THE UNIVERSITY OF MANITOBA

CROP YIELD RESPONSES AND ECONOMIC OPTIMA IN FERTILIZER USE AT VARIOUS LOCATIONS IN THE PRAIRIES, 1959-68

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ECONOMICS

WINNIPEG, MANITOBA

February, 1971

ABSTRACT

CROP YIELD RESPONSES AND ECONOMIC OPTIMA IN FERTILIZER USE AT VARIOUS LOCATIONS IN THE PRAIRIES, 1959-68

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In the period 1945 to 1969, fertilizer sales in Canada increased from 575,107 tons to 1,909,496 tons, an increase of 332 per cent for the twenty-five year period. Because of this large increase in the use of fertilizer, there is an increasing need for more information on the physical and economic relationships involved in the optimum use of fertilizer. With this kind of information, the farmer can then decide how much fertilizer to use.

With this goal in mind, the objectives of this study were:

1. To determine the yield response to varying levels and combinations of N and P_2O_5 for the crops, wheat, oats, barley and rye seeded on summerfallow and stubble, at various locations in the Prairie Provinces, for the years 1959 to 1968.

2. To derive the least cost combinations for specified crop yields and the maximum profit positions for selected crop prices, and to compare these economic optima among locations, among years at given locations and among the different crops in a given year and location.

The data used in this study were the results of fertilizer experiments in cereals that were conducted in the Prairie Provinces and the Peace River area of British Columbia in the ten year period, 1959 to 1968. Of the 4,385 fertilizer experiments whose results were tabulated, 3,458 of these experiments were excluded from further analysis in the study. Most

of the experiments were excluded because they did not have a sufficient number of observations to estimate a yield response function to fertilizer inputs.

Four different production functions were fitted by least squares regression to the observations in each of the remaining 927 experiments. Although regression equations were obtained for the 927 experiments, there were only 93 experiments in which the signs of the regression coefficients for the four derived equations were the same as hypothesized. The hypothesized signs of the regression coefficients for the linear, Cobb Douglas, quadratic and square root functions are shown in the following equations:

$$\hat{Y} = b_o + b_1 N + b_2 P$$

$$\hat{Y} = b_o N^{b_1} N^{b_2}$$

$$\hat{Y} = b_o + b_1 N + b_2 P - b_3 N^2 - b_4 P^2 + b_5 NP$$

$$\hat{Y} = b_o - b_1 N - b_2 P + b_3 \sqrt{N} + b_4 \sqrt{P} + b_5 \sqrt{NP}$$

The quadratic form of the production function was selected as the "best estimate" of the physical relationship between the fertilizer inputs and the crop yields. The selection was made on the basis of certain regression statistics obtained for each function. Because there were 93 experiments involved, the selection was based on the average values for these statistics for each function.

The quadratic production equations derived for each of the 93 experiments were then used to obtain the least cost nutrient combinations for specified crop yields and the maximum profit positions for selected crop prices for each of these experiments. However, the least cost nutrient combinations and the maximum profit positions for only 56 experiments are presented in the thesis. The economic optima for 36 experiments are not presented, because in most of these experiments the most profitable application of N and/or P_2O_5 was negative.

The maximum profit positions of N, P_2O_5 and yield were compared among years at given locations and among locations for a given price. These comparisons could not be made for every crop, because in some cases there were only one or two fertilizer experiments for the crop. There was considerable variation in the maximum profit yields for both wheat on summerfallow and barley on stubble, while in the case of wheat on stubble, most of the experiments had optimal yields which fell within the range of 25 to 35 bushels per acre. The combinations of N and P_2O_5 for both the maximum profit positions and the least cost combinations for specified yields were also quite variable among years for given locations and among locations. Comparisons of the economic optima for different crops could only be made for two locations.

The regression-equation approach not only expresses the physical relationships between fertilizer levels and yields, but it also permits one to determine the economic optima in fertilizer use. The fertilizer-input crop -output relationships, however, apply to particular soils for certain years; production surfaces obtained under other rainfall and soil conditions can be expected to differ from those obtained in the experiments reported.

ACKNOWLEDGEMENTS

The author would like to take this opportunity to express his sincere appreciation to all of those people who have assisted him in so many ways in the preparation of this thesis.

The author would like to especially thank his thesis committee chairman, Dr. W. J. Craddock, whose supervision and advice were invaluable to the study.

Thanks are also due to Dr. J. C. Gilson, Dr. M. Cormack and Dr. C. F. Shaykewich for their comments and constructive criticisms of this thesis.

The author would also like to thank Lynne Schlamb, Liisa Ikonen and Barbara Deviaene for their contributions to this thesis. Sincere thanks are also due to Miss Mary Ann Hildebrand for typing this thesis.

Finally, the author most gratefully acknowledges the financial assistance provided by the University of Manitoba.

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Chapter 1

INTRODUCTION

THE PROBLEM

Fertilizer use in agriculture in Canada and in the Prairie Provinces has increased significantly. Between 1945 and 1969 sales of fertilizer in Canada increased from 575,107 tons to 1,909, 496 tons, an increase of 332 per cent for the twenty-five year period (Table A.1 of Appendix A). Fertilizer sales in the Prairie Provinces increased by 2037 per cent for the same period. The increase in the Prairie Provinces has not been continuous, however. Fertilizer consumption fell off sharply in the period 1954 to 1958 and again 1969. In 1970 in the Prairie Provinces, it was estimated that farmers intended to use 30 per cent less fertilizer than was used in 1969.[1] The reduction in fertilizer use in these two periods is due in part to the reduced crop acres and the decline in wheat exports as compared with the immediately preceding periods (Table A.2 and Table A.3).

One of the reasons why fertilizer use has increased in the period 1945 to 1969, particularly in the Prairie Provinces, is that farmers are moving towards more intensive, rather than extensive, production. The disappearance of the land frontier has tended to place greater premiums on the existing land resources. Consequently, as land prices increase, farmers often find it more profitable to invest their limited capital in more intensive production through the use of fertilizer than in additional land. The expansion in livestock production in this period has also

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[1] Dominion Bureau of Statistics, Agriculture Division, Crops Section, "Intended Acreage of Principal Field Crops in Canada, 1970", Field Crop Reporting Series, (No. 2, 1970).

increased the use of fertilizer in the Prairie Provinces. In the last ten years an increasing proportion of the coarse grains, oats and barley, were grown on stubble land which require higher rates of application of fertilizer than crops grown on summerfallow.[2] Also, fertilizer use increased as a result of the increase in the acreage of the major field crops (all wheat, oats, barley, all rye, mixed grains, flaxseed, rapeseed and tame hay) in this period (see Table A.2). In 1945-46 in the Prairie Provinces, the acreage of these crops was 41,732,000 acres. In 1969-70, there were 50,126,000 acres of these crops. Although the 1969-70 acreage was down from that of the previous crop year, nevertheless, it is still substantially larger than the 1945-46 acreage. Because of the large amount of money presently being expanded on fertilizer, there is an urgent need for expanded research into the physical and economic relationships involved in determining the optimum combinations and levels of fertilizer use.

Initial research in fertilizer in agriculture has been concerned with determining whether or not there is a significant response in crop yield from the application of fertilizer. However, once responses have been found to exist, the farmer needs to consider fertilizer along with other farm inputs and practices in his farm management decisions. First, he must decide whether or not to use any fertilizer. While yield responses to fertilizer may be certain, he must decide whether or not a dollar put in fertilizer will return more than the same dollar invested in livestock, seed, chemicals, land or other investment alternatives. If he decides to use fertilizer, he must then decide: (1) where to use fertilizer in

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[2] Dominion Bureau of Statistics, Agriculture Division, Crops Section, "Summerfallow and Stubble, Acreage and Yield of Specified Crops Prairie Provinces", Field Crop Reporting Series, (No. 1, 1963 - 1970).

terms of which soils and crops will give the highest return for each one dollar invested; (2) what combination of fertilizer nutrients to use; and (3) how much of a given nutrient combination to apply on a given crop. These decisions can be made only if fertilizer information is provided in the form of incremental response data, that is, data which show the successive additions to yield resulting from successive fertilizer applications. Accordingly, if the initial research shows that crop yields do respond to fertilizer, the next steps in fertilizer research are to derive (1) the incremental yields forthcoming from various rates of fertilizer application under specified crop and soil conditions, and (2) the economic optimum quantity of fertilizer, considering crop and fertilizer prices.

The economic optimum quantity of fertilizer and the corresponding optimum yield will not be the same for every year in a particular area or location. The yield responses to the various rates of fertilizer application are affected by such factors such as weather, soil moisture, and soil fertility which change from one year to the next. In some years, the optimum rate of fertilizer application may be quite high; yet the optimum yield may be quite low because of the low soil fertility, rainfall and soil moisture. In other years, the exact opposite may be the case. If the optimum yields and quantities of fertilizer were obtained for a number of years, the farmer would then be in a better position to decide how much he should invest in fertilizer. The farmer with the limited capital will tend to fertilize at a lower rate than the farmer with the unlimited capital, because of the greater risk and uncertainty associated with the heavier rates of fertilizer application. The farmer whose capital is limited is not only concerned with the risk involved in a large investment in fertilizer, but also whether or not a higher return could be obtained if the capital was invested elsewhere in the farm business. The farmer with the unlimited capital can afford to take a greater risk and is therefore able to apply the heavier rates of fertilizer.

The economic optimum in fertilizer use will also differ among locations. Differences in soil moisture, soil fertility and weather as well as differences in soil type will affect the optimum use of fertilizer among the various locations. Because these differences in the optimum use of fertilizer do exist among locations, it is not advisable for a farmer in one area to fertilize on the basis of the results obtained in another. He may be applying too much fertilizer, particularly if, he is located in a drier area and in a different soil zone. For example, if a farmer in the Swift Current area of Saskatchewan were to apply the optimum quantity of fertilizer derived for the Melfort area, then he would be applying in most years too much fertilizer. On the other hand, a farmer may be applying not enough fertilizer if the area in which he is located has a wetter climate and a more productive soil. If the economic optimum in fertilizer use were derived for a number of locations, then the farmer would be able to choose the optimum quantity of fertilizer which is the most appropriate for his farm.

This, in part, summarizes the problem facing the farmer in determining what is the optimum quantity of fertilizer to apply, given certain crop and fertilizer prices. The problem is further complicated by the fact that the optimum quantity of fertilizer changes from one year to the next and from one location to another.

OBJECTIVES OF THE STUDY

The major objectives of this study are:

1. To determine the yield response to varying levels and combinations of the fertilizer nutrients, N and P_2O_5, for the selected crops, wheat, oats, barley, and rye seeded on summerfallow and on stubble, at various locations in the Prairie Provinces, for the years 1959 to 1968.

2. To determine the least cost combination of N and P_2O_5 in producing specified yields for each of these crops for the various locations and years.

3. To determine the most profitable application of N and P_2O_5 for five selected prices of each crop for all locations and years.

Because the optimum application of fertilizer and the corresponding yield are not the same for every year at a particular location, and because they also differ among locations, two further objectives of the study are:

1. To compare the maximum profit position of N, P_2O_5 and yield among years at given locations.

2. To compare the maximum profit position of N, P_2O_5 and yield among locations.

The least cost combination of fertilizer nutrients for specified yields will also vary among years at each location and among locations. Therefore, two additional objectives of the study are to compare the least cost combinations of N and P_2O_5 for the same crop yield among years and among locations.

Another objective is to compare the return per dollar invested in fertilizer for the different crops in a given year and location.

Since several of the objectives involve economic production principles, these principles will be discussed in the next chapter. A description of the nature and source of the fertilizer-yield data and an evaluation of the different types of functions that can be used to estimate the yield responses to fertilizer inputs will be presented in Chapter 3. The methodological procedures and the equations involved in determining the economic optima in fertilizer use will be examined in the first section of Chapter 4. In the second section, the economic optima for fertilizer experiments conducted at various locations in the Prairies will be presented and compared. Chapter 5 will be a summary and conclusion.

Chapter 2

THEORETICAL CONSIDERATIONS INVOLVED IN ALLOCATION OF FACTORS OF PRODUCTION

There are three basic relationships in production economics. These are the factor-product, the factor-factor, and the product-product relationship. They provide the framework within which economic efficiency is determined, whether the choices relate to an individual farm, the agricultural industry, or the nation as a whole.[1] In the factor-product type of relationship, one is concerned with the transformation of a single variable factor of production into a single product. In the second type, one is looking at the relation between two variable factors of production and a single product. In the product-product type of relationship, one is concerned with the substitution between two products for various levels of input. In this chapter, only the first two will be dealt with in detail.

THE SINGLE VARIABLE FACTOR-PRODUCT CASE

This first section will examine the production principles associated with the input of a single variable factor of production, with all other factors held constant at some level, to yield a single product. Many farm decisions fall within the framework of a single variable factor-product type of relationship. The problem involved is usually one of intensity of production. For example, how much fertilizer to apply per acre is a decision that has to be made by many farmers. Similarly,

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[1] Earl O. Heady, <u>Economics of Agricultural Production and Resource Use</u> (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965), p. 26.

decisions have to be made on the amount of feed to be fed per animal, the amount of labor or capital to be applied per acre or to a farm of a given size. The problem of intensity can also apply to output. The decision as to what level of production per acre, per animal, or for the farm is most profitable, is dependent upon a factor-product relationship.

The term production function refers to the physical relationship between the input of a factor or factors and the output of a product. It can be expressed in mathematical terminology as:

$$Y = f(X_1 \mid X_2, X_3, \ . \ . \ . \ , X_n).$$

This expression states that the output of product Y is a function of, or is dependent on, the input of the variable factor X_1, with factors X_2, X_3 to X_n fixed at some level. For example, the yield of wheat per acre is a function of the input of fertilizer. As the use of fertilizer is varied, the seeding rate, land, labour and machinery inputs are likely to remain constant.

A particular level of output may be produced from a number of different combinations of inputs (non-variable inputs included). Alternatively, the same combination of production inputs may give different amounts of output, depending upon how efficiently the productive inputs are organized. For instance, the hay yield per acre obtained when fertilizer is broadcasted in the fall may be higher than that obtained when fertilizer is broadcasted in the spring. Therefore, if the production function is to give only one value for the output from a given input combination, the function must be so defined that it expresses "the maximum product attainable from the combination at the existing state of technical knowledge".[2]

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[2] Sune Carlson, A Study of the Pure Theory of Production (New York, New York: Sentry Press, 1965), pp. 14-15.

The production function can be plotted on a graph in which the total physical product curve, $TPPx_1$, represents the total output of the product for various levels of input of the variable factor, with the other factors held constant at some specified level. The total physical product for variable input X_1, $TPPx_1$, can: (1) increase at an increasing rate, (2) increase at a constant rate, (3) increase at a decreasing rate, and (4) decrease with increases in the variable factor X_1. These relationships are shown in Figure 2.1. It is not necessary that any particular production function should exhibit all situations described above.

The average and marginal physical products can be derived from the total physical product. The average physical product curve, $APPx_1$, denotes the amount of product per unit of the variable input. The marginal physical product curve, $MPPx_1$, represents the addition or reduction in the output of the product resulting from an additional unit of variable factor X_1. In other words, it denotes the changes in the slope of the total physical product curve.

Production functions can be divided into three segments called stages of production, which are distinguished by whether their marginal physical products are increasing, decreasing or negative. The classic production function which is characterized by all three stages is illustrated in Figure 2.1. Stage 1 extends from the origin to the level of input where the average physical product curve reaches a maximum. The marginal physical product first increases and then decreases in this stage. Stage 2 extends from the input level denoting maximum average physical product to the one where the marginal physical product becomes zero. The marginal physical product becomes zero when the total physical product reaches a maximum. Stage 3 includes all input levels which have

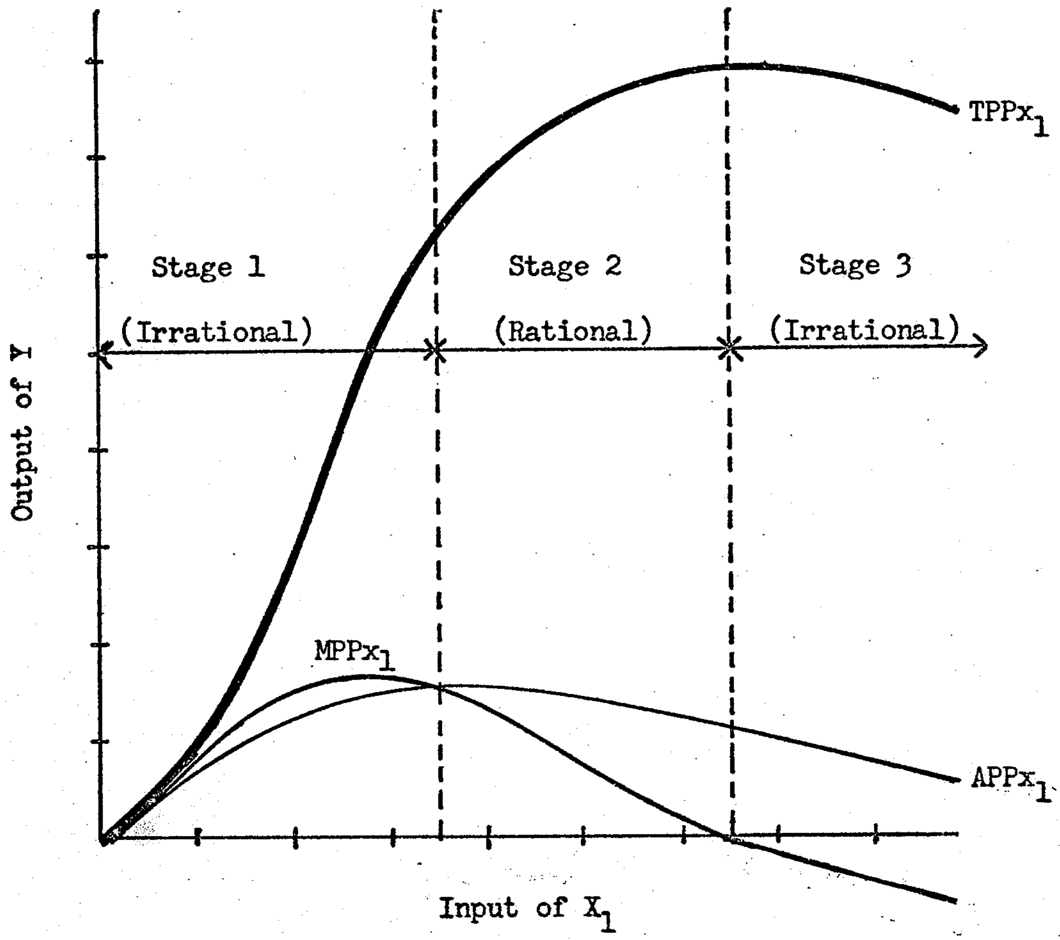

Figure 2.1. An Input-Output Relationship Showing Total, Average and Marginal Physical Products and the Three Stages of Production.