CORN AND GRAIN SORGHUM RESPONSE TO FERTILIZERS ON IRRIGATED LAND IN WEST-CENTRAL KANSAS

by

YUNG LIU

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Approved by:

Frank Orazem

Major Professor

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I. INTRODUCTION

Greater use of fertilizer has been one of the important innovation in the United States over the past three decades. Total fertilizer consumption in the United States increased from 5 million tons to 31 million tons between 1933 and 1963.[1] The trend in fertilizer use is still upward and fertilizer has become an extremely important factor of production in the nation's agricultural economy. Moreover, in the agricultural production process, fertilizer is becoming an important substitute for labor, land and for other forms of capital. But the amount of fertilizer's contribution depends on many other yield influencing factors with which the fertilizer is combined, such as different crops, soils, climatic conditions and management.

Fertilizer is a resource which can be used in large or small quantities. Its supply is of coninuous form. Capital expended for fertilizer can be large or small, depending on the circumstances of the farm, the capital market, or the fertilizer market. How to use commercial fertilizer is a problem that confronts farm operators and others who are concerned with farm production.

Use of commercial fertilizers has become increasingly important in Kansas. Kansas farmers have increased their use of commercial fertilizers about three hundred fold during the past three decades. In 1963 Kansas farmers applied 610,288 tons fertilizer compared to 2,000 tons applied in 1933.[1] The economic use of fertilizers has been becoming a necessary practice in farming. Farmers need to know the most profitable rate of application of fertilizer for maximum profits. They want to realize full benefits that fertilizer will bring and

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1. Agricultural Statistics, U. S. D. A., United States Government Printing Office, Washington, 1933, p. 397, 1965, p. 489.

they want to avoid waste.

Knowledge of yield responses to different rates and combinations of fertilizers is necessary in order to decide upon the most profitable application of fertilizer. Knowledge of this type would guide farmers in making a choice as to expenditures. Farmers may not be aware of the effect changes in prices and costs have on rates that should be applied for maximum returns. Economic analyses can provide answers as to the most profitable rates and combinations for any crop price-fertilizer cost relationships.

Studies have been made to determine yields to be obtained from varying rates of application of fertilizers on irrigated land in West-Central Kansas. It is well known that soil moisture is one of the important factors for the satisfactory production of corn and grain sorghum. Lack of soil moisture often makes it impossible to produce grain. Since soil moisture and fertilizer are interdependent, the weather conditions that cause large variabilities in soil moisture make crop response to fertilizer difficult to predict. In general, the deeper the level of moisture, the greater the response to fertilizer. Yield response during years of adequate moisture is better than during years of dryness.[1] In this study, the soil moisture level was not limiting during the growing season of the crops.

Notable increases in the yields of corn and grain sorghum (RS 610)[2] have been obtained with nitrogen fertilizer in the experiments conducted on irrigated

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1. Frank Orazem and Roy B. Herring, "Economic Aspects of the Effects of Fertilizers, Soil Moisture and Rainfall on the Yields of Grain Sorghum in the Sandy Lands of Southwest Kansas", Journal of Econ., Vol. XL, no. 3, Aug. 1958, p. 697.

2. One kind of varieties of grain sorghum.

land in West-Central Kansas. It has been found that yields of corn or grain sorghum in this area are rarely limited by lack of phosphorus and potassium fertilizers. As yields of corn and grain sorghum can be increased with nitrogen fertilizer, additional information is needed regarding the use of fertilizer to get the most profitable response. Results of experiments provide valuable data which may help guiding fertilizer programs in specific farm situations.

The chief aim of this study is to illustrate: (1) some of the problem involved in economic analysis of fertilizer-rate experiments; (2) procedures for developing yield response curves and related steps involved in determining profitable use of fertilizers; (3) predicting the yields of corn and grain sorghum under varied fertilizer conditions; (4) determining the effect in changes in relative prices of crops and fertilizers.

The study is divided into two major parts. The first part deals with theoretical aspects of economic interpretation of crop responses to fertilizers and the most profitable rates of fertilizer applications. The second part deals with the economic analysis of the experimental data by applying theoretical principles.

II. METHODS USED IN THE ANALYSIS

1. Input-Output Relationships

Some relationships exist between the yields of farm commodities and the quantities of resources applied in a given area of land. Fertilizer is one of the important resources used in crop production. Agronomists have hypothesized for years that plant nutrients and crop yields are functionally related, and the economists call the functional relationships between plant nutrients and crop yields "production function" -- which is assumed to be characterized by some specified algebraic forms. Basic to the economic analysis of the response of a crop to fertilizer are the functional relationships between the quantity of fertilizer applied and the resulting crop yields.

Fig. 1 refers to the general transformation function between the input

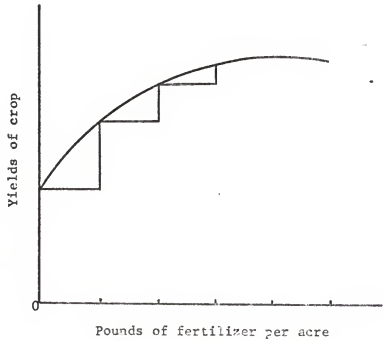

Fig. 1. Estimated Yield

of fertilizer and the output of the crop. As more and more units of fertilizer are applied, the additional quantity of crop produced with each successive unit of fertilizer become smaller and smaller until a maximum yield is obtained. That is, the response curve indicates diminishing marginal productivity of the fertilizer.

2. Response Curves

There are numerous factors that influence the response curves for the average yield of a crop, such as : (1) different kind of soil with various nutrient power, (2) the soil moisture level, (3) seed quantity, harvesting procedures, fertilizer carriers, time and method of fertilizer application, (4) weather and other environmental factors, (5) management practices. A study which takes all the factors into consideration is prohibitive. For this reason various studies limited to given conditions are being made. Usually all factors, except one which is under study, are fixed at some level.

Diminishing return curve is considered typical response curve for most crop-fertilizer relationships. Under the assumption that all growth factors except those under study are fixed at a given level, the amount of yield will increase as the quantity of the nutrient factor is increased, but the rate of the yield increase declines for higher amounts of fertilizer. The effect on the product may actually be harmful when extremely large quantities of the growth factor under study are applied (to relatively low levels of one or more of the fixed growth factors), and in consequence yields will decline.

A response curve gives a more detailed information with respect to the effectiveness of fertilizer on a given crop. After the type of response curve that best fits the particular set of data is calculated, the maximum yield resulting from a particular fertilizer and the optimum amount of fertilizer to be used at various fertilizer-crop price ratios can be estimated.

Knowledge of the response curves is equally important for both the farmer who considers his crop enterprises in the environment of unlimited capital as well as for the farmer with limited capital. It is needed as an aid in farm planning and linear programming. In general it improves the choice-making with respect to how and where fertilizer fits into the program of the farm as a whole.

3. Maximum Yield

When some of the factors are considered fixed, the question with respect the achievement of the maximum yield of a crop can be answered with the aid of marginal physical product. In order to get the maximum yield of a crop, therefore, the physiological relationship between fertilizer and yield of a crop must be known. Fig. 2 shows the marginal physical product (MPP) of each additional quantity of fertilizer. The MPP curve is decreasing as the fertilizer increases; i.e. each additional unit of input adds less to total output than the previous unit. This kind of diminishing return will continue until marginal physical product reaches zero at point A. After point A, any increase in input of fertilizer would result in negative marginal physical product. It is well known that there exists a relationship between the marginal physical product and the total physical product (TPP). As the MPP is decreasing and greater than zero, the TPP curve would increase at decreasing rate; when MPP is equal to zero, TPP curve reaches its maximum; when MPP is negative, TPP decreases with successive increases of input. The maximum yield of any crop with a given variable input is the yield at which the MPP of the last unit of variable input that applies in the production is equal to zero.

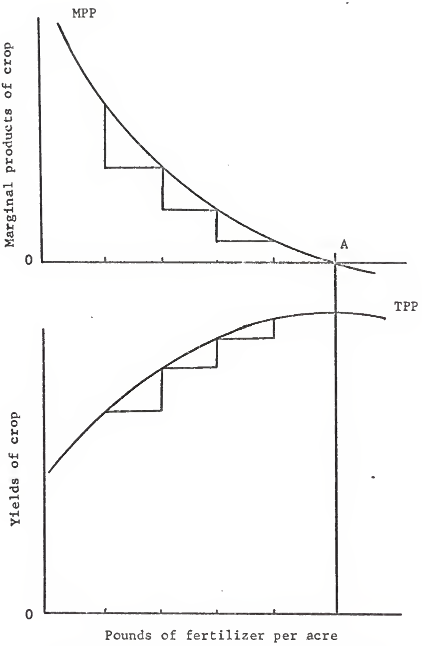

Fig. 2. The relationship between marginal physical product and the total physical product.

4. Most Profitable Level of Fertilizer Application and Maximum Profits

The physiological relationships between crop yields and the fertilizer inputs are very important in determination of the most profitable level of fertilizer application. But it is not the only one determinant, the prices of crops, the cost of fertilizer and the fluctuations in prices would also need to be taken into account in deciding upon the economically optimal level of application of fertilizers. For a farmer with unlimited capital, the greatest net return is obtained when fertilizer is applied at the level where the value of additional yield increment is equal to the cost of additional increment of fertilizer applied. Neither smaller nor larger application would pay as well. (It is illustrated at point X in Fig. 3 and the greatest net return is illustrated by the shaded area of Fig. 3.[1])

If the price of fertilizer is expressed in terms of the weight of the crop of equal value, the total cost of fertilizer can be shown in the same figure with total physical product (Fig. 4). It can be represented by a straight line (OC) through the origin. The vertical distance between the total cost curve and the total physical product curve illustrates the return above the cost of fertilizer at any rate of application. If the cost of fertilizer is the only cost to be considered, by drawing a line which is tangent to the total physical product and parallel to the total cost curve, the most profitable quantity to apply can be obtained. Line EG in Fig. 4 is so obtained and it is the largest distance between total physical product curve and total

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[1] J. L. Pashal, and B. L. French, "A Method of Economic Analysis Applied to Nitrogen Fertilizer Rate Experiments on Irrigated Corn", U. S. D. A., Tech. Bul., no. 1141, pp. 3 - 5.

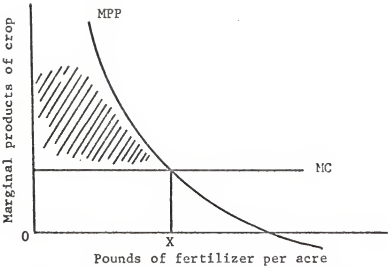

Fig. 3. Marginal physical products and maximum profits.

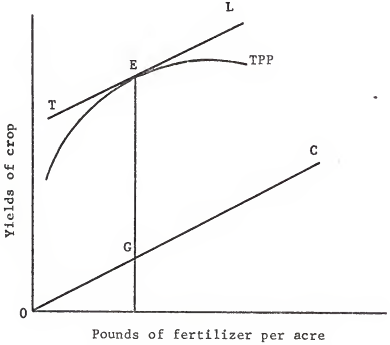

Fig. 4. Total physical products and maximum profits.

cost curve. Since the slope of TPP represents the marginal products of the fertilizer, the slope of OC represents the marginal cost of fertilizer and the tangent line TL has the same slope as OC. It can be also said that the most profitable level of fertilizer application and the maximum profits can be gotten when marginal cost of fertilizer is equal to marginal revenue of it.

The method of finding the most profitable level of a single input may also be expressed as a mathematical equation; i.e.

$$\Delta Y/\Delta F = P_F/P_Y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where ΔY and ΔF are the changes in the amount of yield and fertilizer and P_Y, P_F are the prices for crop and fertilizer respectively. Solving this equation gives the optimal level of nutrients for a given set of crop and fertilizer prices. Whenever the factor/product price ratio is greater than the marginal product ($P_F/P_Y > \Delta Y/\Delta F$), profits can be increased by using less of fertilizer. Whenever the factor/product price ratio is less than the marginal product ($P_F/P_Y < \Delta Y/\Delta F$), profits can be increased by using more of fertilizer.[1] The maximum profit from a single input can only be obtained when factor/product price ratio is equal to the marginal physical product of the input. The price ratio thus is a criterion by which decision is made.

The equation (1) also indicates that profits can be at maximum only when the marginal cost of a unit of input is equal to the value of the change in output of crop yield, $P_F(\Delta F) = P_Y(\Delta Y)$. This statement represents different way of saying that the maximum profit exists if the marginal cost of a unit of input is equal to marginal revenue of a unit of output.

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1. Earl O. Heady, Economics of Agricultural Production and Resource Use, Englewood Cliffs, N. J., Prentice-Hall, Inc., p. 101.

In actual practice, the prices of crops and fertilizers are not constant and the factor/product price ratios are continually changing. Thus the most profitable level of fertilization changes as the price ratio changes even if physiological relationships remain constant. The change is greater in the year when the price of crop is relatively higher and fertilizer costs are relatively lower than in the year when the price of crop is relatively lower and fertilizer costs are relatively higher. In other words, the greater the factor/product ratio is, the less the most profitable level of fertilization will be. The return to fertilizer increases as the price of fertilizer decreases when the rate of application is adjusted to the lower fertilizer price. The return also increases as the price of nitrogen decreases when the rate of application remains constant.

5. Derivation of Demand Curve for Fertilizer

A fertilizer demand curve is a curve which shows the quantities of fertilizer that farmers would be willing to buy at various prices. It has already been indicated that the maximum profits can be denoted through the equation of the marginal product of fertilizer with the factor/product price ratio, $dY/dF = P_F/P_Y$. By multipling the price of crop to both sides of the equation the following changes could be obtained:

$$P_Y \cdot dY/dF = P_Y \cdot P_F/P_Y$$

$$P_Y \cdot MPP_Y = P_F$$

Since MPP_Y times the price of crop is the value marginal product (VMP_Y), the equation (2) can be derived

$$VMP_Y = P_F \quad . \quad (2)$$

Because equal amounts are added to total costs by each unit of factor purchased, the marginal cost of each unit of factor is identical. The price of fertilizer may also be considered as the marginal cost of fertilizer. The equation (2), therefore, is another way of expressing maximum profits for fertilizer, and its emphasis is on the optimum quantity of the resource to be demanded. For this reason, the demand curve can be derived from response curve by using the marginal physical yield of crop multiplied by the price of the crop (i.e. value of marginal yield of crop). The demand curve for fertilizer is always sloping downward, which means that the lower the prices of fertilizer the larger the quantities of fertilizer demanded. If curve AB in Fig. 5 is the value marginal product curve of a given response curve at a given price of crop, then it also represents the demand curve of fertilizer. When the price of fertilizer is at P_1, in order to obtain maximum profits, the quantities of fertilizer which farmers would be willing to buy will be Of_1. If price of fertilizer falls from P_1 to P_2 as shown in Fig. 5, the farmers will be willing to buy of Of_2 fertilizer to obtain maximum profits.

The change in price of crop will influence the position of the demand curve for fertilizer. As it is shown above that demand curve is the influenced factor of the marginal physical product of fertilizer and the price of crop. The higher the price of a crop the greater the value of the marginal product, the lower the price of a crop the smaller the value of the marginal product. A rise in the price of a crop, therefore, causes the demand curve shifting to the upper right-hand corner in Fig. 5 and increasing the demand for fertilizer at a given price of fertilizer. A fall in the price of a crop causes the demand curve shifting to the lower left-hand corner and decreases the demand for fertilizer at a given price of fertilizer.

Since different demand curves result from different prices of a crop, the demand curve for fertilizer can not be represented by a single value marginal product curve. But if the demand curve is derived by using fertilizer/

crop price ratio instead of absolute prices, a single demand curve that does not shift its position with each change in price of a crop is obtained. This single demand curve indicates when a decrease in the price of crop or an increase in the price of fertilizer increases the fertilizer/crop price ratio and tends to reduce the use of fertilizer; an increase in the price of crop or a decrease in the price of fertilizer lowers the fertilizer/crop price ratio and tends to increase the use of fertilizer. This kind of relationship can be represented by Fig. 6. Curve CD represents the demand curve which is derived by using fertilizer/crop price ratios. By moving along the demand curve from point C to point D, the fertilizer/crop price ratio becomes smaller and smaller, and the quantities of fertilizer to be used increase gradually.[1]

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1. Frank Orazem & Floyd W. Smith, "An Economic Approach to the Use of Fertilizer", Kansas State College of Agriculture and Applied Science, Tech. Bul. 94, May 1958, pp. 13 - 17.

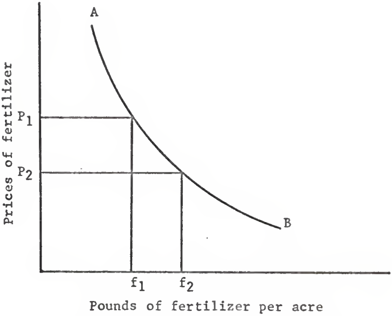

Fig. 5. Value marginal product curve

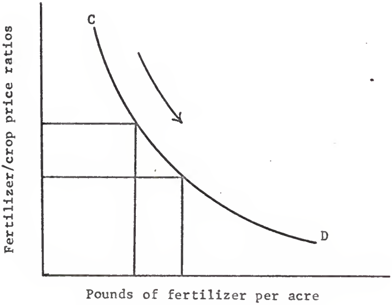

Fig. 6. Derived demand curve

III. ECONOMIC ANALYSIS OF EXPERIMENTAL DATA

1. Source of Data

The basic principles dealt with in preceding section serves as a guide in providing the rate of fertilizer application which results in maximum product and the rate of fertilizer application which will maximize profits from fertilizer use. By using the basic principles, the relevant production relationships are derived from the experimental data.

The data on which this study is based are from the experiments conducted from 1961-1965 for corn and from 1959-1965 for grain sorghum(RS 610) on irrigated land in West-Central Kansas.[1] Nitrogen(N), phosphorus(P_2O_5) and potassium(K_2O) are the variable elements. These were applied in various combinations; with nitrogen applied in increments of 40 pounds over a range from 0 to 200 pounds, with P_2O_5 and K_2O applied at 0 pounds or 40 pounds. Yields of corn and grain sorghum obtained from various fertilizers for six levels of nitrogen, two levels of P_2O_5 and K_2O (including zero rate) are reported in Table 1 for corn and Table 2 for grain sorghum. The rates of nitrogen considered are: 0, 40, 80, 120, 160, 200 pounds per acre and the rates of P_2O_5 and K_2O are 0 and 40 pounds per acre. The experiments included 18 fertilizer treatments. Each of the 18 treatment combinations was replicated five times, making a total of 450 observations for corn and of 630 observations for grain sorghum.

The soil moisture level was not limiting during the growing season of corn and grain sorghum in this area. The water was applied in pre-plant and in sufficient amounts during the growing season to keep moisture not a limiting

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1. The experimental data was obtained from Tribune Branch, Kansas Agricultural Experiment Station.

factor in corn and grain sorghum production.

The soil test on irrigated land of West-Central Kansas indicated high availability of phosphorus and potassium, and low availability of nitrogen. Responses of corn and grain sorghum yields to nitrogen are large, and a strong interaction exists between nitrogen and yields. Table 3 and Table 4 show the means of the reported yields for each of the 18 treatments for corn and grain sorghum, respectively. It can be seen that treatment without fertilizer averaged 49 bushels per acre for corn and 72.2 bushels per acre for grain sorghum. Average yields of the treatments receiving 40 pounds of P_2O_5 or K_2O do not differ greatly with those with no application of P_2O_5 or K_2O. However, an increase in yields is obtained for all treatments from nitrogen. This forms the reason that the effect of nitrogen is considered most significant while P_2C_5, K_2O fail to show a significant effect. In other words, nitrogen gives a statistically significant increase in yield while phosphorus and potassium do not.

Table 3 and Table 4 also show that positive relationships exists between yields of corn (or grain sorghum) and nitrogen. These relationships appear to be curvilinear; the average increases in yield from fertilizer input is increasing at a decreasing rate. For example, an average increase of 38.2 bushels per acre for corn is obtained for all plots receiving 40 pounds of nitrogen. However, at 80 pounds of nitrogen, the average additional yield increase is only 30.5 bushels per acre. The increased rated in yields continuous by decrease as more and more nitrogen is applied.

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[1]. Information obtained from Tribune Branch, Kansas Agricultural Experiment Station.

Table 1.1 Corn yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas
1961

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre					
		0	40	80	120	160	200
0	0	34.8	93.6	116.1	115.9	127.4	129.3
		33.8	97.9	123.3	129.4	154.5	130.7
		36.2	88.9	123.7	119.7	145.9	129.3
		56.4	91.2	122.3	124.8	140.7	137.3
		44.2	96.0	114.1	116.9	127.0	123.6
		41.1*	93.5	119.9	121.3	139.1	130.0
40	0	33.7	65.7	121.5	131.8	126.5	128.9
		48.9	85.4	121.8	134.2	136.5	152.0
		28.5	101.4	102.9	130.4	128.4	134.1
		43.6	81.7	123.4	116.7	141.3	132.2
		53.6	91.8	121.0	122.8	136.5	144.9
		41.7*	85.2	118.1	127.2	133.8	138.4
40	40	32.2	84.0	115.6	122.7	127.8	132.2
		46.0	100.4	122.3	125.6	144.0	137.9
		50.6	93.0	107.0	137.7	131.6	133.1
		40.9	72.7	125.5	141.6	126.4	126.5
		48.2	90.1	111.7	146.0	132.6	131.3
		43.6*	88.0	116.4	134.7	132.5	132.2

*Average yield of five replications.

Table 1.2 Corn yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1962

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre					
		0	40	80	120	160	200
0	0	69.4	71.3	135.5	149.1	147.1	154.9
		53.8	105.7	116.0	149.1	164.0	157.5
		60.3	108.2	146.5	150.4	145.2	150.4
		42.1	97.2	144.5	134.2	174.4	164.0
		93.3	110.8	117.3	155.6	145.2	151.0
		63.8*	98.6	132.0	147.7	155.2	155.6
40	0	41.5	134.2	145.8	153.6	153.6	167.2
		65.5	112.1	129.6	159.5	151.7	156.2
		68.1	107.6	107.6	148.4	144.5	146.5
		64.2	128.3	153.0	144.5	134.8	150.4
		77.8	132.2	143.9	153.0	156.2	170.5
		63.4*	122.9	136.0	151.8	148.2	158.2
40	40	59.6	119.3	135.5	135.5	162.7	147.8
		82.3	110.2	135.5	159.5	149.1	158.2
		75.8	102.4	119.9	169.2	144.5	155.6
		60.3	127.0	138.7	156.2	161.4	144.5
		64.8	90.1	142.0	154.3	158.2	169.8
		68.6*	109.8	134.3	154.9	155.2	155.2

*Average yield of five replications.

Table 1.3 Corn yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1963

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre					
		0	40	80	120	160	200
		42.9	61.5	113.6	122.5	147.9	130.8
		51.0	70.4	106.9	112.5	128.5	127.4
0	0	42.9	74.9	105.4	109.9	124.8	131.9
		25.3	86.8	112.9	114.7	146.0	135.6
		44.0	76.8	87.2	103.6	111.4	139.3
		41.2*	74.1	105.2	112.6	131.7	133.0
		22.0	96.1	106.9	135.6	119.2	125.5
		74.9	80.8	131.1	114.4	146.0	149.4
40	0	57.0	87.9	93.9	112.1	157.2	142.7
		32.4	76.4	114.7	113.6	131.9	149.8
		32.8	69.7	99.1	121.1	109.9	129.6
		43.8*	82.2	109.1	119.4	132.8	139.4
		45.8	73.4	99.5	113.6	137.4	149.4
		39.9	85.7	119.2	132.6	157.2	139.3
40	40	60.0	77.8	117.0	138.2	136.7	159.4
		26.8	89.4	101.3	127.4	127.0	144.5
		47.3	71.2	79.7	117.7	123.0	128.1
		44.0*	79.5	103.3	125.9	136.3	144.1

*Average yield of five replications.

Table 1.4 Corn yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1964

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre 0	40	80	120	160	200
		56.7	83.8	128.7	127.1	130.2	139.4
		49.7	82.6	121.0	127.6	131.3	144.7
0	0	61.3	88.0	121.0	139.4	131.3	118.5
		54.3	82.0	125.8	133.5	139.6	130.7
		53.2	83.8	118.0	119.3	126.0	123.7
		55.0*	84.0	122.9	129.4	131.7	131.4
		55.0	93.1	135.0	134.6	101.1	142.2
		59.6	85.5	105.4	137.0	135.5	145.7
40	0	59.1	85.5	126.7	131.6	149.7	134.6
		44.4	88.4	104.2	118.9	139.0	138.7
		54.9	99.6	118.4	132.8	136.1	141.6
		54.6*	90.4	117.9	131.0	132.3	140.6
		52.6	91.5	120.1	128.7	144.6	160.5
		46.2	69.9	117.1	136.5	145.2	149.8
40	40	58.9	87.0	112.4	144.2	144.6	142.7
		52.6	90.9	115.0	123.4	138.0	132.0
		49.7	83.0	110.1	132.3	131.4	146.2
		52.0*	84.5	114.9	133.0	140.8	146.2

*Average yield of five replications.

Table 1.5 Corn yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas
1965

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre 0	40	80	120	160	200
0	0	43.2	65.3	104.3	129.8	139.5	146.7
		44.1	74.2	114.2	115.7	122.8	140.9
		40.6	84.8	123.3	122.9	146.3	137.7
		56.5	84.5	128.0	123.2	140.9	134.4
		38.6	78.0	104.3	128.1	153.6	118.2
		44.6*	77.4	114.8	123.9	140.6	135.6
40	0	42.1	77.4	109.6	151.6	151.6	143.6
		40.0	69.0	123.2	147.1	157.2	161.1
		54.1	78.7	118.8	151.9	158.6	143.5
		48.7	72.0	127.4	132.4	154.7	136.5
		50.4	90.8	124.9	143.6	163.2	142.4
		47.1*	77.6	120.8	145.3	157.1	145.4
40	40	53.9	81.1	104.9	138.9	138.6	135.2
		45.5	59.6	118.3	147.9	158.8	160.6
		56.0	88.2	126.0	145.9	136.6	156.0
		40.8	88.2	121.8	140.3	160.6	163.0
		53.9	83.8	127.6	140.6	151.2	139.8
		50.0*	80.2	119.7	142.7	149.2	150.9

*Average yield of five replications.

Table 2.1. Grain sorghum yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1959

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre 0	40	80	120	160	200
		86.4	110.9	107.0	109.3	104.8	129.9
		99.4	94.1	114.7	128.5	116.2	113.9
		110.9	113.1	133.8	122.4	137.6	131.5
0	0	87.2	113.1	128.5	131.5	120.8	133.8
		85.6	111.6	119.3	128.5	115.8	146.8
		93.9*	108.6	120.7	124.0	119.0	131.2
		74.2	109.3	105.6	113.1	109.3	123.8
		88.0	113.9	121.6	120.0	128.5	144.5
40	0	110.1	110.9	123.8	138.4	96.3	130.7
		107.8	118.5	127.7	129.9	121.6	140.6
		87.2	116.2	122.4	117.0	133.1	143.7
		93.5*	113.8	120.2	123.7	117.8	136.7
		94.3	100.3	111.0	114.8	108.6	114.0
		85.9	85.1	122.3	121.6	130.8	129.9
40	40	91.9	107.2	123.9	137.6	133.8	146.0
		98.8	121.6	136.0	133.0	133.0	129.9
		99.6	117.8	117.8	123.9	146.0	128.5
		94.1*	106.4	122.2	126.2	130.4	129.7

*Average yield of five replications.

Table 2.2 Grain sorghum yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1960

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre 0	40	80	120	160	200
0	0	77.1	117.5	132.7	137.8	145.2	139.3
		64.9	104.8	117.3	126.3	141.8	143.0
		79.2	116.4	134.1	140.6	139.5	135.7
		73.2	109.4	147.4	136.9	136.9	134.4
		90.8	112.9	129.5	137.2	140.5	146.1
		77.0*	112.2	132.2	135.8	140.8	139.7
40	0	92.7	128.3	132.3	136.1	136.6	136.2
		86.1	126.0	137.2	140.6	146.7	142.8
		73.4	117.1	133.1	138.9	138.1	147.5
		96.5	118.4	132.5	123.5	146.8	134.8
		109.7	139.7	132.3	133.6	143.1	132.3
		91.7*	125.9	133.5	134.5	142.3	138.7
40	40	72.5	128.3	130.6	136.8	136.6	134.2
		74.6	119.8	122.2	128.1	152.1	142.0
		107.2	116.8	132.3	134.7	149.1	143.9
		58.3	123.6	126.2	132.7	143.5	146.9
		92.2	110.9	144.2	139.9	151.6	152.1
		81.0*	119.9	131.1	134.4	146.6	143.8

*Average yield of five replications.

Table 2.3 Grain sorghum yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1961

Unit: bu.

Pounds	Pounds	Pounds of Nitrogen Per Acre					
P_2O_5	K_2O	0	40	80	120	160	200
0	0	49.6	88.2	115.7	115.7	122.6	119.0
		48.2	94.7	110.9	121.8	127.9	128.7
		69.0	122.5	117.1	121.3	125.1	129.7
		52.4	93.8	115.7	122.2	130.7	123.1
		67.6	102.8	113.8	125.5	128.8	123.1
		57.4*	100.4	114.6	121.3	127.0	124.7
40	0	46.2	99.4	109.9	123.9	124.7	129.5
		61.5	106.4	117.8	118.3	126.1	129.9
		80.2	112.4	115.9	121.6	117.2	128.1
		66.1	96.2	116.4	117.9	124.7	131.7
		66.6	89.6	114.5	116.0	117.2	116.9
		64.1*	100.8	114.9	119.5	122.0	127.2
40	40	27.5	97.2	124.5	129.5	125.1	129.3
		94.8	104.7	118.6	132.8	130.7	119.4
		74.9	111.3	119.1	128.5	130.2	128.8
		50.7	97.2	117.2	117.2	130.7	125.0
		51.2	112.3	110.8	125.7	118.6	126.9
		59.8*	104.5	118.0	126.7	127.1	125.9

*Average yield of five replications.

Table 2.4 Grain sorghum yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1962

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre 0	40	80	120	160	200
0	0	83.2	111.2	126.0	128.4	136.9	136.9
		69.2	119.0	131.5	129.1	129.1	143.9
		94.9	128.4	131.5	139.2	133.0	134.6
		86.3	113.6	126.0	142.4	135.4	141.6
		102.7	113.6	131.5	133.8	138.5	139.2
		87.3*	117.2	129.3	134.6	134.6	139.2
40	0	77.8	131.5	110.5	140.8	138.5	135.4
		93.3	124.5	136.1	133.8	137.7	133.0
		92.6	126.0	140.8	134.6	139.2	139.2
		100.3	124.5	138.5	129.9	145.5	143.1
		89.5	125.2	134.6	140.0	140.0	143.9
		90.7*	126.3	132.1	135.8	140.2	138.9
40	40	84.0	130.7	131.5	136.1	151.7	137.7
		120.6	122.9	141.6	145.5	144.7	146.2
		99.6	129.1	138.5	143.9	147.0	137.7
		75.5	122.9	141.6	139.6	136.1	141.6
		84.0	124.5	120.6	139.2	133.8	146.2
		92.7*	126.0	134.8	140.9	142.7	141.9

*Average yield of five replications.

Table 2.5 Grain sorghum yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1963

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre 0	40	80	120	160	200
		72.9	112.4	141.4	125.8	128.0	136.2
		78.9	114.6	128.7	134.0	134.0	123.5
0	0	82.6	107.2	119.8	135.4	127.3	125.8
		76.7	102.7	138.4	125.8	136.2	133.2
		90.0	92.3	127.3	129.5	127.3	134.0
		80.2*	105.8	131.1	130.1	130.6	130.5
		74.4	124.3	119.1	107.9	139.9	131.0
		86.3	108.7	123.5	140.7	137.7	132.5
40	0	103.4	101.7	120.6	134.0	141.4	143.6
		84.1	105.9	127.3	119.1	140.7	130.2
		89.3	122.8	119.1	130.2	138.4	132.5
		87.5*	112.7	121.9	126.4	139.6	134.0
		87.8	116.1	142.1	143.6	134.7	141.4
		95.3	104.9	125.0	126.3	119.8	127.3
40	40	87.8	114.6	125.0	131.0	132.5	128.0
		66.2	113.1	118.3	131.0	137.7	139.2
		75.2	112.4	121.3	129.5	150.3	148.8
		82.5	112.2	126.3	132.3	135.0	136.9

*Average yield of five replications.

Table 2.6 Grain sorghum yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1964

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre 0	40	80	120	160	200
		48.7	89.8	135.8	125.6	134.4	145.8
		50.6	100.8	128.1	129.5	125.2	140.5
0	0	65.3	103.7	129.0	139.7	141.1	135.8
		55.8	92.6	133.3	132.0	147.4	138.1
		61.0	89.8	132.0	146.0	128.6	146.2
		56.3*	95.3	131.6	134.6	135.3	141.3
		46.8	106.7	119.2	140.1	138.8	144.0
		59.6	103.4	137.8	136.8	146.9	140.2
40	0	60.6	89.9	133.1	138.7	144.0	141.7
		59.1	105.8	129.3	134.9	144.6	152.2
		92.0	114.9	143.1	133.4	131.2	137.8
		63.6*	104.1	132.5	136.8	141.1	143.2
		52.5	101.6	139.7	131.0	140.2	141.3
		58.7	106.4	123.9	148.3	150.3	128.4
40	40	80.1	109.2	128.2	150.2	150.3	137.1
		56.8	116.0	134.9	144.5	146.5	142.3
		72.0	99.7	120.1	143.0	147.9	150.9
		64.0*	106.6	129.4	143.4	147.0	140.0

*Average yield of five replications.

Table 2.7 Grain sorghum yields (bushels) per acre for different fertilizer treatments on irrigated land of West-Central Kansas 1965

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Pounds of Nitrogen Per Acre 0	40	80	120	160	200
0	0	46.0	89.2	101.4	103.0	102.3	114.4
		46.4	79.5	92.7	87.7	92.1	109.7
		50.2	87.4	106.5	111.0	111.6	108.8
		61.8	84.6	108.4	123.1	105.1	113.4
		62.2	78.5	103.8	124.9	104.6	116.7
		53.3*	83.8	102.6	109.9	103.1	112.6
40	0	39.0	87.7	95.3	111.2	113.0	116.4
		47.8	93.3	107.8	122.4	120.0	118.2
		51.4	78.3	102.3	106.1	118.2	111.8
		52.4	94.2	99.0	113.5	114.9	121.0
		63.4	92.8	115.3	108.0	115.9	125.6
		50.8*	89.3	103.9	112.2	116.4	118.6
40	40	47.5	87.8	116.8	117.6	119.8	114.6
		56.8	79.4	112.2	110.6	121.2	110.9
		59.0	83.6	104.6	125.5	124.5	125.2
		54.0	86.4	109.4	115.8	111.5	120.1
		55.4	88.2	105.1	119.5	110.5	120.5
		54.5*	85.1	109.6	117.8	117.5	118.3

*Average yield of five replications.

Table 3 Five-year averaged yields of corn per acre for different treatments on irrigated land of West-Central Kansas 1961 - 1965

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Year	Pounds of Nitrogen Per Acre					
			0	40	80	120	160	200
0	0	1961	41.1	93.5	119.9	121.3	139.1	130.0
		1962	63.8	98.6	132.0	147.7	155.2	155.6
		1963	41.2	74.1	105.2	112.6	131.7	133.0
		1964	55.0	84.0	122.9	129.4	131.7	131.4
		1965	44.6	77.4	114.8	123.9	140.6	135.6
		Average	49.1	85.5	119.0	126.9	139.7	137.1
40	0	1961	41.7	85.2	118.1	127.2	133.8	138.4
		1962	63.4	122.9	136.0	151.8	148.2	158.2
		1963	43.8	82.2	109.1	119.4	132.8	139.4
		1964	54.6	90.4	117.9	131.0	132.3	140.6
		1965	47.1	77.6	120.8	145.3	157.1	145.4
		Average	50.1	91.7	120.4	134.9	140.8	144.4
40	40	1961	43.6	88.0	116.4	134.7	132.5	132.2
		1962	68.6	109.8	134.3	154.9	155.2	155.2
		1963	44.0	79.5	103.3	125.9	136.3	144.1
		1964	52.0	84.5	114.9	133.0	140.8	146.2
		1965	50.0	80.2	119.7	142.7	149.2	150.9
		Average	51.6	88.4	117.7	138.3	142.8	145.7

Table 4. Seven-year averaged yields of grain sorghum per acre for different treatments on irrigated land of West-Central Kansas 1959 - 1965

Unit: bu.

Pounds P_2O_5	Pounds K_2O	Year	Pounds of Nitrogen Per Acre					
			0	40	80	120	160	200
0	0	1959	93.9	108.6	120.7	124.0	119.0	131.2
		1960	77.0	112.2	132.2	135.8	140.8	139.7
		1961	57.4	100.4	114.6	121.3	127.0	124.7
		1962	87.3	117.2	129.3	134.6	134.6	139.2
		1963	80.2	105.8	131.1	130.1	130.6	130.4
		1964	56.3	95.3	131.6	134.6	135.3	141.3
		1965	53.3	83.8	102.6	109.9	103.1	112.6
		Average	72.2	103.3	123.2	127.2	127.2	131.3
40	0	1959	93.5	113.8	120.2	123.7	117.8	136.7
		1960	91.7	125.9	133.5	134.5	142.3	138.7
		1961	64.1	100.8	114.9	119.5	122.0	127.2
		1962	90.7	126.3	132.1	135.8	140.2	138.9
		1963	87.5	112.7	121.9	126.4	139.6	134.0
		1964	63.6	104.1	132.5	136.8	141.1	143.2
		1965	50.8	89.3	103.9	112.2	116.4	118.6
		Average	77.4	110.4	122.7	127.0	131.3	133.9
40	40	1959	94.1	106.4	122.2	126.2	130.4	129.7
		1960	81.0	119.9	131.1	134.4	146.6	143.8
		1961	59.8	104.5	118.0	126.7	127.1	125.9
		1962	92.7	126.0	134.8	140.9	142.7	141.9
		1963	82.5	112.2	126.3	132.3	135.0	136.9
		1964	64.0	106.6	129.4	143.4	147.0	140.0
		1965	54.5	85.1	109.6	117.8	117.5	118.3
		Average	75.5	108.7	124.5	131.7	135.2	133.8

2. Regression Analysis

The basic purpose of this study is to estimate crop yield production function for fertilizer. Regression analysis is used on 18 treatment-yields involving different years to determine the relationship between fertilizer and yield.

In this study, various forms of the corn (or grain sorghum)-fertilizer production functions have been estimated. Several algebraic forms of the yield predicting equations are derived from the original data shown in Table 1 and Table 2. Three different types of functions are used for corn and two different types of functions are used for grain sorghum. Within each type of function, four equations are estimated; for example, there are four quadratic equations for variable nitrogen -- one for 0 pounds of P_2O_5 and K_2O, one for 40 pounds of P_2O_5 and 0 pounds of K_2O, one for 40 pounds of both P_2O_5 and K_2O, and one for all the treatments in the experiment. The estimated coefficients of each production function are written in their respective algebraic forms below:

Corn: A. Square root production function (single nutrient variable)

$$Y = a + bN + cN^2 + d\sqrt{N}$$

(1) (K_2O = zero; P_2O_5 = zero; N variable)

$$Y = 48.9931 + .9640N - .0029N^2 + .7187\sqrt{N} \quad (3)$$

(2) (K_2O = zero; P_2O_5 = 40; N variable)

$$Y = 49.9882 + .7266N - .0023N^2 + 2.7702\sqrt{N} \quad (4)$$

(3) (K_2O = 40; P_2O_5 = 40; N variable)

$$Y = 51.5529 + 1.1007N - .0031N^2 - .2694\sqrt{N} \quad (5)$$

(4) (N variable; quantities of P_2O_5 and K_2O not taken into consideration)

$$Y = 50.1771 + .9301N - .0027N^2 + 1.0755\sqrt{N} \text{ .... } (6)$$

B. Quadratic production functions (single nutrient variable)

$$Y = a + bN + cN^2$$

(1) (K_2O = zero; P_2O_5 = zero; N variable)

$$Y = 49.4445 + 1.0558N - .0031N^2 \text{ .... } (7)$$

(2) (K_2O = zero; P_2O_5 = 40; N variable)

$$Y = 51.7248 + 1.0803N - .0031N^2 \text{ .... } (8)$$

(3) (K_2O = 40; P_2O_5 = 40; N variable)

$$Y = 51.3849 + 1.0663N - .0030N^2 \text{ .... } (9)$$

(4) (N variable; quantities of P_2O_5 and K_2O not taken into consideration)

$$Y = 50.8527 + 1.0674N - .0031N^2 \text{ .... } (10)$$

C. Square root production function with more than one variable

$$Y = a + bN + cP + dK + eN^2 + fP^2 + gK^2 + h\sqrt{N}\sqrt{P}\sqrt{K}$$

(1) $Y = 48.6760 + 1.0553N + 1.7736P + 1.3437K - .0030N^2$

$$-.0410P^2 - .0363K^2 + .0071\sqrt{N}\sqrt{P}\sqrt{K} \text{ .... } (11)$$

Grain Sorghum:

A. Square root production functions (single nutrient variable)

(1) (K_2O = zero; P_2O_5 = zero; N variable)

$$Y = 70.8520 - .3251N + .00012N^2 + 8.2181\sqrt{N} \text{ .... } (12)$$

(2) (K_2O = zero; P_2O_5 = 40; N variable)

$$Y = 77.2960 - .2411N + .00014N^2 + 6.9406\sqrt{N} \text{ .... } (13)$$

(3) (K_2O = 40; P_2O_5= 40; N variable)

$$Y = 75.5118 + .2541N - .0012N^2 + 3.9178\sqrt{N} \text{ .... } (14)$$

(4) (N variable; quantities of K_2O and P_2O_5 not taken into consideration)

a. $Y = 74.2637 - .2425N + .00005N^2 + 7.3926\sqrt{N}$ ....(15)

b. $Y = 74.8726 - .1947N + 6.8270\sqrt{N}$ ....(16)

B. Cobb-Douglas function (single nutrient variable)[1]

$Y = a\ N^b$

(1) (K_2O = zero; P_2O_5 = zero; N variable)

$Y = 69.50\ N^{.1203}$,................................(17)

(2) (K_2O = zero; P_2O_5 = 40; N variable)

$Y = 74.40\ N^{.1104}$ ....(18)

(3) (K_2O = 40; P_2O_5 = 40; N variable)

$Y = 72.04\ N^{.1201}$ ....(19)

(4) (N variable; quantities of P_2O_5 and K_2O not taken into consideration)

$Y = 71.95\ N^{.1170}$ ....(20)

In all these equations, Y refers to the estimated total yield in bushels per acre which is taken to be the dependent variable to be estimated, N refers to pounds of nitrogen per acre, P refers to pounds of P_2O_5 per acre and K refers to pounds of K_2O per acre; N, P, K, are independent variable which are varied in a controlled manner. The coefficients of the independent variables are parameters whose values are to be estimated from the data. Values of t (or F) for the regression coefficients in order that appear in each function and the correlation coefficients, R, of each equation are presented

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1. Earl O. Heady, Agricultural Production Function, Ames, Iowa State University Press, 1961, p. 229.

"the Cobb-Douglas function implies that at least some quantity of each input must be used if output is to be nonzero. In the real world, such a condition does not hold true .... To overcome this problem, assuming there are strong grounds for using a Cobb-Douglas model, the zero observations may be replaced by some figure of arbitrary small size ..."

in Table 5.

To test what kind of functions fits the data best, t value test, F ratio test and R^2 are used as indicators of goodness of fit in this study. (R^2 is interpreted as the proportion of variation accounted for and presumably the larger the R^2 value, the better the fit). The quadratic equations for corn are regarded as more appropriate for economic analysis because (1) the level of significance of all coefficients in the quadratic functions are at the 0.01 percent level which makes the estimated yields of corn from quadratic functions more reliable than from the others, (2) the R^2 values for quadratic functions for corn as listed in Table 5 are 0.86, 0.83, 0.87, 0.85 respectively, which means that 86, 83, 87 and 85 percent of the variation in yields is statistically explained by the variations in nitrogen application,[1] (3) the standard derivations of coefficients b, c are 0.0565, 0.0003; 0.0640, 0.0003; 0.0556, 0.0003; and 0.0342, 0.0002; respectively. The negative N^2 in the equations are important because they result in diminishing returns to additional nitrogen inputs and make the response curves of corn to nitrogen realistic; (i.e. the yield increase at decreasing rate with additional inputs of nitrogen at first, the increase continues until the inputs of nitrogen reach a level, after that level any more additional inputs of nitrogen would result in diminishing total yield).

The Cobb-Douglas function is considered to be the most appropriate one for the analysis of grain sorghum experiment. As it is shown in Table 2, there is no diminishing total yield even if the input of nitrogen increases to 200 pounds per acre. Thus the maximum yields resulted from nitrogen inputs

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1.R. E. Patterson, "Economic Decision in Producing Irrigated Grain Sorghum on the Northern High Plains of Texas", Texas A&M University, Texas Agricultural Experiment Station, MP-747, Dec. 1964, p. 6.

Table 5. Values of R and t(or F)* for individual regression coefficients

Response Curve	Value of R	Value of t(or F) for Coefficients in Order Listed in Response Curves with Significance Levels in Parenthesis						
Corn:								
A. (1)	.93	4.11	4.66	0.40				
		(0.001)	(0.001)	(0.60)				
(2)	.91	2.75	3.28	1.38				
		(0.01)	(0.005)	(0.20)				
(3)	.94	4.77	5.07	0.15				
		(0.001)	(0.001)	(.50)				
(4)	.92	6.57	7.37	1.00				
		(0.001)	(0.001)	(0.40)				
B. (1)	.93	18.68	11.42					
		(0.001)	(0.001)					
(2)	.91	16.87	10.21					
		(0.001)	(0.001)					
(3)	.93	19.18	11.22					
		(0.001)	(0.001)					
(4)	.92	31.22	18.75					
		(0.001)	(0.001)					
C.	.93	29.15	0.99	0.80	18.38	0.92	0.83	0.96
		(0.001)	(0.50)	(0.50)	(0.001)	(0.50)	(0.50)	(0.50)
Grain Sorghum:								
A: (1)	.66	3.49	1.57	6.92				
		(0.001)	(0.20)	(0.001)				
(2)	.76	1.01	0.22	3.82				
		(0.50)	(.50)	(0.001)				
(3)	.84	1.27	2.27	2.60				
		(0.40)	(0.025)	(0.01)				

Table 5. Values of R and t(or F)* for individual regression coefficients (continued)

Response Curve	Value of R	Value of t(or F) for Coefficients in Order Listed in Response Curves with Significance Levels in Parenthesis		
Grain Sorghum:				
A. (4) a.	.74	5.26	1.16	12.77
		(0.001)	(0.40)	(0.001)
b.	.74	12.21	22.08	
		(0.001)	(0.001)	
B. (1)	.84	484.70		
		(0.001)		
(2)	.81	391.39		
		(0.001)		
(3)	.82	424.97		
		(0.001)		
(4)	.82	1280.25		
		(0.001)		

*Used in Cobb-Douglas functions.

have not been reached when the inputs of nitrogen are less or equal to 200 pounds per acre. Besides, the values of F and R^2 for all of the Cobb-Douglas functions which are obtained from the original data in Table 2 are more significant than from any other functions. For these reasons the Cobb-Douglas type production function is chosen in estimation of grain sorghum responses to fertilizers.

3. Predicted Yield and Response Curve

Functions chosen to characterize the production relationship between inputs and outputs influence the estimated transformation of inputs into outputs. There are different kinds of functions: (1) functions which make the predicted yield reach a maximum and then decrease, (2) functions which make the predicted yield never reach a maximum, (3) functions which make the predicted yield approach a maximum asmptotically.[1]

A. Corn

The experimental data of yields of corn response to nitrogen in West-Central Kansas show that the yield of corn first increases, it reaches a maximum at certain level of nitrogen application and then it decreases. A production function which has such kind of characteristic is therefore considered relatively more appropriate than other. The quadratic production function is regarded to be the most appropriate for predicting the yields of corn in this study. It is chosen not only for this reason but also for

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1.A. P. Stemberger, "Economic Implications of Using Alternative Productions Functions for Expressing Corn-Nitrogen Production Relationships", North Carolina Agricultural Experiment Station, Tech. Bul. 126, p. 4.

statistical considerations (such as t value test, R^2) as illustrated in preceding section.

Yield estimations of corn from quadratic production functions (7), (8), (9) are presented in Table 6. These yields are derived by substituting into equations (7), (8), (9) the amount of nitrogen listed in Table 6, column 1 (under the assumption that P_2O_5 and K_2O are fixed at a constant level). Table 6 shows that highest predicted yield resulting from selected level of nitrogen input at the zero pounds of P_2O_5 and K_2O is 139.3 bushels per acre when nitrogen application is 170 pounds per acre; at the 40 pounds of P_2O_5 and zero pounds of K_2O it is 145.8 bushels per acre when nitrogen application is 170 pounds per acre; and at 40 pounds of P_2O_5 and K_2O it is 146.1 bushels when nitrogen application is 180 pounds per acre. This is a 89.9, 94.1, 94.7 bushels over the lowest predicted yields in Table 6. The marginal yields of corn response to each additional unit of nitrogen input of equations (7), (8), (9) are also presented in Table 6 at three different combinations of P_2O_5 and K_2O as indicated in the table. There are no significant differences in predicted marginal yields among the three equations.

Graphic views of predicted corn response curves and marginal yield curves are provided in Fig. 7 and Fig. 8. The height of each curve represents yields while the horizontal axis represents the amounts of nitrogen application. The curves in these two Figures are derived from the estimated yields reported in Table 6.[1] The response curves show the estimated corn yields due to differ-

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1. Frank Orazem and Roy B. Herring, "Economic Aspects of the Effects of Fertilizers, Soil Moisture and Rainfall on the Yield of Grain Sorghum in the Sandy Lands of Southwest Kansas", Journal of Farm Econ., Vol. XL, no. 3, Aug. 1958, pp. 700 - 706

ent amount of nitrogen application, the marginal yield curves show the estimated additional yields added to the total yields with each additional unit of nitrogen input. Both of these two Figures indicate that the margins among the three response curves or among the three marginal yield curves are so small that we can neglect the influence of the amount of P_2O_5 and K_2O on the estimated yields. It can assumed, therefore, the change in the amount of P_2O_5 and K_2O application has no significant influence on predicted yields in this area. Table 6 shows that yields do not change appreciable with the application of P_2O_5 and K_2O. In other words, the production of corn is not limited by the amount of P_2O_5 and K_2O on irrigated land in West-Central Kansas.

Statistical tests also indicate that the best positive relationship among all the variables considered is that between the yields and the amount of nitrogen. The corn response to nitrogen on irrigated land in West-Central Kansas is of decreasing return nature; each additional amount of nitrogen adds less to the total yield than the preceding one.

For the above reasons, the equation (10) is derived by taking all the observations into account and neglecting the influence of the amount of P_2O_5 and K_2O. According to equation (10), yield is predicted to start on the average at 50.9 bushels per acre with no application of nitrogen, at 88.6 bushels per acre with 40 pounds of nitrogen and at 116.4, 134.3, 142.3, 140.3 bushels per acre with 80, 120, 160, 200 pounds of nitrogen respectively. The estimated rates of transformation of nitrogen into corn is represented by Fig. 9, 10 and shown in Table 7. The highest predicted yield, resulting from the selected levels of nitrogen in Table 7, is 142.7 bushels per acre attained at 170 pounds of nitrogen application. This is a 91.8 bushels increase over the lowest predicted yield.

Table 6. Predicted and marginal yields of corn associated with each additional 10 pounds of nitrogen application per acre on irrigated land of West-Central Kansas

Unit:bu.

Applications of N per acre Pounds	With P_2O_5, K_2O = 0			With P_2O_5 = 40, K_2O = 0			With P_2O_5 = 40, K_2O = 40		
	Predicted Total Yields	Marginal Yields		Predicted Total Yields	Marginal Yields		Predicted Total Yields	Marginal Yields	
		Exact	Average		Exact	Average		Exact	Average
0	49.4			51.7			51.4		
10	59.7	.99	10.3	62.2	1.02	10.5	61.7	1.03	10.3
20	69.3	.93	9.6	72.1	.96	9.9	71.5	.95	9.8
30	78.3	.87	9.0	81.3	.89	9.2	80.7	.89	9.2
40	86.7	.81	8.4	90.0	.83	8.7	89.2	.83	8.5
50	94.5	.75	7.8	98.0	.77	8.0	97.2	.77	8.0
60	101.6	.68	7.1	105.4	.71	7.4	104.6	.71	7.4
70	108.2	.62	6.6	112.2	.65	6.8	111.3	.65	6.7
80	114.1	.56	5.9	118.3	.58	6.1	117.5	.59	6.2
90	119.4	.50	5.3	123.8	.52	5.5	123.1	.53	5.6
100	124.0	.44	4.6	128.8	.46	5.0	128.0	.47	4.9
110	128.1	.37	4.1	133.1	.40	4.3	132.4	.41	4.4
120	131.5	.31	3.4	136.7	.34	3.6	136.1	.35	3.7
130	134.3	.25	2.8	139.8	.27	3.1	139.3	.29	3.2
140	136.5	.19	2.2	142.2	.21	2.4	141.9	.23	2.6
150	138.1	.13	1.6	144.0	.15	1.8	143.8	.17	1.9
160	139.0	.06	0.9	145.2	.09	1.2	145.2	.11	1.4
170	139.3	.00	0.3	145.8	.03	0.6	146.0	.05	0.8
180	139.0	-.06	-0.3	145.8	-.04	0.0	146.1	-.01	0.1
190	138.1	-.12	-0.9	145.1	-.10	-0.7	145.7	-.07	-0.4
200	136.6	-.18	-1.5	143.8	-.16	-1.3	144.6	-.13	-1.1

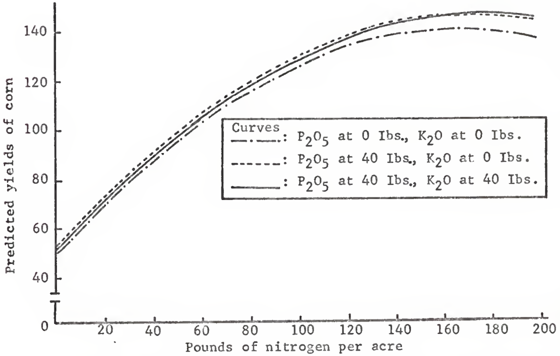

Fig. 7. Predicted yields of corn on irrigated land in West-Central Kansas.

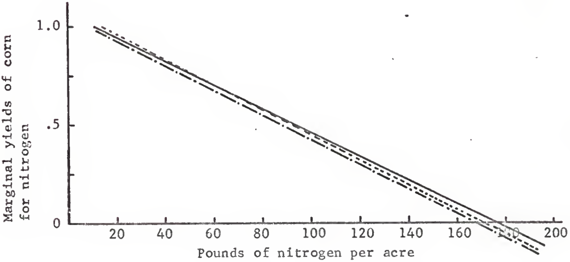

Fig. 8. Marginal yields of corn on irrigated land in West-Central Kansas.

Table 7. Predicted total and marginal yields of corn associated with each additional 10 pounds of nitrogen application per acre on irrigated land of West-Central Kansas*

Unit:bu.

Applications of N Per Acre Pounds	Predicted Total Yields	Marginal Yields	
		Exact	Average
0	50.9		
10	61.2	1.01	10.3
20	71.0	.94	9.8
30	80.1	.88	9.1
40	88.6	.82	8.5
50	96.5	.76	7.9
60	103.7	.70	7.2
70	110.4	.63	6.7
80	116.4	.57	6.0
90	121.8	.51	5.4
100	126.6	.45	4.8
110	130.8	.39	4.2
120	134.3	.32	3.5
130	137.2	.26	2.9
140	139.5	.20	2.3
150	141.2	.14	1.7
160	142.3	.08	1.1
170	142.7	.01	0.4
180	142.5	-.05	-0.2
190	141.7	-.11	-0.8
200	140.3	-.17	-1.4

*All observations are used in estimating reported relationship.

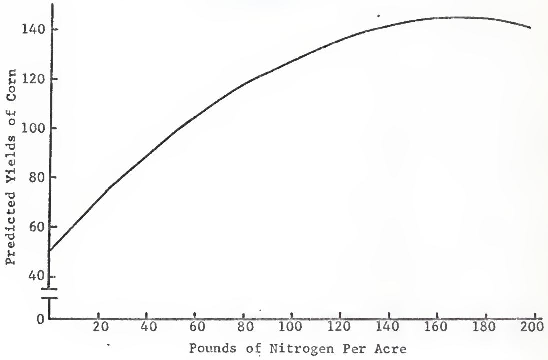

Fig. 9. Predicted yields of corn on irrigated land in West-Central Kansas.

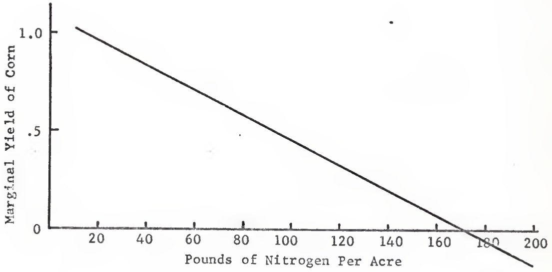

Fig. 10. Marginal yields of corn on irrigated land in West-Central Kansas.

The response curve in Fig. 9 also indicates the decreasing total yields at higher level of nitrogen. As the amount of nitrogen increases to 180 pounds, the corn-response-to-nitrogen curve indicates negative returns (which can be shown by the negative slope over the last portion of the response curve in Fig. 9 and by the negative marginal yield of nitrogen in Fig. 10).

B. Grain Sorghum

The experimental data of yields of grain sorghum response to fertilizer in West-Central Kansas show that the yields of grain sorghum do not reach a maximum even with nitrogen application of 200 pounds. This indicates that the grain sorghum yield continuously increases within 0 - 200 pounds of nitrogen range. For this reason, the Cobb-Douglas function is considered more appropriate for estimation of sorghum-nitrogen relationships.

Yield estimates of grain sorghum by using equations (17), (18), (19) are presented in Table 8. These estimated yields are obtained by substituting into equations (17), (18), (19) the amount of nitrogen listed in column 1, Table 8, respectively.[1] The predicted yield of sorghum, for example, with no application of P_2O_5 and K_2O and nitrogen at 200 pounds is 131.4 bushels per acre. At 40 pounds of P_2O_5, zero pounds of K_2O and 200 pounds of nitrogen it is 133.4 bushels per acre; and at 40 pounds of P_2O_5 and K_2O and 200 pounds of nitrogen it is 136.2 bushels per acre. The lowest predicted yields of grain sorghum for equations (17), (18), (19) are 69.5, 74.4, 72.0 bushels respectively. The marginal yields of grain sorghum due to each additional unit of nitrogen are presented in Table 8 also. There is no significant difference

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[1] The zero level is replaced by 1.

Table 8. Predicted and marginal yields of grain sorghum associated with each additional 10 pounds of nitrogen application per acre on irrigated land of West-Central Kansas

Unit:bu.

Applications of N per acre Pounds	With P_2O_5, K_2O = 0			With P_2O_5 = 40, K_2O = 0			With P_2O_5 = 40, K_2O = 40		
	Predicted Total Yields	Marginal Yields		Predicted Total Yields	Marginal Yields		Predicted Total Yields	Marginal Yields	
		Exact	Average		Exact	Average		Exact	Average
0	69.5			74.4			72.0		
10	91.7	1.10	22.2	95.9	1.06	21.5	95.0	1.14	23.0
20	99.7	.60	8.0	103.6	.57	7.7	103.3	.62	8.3
30	104.6	.42	4.9	108.3	.40	4.7	108.4	.43	5.1
40	108.3	.33	3.7	111.8	.31	3.5	112.2	.34	3.8
50	111.3	.27	3.0	114.6	.25	2.8	115.3	.28	3.1
60	113.7	.23	2.4	116.9	.22	2.3	117.8	.24	2.5
70	115.8	.20	2.1	118.9	.19	2.0	120.0	.21	2.2
80	117.7	.18	1.9	120.7	.17	1.8	122.0	.18	2.0
90	119.4	.16	1.7	122.3	.15	1.6	123.7	.17	1.7
100	120.9	.15	1.5	123.7	.14	1.4	125.3	.15	1.6
110	122.3	.13	1.4	125.0	.13	1.3	126.7	.14	1.4
120	123.6	.12	1.3	126.2	.12	1.2	128.1	.13	1.4
130	124.8	.12	1.2	127.3	.11	1.1	129.3	.12	1.2
140	125.9	.11	1.1	128.4	.10	1.1	130.5	.11	1.2
150	127.0	.10	1.1	129.4	.10	1.0	131.6	.11	1.1
160	128.0	.10	1.0	130.3	.09	0.9	132.6	.10	1.0
170	128.9	.09	0.9	131.2	.09	0.9	133.6	.09	1.0
180	129.8	.09	0.8	132.0	.08	0.8	134.5	.09	0.9
190	130.6	.08	0.8	132.7	.08	0.7	135.4	.08	0.9
200	131.4	.08	0.8	133.4	.08	0.7	136.2	.08	0.8

among the three production functions (17), (18), (19). This indicates that yields of sorghum have no significant response to P_2O_5 and K_2O.

Graphic views of predicted grain sorghum response curves and predicted marginal yield curves are provided in Fig. 11 and Fig. 12. The height of each curve represents yields while the horizontal axis represents the amounts of nitrogen application. The curves in those two figures are derived from the estimated yields reported in Table 8. The response curves show the estimated yields due to different amount of nitrogen; the marginal yield curves show the estimated additional yield added to the total yield with each additional unit of nitrogen input. Both Fig. 11 and Fig. 12 indicate that the differences among the three response curves, or among the three exact marginal curves, are very small and that the influence of P_2O_5 and K_2O can be neglected. Statistical tests also indicate that the best positive relationship among all the variables considered is that between the grain sorghum yields and nitrogen.

The equation (20) is obtained by using all the observations of the experiment for grain sorghum regardless of the amount of P_2O_5 or K_2O is used. according to equation (20), yield is predicted to start at 72.0 bushels per acre with 1 pound of nitrogen applied and at 110.8, 120.1, 126.0, 130.3, and 133.7 bushels with 40, 80, 120, 160, and 200 pounds of nitrogen applied per acre respectively. The estimated transformation of nitrogen into grain sorghum yields is reported in Table 9 and also illustrated in Fig. 13 and Fig. 14.

The response curve and the marginal yield curve of grain sorghum to nitrogen are shown in Fig. 13 and 14 respectively. The Fig. 13 indicates that yields increase faster at relatively lower nitrogen inputs than at higher nitrogen inputs. When the nitrogen input is over 100 pounds, the response of yield to additional nitrogen input becomes relatively small. On the other

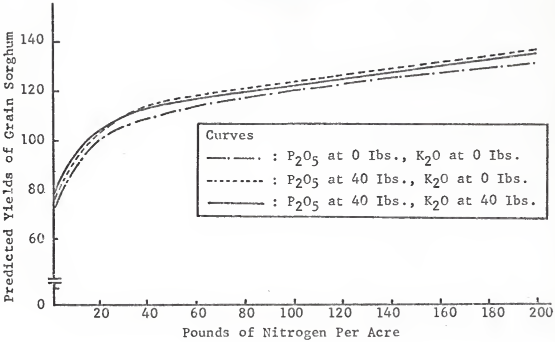

Fig. 11. Predicted yields of grain sorghum on irrigated land in West-Central Kansas.

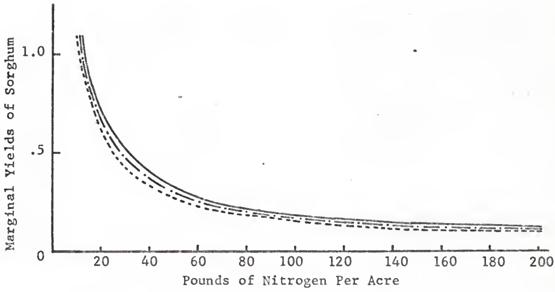

Fig. 12. Marginal yields of grain sorghum on irrigated land in West-Central Kansas.

Table 9. Predicted total and marginal yields of grain sorghum associated with each additional 10 pounds of nitrogen application per acre on irrigated land of West-Central Kansas*

Unit:bu.

Applications of N Per Acre Pounds	Predicted Total Yields	Marginal Yields	
		Exact	Average
1**	72.0		
10	94.2	1.10	22.2
20	102.1	.60	7.9
30	107.1	.42	5.0
40	110.8	.32	3.7
50	113.7	.27	2.9
60	116.2	.23	2.5
70	118.3	.20	2.1
80	120.1	.18	1.8
90	121.8	.16	1.7
100	123.3	.14	1.5
110	124.7	.13	1.4
120	126.0	.12	1.3
130	127.2	.11	1.2
140	128.3	.11	1.1
150	129.3	.10	1.0
160	130.3	.10	1.0
170	131.2	.09	0.9
180	132.1	.09	0.9
190	132.9	.08	0.8
200	133.7	.08	0.8

*All observations are used in estimating reported relationship.

**The Cobb-Douglas function implies that at least some quantity of each unit must be used if output is to be non-zero.

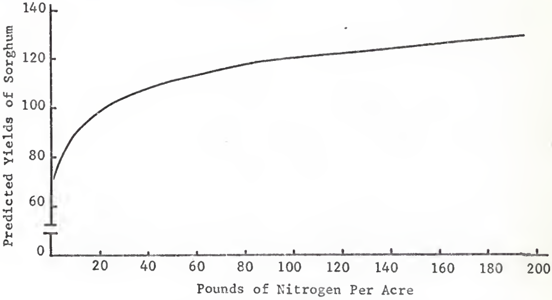

Fig. 13. Predicted yields of grain sorghum on irrigated land in West-Central Kansas.

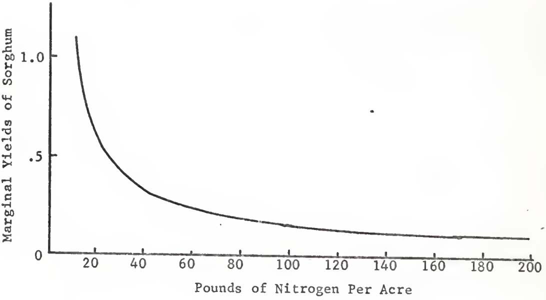

Fig. 14. Marginal yields of grain sorghum on irrigated land in West-Central Kansas.

hand, the marginal yield of nitrogen is higher at smaller quantities of nitrogen; it declines quickly as more and more nitrogen is applied (Fig. 14). The exact marginal yield curve starts at 1.10 bushels per acre when the 10th pound of nitrogen is applied, it is at 0.14 bushels per acre when the 100th pound of nitrogen is used. When nitrogen application is over 100 pounds, the marginal yield declines very slowly and it almost parallel the horizontal axis within the 100 -200 pounds nitrogen range.

4. Maximum Yields and Economic Optima

A. Corn

The maximum yield for corn resulting from appling nitrogen can be measured by marginal physical product (MPP) of corn due to nitrogen. The MPP equation for corn and its relationship to nitrogen is as follows:

$$dY/dN = 1.0674 - .0062\ N \qquad (21)$$

Table 7 contains the exact MPP of corn resulting from nitrogen. It is obtained by substituting input of nitrogen (as listed in column 1, Table 7) into equation (21). The MPP of corn for nitrogen has been already presented in Fig. 10. Its response to nitrogen is of decreasing nature. For example, the MPP is 1.01 bushels per acre at the 10th pound of nitrogen, and it is only 0.01 bushels at 170th pound of nitrogen. The MPP would become negative at higher nitrogen applications. The rate of nitrogen needed for maximum yield of corn can be found by setting the equation (21) equal to zero and solving for N. The result is 142.7 bushels at 172.2 pounds of nitrogen per acre. The estimated total yield curve also indicates that when the nitrogen application is at 172.2 pounds per acre the yield is at a maximum (Fig. 9 and 10).

The maximum yield of corn resulting from nitrogen application is not the most important consideration for extension workers and farmers. What they are mostly concerned is finding the most profitable rate of nitrogen for any corn price-nitrogen cost relationship. Thus the discussion turns to finding the point on the total yield curve that is associated with the most profitable rate of nitrogen application. It is also the point at which the total returns from corn above the cost of nitrogen are being maximized.

After deriving an estimated production function for nitrogen, the most profitable rate of nitrogen application can be found by equating MPP with the nitrogen/corn price ratio; i.e. by equating equation (21) with the nitrogen/corn price ratio. The solution makes the last pound of nitrogen pay for its cost but each preceding pound of nitrogen contributes more than its cost. In order to get the most profitable rate of nitrogen application, therefore, it is necessary to know the addition to the total yield due to nitrogen and the price of both corn and nitrogen.

With corn,for example, at \$1.12 per bushel and nitrogen at \$0.13 per pound, the price ratio is 0.13/1.12 = 0.1161. Hence the equation (21) for corn yield with respect to nitrogen is set equal to the price ratio as below:

$$dY/dN = 1.0674 - .0062\,N = 0.1161 \quad \ldots\ldots \quad (22)$$

Solving equation (22), 153.4 pounds of nitrogen is the most profitable rate of application. The corresponding yield is 141.6 bushels per acre. With corn at \$1.50 per bushel and nitrogen at \$0.15 per pound, the price ratio is 0.15/1.50 = 0.10 and 156.0 pounds of nitrogen is the level of fertilization which in this case maximizes profits. In general, it can be said that the greater the price ratio the lower the most profitable rate of nitrogen application the smaller the price ratio the larger the rate of the most profitable rate of nitrogen application. Table 10 reports the most profitable rate of nitrogen application at 11 different nitrogen/corn price ratios for the range of 0.08 to 1.00. The price ratio of 0.08 in Table 10 represents an extremely favorable nitrogen/corn price situation. This price ratio suggests the use of 159.3 pounds of nitrogen. On the other hand, the price ratio of 1.00, in Table 10, represents an extremely unfavorable nitrogen/corn price situation. This price situation would suggest the use of only 10.9 pounds of nitrogen. The most economic rate of nitrogen per acre at the 0.10 price ratio is 156.0 pounds, at the 0.20 price ratio is 139.9 pounds, at the 0.40 price ratio is 107.6. There is no nitrogen application at price ratios of 1.0674 and higher.

Table 10. Optimum rates of nitrogen application

Nitrogen/Corn Price Ratios	Optimum Rates of N Applications Pounds	Nitrogen/Corn Price Ratios	Optimum Rates of N Applications Pounds
0.08	159.3	0.20	139.9
0.10	156.0	0.40	107.6
0.12	152.8	0.60	75.4
0.14	149.6	0.80	43.1
0.16	146.4	1.00	10.9
0.18	143.1		

Another way of finding the most profitable rate of nitrogen application is that of equating the additional cost of a pound of nitrogen with the value of marginal yield of corn (VMP = MC). Table 11 is derived for this kind of analysis. The second column indicates the additional yield in bushels of corn attributed to one pound of nitrogen. Column 3 to 9 show the marginal value productivity of corn due to different rates of nitrogen application when the corn price is at $1.00, $1.12, $1.20, $1.30, $1.40, $1.50, or $1.60 per bushel.

Table 11. Marginal yields of corn and optimum rates of nitrogen for specified corn and nitrogen prices

Rate of N Per Acre	Marginal Yields of Corn	Value of Marginal Yield When Price of Corn at						
Pounds	Bushels	$1.00	$1.12	$1.20	$1.30	$1.40	$1.50	$1.60
10	1.01	1.01	1.13	1.21	1.31	1.41	1.52	1.62
20	.94	.94	1.05	1.13	1.22	1.32	1.41	1.50
30	.88	.88	.99	1.06	1.14	1.23	1.32	1.41
40	.82	.82	.92	.98	1.07	1.15	1.23	1.31
50	.76	.76	.85	.91	.99	1.06	1.14	1.22
60	.70	.70	.78	.84	.91	.98	1.05	1.12
70	.63	.63	.71	.76	.82	.88	.95	1.01
80	.57	.57	.64	.68	.74	.80	.86	.91
90	.51	.51	.57	.61	.66	.71	.77	.82
100	.45	.45	.50	.54	.59	.63	.68	.72
110	.39	.39	.44	.47	.51	.55	.59	.62
120	.32	.32	.36	.38	.42	.45	.48	.51
130	.26	.26	.29	.31	.34	.36	.39	.42
140	.20	.20	.22	.24	.26	.28	.30	.32
150	.14	.14	.16	.17	.18	.20	.21	.22
160	.08	.08	.09	.10	.10	.11	.12	.13
170	.01	.01	.01	.01	.01	.01	.02	.02
180	-.05	-.05	-.06	-.06	-.07	-.07	-.08	-.08
190	-.11	-.11	-.12	-.13	-.14	-.15	-.17	-.18
200	-.17	-.17	-.19	-.20	-.22	-.24	-.26	-.27

Since equal amounts are added to the total cost by each additional unit of nitrogen purchase, the additional value of a pound of nitrogen is identical. With marginal cost of nitrogen at $0.13 per pound, application of nitrogen up to 150 pounds is profitable when the marginal value productivity of fertilizer is based on a corn price of $1.00 per bushel (the value of the marginal product of $0.14 is greater than the marginal cost of nitrogen); application of 160 pounds of nitrogen is not profitable, because the marginal product of $0.08 is less than the marginal cost of nitrogen. With nitrogen price at $0.13 per pound and corn price at $1.12 per bushel, application of 153 pounds of nitrogen per acre is profitable; with nitrogen price at $0.15 and corn price at $1.20, application of about 155 pounds of nitrogen per acre is profitable.

The most profitable rate of nitrogen can also be presented graphically. Fig. 15 portrays the value marginal productivity of nitrogen as line VMP; the line MC represents the marginal cost of nitrogen. With nitrogen price at $0.13 per pound and corn price at $1.12 per bushel, profits are maximized with a nitrogen input of about 153 pounds as it is shown in Fig. 15. The position of VMP curve is changed with the change of price of corn and the MC curve is also changed with different price of nitrogen. For every different combination of prices of corn and nitrogen, a different amount of most profitable rate of nitrogen application can be obtained. At any given level of nitrogen price, the higher the price of corn is the more the VMP curve will move to the upper right-hand corner in Fig. 15 and the larger the suggested quantity of nitrogen application. Moreover, since the VMP curve of corn for nitrogen is negatively sloped, the higher the price of nitrogen the smaller the quantity of suggested nitrogen application at any given level of corn price.

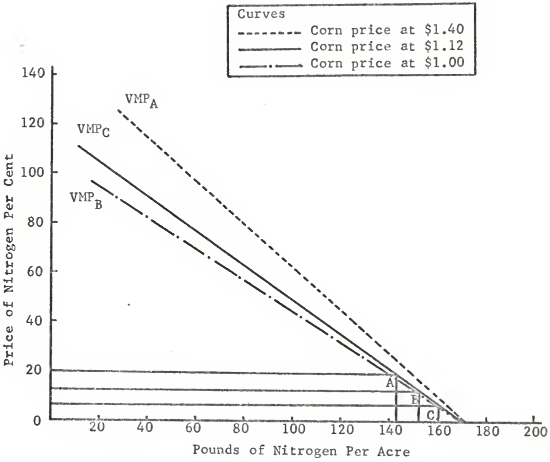

Fig. 15. The value marginal product curves of corn for nitrogen on irrigated land in West-Central Kansas.

B. Grain Sorghum

Cobb-Douglas function assumes that no range of decreasing total product. This kind of function is difficult to fit to nitrogen-response data of grain sorghum when the nitrogen application is at relatively higher level. The experiment conducted in West-Central Kansas considers nitrogen application between the range of zero pounds to 200 pounds per acre. The equation (20), which is obtained from these data, therefore, can be effective in predicting yields of grain sorghum response to nitrogen only within this range. To predict the yields beyond this range would be dangerous.

The level of nitrogen which will maximize the per acre profits is obtained in the same way as that shown for corn.

$$dY/dN = 8.41815\ N^{-.8830} = P_N/P_S \quad \text{.............................} \quad (23)$$

With grain sorghum at \$0.91 per bushel and nitrogen at \$0.13 per pound, the price ratio of P_N/P_S is equal to 0.1167. Thus solving equation (24), 101.1 pounds of nitrogen is the most profitable rate of application. The corresponding grain sorghum yield is 123.5 bushels per acre. With the grain sorghum

$$8.41815\ N^{-.8830} = 0.1167 \quad \text{.....................................} \quad (24)$$

at \$1.30 per bushel and nitrogen at \$.15 per pound, the price ratio is equal to .1154 and 128.8 pounds of nitrogen is the suggested level of nitrogen which will maximize the per acre profits.

When the price ratio (P_N/P_S) is higher, the most profitable rate of nitrogen application is smaller; when the price ratio is relatively lower, the most profitable rate of nitrogen application is higher. This kind of relationship between nitrogen and grain sorghum yields is presented in Table 12. The most economic rate of nitrogen per acre at 0.08 price ratio is 195.0 pounds per acre, at 0.10 price ratio is 151.5 pounds per acre, and at 0.20 price ratio is 69.1 pounds per acre. By comparing Table 10 with Table 12, it can be seen that when the price ratio becomes larger and larger, the most economic rate of nitrogen per acre for grain sorghum declines faster than that for corn. For this reason, it can be said that the price change influences the most profitable rate of nitrogen application more in grain sorghum than in corn.

Table 12. Optimum rates of nitrogen application for grain sorghum

Nitrogen/Sorghum Price Ratios	Optimum Rates of N Applications Pounds	Nitrogen/Sorghum Price Ratios	Optimum Rates of N Applications Pounds
.08	195.0	.20	69.1
.10	151.5	.40	31.5
.12	123.2	.60	19.9
.14	103.5	.80	14.4
.16	88.9	1.00	11.2
.18	77.8		

By introducing the value of marginal yields and costs of nitrogen into the analysis, the maximum profits resulting from nitrogen application can be derived. Table 13 is set up for this kind of analysis. The first column in this table indicates the amount of nitrogen input, the second column indicates the additional yield in bushels of sorghum attributed to one pound of nitrogen. Column 3 to 10 show the marginal value productivity of nitrogen when grain sorghum price is at $.60, $.70, $.80, $.90, $1.00, $1.10, $1.20, $1.30 per bushel. With the marginal cost of nitrogen at $0.14 per pound (assumed the value of each additional unit of nitrogen purchased is identical), 60 pounds of nitrogen application per acre is profitable when the VMP of sorghum for nitrogen is based on a grain sorghum price of $.60 per bushel, for the value

Table 13. Marginal yields of grain sorghum and optimum rates of nitrogen for specified grain sorghum and nitrogen prices

Rate of N Per Acre	Marginal Yields of Corn	Value of Marginal Yield When Price of Sorghum at							
Pounds	Bushels	$0.60	$0.70	$0.80	$0.90	$1.00	$1.10	$1.20	$1.30
10	1.10	.66	.77	.88	.99	1.10	1.21	1.32	1.43
20	.60	.36	.42	.48	.54	.60	.66	.72	.78
30	.42	.25	.29	.34	.38	.42	.46	.50	.55
40	.32	.19	.22	.26	.29	.32	.35	.38	.42
50	.27	.16	.19	.22	.24	.27	.30	.32	.35
60	.23	.14	.16	.18	.21	.23	.25	.28	.30
70	.20	.12	.14	.16	.18	.20	.22	.24	.26
80	.18	.11	.13	.14	.16	.18	.20	.22	.23
90	.16	.10	.11	.13	.14	.16	.18	.19	.21
100	.14	.08	.10	.11	.13	.14	.15	.17	.18
110	.13	.08	.09	.10	.12	.13	.14	.16	.17
120	.12	.07	.08	.10	.11	.12	.13	.14	.16
130	.11	.07	.08	.09	.10	.11	.12	.13	.14
140	.11	.07	.08	.09	.10	.11	.12	.13	.14
150	.10	.06	.07	.08	.09	.10	.11	.12	.13
160	.10	.06	.07	.08	.09	.10	.11	.12	.13
170	.09	.05	.06	.07	.08	.09	.10	.11	.12
180	.09	.05	.06	.07	.08	.09	.10	.11	.12
190	.08	.05	.06	.06	.07	.08	.09	.10	.10
200	.08	.05	.06	.06	.07	.08	.09	.10	.10

of marginal product ($0.14) is equal to the marginal cost of nitrogen when 60 pounds of nitrogen are used. With nitrogen priced at $0.13 per pound and sorghum priced at $1.00 per bushel, nitrogen application at 110 pounds is profitable. With nitrogen priced at $0.15 and grain sorghum priced at $0.90, 85 pounds of nitrogen application is profitable.

The graphical presentation of most profitable rate of nitrogen application is shown in Fig. 16. The intersection of VMP curve and MC curve at a certain amount of nitrogen (depending on the price of nitrogen and grain sorghum) gives the economic rate of nitrogen application. With nitrogen priced at $0.15 per pound and grain sorghum priced at $0.60 per bushel, profit is maximized when nitrogen input is about 54 pounds per acre. With nitrogen priced at $0.15 per pound and grain sorghum at $.90 per bushel, profit is maximized when nitrogen input is about 85 pounds per acre. In general, with a given price of nitrogen, the higher the price of grain sorghum the greater the most profitable rate of nitrogen; the lower the price of grain sorghum, the smaller the most profitable rate of nitrogen. On the other hand, with a given price of grain sorghum, the lower the price of nitrogen the greater the economic rate of nitrogen application. It is shown in Fig. 16, when price of grain sorghum is given as $0.90 per bushel, 62 pounds of nitrogen is profitable when nitrogen priced at $.20; 85 pounds of nitrogen is profitable when nitrogen price is at $0.15 per pound.

5. Derived Demand Curves for Nitrogen

A. Corn

The marginal physical product of corn times the price of corn is the value of marginal product. The demand curves for nitrogen with various prices

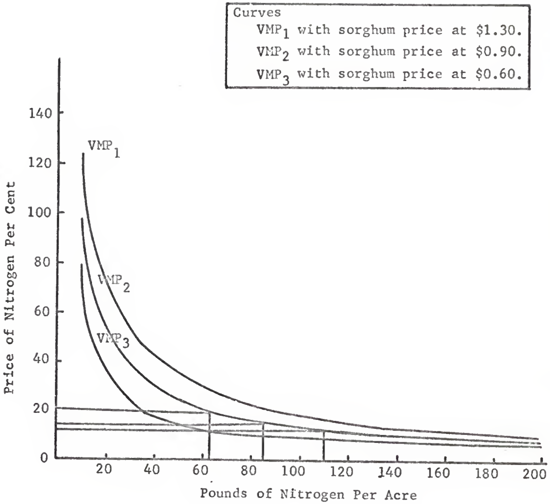

Fig. 16. Marginal value products for grain sorghum.

of corn can be derived by the value of marginal product curves. This kind of demand curves for nitrogen shifts its position with any change in the price of corn. When price of corn increases, the demand curve for nitrogen shifts to upper right-hand corner in Fig. 15; when price of corn decreases, the demand curve for nitrogen shifts to lower left-hand corner in Fig. 15. For example, with corn at $1.00 per bushel, VMP_B is the demand curve for nitrogen at that corn price; with corn at $1.12 per bushel, VMP_C is the demand curve for nitrogen; and with corn at $1.40 per bushel, VMP_A is the demand curve for nitrogen. Every point on each VMP curve indicates that under a given price of nitrogen, a certain amount of nitrogen is demanded. The demand curves for nitrogen are sloping downward to the right-hand corner, it implies that the lower the price of nitrogen the larger the quantity of nitrogen demanded. Taking the line VMP_C in Fig. 15 as an example, it is negatively sloped and point A indicates that 143 pounds of nitrogen per acre is demanded when nitrogen price is at $.20 per pound, point B indicates that 153 pounds of nitrogen per acre is demanded when nitrogen price is at $.13 per pound, and point C indicates that 160 pounds of nitrogen per acre is demanded when nitrogen price is at $0.08 per pound. In other words, a purchase of 143 pounds of nitrogen per acre is profitable when nitrogen price is at $.20 per pound; a purchase of 153 pounds of nitrogen per acre is profitable when nitrogen price is at $0.13 per pound; and a purchase of 160 pounds of nitrogen per acre is profitable when nitrogen price is at $0.08 per pound.

There is another way for obtaining a single demand curve for nitrogen with various prices of corn. It is based on nitrogen/corn price ratios instead of absolute prices. Line AB in Fig. 17 is derived by using the data of Table 10. It is a single demand curve for nitrogen that does not shift

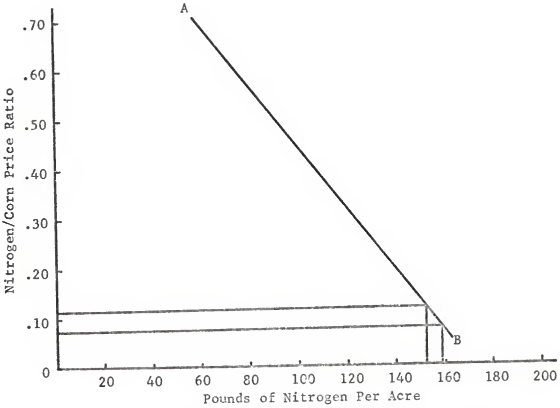

Fig. 17. Derived demand curve for nitrogen on irrigated land in West-Central Kansas.

its position as price of corn changes.[1] 159 pounds of nitrogen per acre is demanded when nitrogen/corn price ratio is 0.08; 153 pounds of nitrogen per acre is demanded when nitrogen/corn price ratio is 0.12. In short, moving along the Line AB from point A to point B, the nitrogen/corn price ratio becomes smaller and smaller and the demand of nitrogen is increased gradually.

B. Grain Sorghum

The demand curve of nitrogen used for grain sorghum can also be derived by the marginal value product of grain sorghum. The VMP curves in Fig. 16 are the demand curves for nitrogen at different prices of grain sorghum. When the price of grain sorghum changes, the corresponding VMP curve or demand curve for nitrogen changes its position too. Fig. 16 shows that as the price of grain sorghum increases from \$.60 to \$.90 per bushel the position of demand curve for nitrogen moves from VMP_3 to VMP_2; as the price of grain sorghum increases from \$.90 to \$1.30 per bushel the position of demand curve for nitrogen moves from VMP_2 to VMP_1. As the price of sorghum becomes higher and higher, the demand curve for nitrogen shifts toward the upper right-hand corner in the Figure. This kind of VMP curves are sloped downward to the right; the lower the price of nitrogen the larger the quantity of nitrogen demanded. For example, with price of grain sorghum at \$.90 per bushel, 110 pounds of nitrogen per acre is demanded when nitrogen price is at \$.12 per pound, 85 pounds of nitrogen per acre is demanded with nitrogen price at \$.15 per pound.

By using nitrogen/grain sorghum price ratios (P_N/P_S) price ratios and

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1. Frank Orazem and F. W. Smith, "An Economic Approach to the Use of Fertilizer", Agricultural Experiment Station, Kansas State College of Agricultural and Applied Science, Tech. Bul. 94, May, 1958, pp. 15 - 16

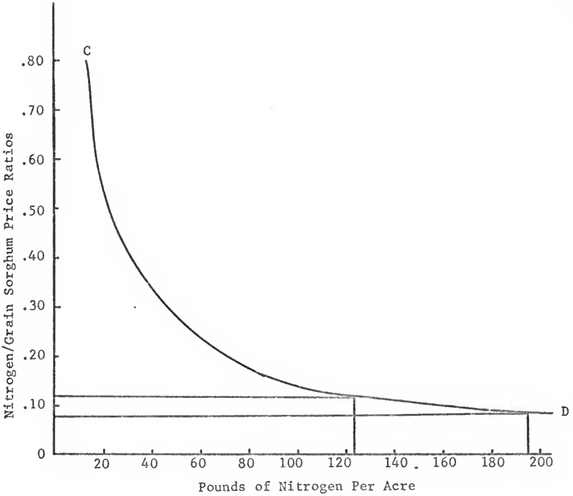

Fig. 18. Derived demand curve for nitrogen on irrigated land in West-Central Kansas.

the optimum rate of nitrogen application as shown in Table 12, a single demand curve for nitrogen is obtained that does not shift its position when price of grain sorghum changes. The Line CD in Fig. 18 is so obtained. When P_N/P_S is at 0.08, 195 pounds of nitrogen per acre is demanded; when P_N/P_S is at 0.12, 123 pounds of nitrogen per acre is demanded. Moving along Line CD from point C to point D, the P_N/P_S becomes smaller and smaller and the demand of nitrogen increases with the decrease of P_N/P_S ratio.

6. Returns to Different Amounts of Nitrogen[1]

Fertilizer has been playing an important role in agricultural production, but it is not the only one cost used in producing a crop. A substantial return to fertilizer does not necessarily indicate that production of the crop is profitable. However, the use of fertilizer may result in great increase in crop yields, without it, the yield may be too low to pay for the other costs. Additional fertilizer may result in yields sufficient to change production of a crop into a profitable enterprise. Therefore, an analysis of returns to fertilizer is very important for crop production.

An analysis of returns to different amounts of nitrogen applied for corn and grain sorghum is presented in this section. The most profitable rate of nitrogen for corn and grain sorghum, as it was discussed in preceding section, is used as a guide to provides information on deciding the quantity of nitrogen to be applied for maximum returns.

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1. The method used in this section is similar to the method used by Mr. J. L. Paschal & B. L. French in their "A Method of Economic Analysis Applied to Nitrogen Fertilizer Rate Experiment on Irrigated Corn", U. S. D. A., Tech. Bul., no. 1141, pp. 29 - 34.

A. Corn

Measures of returns for corn with nitrogen priced at \$.13 per pound and corn priced at \$1.12 per bushel are presented in Table 14. Data in column 1 represent units of nitrogen -- each unit represents 10 pounds of nitrogen, data in column 2 through column 6 show the increase in yields, the values of additional increase in yields, the costs of additional unit of nitrogen, the returns above cost of additional unit of nitrogen, and the return per dollar on the last unit of nitrogen, for individual sucessive 10-pounds unit of nitrogen. And data in column 8 through column 10 are cumulative results from increasing rates of nitrogen application as shown in column 7. All the data used in this table are based on the predicted yields of corn in Table 7.

The increases in yields of corn responses to successive 10-pounds of nitrogen are presented in column 2. The data show decreasing returns in corn yields as more and more units of nitrogen are applied. The diminishing additional yield of corn resulting from additional units of nitrogen applied and the constant cost of each unit of nitrogen makes the returns above the cost of each unit of nitrogen from the first several units of nitrogen applied greater than from the latter units. For example, the value of the increase in yield from the first unit is \$11.54, the return above the unit cost of nitrogen is \$10.24; but the value of the increase in yield from the 16th unit is only \$1.23 which is less than the unit cost of nitrogen. As the units of nitrogen application increase, the returns above the cost of 1 unit of nitrogen become smaller and smaller (column 5). When nitrogen application reaches the 16th unit, the cost of the unit of nitrogen is seven cents greater than the value of the increase in the yield of corn. This relationship is represented by Fig. 19. When the curve of the "additional return above the

Table 14. Measures of return from application of nitrogen at varying rates to irrigated corn on irrigated land in West-Central Kansas

	Results by Successive 10-Pound Units of Nitrogen				
N Applied Per Acre (Units) (1)	Increase in Yield (2)	Value of Additional Increase in Yield (3)	Cost of Additional Unit of Nitrogen (4)	Return above Cost of Additional Unit of Nitrogen (5)	Return Per Dollar on the Last Unit of Nitrogen (6)
	bu.*	$	$	$	$
1	10.3	11.54	1.30	10.24	8.88
2	9.8	10.98	1.30	9.68	8.45
3	9.1	10.19	1.30	8.89	7.84
4	8.5	9.52	1.30	8.22	7.32
5	7.9	8.85	1.30	7.55	6.81
6	7.2	8.06	1.30	6.76	6.20
7	6.7	7.50	1.30	6.20	5.77
8	6.0	6.72	1.30	5.42	5.17
9	5.4	6.05	1.30	4.75	4.65
10	4.8	5.38	1.30	4.08	4.14
11	4.2	4.70	1.30	3.40	3.62
12	3.5	3.92	1.30	2.62	3.02
13	2.9	3.25	1.30	1.95	2.50
14	2.3	2.58	1.30	1.28	1.98
15	1.7	1.90	1.30	.60	1.46
16	1.1	1.23	1.30	- .07	.95
17	.4	.45	1.30	- .85	.35
18	- .2	- .22	1.30	-1.52	- .17
19	- .8	- .90	1.30	-2.20	- .69
20	-1.4	-1.57	1.30	-2.87	-1.21

*With price of corn at $1.12 per bushel.

Table 14. Measures of return from application of nitrogen at varying rates to irrigated corn on irrigated land in West-Central Kansas (continued)

Cumulative Results from Increasing Rates of Nitrogen Application					
Total Application of Nitrogen (7)		Total Increase in Yield (8)		Total Return to Nitrogen (9)	Average Return Per Dollar Spent on Nitrogen (10)
lb.	$	bu.	$	$	$
10	1.30	10.3	11.54	10.24	8.88
20	2.60	20.1	22.52	19.92	8.66
30	3.90	29.2	32.71	28.81	8.39
40	5.20	37.7	42.23	37.03	8.12
50	6.50	45.6	51.08	44.58	7.86
60	7.80	52.8	59.14	51.34	7.58
70	9.10	59.5	66.64	57.54	7.32
80	10.40	65.5	73.36	62.96	7.05
90	11.70	70.9	79.41	67.71	6.79
100	13.00	75.7	84.79	71.79	6.52
110	14.30	79.9	89.49	75.19	6.26
120	15.60	83.4	93.41	77.81	5.99
130	16.90	86.3	96.66	79.76	5.72
140	18.20	88.6	99.24	81.04	5.45
150	19.50	90.3	101.14	81.64	5.19
160	20.80	91.4	102.37	81.57	4.92
170	22.10	91.8	102.82	80.72	4.65
180	23.40	91.6	102.60	79.20	4.38
190	24.70	90.8	101.70	77.00	4.12
200	26.00	89.4	100.13	74.13	3.85

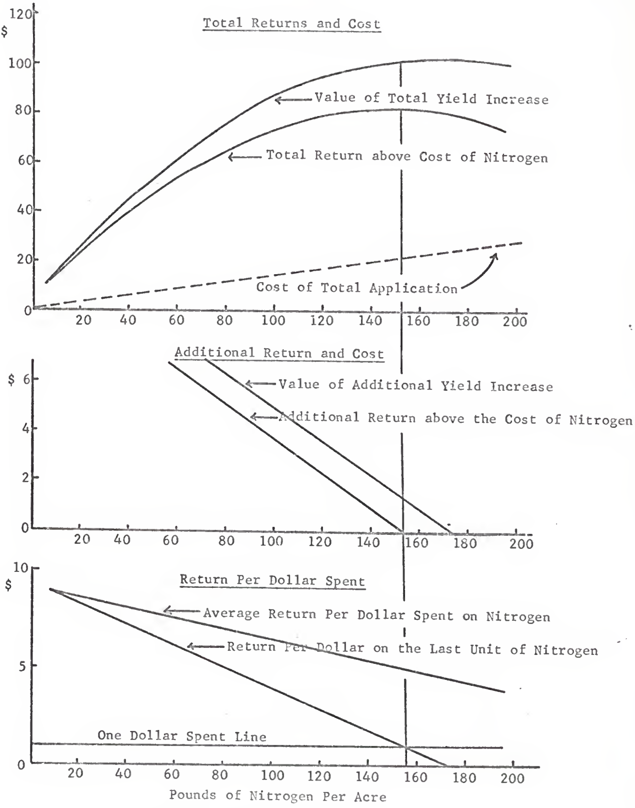

Fig. 19. Measures of return for corn to nitrogen on irrigated land in West-Central Kansas.

cost of nitrogen" intersects the horizontal axis, the nitrogen application is between the 15th and 16th unit. Before this intersection point, the value of the increase in yield is greater than the cost of nitrogen; after this point, the value of the increase in yield is less than the cost of nitrogen.

Column 6 in Table 14 shows the return per dollar on the last unit of nitrogen. It is decreasing as the units of nitrogen increase : $8.88 is the return per dollar spent for nitrogen when the first 10 pounds of nitrogen is applied, $1.46 is the return per dollar spent for nitrogen when the 15th unit of nitrogen is applied. The returns per dollar spent for nitrogen are positive for each dollar spent as the nitrogen application is between the first unit and the 15th unit of nitrogen applied. The negative values for each dollar spent from nitrogen result as the nitrogen application is 16 or more units. Thus it is evident that profitable application of nitrogen does not go beyond the 16th unit.

Fig. 19 shows that the quantity of nitrogen applied for the largest net return is about 153 pounds per acre, which is at the point where the net marginal return curve intersects the horizontal line and also the point where the curve of the "additional return per dollar on the last unit of nitrogen" intersects the "1 dollar spent line". The distance between the zero line and the curve of the "total return above cost of nitrogen" represents the return to nitrogen applied, and amounts to $81.74 per acre.

Column 10 in Table 14 shows the average return per dollar spent for nitrogen. It is a measure of the profitableness of total expenditures for nitrogen at specific rate. An average return of $4.65 per dollar spent on 170 pounds of nitrogen appears to be profitable but the return per dollar on the 17th unit of nitrogen is only $.35. At the most profitable rate of 153 pounds, the average return per dollar is $5.19 compared with a return of $1.46 per dollar spent for the 15th unit. As the units of nitrogen applied increase from 153 pounds to 200 pounds there is an increasing loss per dollar spent.

B. Grain Sorghum

Measures of return for grain sorghum with nitrogen at $.13 per pound and grain sorghum at $.91 per bushel are presented in Table 15. Data in column 2 are derived from the predicted yields of grain sorghum in Table 9. Data in column 3 through column 6 are derived from column 1 and column 2. But data in column 8 through column 10 are cumulative results from increasing rates of nitrogen application as shown in column 7.

The increase in yields of grain sorghum response to successive 10-pound units of nitrogen is at a decreasing rate. The return above the cost of each unit of nitrogen from the first several units of nitrogen applied is greater than from the latter units. For example, the value of the increase in yield from the first unit is $20.20, it is $18.90 above the unit cost of nitrogen; the value of the increase in yield from the 6th unit is $2.28, it is only $0.98 above the unit cost of nitrogen; and the value of the increase in yield from the 11th unit is $1.27, it is $0.03 less than the unit cost of nitrogen. Column 5 in Table 15 shows the returns above the cost of additional units of nitrogen. It decreases as more units of fertilizer are applied. It is negative when the application of nitrogen goes beyond 11 units, i.e. the unit cost of additional nitrogen is greater than the value of the increase in yield beyond that point. So the application of nitrogen beyond 110 pounds is unreasonable in producting grain sorghum. This relationship can be presented by Fig. 20. When the nitrogen application is between 10 and 11 units, the curve

Table 15. Measures of return from application of nitrogen at varying rates to irrigated grain sorghum on irrigated land in West-Central Kansas

	Results by Successive 10-Pound Units of Nitrogen				
N Applied Per Acre (Units) (1)	Increase in Yield (2)	Value of Additional Increase in Yield (3)	Cost of Additional Unit of Nitrogen (4)	Return above Cost of Additional Unit of Nitrogen (5)	Return Per Dollar on the Last Unit of Nitrogen (6)
	bu.*	$	$	$	$
1	22.2	20.20	1.3	18.90	15.54
2	7.9	7.19	1.3	5.89	5.53
3	5.0	4.55	1.3	3.25	3.50
4	3.7	3.37	1.3	2.07	2.59
5	2.9	2.64	1.3	1.34	2.03
6	2.5	2.28	1.3	.98	1.75
7	2.1	1.91	1.3	.61	1.47
8	1.8	1.64	1.3	.34	1.26
9	1.7	1.55	1.3	.25	1.19
10	1.5	1.37	1.3	.07	1.05
11	1.4	1.27	1.3	- .03	.98
12	1.3	1.18	1.3	- .12	.91
13	1.2	1.09	1.3	- .21	.84
14	1.1	1.00	1.3	- .30	.77
15	1.0	.91	1.3	- .39	.70
16	1.0	.91	1.3	- .39	.70
17	.9	.82	1.3	- .48	.63
18	.9	.82	1.3	- .48	.63
19	.8	.73	1.3	- .57	.56
20	.8	.73	1.3	- .57	.56

Table 15. Measures of return from application of nitrogen at varying rates to irrigated grain sorghum on irrigated land in West-Central Kansas (continued)

Cumulative Results from Increasing Rates of Nitrogen Application					
Total Application of Nitrogen (7)		Total Increase in Yield (8)		Total Return to Nitrogen (9)	Average Return Per Dollar Spent on Nitrogen (10)
Ib.	$	bu.	$	$	$
10	1.3	22.2	20.20	18.90	15.54
20	2.6	30.1	27.39	24.79	10.53
30	3.9	35.1	31.94	28.04	8.19
40	5.2	38.8	35.31	30.11	6.79
50	6.5	41.7	37.95	31.45	5.84
60	7.8	44.2	40.23	32.43	5.16
70	9.1	46.3	42.14	33.04	4.63
80	10.4	48.1	43.78	33.39	4.21
90	11.7	49.8	45.33	33.63	3.87
100	13.0	51.3	46.70	33.70	3.59
110	14.3	52.7	47.97	33.67	3.35
120	15.6	54.0	49.15	33.55	3.15
130	16.9	55.2	50.24	33.34	2.97
140	18.2	56.3	51.24	33.04	2.82
150	19.5	57.3	52.15	32.65	2.67
160	20.8	58.3	53.06	32.26	2.55
170	22.1	59.2	53.88	31.78	2.44
180	23.4	60.1	54.70	31.30	2.34
190	24.7	60.8	55.43	30.73	2.24
200	26.0	61.7	56.16	30.16	2.16

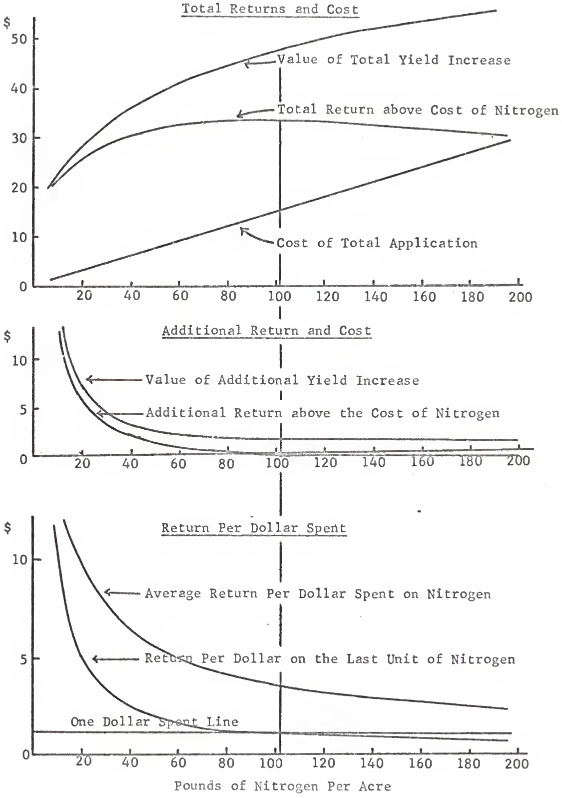

Fig. 20. Measures of return for grain sorghum to nitrogen on irrigated land in West-Central Kansas.

of the "additional return above the cost of nitrogen" intersects the horizontal line. Before this intersection point of these two curves, the value of the increase in yield is greater than the cost of nitrogen. After this intersection point the value of the increase in yield is less than the cost of nitrogen. At this intersection point, the value of the increase in yield is equal to the cost of nitrogen and will result in maximum profits. The slope of the curve is steeper with the first several units of nitrogen, and it becomes flatter as more units are used. This relationship implies that the returns above cost of nitrogen are greater at first, then decline as more nitrogen is used, and they reach zero at about 101 pounds of nitrogen.

Column 6 in Table 15 represents the return per dollar on the last unit of nitrogen. For example, the first 10 pounds of nitrogen result in $15.54 return per dollar spent on nitrogen, the 10th unit of nitrogen results in $1.05 return per dollar spent on nitrogen, but the 11th unit of nitrogen results in only $0.98 return per dollar spent on nitrogen. In Fig. 20, the returns per dollar spent from nitrogen are positive when the nitrogen application is between the first and the 10th unit of nitrogen; the returns per dollar spent from nitrogen are shown as negative when the nitrogen application is equal to 101 pounds or more. Fig. 20 also indicates that the intersection point of the curve of the "additional return per dollar on the last unit of nitrogen" and the curve of the "one dollar spent line" is the most profitable rate of nitrogen.

By comparing all the curves in Fig. 20, the quantity of nitrogen to apply for the largest net return is shown to be about 101 pounds, it is at a point where the net marginal return curve intersects the zero line and also where the curve of the "additional return per dollar on the last unit of nitrogen" intersects the "one dollar spent line". The distance between the zero line and the curve of the "total return above cost of nitrogen" represents the return to nitrogen applied, and amounts to $33.70 per acre.

Column 10 in Table 15 is the average return per dollar spent for nitrogen. It is a measure of the profitableness of total expenditures for nitrogen at a specificed rate. A return of $3.35 per dollar spent on 110 pounds of nitrogen appears to be profitable but the return per dollar spent on the 11th unit is only $0.98. At the most profitable rate of 101 pounds, the average return per dollar is $3.59. This return compares with $1.05 per dollar spent for the 10th unit. As the nitrogen applied is increased from 100 pounds to 200 pounds, there is an increasing loss per dollar spent.[1]

7. The Effect of Price of Corn, Grain Sorghum and Nitrogen on the Most Profitable Rate of Nitrogen Application and on Return to Nitrogen above Its Cost

There are three main elements which determine the most profitable rate of nitrogen application. They are (1) the shape of the response curve of corn or grain sorghum, (2) the price of nitrogen per pound, and (3) the price of corn or grain sorghum per bushel. Change in any one of those elements would result in a change of the most profitable rate of nitrogen application. Since the quadratic equation ($Y = 50.8527 + 1.0674N - .0031N^2$) is regarded as more appropriate for corn under given experimental data and the Cobb-Douglas function ($Y = 71.95\ N^{.1170}$) is regarded as more appropriate for grain sorghum under given experimental data, the shapes of response curves for corn and grain

1. J. L. Paschal & B. L. French, "A Method of Economic Analysis Applied to Nitrogen Fertilizer Rate Experiments on Irrigated Corn", U. S. D. A., Tech. Bul., no. 1141, pp. 34 - 35.

sorghum are considered unchanged. The elements which influence the most profitable rate of nitrogen application are only changes in relative prices of nitrogen, corn, or grain sorghum.

A. Effect of the Price of Nitrogen on the Most Profitable Rate of Nitrogen Application and on Return to Nitrogen above Its Cost

In actual practice, both the price of nitrogen and the price of corn or grain sorghum are not constant. Any change of them would affect the most profitable rate of nitrogen application. In this section it is assumed that the prices of corn and grain sorghum remain unchanged (with the price of corn at $1.12 per bushel and the price of grain sorghum at $0.91 per bushel). As the price of nitrogen per pound increases, the most profitable rate of nitrogen would decrease. Table 16 presents a successive one cent change a pound in the price of nitrogen (from $0.10 to $0.18) and its influence upon the most profitable rate of nitrogen application and returns to nitrogen above its cost. For corn, a one cent change a pound in nitrogen price alters the most profitable rate by only 1 to 2 pounds per acre through all the price range sets in the Table. For example, when nitrogen price changes from $0.10 to $0.11 per pound, the most profitable rate of nitrogen application alters from 157.8 pounds per acre to 156.3 pounds per acre. It represents only a 1.5 pounds decrease in nitrogen input. The small quantity adjustment in response to the one cent change in nitrogen price is true for all other one cent price changes in Table 16. The change of one cent in nitrogen price will have greater influence on the most profitable rate for grain sorghum application than for corn. With nitrogen price increasing from $.10 per pound to $0.11 per pound, the most profitable rate changes from 136.1 pounds per acre to 122.2 pounds

Table 16. The effect of the price of nitrogen per pound on the most profitable rate of nitrogen application per acre and on return to nitrogen above its cost

Price of Nitrogen Per Pound	Most Profitable Rate of Nitrogen	Estimated Yield under Most Profitable of Nitrogen	Increase Yield for Application of Nitrogen*	Return to Nitrogen above Its Cost**
$	Ib.	bu.	bu.	$
		Corn		
.10	157.8	142.1	91.2	86.42
.11	156.3	141.9	91.0	84.85
.12	154.9	141.8	90.9	83.29
.13	153.4	141.6	90.7	81.74
.14	152.0	141.5	90.6	80.23
.15	150.6	141.3	90.4	78.70
.16	149.1	141.1	90.2	77.21
.17	147.7	140.9	90.0	75.72
.18	146.2	140.7	89.8	74.26
		Grain Sorghum		
.10	136.1	127.8	55.8	33.09
.11	122.2	126.2	54.2	33.44
.12	110.7	124.8	52.8	33.66
.13	101.1	123.5	51.5	33.72
.14	93.0	122.3	50.3	33.68
.15	86.1	121.2	49.2	33.60
.16	79.9	120.1	48.1	33.38
.17	74.6	119.2	47.2	33.25
.18	70.0	118.3	46.3	33.03

*Obtained by substracting 50.9 bushels for corn and 72.0 bushels for grain sorghum from the estimated yields.

**With corn at price $1.12, grain sorghum at price $0.91 and nitrogen at the price as shown in column 1.

per acre. It represents a 13.9 pounds decrease in nitrogen application. But change in most profitable rate for grain sorghum as a result from increases in nitrogen price will become smaller and smaller as the nitrogen price becomes higher and higher. It can be seen in Table 16 the second one cent increase in nitrogen price results in 11.5 pounds decrease in nitrogen application, the third one cent increase results in 9.6 pounds decrease in nitrogen application. When the price of nitrogen is relatively lower, the change in nitrogen price would result in greater change in most profitable rate. This is only true for grain sorghum not for corn. It seems that one cent change in price of nitrogen will result in almost the same degree of change in most profitable rates of nitrogen application for corn regardless whether the price of nitrogen increases or decreases.

Return to nitrogen above its cost at the most profitable rate for specific prices of nitrogen is also shown in Table 16. As the price of nitrogen changes by one cent a pound and the most profitable rate is adjusted accordingly, the difference in return to nitrogen above its cost is about $1.5 for corn and about $0.30 or less for grain sorghum.

B. The Effect of Price of Corn or Grain Sorghum on the Most Profitable Rate of Nitrogen Application and on Return to Nitrogen above Its Cost

It is well known that the price of corn or grain sorghum is not constant, it is changeable from year to year. Take the price of corn for all purpose in Kansas as an example, it was $1.08 per bushel in 1961, $1.10 per bushel in 1962, $1.12 per bushel in 1963, and $1.19 per bushel in 1964. The same thing holds true for the price of grain sorghum.[1] The effect of price changes of corn or grain sorghum on the most profitable rate of nitrogen application and on return to nitrogen above its cost is important on economic use of nitrogen.

With the price of nitrogen fixed at $0.13 per pound, an equivalent price rise of corn or grain sorghum has different effects on the most profitable rate of nitrogen application between corn and grain sorghum. In response to a constant successive unit increase in the price of corn, the most profitable rate of nitrogen application is increasing at a decreasing rate. But this is not true for grain sorghum. The most profitable rate of nitrogen application increases respectively by 11.2, 6.4, 4.0, 2.9, 2.1, and 1.6 pounds per acre (see Table 17) as the price of corn increases by units of 20 cents; but it increases the use of nitrogen per acre by 23.9, 24.7, 27.6, 24.1, 22.0, and 31.8 pounds per acre as the price of grain sorghum increases in unit of 20 cents. It makes the change in nitrogen application for grain sorghum greater than that for corn when the change in price of corn and grain sorghum is the same.

If the nitrogen application rate is not adjusted to the most profitable rate with a change in the price of corn or grain sorghum, the return to nitrogen above its cost is altered proportionally to the change in price of corn or grain sorghum. With the price of corn at $0.52 per bushel, 131.8 pounds of nitrogen per acre is the most profitable rate. If the nitrogen rate remains unchanged and the price of corn increases from $0.52 to $0.72, there is a $17.37 ($0.20 x 86.83) increase in the return to nitrogen above its cost. Furthermore, for each $0.20 per bushel increase in the price of corn there is

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1. *Kansas Agriculure*, 48th Report, Kansas State Board of Agriculture, 1964 - 1965, p. 150.

Table 17. The effect of the price of corn on the most profitable rate of nitrogen application per acre and on return to nitrogen above its cost on irrigated land in West-Central Kansas

Price of Crop Per Bushel*	Most Profitable Rate of Nitrogen	Cost of Nitrogen**	Yield at Most Profitable Rate	Yield Increase from Nitrogen	Value of Increased Yield**	Return to Nitrogen above Its Cost***
$	Ib.	$	bu.	bu.	$	$
			Corn			
.52	131.8	17.13	137.68	86.83	45.15	28.02
.72	143.0	18.59	140.10	89.25	64.26	45.67
.92	149.4	19.42	141.13	90.28	83.06	63.64
1.12	153.4	19.94	141.64	90.79	101.68	81.74
1.32	156.3	20.32	141.96	91.11	120.27	99.95
1.52	158.4	20.59	142.15	91.30	138.78	118.19
1.72	160.0	20.80	142.28	91.43	157.26	136.46
			Grain Sorghum			
.51	52.5	6.82	114.36	42.36	21.60	14.78
.71	76.4	9.93	119.49	47.49	33.72	23.79
.91	101.1	13.15	123.48	51.48	46.85	33.70
1.11	128.7	16.72	127.01	55.01	61.06	44.34
1.31	153.8	19.86	129.59	57.59	75.44	55.58
1.51	174.8	22.73	132.05	60.05	90.68	67.95
1.71	206.6	26.86	134.25	62.25	106.45	79.59

*Price used to calculate the most profitable rate of nitrogen application.

**With nitrogen at $0.13 a pound and corn or grain sorghum at the price indicated in the first column.

***At most profitable rate of application with indicated price of corn or grain sorghum.

a $17.37 increase in the return to nitrogen above its cost. In case of grain sorghum, the increase would be constant at $8.47 for each additional increase of 20 cents in the price of grain sorghum when the rate of nitrogen application is not adjusted to the most profitable rate with the change in the price of grain sorghum.[1]

When the nitrogen application is adjusted to the most profitable rate in response to changes in the price of corn or grain sorghum, the return to nitrogen above its cost will increase more than in the case where the amount of nitrogen is unchanged. In the example, as shown in Table 17, with price of corn increasing from $0.52 to $0.72, the most profitable rate of nitrogen increases from 131.8 pounds per acre to 143.0 pounds per acre and results in a $17.65 increase (which is slightly larger than $17.37) in the return to nitrogen above its cost. Progressive increases of 20 cents per bushel in price of corn from 72 cents per bushel increase the return to nitrogen above its cost respectively by $17.97, $18.10, $18.21, $18.24, and $18.27. All of these successive increases are greater than $17.37 -- which results when the nitrogen application is not adjusted to the most profitable rate with change in the price of corn. Similar differences in returns above nitrogen costs can be observed in the case of grain sorghum as shown in Table 17.

In practice, it is impossible to estimate the exact price of corn or grain sorghum at planting time or at times when fertilizer is applied. The inaccurate estimates of the price of corn or grain sorghum will result in lower returns to nitrogen when nitrogen rate differs from the most profitable

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1. J. L. Paschal and C. E. Evans, "Economic Interpretations of Yield Data from a Nitrogen Rate Experiment with Irrigated Grain Sorghum", Soil Science Society of America, Proceedings, Vol. 18, no. 4, Oct. 1954, pp. 455 - 458.

rate. A higher estimated price for corn or grain sorghum than actual price will result in a larger nitrogen application than the most profitable rate and it will make a real reduction in return to nitrogen above its cost; a lower estimated price for corn or grain sorghum than actual price will cause a smaller amount of nitrogen application than the most profitable rate and it will make a reduction in potential return (it might have been obtained by higher rate of application). The relationships between the inaccurate estimates of prices and the return to nitrogen above its cost for corn and grain sorghum are shown in Fig. 21 and 22 respectively. When the expected price is estimated as \$1.12 per bushel for corn or \$0.91 per bushel for grain sorghum. It is noted that the return to nitrogen above its cost is reduced by less than 10 cents per acre for corn and 50 cents per acre for grain sorghum, when actual sale price is 20 cents a bushel above or below the predicted prices on which the most profitable rate is calculated. If the margin between estimated price and actual sale price is 40 cents a bushel, the reduction in return to nitrogen above its cost is less than 25 cents per acre for corn and \$2.0 for grain sorghum. The reduction in returns to nitrogen in response to an equal amount of error in overestimating or underestimating of prices in corn and grain sorghum is greater for grain sorghum than corn. Both of them have smaller reductions in returns to nitrogen when the prices are overestimated than when they are underestimated.[1]

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[1]. J. L. Paschal and C. E. Evans, "Economic Interpretations of Yield Data from a Nitrogen Rate Experiment with Irrigated Grain Sorghum", Soil Science Society of America, Proceedings, Vol. 18, no. 4. Oct. 1954. PP. 456 - 457.

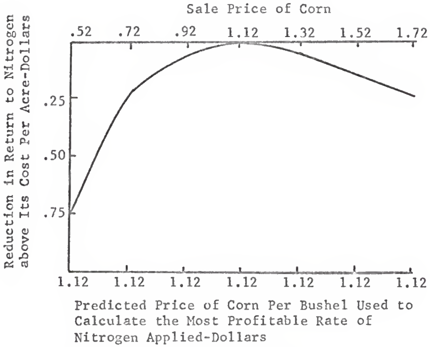

Fig. 21. Effect of deviations from the expected price of $1.12 per bushel on return to nitrogen above its cost.

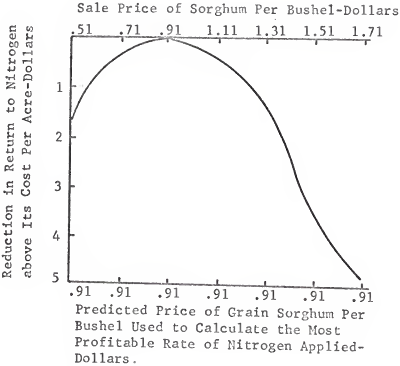

Fig. 22. Effect of deviations from the expected price of $0.91 per bushel on return to nitrogen above its cost.

IV. APPLICATION TO FARM CONDITIONS

The preceding analysis of fertilizer experimental data is an attempt to increase the per acre returns for irrigated corn and grain sorghum production. The analysis can be of help but it can not be applied directly to any particular farm situation for the following reason:

(1) The response curves for corn and grain sorghum represent an average response of five years (1961 - 1965) for corn and of seven years (1959 - 1965) for grain sorghum. In practice the yield expectations are not single but they are ordinarily multi-valued. Also there are statistical and experimental errors within the data which affect the estimated response curves and it should be taken into account before any recommendations are made.

(2) Experimental research is usually limited to small plots. The experiments are controlled more than it would be practical for farm situations. Under given prices of crops and fertilizers, the calculated most profitable rates of fertilizers based on the experimental data are higher than those commonly applied on farms.

(3) All of the experimental treatments concerned in this study received enough preplant irrigation water and sufficient amounts of water during the growing season so that moisture was not a limiting factor. Thus findings of this study can be applied only to situations where soil moisture does not limit the growth of corn or grain sorghum.

(4) Maximization of net returns from a particular acre of corn or grain sorghum is assumed as the objective throughout the study. In practice, the maximum monetary income from a particular acre of crop may not be the objective of farmers. What they may be interested in is working toward maximum

income from the farm as a whole. Since there are usually several feasible enterprises available to farmers, there is competition among enterprises for available resources. Finding maximum profit combinations for entire farms are relatively complicated and it is beyond the range of this study.

(5) There are many other conditions which may also influence the farmer's decision with respect to the rate of fertilizer application such as different kinds of soils, climate, different environmental factors, and different levels of management. All of these have an effect on crop production and resources use.

Although the analysis of experimental data can not be applied directly to any particular farm situation, some generalized recommendations can be made provided that recognition is made of the differences between the conditions under which the experimental data are collected and the farm conditions. In general experimental research conducted by experiment stations can indicate the nature of the response curves and can serve as a useful guide to all who are dealing with fertilizers. The degree to which the results of experimental research will help the farmers in application of fertilizers also depends upon the individual farmer's ingenuity.

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1. R. E. Patterson, "Economic Decisions in Producing Irrigated Grain Sorghum on the Northern High Plains of Taxes", Taxes Agricultural Experiment Station, Taxes A & M University, MP-474, Dec. 1964, pp. 11 - 12.

V. SUMMARY

This study presents an economic interpretation of corn and grain sorghum yield response to different rates and combinations of fertilizers on irrigated land in West-Central Kansas. It is based on experimental data conducted during the years 1961-1965 for corn and 1959-1965 for grain sorghum.

Three nutrients, nitrogen(N), phosphorus(P_2O_5) and potassium(K_2O) were used in the experiment but the data and statistical tests showed the yield response to phosphorus and potassium to be negligible. Nitrogen was considered as the only important fertilizer in determining the yields of corn and grain sorghum. Since the response of corn or grain sorghum to nitrogen is known to vary with soil, climate, and other environmental factors, the interpretations developed herein are intended to apply only to conditions underlying this experiment.

While several input-output relationships were tested, the algebraic forms $Y = 50.8527 + 1.0674\ N - .0031\ N^2$ for corn and $Y = 71.95\ N^{.1170}$ for grain sorghum appear to describe the crop-nitrogen relationship best. In these equations, Y is the estimated yield of corn or grain sorghum and N is nitrogen.

With the price of corn at \$1.12 a bushel and the price of nitrogen at 13 cents a pound, the most profitable rate of nitrogen application is 153 pounds per acre. The most profitable rate is 101 pounds per acre for grain sorghum, when the price of sorghum is \$0.91 a bushel and the price of nitrogen is 13 cents a pound. When nitrogen is applied at its most profitable rate with the above given prices, the returns to nitrogen above its cost are \$81.74 per acre for corn and \$33.70 per acre for grain sorghum.

The price of corn (or grain sorghum) per bushel and the price of nitrogen per pound are the determinants of the most profitable rate of nitrogen application. Any change in the relative prices of nitrogen or corn (or grain sorghum) results in a change of the most profitable rate of nitrogen application; the change is greater for grain sorghum than it is for corn. If the nitrogen application rate is not adjusted to the most profitable rate when relative prices of crops and nitrogen change, the returns to nitrogen are less than when the rate is adjusted to the new price situation. A variation of 20 cents per bushel in the price of corn above $1.12 affects the most profitable rate of nitrogen application by 2.9 pounds per acre. Failure to apply the most profitable rate in response to the change in corn price results in a loss of 5 cents per acre for a 20 cents increase in the price of corn. A variation of 20 cents per bushel in the price of sorghum above $0.91 affects the most profitable rate of nitrogen application by 27.6 pounds per acre. Failure to apply the most profitable rate of nitrogen in response to the change in sorghum price results in a loss of returns of 35 cents per acre for a 20 cents increase in the price of sorghum.

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CORN AND GRAIN SORGHUM RESPONSE TO
FERTILIZERS ON IRRIGATED LAND IN WEST-CENTRAL KANSAS

by

YUNG LIU

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While several input-output relationships were tested, the algebraic forms $Y = 50.8527 + 1.0674\ N - .0031\ N^2$ for corn and $Y = 71.95\ N^{.1170}$ for grain sorghum appear to describe the crop-nitrogen relationship best. In these equations, Y is the estimated yield of corn or grain sorghum and N is nitrogen.

With the price of corn at $1.12 a bushel and the price of nitrogen at 13 cents a pound, the most profitable rate of nitrogen application is 153 pounds per acre. The most profitable rate is 101 pounds per acre for grain sorghum, when the price of sorghum is $0.91 a bushel and the price of nitrogen is 13 cents a pound. When nitrogen is applied at its most profitable rate with the above given prices, the returns to nitrogen above its cost are $81.74 per acre for corn and $33.70 per acre for grain sorghum.

The price of corn (or grain sorghum) per bushel and the price of nitrogen per pound are the determinants of the most profitable rate of nitrogen application. Any change in the relative prices of nitrogen or corn (or grain sorghum) results in a change of the most profitable rate of nitrogen application; the change is greater for grain sorghum than it is for corn. If the nitrogen application rate is not adjusted to the most profitable rate when relative prices of crops and nitrogen change, the returns to nitrogen are less than when the rate is adjusted to the new price situation. A variation of 20 cents per bushel in the price of corn above $1.12 affects the most profitable rate of nitrogen application by 2.9 pounds per acre. Failure to apply the most profitable rate in response to the change in corn price results in a loss of 5 cents per acre for a 20 cents increase in the price of corn. A variation of 20 cents per bushel in the price of sorghum above $0.91 affects the most profitable rate of nitrogen application by 27.6 pounds per acre. Failure to apply the most profitable rate of nitrogen in response to the change in sorghum price results in a loss of returns of 35 cents per acre for a 20 cents increase in the price of sorghum.