables, independent and dependent variables. Independent variables are sometimes referred to as predictor variables and can either be set to a desired value or take values that can be observed but not controlled. The dependent or response variables as the name implies "depends" on or is caused by the independent variable(s). In general, we shall be interested in finding how changes in the predictor variables affect the values of response variables; therefore, we try to discover a relationship of a response variable to one or several predictor variables.

Regression analysis is a method of estimating the relationships among variables. A simple linear regression equation considers the net relationship between one independent (explanatory) variable and one dependent variable. The following equation describes this linear relationship.

$$(7) \quad Y = B_0 + B_1X_1 + e$$

where Y = observable dependent variable

B_0 = constant (intercept)

B_1 = unknown population parameter to be estimated

X_1 = observable independent variable

e = unobserved error term

Equation 7 states that Y depends linearly on the observed X . The value B_1 is a parameter that shows how many units of change in the dependent variable is associated with one unit of change in the independent variable. This coefficient is used in determining the value of marginal product of an input.

Regression analysis is a process whereby a functional relationship is determined by minimizing the squared deviations between sample points of the dependent variables and the predicted estimated function. This mathematical process is called the method of least squares. Figure 2 illustrates the method of least squares. The "predicted regression line" is the regression equation of the line computed by the least squares method. Points A through F were used in this calculation. This line is the "best" straight line through the given data to relate variables Y and X .

Multiple regression uses the same principles as the single linear regression model; however, the difference is that more than one independent variable is used in the computation. The general equation used for the multiple linear regression model is as follows:

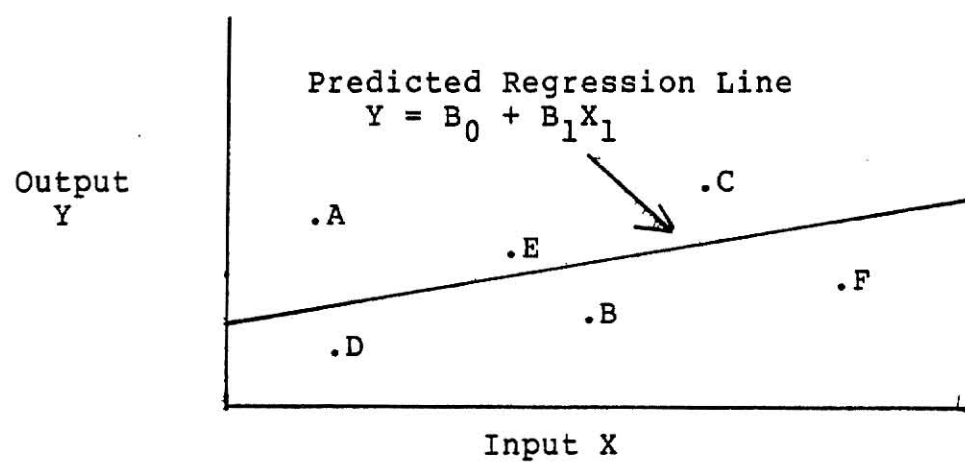
$$(8) \quad Y = B_0 + B_1X_1 + B_2X_2 + \dots + B_nX_n + e$$

where Y = observed dependent variable

B_0 = constant (intercept)

B_n = unknown population parameters to be estimated

FIGURE 2. Hypothetical Regression Analysis Equation



X_n = observable independent variables, n in number. This study uses the multiple linear regression model and gross income is the dependent variable while machinery repair, interest paid, seed expense, fertilizer expense, fuel expense, and pesticide expense are the independent variables.

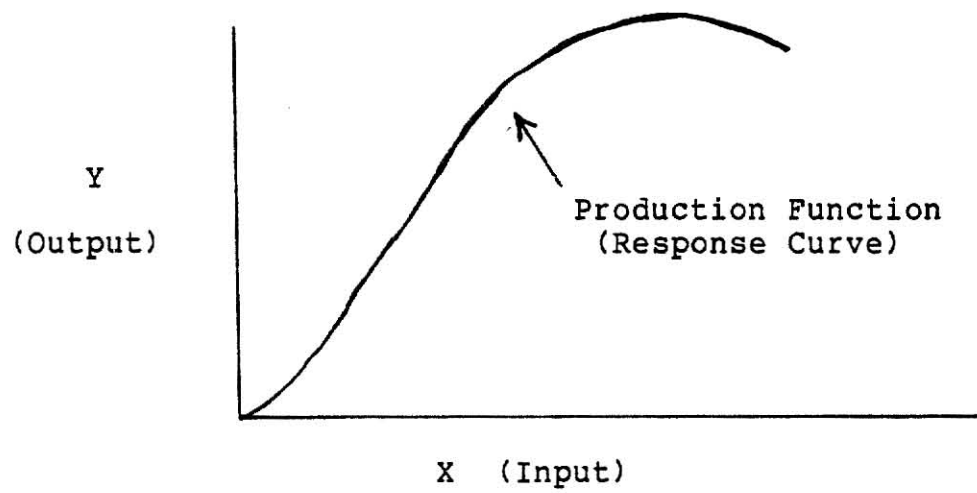
Two non-linear regression functions were studied. Figure 3 shows a non-linear regression line. In some cases a non-linear regression equation may provide a better fit. For example, using this type of regression model, diminishing marginal returns are usually present. Also, most agricultural production functions are best described using a non-linear type. More discussion concerning various non-linear equations will be reviewed later.

Statistical Concepts

The $B_1, B_2, \dots, B_n$ are estimates of the net relationship between the X's and Y's. Each is an estimate of the change in the dependent variable to a one unit change in a particular independent variable. The accuracy of this estimated regression is shown by several statistical concepts.

First, the coefficient of multiple determination, R^2 is a measure of the degree of linear association between the dependent variable and the collective independent variables. This is sometimes referred to as the correctness of fit statistic which measures the percentage of the variance of the dependent variable explained by the independent

FIGURE 3. General Non-linear Function



variable(s). The R^2 value has a range from zero to one. The larger the R^2 statistic (close to 1) the better the equation is said to explain the occurrence of the dependent by the independent variables.

Another statistical concept in relation to regression analysis is the use of correlation coefficients which measure the linear association between dependent and each independent variable. If the correlation is positive one (+1), then the variables being examined are positively correlated and the observed values of the variables lie on a straight line with a positive slope. If the correlation coefficient is negative one (-1), then the variables are negatively correlated and the observed values lie on a straight line with a negative slope. If the correlation coefficients have values close to zero, then the observed variables are said to be uncorrelated or the variables are unassociated with each other.

The t-statistic also describes the relationship between dependent and independent variables. The t-statistic is the estimated regression coefficient divided by the standard error of estimate for the independent variable being examined. The standard error of estimate is the square root of the variance of regression; thus, the standard error provides a measure of variability in the same units as the independent variable and a relatively small standard error of estimate is preferred. The t-statistic indicates the significance of the independent variable. If the t-

statistic has a value greater than two (2), then the variable is significant at the 95 percent confidence level. Stated differently, if an independent variable has a t-statistic greater than 2, there is only a 5 percent chance of accepting a false hypothesis regarding the significance of a variable. The estimated regression coefficient should be two or more times the size of its standard error. In presenting results, some researchers report the standard errors below the respective coefficients; however, this study reports the t-statistic for each of the variables used, instead of the standard errors.

The number of degrees of freedom of the sample size has affects the t-statistic. The degrees of freedom is the sample size minus the number of independent variables used in the equation. The more degrees of freedom the lower the t-statistic can be and still be significant.

The mean square error describes the variance about the regression and represents a measure of the error in using the determined regression equation. Therefore, a low mean square error is preferred because it indicates smaller variability.

In this study, the regression analysis was done using the Statistical Analysis Systems (SAS). The General Linear Model (GLM) and the Stepwise routines were used to determine the regression equations. The GLM procedure uses the least squares method to fit linear and multiple linear regression models. The stepwise regression procedure selects the most

significant independent variables to be included in the regression equation. This method is used when there are several independent variables that need to be examined. For instance, the stepwise routine adds a variable to the model if the F statistic for that variable tests to be significant. If all the variables are included in the model, then the procedure deletes any variable that does not produce a significant F statistic.

Types of Regression Models

This study examined three different types of regression equations. The three types included: multiple linear, quadratic, and the Cobb-Douglas form. The multiple linear regression equation was introduced and discussed in the preceding discussion.

The quadratic and Cobb-Douglas types of regression equations are two forms of non-linear regression analysis. The quadratic equation has the following general form:

$$(9) \quad Y = B_0 + B_1X_1 + C_1X_1^2 + B_2X_2 + C_2X_2^2 + \dots + B_nX_n + C_nX_n^2 + e$$

where Y = observable dependent variable

B_0 = constant (intercept)

X_i = observable independent variable

X_i^2 = observable independent variable squared

B_i = unknown population parameter to be estimated

C_i = unknown population parameter to be estimated
in relation to the squared terms and

e = unobservable error term

The quadratic equation has a curved regression line corresponding to the law of diminishing marginal returns. If the squared term takes on a negative value, output increases at a decreasing rate until reaching a maximum point and then decreases as input increases. Figure 4 illustrates the non-linear quadratic function. Because of its characteristics, the quadratic function has great flexibility in describing various livestock and crop response surfaces.

The second type of non-linear regression analysis examined was the Cobb-Douglas form of regression. The Cobb-Douglas takes the general form:

$$(10) \quad Y = B_0 X_1^{B_1} X_2^{B_2} \dots X_n^{B_n} e$$

where Y = independent variable

$B_1, B_2 \dots, B_n$ = representing the elasticities of
production coefficients

$X_1, X_2, \dots, X_n$ = independent variables

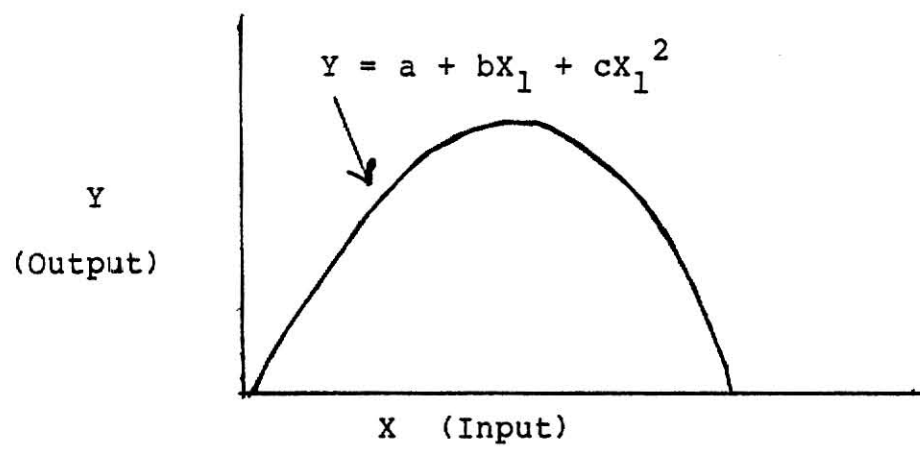
e = error term

The Cobb-Douglas equation is usually estimated by converting values to common logarithmic values. Equation 4.5 gives the Cobb-Douglas in common log form.

$$(11) \quad \log Y = \log B_0 + B_1 \log X_1 + B_2 \log X_2 + \dots + B_n \log X_n + \log e$$

The B coefficients represent the elasticities of production. The elasticity of production is a concept that measures the degree of responsiveness between output and input. If the b coefficient is less than 1, output increases less than 1

FIGURE 4. General Quadratic Function Curve

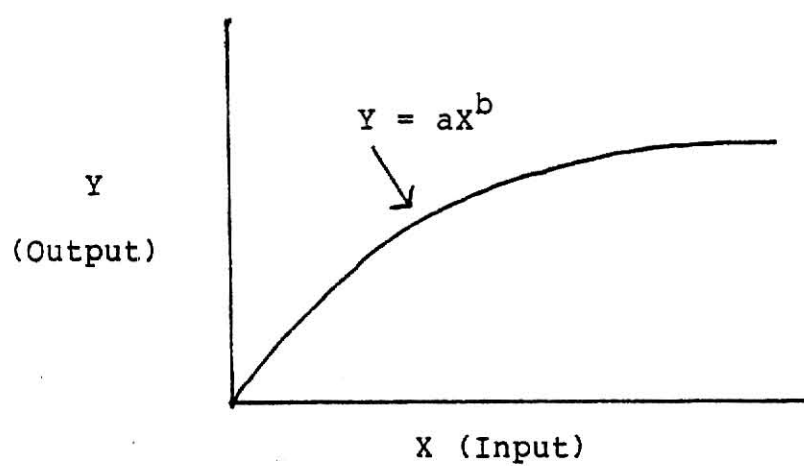


percent for each percent increase in input. If the b coefficient is equal to 1, output increases 1 percent for each percent increase in input. If the sum of the b coefficients is less than 1, output increase less than 1 percent for a percent increase in all inputs. The degree of responsiveness between output and inputs reflects the concept of diminishing marginal returns. However, if the elasticity of production is less than 1.0, the curve approaches the production limit but does not allow for a decrease in total output.

The primary problem is that the Cobb-Douglas function can not be used where both increasing and decreasing marginal returns exist. Nevertheless, the Cobb-Douglas function is commonly used because decreasing returns is assumed rather than increasing returns. Figure 5 graphically shows the general Cobb-Douglas equation.

"Cobb-Douglas functions are frequently used in farm input analyses. The reason for this is that the algebraic model provides (a) adequate fit of the data, (b) computation feasibility, (c) sufficient unused degrees of freedom to allow for statistical testing when the sample size is small, and (d) it is an easy way to fit non-linear data."(15)

FIGURE 5. General Cobb-Douglas Function Curve



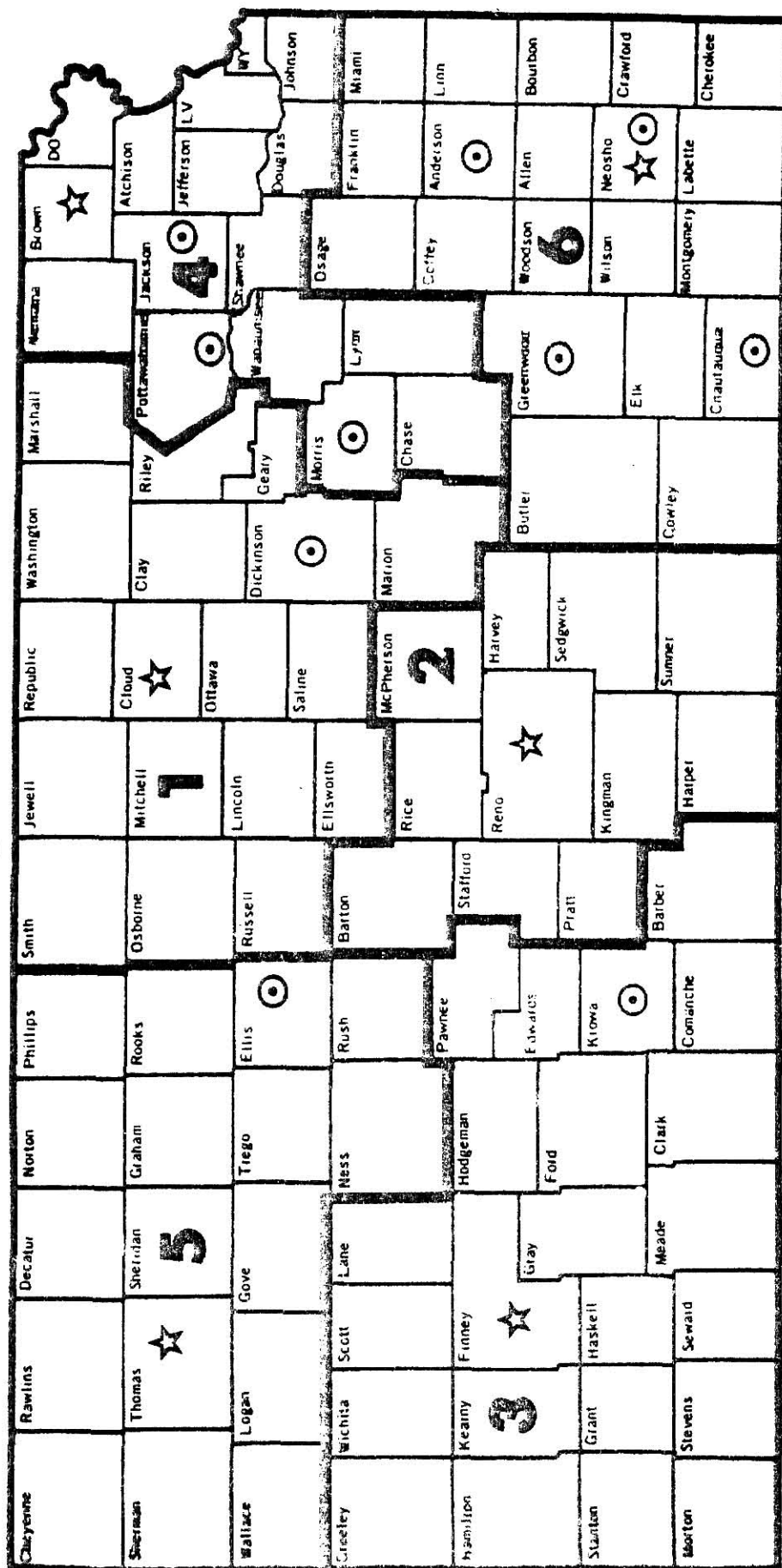
Description of Farm Data

The data used is from the Kansas Farm Management Associations. This is a record keeping program that divides Kansas into 6 regions. This study only examined the farmer's records from the Farm Management Association's (FMA) areas 3 and 5. Figure 6 shows a map of the locations of the associations. Associations 3 and 5 represent the western one-third of the state of Kansas. Agriculture in these associations relies heavily on irrigation for production of farm commodities. The farmers are dependent on the Ogallala aquifer which accounts for nearly all irrigation water in the area.

This region was chosen because of the importance of irrigation. This study examined records of farmers who only irrigate corn or grain sorghum. These farmers may have some non-irrigated crops also. By examining only corn and grain sorghum irrigators, a better regression analysis should result because most of the effect of non-irrigated crop practices has been eliminated.

The farmers selected did not consist of a random sample. Farms in the Farm Management Association records tend to be better managed; therefore, the study results may not apply to the average farm in the west. Also, the sample used in this study was believed to consist of larger than average size farms for the area; thus higher gross and net incomes would be expected.

FIGURE 6. Farm Management Associations



☆ Association Headquarters

⊙ Satellite Office

Several problems arise when analyzing data of farmers cooperating in record keeping projects. The data used is not representative of the population. Also, the data regarding input use tends to cluster around the high profit point and in least cost combinations for inputs. This tendency to cluster around the high profit point reduces the variance in the input observations. This reduction increases the standard error of the regression coefficients which reduces the reliability of estimates. The formula for the standard error of the regression coefficient follows:

$$(12) \quad S_b = \sqrt{\frac{\bar{S}_{y \cdot x}}{S_x \sqrt{n}}}$$

where $\bar{S}_{y \cdot x}$ is the standard error of estimate, and

S_x is the standard deviation in observation of input x . Input data clustering in least cost combinations causes a high intercorrelation among the independent variables. This intercorrelation reduces the reliability in which the regression coefficients were estimated. Estimating individual variable effects is made more difficult because of the intermingled relationship between most of the variables due to intercorrelation. (14)

The Sample

This study used both cross-sectional and time series data. For the seven year period from 1973 to 1979, a total of 116 irrigated corn and 59 irrigated grain sorghum farms were examined. Table 8 shows the gross income, net income,

TABLE 8. Total And Irrigated Acres, Gross And Net Income, And Capital Managed Per Farm For Irrigated Corn And Grain Sorghum Farms (1973-1979)

Variable	Corn	Grain Sorghum
Total Acres Per Farm	1507	1369
Gross Income Per Farm	\$144822	\$110150
Net Farm Income Per Farm	\$ 45363	\$ 36480
Capital Managed Per Farm	\$816324	\$728874
Irrigated Corn or Grain Sorghum Per Farm	360	171
Rate of Return on Capital Managed	4.48	3.83
Rate of Return on Net Worth	10.52	2.81

TABLE 9. Total Number of Farms Irrigating Corn And Grain Sorghum And Number By Year In The Sample

Variable	Corn	Grain Sorghum
Total Irrigated Acres	41817	10099
Total Number of Observations	116	59
Number of 1973 Observations	18	10
Number of 1974 Observations	14	4
Number of 1975 Observations	20	5
Number of 1976 Observations	19	10
Number of 1977 Observations	15	13
Number of 1978 Observations	18	8
Number of 1979 Observations	12	9

capital managed, and acreage of irrigated corn and grain sorghum of the farms used in the sample. Table 9 shows the total number of irrigated corn and grain sorghum farms broken down by individual years.

Variables Examined

Dependent Variable:

The dependent variable used was gross income received from the production of only irrigated corn or irrigated grain sorghum. Using time series data variability in gross income is caused by changes in commodity price. To solve this problem, gross income was deflated each year. The implicit Gross National Product (GNP) deflator and the index of "prices received by farmers" deflator were used (Table 10).

Independent Variables:

Twelve independent variables were used; however, most of the analysis was based on only six variables. The six major independent variables used were: machinery repair expense, interest paid, seed expense, fertilizer expense, fuel expense, and pesticide expense. These six variables were of major importance because they comprise the primary inputs used in corn and grain sorghum production. Estimating a production function with only one variable pesticide

TABLE 10. Indices Used To Deflate Gross Income (1973-1979)

Year	GNP*
1973	105
1974	115
1975	125
1976	132
1977	140
1978	150
1979	163

* GNP equivalent to Gross National Product

would leave too much of the variability in gross income unexplained. The data used has gross income variability caused by variation in all inputs and not just pesticides. The pesticide expense variable is comprised of herbicides, insecticides, and fungicides. In addition, determining the marginal productivity of inputs other than pesticides was of interest. The other six variables of secondary importance were: labor expense, irrigation expense, real estate tax expense, personal property tax expense, insurance expense, and cash rent.

Tables 11 and 12 show the means values per farm and per acre of these variables respectively. Likewise, the independent variables were also deflated using prices paid indexes, Table 13.

Each of the independent variables affects gross income in a positive fashion because annual expenses are for inputs used in production within one crop year. As the farmer increases one or any combination of these inputs, production increases as does gross income. So, the regression coefficients for the independent variables should have a positive value.

Dummy Variables:

Dummy variables were used as independent variables to account for yearly differences in the data. For each year from 1973 to 1979 a dummy variable was incorporated into the

TABLE 11. Independent Variable Means Per Farm For The
Irrigated Corn and Grain Sorghum Farms (1973-1979)

Variables	Dollars/Farm	
	Corn	Grain Sorghum
Machinery Repair	\$ 9402	\$7424
Interest Paid	\$ 9881	\$7530
Seed Expense	\$ 7069	\$2532
Fertilizer Expense	\$12680	\$6557
Fuel Expense	\$ 9816	\$6672
Pesticide Expense	\$ 5122	\$1796
Labor Expense	\$ 5879	\$3280
Irrigation Expense	\$ 184	\$ 117
Real Estate Property Tax Expense	\$ 2239	\$1982
Personal Property Tax Expense	\$ 1245	\$1200
Insurance Expense	\$ 945	\$ 667
Cash Rent	\$ 1847	\$3827

Table 12. Independent Variable Means And Standard Deviations Per Acre For The Irrigated Corn And Grain Sorghum Farms (1973-1979)

Variables	Dollars Per Acre		Standard Deviations	
	Corn	Grain Sorghum	Corn	Grain Sorghum
Machinery Repair	\$6.62	\$5.42	5.69	3.62
Interest Paid	6.95	5.50	7.03	6.91
Seed Expense	4.97	1.85	4.92	1.93
Fertilizer Expense	8.92	4.79	12.47	4.19
Fuel Expense	6.91	4.87	7.63	3.30
Pesticide Expense	3.60	1.31	9.33	1.68
Labor Expense	4.14	2.40	5.05	2.77
Irrigation Expense	.13	.08	.95	.54
Real Estate Property Tax Expense	1.58	1.45	1.07	1.16
Personal Property Tax Expense	.88	.88	.71	.81
Insurance Expense	.67	.49	.86	.49
Cash Rent	1.30	2.79	2.46	5.51

TABLE 13. Cost Indices Used To Deflate The Independent Variables (1973-1979)

Variables	Years						
	1973	1974	1975	1976	1977	1978	1979
Machinery Repair	137	161	195	217	238	259	289
Interest Paid	184	223	262	299	339	400	501
Seed Expense	167	215	245	241	261	273	286
Fertilizer Expense	102	167	217	185	181	180	196
Fuel Expense	116	159	177	187	202	212	276
Pesticide Expense	105	119	160	174	157	147	150
Labor Expense	155	178	192	210	226	242	265
Irrigation Expense	142	161	177	187	196	212	241
Real Estate Tax Expense	145	154	166	178	195	210	226
Personal Property Tax Expense	145	154	166	178	195	210	226
Insurance Expense	142	161	177	187	196	212	241
Cash Rent	136	166	199	214	232	248	265

regression equation. The dummy variable coefficient can be interpreted as the yearly difference. A positive coefficient for the dummy variables signifies an increase in gross income for that particular year above the base year. Conversely, a negative coefficient for the dummy variable represents a decrease in gross income for a particular year below the base year. The yearly differences represent factors such as drought and commodity price fluctuations.

Various Pesticide Equations

Determining which type of production function best describes the relationship between pesticide use and output was important in estimating the marginal productivity of pesticides. A positive relationship was assumed between herbicide use and weed control with diminishing returns for additional use. The basic reason for this is younger and weaker weeds are killed through the use of very small quantities of pesticides. As additional units of herbicides are used, weed kill does not increase proportionately because remaining weeds are bigger, healthier or more tolerant to the chemical thus, decreasing marginal returns. Too much herbicide can be applied resulting in crop damage or kill, which signifies stage three of the classical production function. The relationship between insecticides or fungicides is assumed to be similar.

Weed control is positively related to the yield and it is assumed with diminishing returns. This is the result of

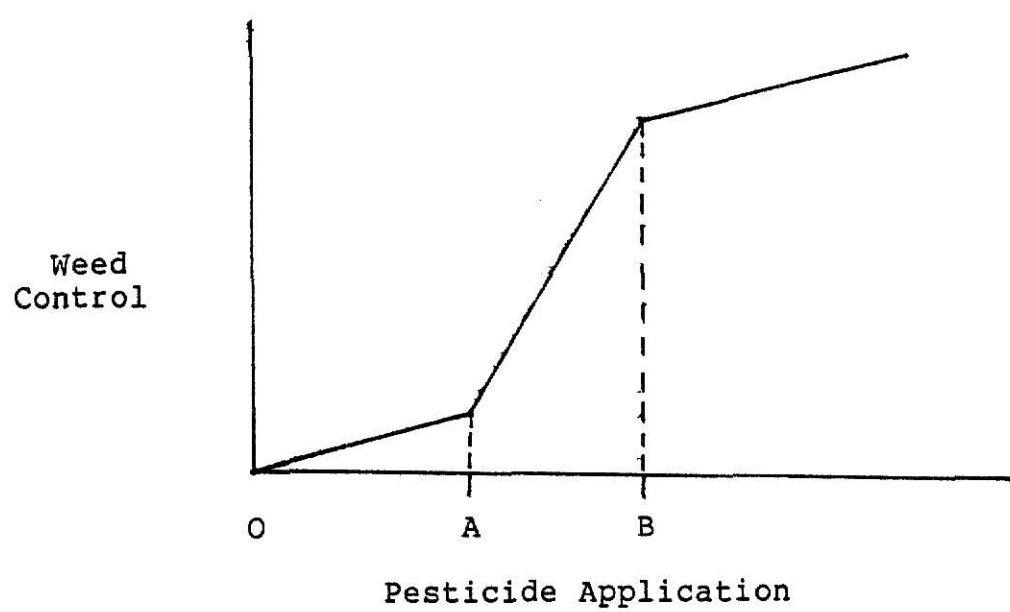
"(a) Weeds compete with the crop for moisture, soil

nutrients, and sunlight. (b) The crop is more difficult to harvest because of the amount of foreign material, such as weeds that must be handled in harvesting. (c) The quality of the crop is reduced." (15)

Furthermore, it was assumed that weed control is positively related to income because yields and income are assumed to have a positive relationship. To summarize, we assumed: 1) weed control is positively related to herbicide usage, 2) weed control is positively related to production yields and 3) production yields are positively related to income. Therefore, we concluded weed control is positively related to income and evaluated the production function that best describes pesticide expense.

The multiple linear, Cobb-Douglas, and quadratic equations were used to describe pesticide usage in western Kansas. Entomologists and agronomists, suggest a "stair-step" equation describes the pesticide production function. Figure 7 graphically shows the "stair-step" concept which shows less control with pesticide use of OA amount, than a large response to increment AB followed by little additional weed control with more than B amount of pesticide use. This stair-step concept illustrates that farmers have a small range in the amount of pesticide between too little or too much use. Between points A and B will most likely be the most profitable control. If less than amount A is applied, weed control is small and high returns result from additional use. But, if an amount over point B is selected then an

FIGURE 7. General Stair-Step Curve For Pesticides



overdosage is being applied.

This stair-step function does not fit any of the traditional functions such as the linear, Cobb-Douglas or quadratic equations. The stairstep function can be described through a series of linear equations.

CHAPTER V

RESULTS

Irrigated Corn Analysis

Deflating the gross income variable of irrigated corn farms using the gross national product (GNP) deflator provided the equation with the best statistical fit. The independent variables were deflated using the cost deflators reported in Table 13. The independent variables data were on a dollar per farm basis; however, this study adjusted the data by dividing the expenses by acres per farm. Therefore, estimated regression coefficients are represented on a per acre basis. The six independent variables used in this analysis included: machinery repair (X1), interest paid (X2), seed expense (X3), fertilizer expense (X4), fuel expense (X5), and pesticide expense (X6) and Y1 is gross income per acre from corn (Table 14).

The estimate for the linear equation is:

$$Y1 = 60.45 + 1.73X1 + .34X2 + .35X3 + 1.10X4 + 2.37X5$$

$$(3.40) \quad (1.79) \quad (.63) \quad (3.85) \quad (4.33)$$

$$+ 1.95X6 + 27.64D73 - 6.90D74 - 31.08D75$$

$$(4.87) \quad (1.34) \quad (.34) \quad (1.54)$$

$$- 50.78D76 - 63.97D77 - 36.18D78$$

$$(13) \quad (2.69) \quad (3.44) \quad (2.09)$$

The t-statistic for each independent variable is beneath the regression coefficient in parenthesis.

The value marginal product of pesticides for the linear equation is computed by taking the partial derivative of

TABLE 14. Regression Variables Used In Study And Their Respective Codes

Variable	Code
Goss Income, GNP deflator	Y1
Machinery Repairs	X1
Interest Paid	X2
Seed Expense	X3
Fertilizer Expense	X4
Fuel Expense	X5
Pesticide Expense	X6
Dummy Variable For Year 1973	D73
Dummy Variable For Year 1974	D74
Dummy Variable For Year 1975	D75
Dummy Variable For Year 1976	D76
Dummy Variable For Year 1977	D77
Dummy Variable For Year 1978	D78
Dummy Variable For Year 1979	D79

gross income from the corn term with respect to the pesticide variable.

$$(14) \quad dY/dX_6 = 1.95$$

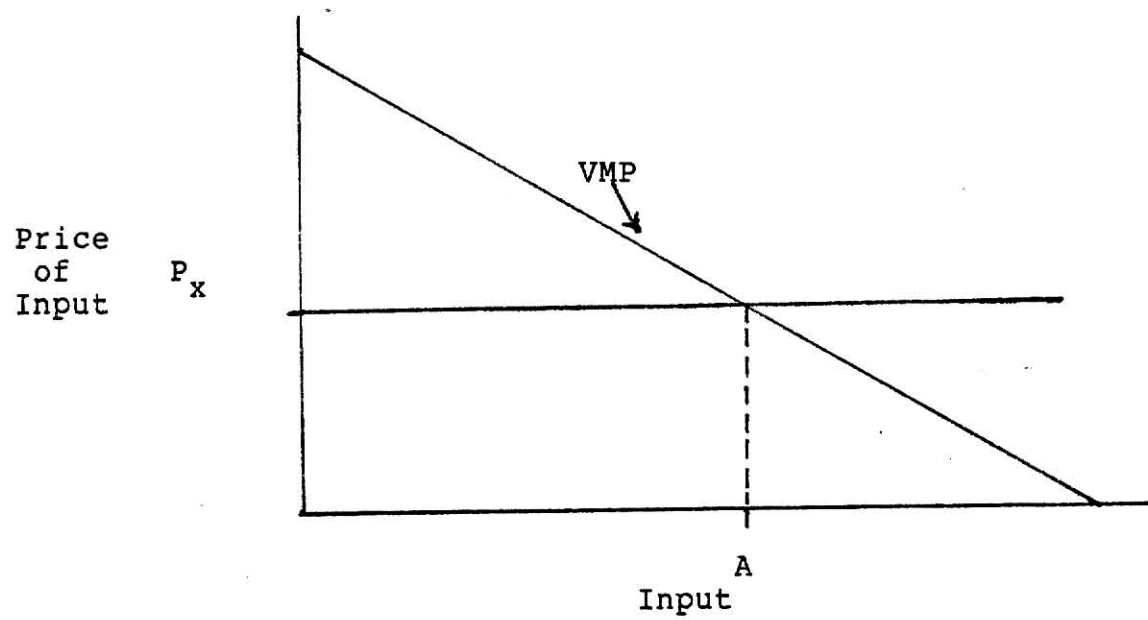
This VMP means that for each dollar spent on pesticides, a \$1.95 return in gross income resulted; therefore, the use of pesticide was profitable. However, economic theory states that the most profitable point is where the value marginal product is equal to the price of the input (Figure 8).

Because the function is linear, the implication is that each successive dollar spent on pesticides results in a \$1.95 increase in gross income. Increasing the amount of pesticide use will not decrease the marginal returns because the linear function does not allow diminishing returns. The VMP for pesticides is most reasonable for the average use reported.

The value marginal products calculated from the linear equation for the other independent variables are found in Table 15. The VMP's from the irrigated corn data, suggests these producers are not receiving an adequate return for interest paid and seed expense although these variables were not statistically significant. The other expenses (machinery repair, fertilizer expense, fuel expense, and pesticide expense) indicate a modest return for their application and use.

The Cobb-Douglas equation was estimated as:

FIGURE 8. General Value Marginal Product Curve



$$(15) \quad Y_1 = 1.463X_1^{.2751}X_2^{-.01242}X_3^{.07806}X_4^{.006465}$$

(3.80) (.49) (1.76) (.16)

$$X_5^{.28796}X_6^{.06774}D_{73}^{.2062}D_{74}^{-.0611}D_{75}^{-.068}$$

(3.65) (2.53) (2.55) (.83) (.95)

$$D_{76}^{-.2109}D_{77}^{-.1925}D_{78}^{-.1035}$$

(3.19) (2.83) (1.62)

The general computation for the VMP from the Cobb-Douglas equation is shown in equation 16:

$$(16) \quad B_i (Y/X_i)$$

where B_i = the exponent of the X_i term

Y = mean of Y and

X = mean of X .

The value marginal product for pesticides using the Cobb-Douglas equation is as follows:

$$(17) \quad .06774 * (101.91/3.60) = 1.92$$

where \$101.91 represents the mean for gross income and \$3.60 is the mean per acre for pesticides. Using less than \$3.60 for pesticides per acre would receive higher returns per dollar than \$1.92, but any producer spending more than \$3.60 would receive less than \$1.92 return for every dollar spent on pesticide. The value marginal products for all variables are found in Table 15.

The Cobb-Douglas equation shows diminishing returns for each input examined because every B_i is less than 1. However, the sum of B_i 's are greater than 1 which means

that if all inputs are increased one percent, gross income increases by more than 1 percent. This shows gross income increasing at a increasing rate for all inputs which is uncharacteristic of an agricultural input/output relationship. The variables interest paid, fertilizer and fuel expenses are not statistically significant.

The estimated quadratic production function is:

$$Y_1 = 56.47 - .8503X_1 + .00005X_1^2 + .6183X_2 - .000001X_2^2$$

(1.63) (1.66) (1.57) (1.55)

$$+ 1.0965X_3 - .000009X_3^2 + .7484X_4 - .000001X_4^2 +$$

(1.96) (1.57) (1.16) (1.17)

$$3.8524X_5 - .000012X_5^2 + 1.5968X_6 - .0000025X_6^2 +$$

(4.43) (2.22) (1.27) (1.37)

$$34.78D_7 - 1.30D_7^2 - 21.02D_7^3 - 44.47D_7^4 -$$

(1.57) (1.01) (1.0) (2.19)

$$58.67D_7^5 - 32.98D_7^6$$

(18) (2.93) (1.72)

The VMP for the quadratic equation can be found by taking a partial derivative of each Y term with respect to the following:

$$(19) \quad X(dY/dX_i) = B_i + 2C_iX.$$

Where B_i = regression coefficient for X_i

C_i = the regression coefficient for the squared term

X = mean for the desired variable.

The value marginal product for the quadratic equation is computed in equation 20.

$$(20) \quad dY/dX_6 = 1.5968 + 2(.0000025)(3.60) = 1.60$$

The \$1.60 VMP represents the return for every dollar spent on pesticides.

The squared term in the quadratic equation is very important, because a negative squared term means that diminishing marginal returns occurs for that variable. Pesticide expense has a negative squared term. This negative term indicates that as the amount of pesticide usage increases, gross income will increase, reach a maximum and then decrease.

For comparison, Table 15 shows the value marginal products for all the variables for the linear, Cobb-Douglas, and quadratic equations respectively.

The correlation coefficient matrix for the variables used in this analysis is found in Table 16. The correlation coefficient between many variables is higher than desired for good statistical analysis. The data used in this study was clustered causing a large degree of intercorrelation between variables. The effect is that a coefficient of one of the highly correlated variables may pick up the effect of the other. Because of the high intercorrelation, it becomes very difficult to separate individual variable effects.

TABLE 15. Corn VMP For All 6 Index Variables

Variable	Linear	Cobb-Douglas	Quadratic
Machinery Repair	1.73	4.23	- .86
Interest Paid	.34	- .18	.62
Seed Expense	.35	1.62	1.10
Fertilizer Expense	1.10	.07	.75
Fuel Expense	2.37	4.25	3.85
Pesticide Expense	1.95	1.92	1.60
R ²	.76	.62	.77

TABLE 16. Corn Correlation Matrix

	Y	X1	X2	X3	X4	X5	X6
Y	1.00	.811	.497	.671	.718	.711	.618
X1		1.00	.476	.522	.690	.620	.566
X2			1.00	.603	.399	.390	.359
X3				1.00	.613	.639	.514
X4					1.00	.639	.254
X5						1.00	.442
X6							1.00

Yearly Differences-Corn

The yearly differences in gross income result from weather, prices, and pest cycles within years. To examine these individual year differences, dummy variables were added to the equations.

The yearly differences are estimated from parameters in equation 13. The regression coefficients associated with the dummy variables represent the affect that year had on gross income. The normal intercept in equation 13 represents the dummy variable for 1979, which in this case is the base year. Comparing each year with 1979, the base, estimates the differences between years. Equation 13 shows that 1974 and 1975 were not significantly different from 1979 in affecting gross income as compared to the other years while 1976, 1977 and 1978 were significantly different in affecting gross income. Equation 13 shows that years 1973 and 1979 had a positive effect on gross income while 1974-1978 were considered "bad" years in terms of decreasing gross income. These yearly differences can be related to current events farmers faced such as drought, or commodity prices.

Equations 15 and 18 show the dummy variables associated with the Cobb-Douglas and quadratic equations respectively. The linear, Cobb-Douglas and quadratic equations were all consistent in showing that 1973 and 1979 were "good years" in terms of effecting gross income.

Individual Year Models

This study also estimated equations for each year by calculating regression equations on a yearly basis rather than for the entire period 1973 to 1979. Five independent variables were used in this analysis. The five variables included: interest paid (X2), seed expense (X3), fertilizer expense (X4), fuel expense (X5), and pesticide expense (X6). Appendix A gives individual year equations of the linear type. The differences between equations shows that some inputs received a profitable return in some years while not in others. To illustrate, in years 1974 through 1978 pesticides received a modest return on their investment while in 1973 and 1979 they were unprofitable. This relationship can be accounted for by many factors that affect the agricultural sector such as moisture, planting dates, and weather conditions.

Irrigated Grain Sorghum Analysis

When analyzing the irrigated grain sorghum farms in western Kansas, gross income was deflated using the gross national product deflator. The independent variables were deflated using the cost deflators found in Table 13. The estimated regression coefficients are represented on a per acre basis. The six independent variables used in this analysis included the same that were used in the corn analysis. These variables included: machinery repair (X1), interest paid (X2), seed expense (X3), fertilizer expense (X4), fuel expense (X5), and pesticide expense (X6).

The estimated linear regression equation for irrigated grain sorghum is as follows:

$$\begin{aligned}
 (21) \quad Y_1 = & 40.42 + 3.27X_1 - .07X_2 - .79X_3 - 1.66X_4 + 2.75X_5 + \\
 & (3.13) \quad (.22) \quad (.63) \quad (1.62) \quad (2.17) \\
 & 4.93X_6 + 39.3D_7 + 72.32D_8 - 7.33D_9 - 9.55D_{10} - \\
 & (1.87) \quad (1.41) \quad (2.28) \quad (.25) \quad (.39) \\
 & 2.92D_{11} + 1.62D_{12} \\
 & (.14) \quad (.10)
 \end{aligned}$$

The t-statistic for each independent variable is beneath the regression coefficient in parenthesis.

The value marginal product for pesticides was \$4.93 which was computed by taking the partial derivative of X_6 with respect to Y_1 . The equation shows that for every dollar spent on pesticide, a \$4.93 return in gross income resulted. This implies that the use of pesticides for irrigated grain sorghum in western Kansas has a profitable return. However, because of the linearity, the \$4.93 value is the return regardless of how much pesticide is applied. The value marginal products for the other independent variables are found in Table 17.

The Cobb-Douglas equation estimated from the irrigated grain sorghum data is found in equation 23.

$$(22) \quad Y1 = 1.57X1^{.451}X2^{-.0093}X3^{-.095}X4^{.02532}$$

$$(3.71) \quad (.25) \quad (1.58) \quad (.42)$$

$$X5^{.0700}X6^{.0362}D73^{.0816}D74^{.1892}$$

$$(.71) \quad (.84) \quad (.66) \quad (1.49)$$

$$D75^{-.1569}D76^{-.1840}D77^{-.1133}D78^{-.0689}$$

$$(1.45) \quad (2.04) \quad (1.45) \quad (.78)$$

The value marginal product calculation is as follows:

$$(23) \quad .0362 * (80.46 / 1.31) = 2.22$$

where \$80.46 represents the mean for gross income per acre and the \$1.31 value is the mean per acre spent on pesticides. Therefore, the \$2.22 return suggests for every dollar spent on pesticide, gross income increases by \$2.22. The value marginal products for the independent variables are found in Table 17.

The Cobb-Douglas equation for the irrigated grain sorghum data shows diminishing marginal returns for each input being used. However, the sum of the elasticities is larger than 1, indicating that gross income increases proportionately more than the dollars spent on the inputs.

The quadratic regression equation function was estimated as:

$$Y1 = 183.57 + 4.868X1 - .00004X1^2 - .474X2 + .000004X2^2$$

(1.68) (.78) (1.01) (1.42)

$$- 4.247X3 + .000133X3^2 - 1.466X4 - .000009X4^2 +$$

(1.97) (2.07) (.69) (.14)

$$4.593X5 - .000024X5^2 + 6.002X6 - .000118X6^2 +$$

(1.70) (.43) (1.73) (.30)

$$56.84D73 + 91.32D74 - .13D75 - .79D76 +$$

(2.55) (.01) (.01) (.01)

$$7.36D77 + 9.78D78$$

$$(24) \qquad \qquad \qquad (.30) \qquad (.36)$$

The VMP calculation from equation 25 is as follows:

$$(25) \qquad 6.001988 + 2(.0001184)(1.31) = 6.00$$

The \$6.00 value represents the return to gross income for every dollar spent on pesticides using the quadratic equation.

Table 17 shows the value marginal products for all variables for the linear, Cobb-Douglas, and quadratic equations respectively. Machinery repair, fuel expense, and pesticide expense were thought to have reasonable coefficients concerning the irrigated grain sorghum data. The correlation coefficient for the irrigated grain sorghum data is found in Table 18.

TABLE 17. Grain Sorghum VMP For All 6 Independent Variables

Variable	Linear	Cobb-Douglas	Quadratic
Machinery Repair	3.27	6.69	4.87
Interest Paid	- .07	- .13	- .47
Seed Expense	- .79	-4.13	-4.25
Fertilizer Expense	-1.66	.43	-1.47
Fuel Expense	2.75	1.16	4.59
Pesticide Expense	4.93	2.22	6.00
R ²	.44	.37	.53

TABLE 18. Grain Sorghum Correlation Matrix

	Y	X1	X2	X3	X4	X5	X6
Y	1.00	.525	.440	.156	.382	.584	.666
X1		1.00	.536	.310	.268	.707	.129
X2			1.00	.241	.149	.563	.193
X3				1.00	.188	.362	.280
X4					1.00	.444	.523
X5						1.00	.450
X6							1.00

Yearly Differences-Grain Sorghum

Equations 21, 22, and 24 show the dummy variables associated with the linear, Cobb-Douglas and quadratic equations respectively. These equations can be used to find the yearly differences between gross income.

CHAPTER VI

CONCLUSION AND IMPLICATIONS

Findings

The objective of this study was to estimate the marginal productivity of pesticides for irrigated corn and grain sorghum farms in western Kansas. The data consisted of a combination of time series and cross sectional data taken from Farm Management Association areas 3 and 5. Regression analysis was used to determine the marginal productivity of pesticides and three types of production functions were derived from the data. The multiple linear, Cobb-Douglas, and quadratic functions were fitted to the model data. The dependent variable gross income and the independent variable pesticide expense were the primary variables examined.

The productivity of pesticide was computed in dollar of gross income received for the marginal dollar spent on pesticide. When examining the irrigated corn data, the estimated marginal products were \$1.94, \$1.92, and \$1.60 for the linear, Cobb-Douglas, and quadratic equations respectively. The value marginal products showed pesticides to be a profitable input for irrigated corn producers in western Kansas. When examining the three types of equations it is believed that the quadratic equation was best because of its significance of the variables and the statistical fit of the data.

In addition, individual year models were derived to

look at pesticide returns for separate years. The individual year returns for pesticides ranged from -\$8.41 in 1973 to a modest \$2.92 return in 1976. Two years received a negative return, while five years out of the seven received a profitable return for pesticides during the 1973 to 1979 period.

The irrigated grain sorghum equations found \$4.93, \$2.22, and \$6.00 marginal products for pesticides using the linear, Cobb-Douglas, and quadratic equations respectively. The value marginal products showed pesticide to be a profitable input for irrigated grain sorghum producers in western Kansas. The quadratic equation was believed to be the best equation for the data.

Limitations and Assumptions of the Study

Many different problems arise when analyzing record keeping data like this study used. A few limitations concerning the use of this data are listed below.

- 1) The data were on a per acre basis; therefore, differences among farmers' practices on different fields have been lost in the aggregation process. This tends to introduce a large amount of intercorrelation among the variables used.
- 2) The data were taken from a specific area in Kansas and came from a specific time period (1973-1979); therefore, the calculated marginal productivity values for the inputs may not represent other areas or other time periods.
- 3) The farms selected from the Farm Management

Association tended to be better than average farms. The farmers examined in this study were assumed to have better than average managerial ability, net income, and larger farm operations.

4) The primary variable observed in this analysis was pesticide expense. The pesticide expense variable was composed of herbicides, insecticides, and fungicides with the assumption being made that farmers used these forms of pesticides according to normal and generally accepted practices.

5) A large degree of multicollinearity between the variables was another problem of concern. Multicollinearity is when two or more independent variables tend to move together in the same pattern because of a high correlation between them. Because of the high correlation it is very difficult to separate the respective effects for individual variables. This problem introduces the concept of using "proxy" variables. Proxy variables are where one variable is replacing or describing another variable's effect. Therefore, the significance of the independent variables can be wrongly stated because of statistical errors among the data.

6) The production functions estimated in this study were derived from aggregate irrigated corn and grain sorghum data; therefore, individual decisions should not be based on the regression coefficients of aggregate data.

REFERENCES

1. Brockington, N. R., Computer Modeling in Agriculture, Clarendon Press, Oxford, 1979.
2. Campbell, H. F., "Estimating the Marginal Productivity of Agricultural Pesticides: The Care of Tree-Fruit Farms in the Okanagan Valley", *Canadian Journal of Agricultural Economics*, Vol. 24, No. 2, July, 1976, pp. 23-30.
3. Carlson, Gerald, A., "Long Run Productivity of Insecticides", *American Journal of Agricultural Economics*, Vol. 59, August, 1977, pp. 543-548.
4. Cashman, C., and Marshall A. Martin, and Bruce A. McCarl, "Indiana Farm Level Impacts of Possible Environmental Protection Agency Bans on Selected Soybean Insecticides", *Southern Journal of Agricultural Economics*, Vol. 12, 1980, pp. 147-152.
5. Chichester, C. O., Research in Pesticides, Academic Press, New York, 1965.
6. Dillion, John L., The Analysis of Response in Crop and Livestock Production, 2nd Edition, Pergamon Press, Oxford, 1977.
7. Doll, John P., and Frank Orazem, Production Economics Theory with Applications, Columbus, Ohio, Grid Inc., August, 1978.
8. Draper, Norman, and Harry Smith, Applied Regression Analysis, 2nd Edition, John Wiley & Sons, Inc., New York, 1981.
9. Hawkins, D. E., F. W. Slife, and E. R. Swanson, "Economic Analysis of Herbicide Use in Various Crop Sequences", *Illinois Agricultural Economics*, January, 1977, pp. 8-13.
10. Headley, J. C., "Estimating the Productivity of Agricultural Pesticides", *American Journal of Agricultural Economics*, Vol. 50, February, 1968, pp. 13-25.
11. Headley, J. C., "Productivity of Agricultural Pesticides", *Economic Research on Pesticides for Policy Decision Making*, Washington D.C., U.S. Department of Agriculture, Proceedings of a Symposium, April, 1970, pp. 80-88.

12. Heady, E., and L. Auer, "Imputation of Production to Technologies", American Journal of Agricultural Economics, Vol. 48, 1966, pp. 309-322.
13. Heady, Earl O., and John L. Dillion, Agricultural Production Functions, Iowa State University Press, Ames, Iowa, 1961.
14. Heady, Earl O., and Glenn L. Johnson, and Lowell S. Hardin, Resource Productivity, Returns to Scale, and Farm Size, The Iowa State College Press, Ames, Iowa, 1956.
15. Janke, H. W., "Estimating the Marginal Productivity of Pesticides on Predominantly Crop Farms in Northeast Kansas", Non-published Masters thesis, Department of Economics, Kansas State University, Manhattan, Kansas, 1978.
16. Langemeier, Larry N., "The K-Mar-105 Whole Farm and Enterprise Data Bank and Retrieval System", Department of Economics Extension, Kansas State University, Manhattan, Kansas.
17. Moffitt, L. Joe, and Richard L. Farnsworth, "Bioeconomic Analysis of Pesticide Demand", Agricultural Economics Research, Vol. 33, No. 4, October, 1981, pp. 12-18.
18. SAS Institute Inc., SAS User's Guide, Statistical Analysis Systems, 1979 Edition, Cary, N.C.
19. Schroder, David, and J. Charles Headley, and Robert M. Finley, "The Contributions of Herbicides and Other Technologies to Soybean Production in the Corn Belt Region, 1965 to 1979", Selected Paper for American Agricultural Economics Association Meetings-Clemson University, University of Missouri-Columbia, 1981.
20. Schroder, David, and J. Charles Headley, and Robert M. Finley, "The Contribution of Pesticides and Other Technologies to Corn Production in the Corn Belt Region, 1964 to 1979", Selected Paper for Southern Agricultural Economics Association Meetings, University of Missouri-Columbia, 1981.
21. Snedecor, George W., and William G. Cochran, Statistical Methods, 6th Edition, The Iowa State University Press, Ames, Iowa, 1978.
22. Swindale, Leslie D., Soil-Resource Data for Agricultural Development, Hawaii Agricultural Experiment Station, University of Hawaii, 1978.

23. U.S. Department of Agriculture, Agricultural Outlook, Washington D.C., Economics Research Service, August, 1981.
24. U.S. Department of Agriculture, Agricultural Statistics, Washington D.C., Economic Reserach Service, 1980.
25. U.S. Department of Agriculture, 1978 Handbook of Agricultural Charts, No. 551, November, 1978, p. 31.
26. U.S. Department of Agriculture, Inputs Used in U.S. Farm Production, Economics and Statistics Service, No. 19, April, 1981.
27. U.S. Department of Agriculture, The Economics of Agricultural Pest Control, Economics and Statistics Service, No. 14, January, 1981.

APPENDIX A

Irrigated Corn Individual Year Models

For 1973 Through 1979

1973 Model:

$$Y = 4254 + 1.09X_2 + 22.73X_3 - 7.69X_4 + 26.17X_5 - 8.41X_6$$

$$R^2 = .76$$

1974 Model:

$$Y = 42765 + 1.43X_2 - 2.96X_3 + 3.25X_4 + 5.48X_5 + .515X_6$$

$$R^2 = .97$$

1975 Model:

$$Y = 40473 + .58X_2 - .18X_3 + 4.00X_4 + 3.77X_5 + 1.60X_6$$

$$R^2 = .87$$

1976 Model:

$$Y = 17216 + 1.49X_2 + 2.47X_3 + .65X_4 + 4.36X_5 + 2.92X_6$$

$$R^2 = .93$$

1977 Model:

$$Y = 40065 + 1.17X_2 + 1.34X_3 - .36X_4 + 3.09X_5 + 2.04X_6$$

$$R^2 = .64$$

1978 Model:

$$Y = 793 + 2.20X_2 - 1.65X_3 + 3.49X_4 + 6.70X_5 + 1.03X_6$$

$$R^2 = .95$$

1979 Model:

$$Y = 49941 + 2.50X_2 + 1.38X_3 - .42X_4 + 7.67X_5 - 4.09X_6$$

$$R^2 = .97$$

ESTIMATING THE MARGINAL PRODUCTIVITY OF PESTICIDES
ON IRRIGATED CORN AND GRAIN SORGHUM FARMS
IN WESTERN KANSAS

by

James R. Sleper

B. S., University of Missouri-Columbia, 1980

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Economics

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1982

ABSTRACT

Agriculture has become very dependent on the use of pesticides, especially since World War II. The rapid increases in production costs during the 1970's has caused many producers to evaluate the use of various inputs.

The objective of this study was to estimate the marginal productivity of pesticides. Data was taken from the Kansas Farm Management Association areas 3 and 5 which consist of the western one-third state of Kansas where irrigation plays a major role in agricultural production. This study was composed of two groups: irrigated corn producers and irrigated grain sorghum producers. Thus, the dependent variable which was gross income, and the independent variables which consisted of various production input expenses represented a unique sample.

The productivity of pesticides were computed in dollars of gross income received for the marginal dollar spent on pesticide. The time series and cross sectional data were fitted using three types of regression production functions. When examining the irrigated corn data, the estimated marginal products for pesticide were \$1.94, \$1.92, and \$1.60 for the linear, Cobb-Douglas, and quadratic equations respectively. The irrigated grain sorghum equations found \$4.93, \$2.22, and \$6.00 marginal products for pesticide using the linear, Cobb-Douglas, and quadratic equations respectively. Therefore, the study showed pesticides to be a profitable input for irrigated corn and grain sorghum

producers in western Kansas.

In addition, individual year models were derived, examining the pesticide return for each year from 1973 to 1979. The individual year models showed large differences during the years examined.