DEMAND FOR FERTILIZER IN CANADIAN AGRICULTURE--AN ECONOMIC INTERPRETATION OF TECHNICAL CHANGES

A Thesis

Presented to

the Faculty of Graduate Studies and Research

University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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August 1968

ABSTRACT

DEMAND FOR FERTILIZER IN CANADIAN AGRICULTURE--

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During recent decades, especially after World War II, the use of fertilizer in Canadian agriculture has rapidly increased. The expansion of fertilizer use has been one of the important factors raising agricultural productivity in Canada. In view of the increased importance of fertilizer input, the attempt of this study is to examine the most important factors affecting the increase in fertilizer use. Because of the diverse nature of Canadian agriculture, it was expected that substantial differences had occurred in the regional use of fertilizer. Therefore, in addition to the national analysis of fertilizer demand regional investigations were also conducted.

In an effort to take account of lag effects and to measure the relative contribution of the major factors studied, models were formulated which incorporated the concepts of growth rate and distributed-lag. The models are all fitted to time series data from 1926 to 1965 for the national analysis and from 1929 to 1965 for the regional investigations. The years 1940-1945 are omitted because of abnormal economic circumstances resulting from the war. In order to compare the difference in fertilizer use between different periods, the total period was divided into two periods; namely, the pre-war period, 1926-1939 (or 1929-1939) and the post-war period, 1946-1965.

The expected quantities of fertilizer demand in all regions for 1970 and 1975 are estimated utilizing the estimated demand functions and their implicit assumptions.

The empirical results show that the real fertilizer price, real farm cash income, the quantity of grains and grain products exported, and improved technical knowledge about fertilizer use in crop production were the major factors affecting fertilizer consumption during the past few decades. The results also indicate that improved technical knowledge has been more important in the post-war period than in the pre-war period.

From considering the regional results, it was found that fertilizer price and improved technical knowledge have been more important factors affecting fertilizer use in Western Canada than in Eastern Canada. The reverse was the case for the effects of farm cash income on fertilizer consumption. In addition, fertilizer use in the Prairie region has been, due to accumulative effects of resource reallocation on farms, strongly influenced by the quantity of fertilizer used in the previous year.

The expected levels of fertilizer use in all regions are projected to increase continuously for the decade following 1965. The highest rate of increase is predicted to be in the Prairie region where the use of fertilizer has been strongly affected by improved technical knowledge, while the lowest rate of increase is projected to be in the Atlantic Provinces where fertilizer consumption has been strongly related to the level of farm cash income.

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Dr. Martin H. Yeh, the academic advisor, for his constructive criticism, inspiration and encouragement during the course of this thesis. Moreover, thanks are due to Professor T. D. Harris who read the draft and made many valuable suggestions.

The Department of Agricultural Economics, University of Manitoba, made this thesis possible through its financial resources.

Appreciation is expressed to Dr. W. J. Craddock and Mr. Neil Longmuir for their programming assistance.

Thanks are also due to Mr. and Mrs. H. Baker for their efforts in correcting sentences and typing this paper.

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CHAPTER I

INTRODUCTION

Major sources of greater productivity in agriculture have been directly or indirectly related to the adjustments in the use of resources by farmers. The increased use of capital inputs such as commercial fertilizer in recent decades has been a significant example. The increased use of commercial fertilizer can be viewed as one of the major innovations in Canadian agriculture since World War II.

Productivity in Canadian agriculture has been increasing over time. The rate of increase in overall agricultural productivity in Canada has averaged 2.4 per cent annually from 1946 to 1965, or 2.0 per cent from 1935 to 1965 [15, p. 15]. The growth of productivity can represent the result of improved efficiency in the combination of factor inputs in the production process and of improvements in the quality of resources employed. Changes in the composition of farm inputs over the past decades may help to explain this increase of productivity. In his study of trends in agricultural productivity, Furniss concluded that in terms of the three main factors of production (real estate, labor and capital), capital inputs, which include machinery, feeds, fertilizers, pesticides and others, appear to have been the most important factors contributing to productivity increases since 1935 [15, p. 20]. Furniss' study indicates that commercial fertilizer is one of the more important capital inputs that contributes to the progress of Canadian agriculture.

A. Objective of the Study

The primary objective of this study is to present a description of fertilizer use and the major factors influencing its use in Canada as a whole and in selected regions during the period of 1926-65. To be more specific, the objectives are:

1. To explain the increase in fertilizer use in Canadian agriculture as a whole and for selected regions in terms of certain important variables such as fertilizer price, farm cash income and technical knowledge.

2. To measure the relative contribution of each variable to the growth of fertilizer use for all Canada and selected regions.

3. To examine the relative influences of the major factors on the use of fertilizer in two different time periods--the pre-war and post-war periods.

4. To examine differential demand trends, under both short-run and long-run patterns, for fertilizer in different regions.

5. To project fertilizer demand for 1970 and 1975.

B. Hypotheses and Assumptions

In order to carry out a systematic analysis and to present a comprehensive interpretation of the empirical results, it is necessary to develop relevant hypotheses. For this study, they are:

1. The tremendous increase in fertilizer use in Canadian agriculture as a whole and in selected regions can be largely explained by

technical changes[1] in both the agricultural and the fertilizer industry.

2. The demand for fertilizer is responsive to the quantity of grains exported.

3. Since technical progress has occurred more rapidly after 1946, the use of fertilizer has been much more affected by the improved technical knowledge about fertilizer use in the post-war period, 1946-1965, than in the pre-war period, 1926-1939.

4. Since the technical knowledge of fertilizer use has been adopted over a longer time period in the older using regions than in the newer using regions, improved technical knowledge about fertilizer use has been relatively less important as a factor affecting fertilizer use in the older using regions than in the newer using regions during the post-war period.[2]

Certain assumptions are also needed to facilitate the testing of hypotheses. These are:

1. Farmers aim at maximizing profits.

2. Either the natural number or the logarithmic values of the variables are additive.

3. Technical changes in both the agricultural and the fertilizer

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[1] Technical change means a shift of the production function, a change in the efficiency of the use of resources. A more specific definition will be discussed in Chapter IV.

[2] The older using regions refer to the Atlantic, Quebec, and Ontario regions while the newer using regions refer to the Prairie and British Columbia regions.

industry are cumulative over time in all regions.

4. Farmers do not adjust the quantity of fertilizer used immediately with respect to changes in such factors affecting its use as fertilizer price, farm cash income, technology of crop production.

With these assumptions, it is possible to apply existing economic theory of demand for resources to the study of fertilizer demand. Also, they provide the possibility to formulate relevant models to proceed with numerical analysis.

C. Methods and Procedures

Before proceeding with the investigation of fertilizer demand, a description of methods and procedures used in this study is made.

The study deals with the national and regional demand for all commercial fertilizer. It is, therefore, an aggregative study, based on time series data related to fertilizer consumption in Canada as a whole and in selected regions, to indicate "gross" relationships between specified variables and the use of fertilizer. No attempt is made to determine the exact factors and decision-making processes of individual farmers about the quantity of fertilizer used.

Because of the diverse nature of Canadian agriculture, it is expected that there will be considerable variation in the use of fertilizer among the different regions. Hence, on the basis of available data, rough homogeneity in type of farming, soil and climate conditions, five regions have been delineated by using provincial groupings: namely, the Atlantic Provinces, including Nova Scotia, New Brunswick, and Prince Edward Island; Quebec; Ontario; the Prairie Provinces of Manitoba, Saskatchewan, and Alberta; and British Columbia. The time period chosen is from 1926 to 1965 for national analysis, and from 1929 to 1965 for regional investigations. The years 1940-1945 have been omitted because of abnormal economic circumstances resulting from the influences of World War II.

The effect of hypothesized variables upon demand for fertilizer will be examined and tested by defining and estimating national and regional demand functions for fertilizer. All demand functions are fitted from time series data by using autoregressive least squares.[3] To compare fertilizer demand between time periods, the total period is divided into two sub-periods, i.e., the pre-war period (1926-1939 or 1929-1939) and the post-war period (1946-1965). Separate regressions are computed for each period. Conventional statistical tests, such as the F-test and t-test, are used to examine the validity of empirical results derived from the proposed demand functions.

The quantity of fertilizer demand for 1970 and 1975 is estimated utilizing the estimated demand functions and is subject to certain assumptions.

D. A Review of Previous Studies

This section provides a brief review of some previous studies of the fertilizer demand which are most relevant to the present study.

Griliches [19, 20], and Heady and Yeh [27], employing different methods, have derived fertilizer demand functions with United States

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[3] Autoregressive least squares is discussed in Chapter IV.

data. In each study, the national and regional demand functions for fertilizer were estimated. By applying the distributed lag model, Griliches assumed that quantity of fertilizer use was, in the short-run, a function of the fertilizer/crop price ratio and the amount of fertilizer used in the previous year. All variables were expressed in logarithms. Griliches observed that the increase in fertilizer use in the United States (from 1911 to 1956) could be largely explained by the decline in the fertilizer/crop price ratio. He emphasized that the fall in the fertilizer price relative to the crop price was caused by technical change in the fertilizer industry. All this was the result of the impact of technical change, leading to new, lower cost, fertilizer production processes, subsequently causing a decline in the fertilizer/crop price ratio. Griliches' application of the distributed lag model and its interpretation with resulting estimates of short-run and long-run demand elasticities was an important beginning for the economic analysis of the demand for fertilizer. The Heady and Yeh model included more variables than the previous one. These included farm cash incomes, total acreage of cropland and time. They found that, in addition to the lower price of fertilizer and increased farm income, the demand for fertilizer was affected by technical change in agriculture itself. This results in an expectation that fertilizer demand functions have shifted to the right over time.

In 1960, Yeh [46] published a study of fertilizer demand functions considering national and regional situations of Canadian agriculture. Both national and regional demand functions were estimated by fitting Cobb-Douglas functions to Canadian data of 1926-1958. Applying the distributed lag model, he derived long-run and short-run demand elasticities. According to his findings, four factors--fertilizer price, farm incomes, technical improvements and the amount of fertilizer used in the previous year--explained more than 77 per cent of the variation in total fertilizer use during the period 1926-1958. The regional analysis suggested that fertilizer price and farm incomes were relatively important factors affecting fertilizer consumption in the Atlantic and Central regions (Ontario and Quebec) while technical knowledge was of greater importance in Western Canada than in Eastern Canada. The findings of Yeh's work provide helpful suggestions to the present study.

In 1963, Heady and Tweeten [26, p. 122-93] presented detailed investigations of national and regional demand functions for the United States. In addition to an analysis of static demand functions based on experimental data, numerous regression models were fitted to time series data for the years 1926 through 1960 with 1944-1950 excluded. In general, the quantitative findings were parallel to the earlier work of Heady and Yeh. This study furnishes basic resource demand theory and numerous demand equations for the empirical study.

Hayami [23] investigated the demand for fertilizer in Japan. In order to identify causal factors and to measure their relative contributions to the increased use of fertilizer, Hayami applied the concept of growth rates to the formulation of demand function for fertilizer. The model, so formulated, was an exponential function which was fitted to time series data for the period 1883-1937. In an attempt to reduce observational errors and distributed-lag effects, he used five-year averages rather than annual observations. The work of Hayami indicated that nearly all of the variations in fertilizer use were explained by technical progress in the fertilizer industry (which lowered the price of fertilizer relative to the price of farm products) and by technical progress in agriculture (which resulted in a continuous shift of the fertilizer demand schedule). About 30 per cent of the increase in commercial fertilizer use was concluded to be attributable to technical progress in the fertilizer industry and about 70 per cent to technical progress in the agricultural industry.

So far, a brief review of several previous studies of demand for fertilizer has been presented. The models used in this study to take account of distributed-lag effects and to measure the contributions of major factors to the fertilizer consumption were derived from these earlier studies. Hayami's, and particularly Griliches' distributed lag models, form the basis for the model used in this study.

E. Organization of the Study

This dissertation consists of seven chapters. Chapter I is an introduction to the study which provides a brief description of the objectives, hypotheses and assumptions, a discussion of methods and procedures, and a review of the previous studies. Chapter II illustrates historical changes both in fertilizer use and prices. Chapter III deals with the theoretical framework. The proposed models and some statistical considerations with regard to estimating coefficients are discussed in Chapter IV. The empirical results and their interpretation are presented in Chapter V. Chapter VI provides the statistical predictions and their implications. Summary and conclusions are given in the final Chapter.

CHAPTER II

HISTORICAL TRENDS IN FERTILIZER USE AND CHANGES IN PRICES

It is well known that economic development has brought about important changes in farm practices. One of these changes is the substitution of inputs produced off the farm for those produced on the farm. Good examples are tractors for horses, chemical fertilizer for manure. The substitution takes place because, as mentioned in Chapter I, these inputs increase productivity in agriculture. Furthermore, due to improved technology of production, price competition and sales promotion among non-farm suppliers, these inputs become available to agriculture at favorable prices. The results tend to substitute these new and improved inputs for old agricultural inputs.

The progress of agricultural development in Canada, like other developed countries, has brought about some changes in methods of production. Changes in input composition represent a distinct example. Over the past forty years, significant changes in Canadian farming have taken place through increased use of capital inputs which are supplied by the non-farm sector and provide agriculture with services for production. This is clearly shown in the data of Table I. This indicates that the use of total capital inputs was increasing continuously, from 1946 to 1965, at an annual growth rate of 2.2 per cent. Percentagewise, use of total capital inputs has increased about 192 per cent, from the average of the period 1935-1939 to 1965 or 49 per cent from the average

TABLE I

INDEXES OF CANADIAN AGRICULTURAL INPUTS BY SELECTED CATEGORIES, 1935-1965* (1949=100)

	Real estate[a]	Labor[b]	Capital					Total inputs
			Machinery and equipment[c]	Purchased feed and seed	Fertilizer and limestone	Miscel- laneous[d]	Total	
1935-39	112	116	52	41	35	73	52	95
1940-45	100	102	66	83	57	82	73	93
1946-50	101	102	96	115	92	100	102	102
1951-55	100	81	119	96	108	105	110	94
1956-60	107	67	125	130	122	116	124	93
1961	112	63	123	131	154	132	128	93
1962	114	61	129	132	168	131	132	94
1963	114	60	133	142	188	141	139	96
1964	114	58	137	150	225	147	146	97
1965	116	55	141	165	243	139	152	98
1961-65	114	60	133	144	196	138	139	96

*Source: I. F. Furniss, "Trends in Agricultural Productivity," Canadian Farm Economics, Vol.2, No. 1, April, 1967, Economics Branch, Canada Department of Agriculture, Ottawa.

[a]Includes interest on investment, depreciation and repairs on buildings, and property taxes for both owned and rented real estate.

[b]Total farm labor force (farm operators, unpaid family labor and hired labor).

[c]Includes fuel and other purchased items associated with machinery operation plus interest on investment and depreciation.

[d]Includes electric power, interest on investment in livestock and purchased livestock, pesticides and other purchased inputs.

of the period 1946-1950, while the corresponding percentage increases in fertilizer use were 594 per cent and 164 per cent, respectively. Percentage increase in fertilizer use from 1946-1950 to 1965 has been the highest as compared with other categories of capital inputs [15, p. 16].

For the purpose of presenting a somewhat detailed review on the changes in fertilizer use and prices, a chronological description of national and regional trends is valuable. The first two sections of this chapter provide national and regional trends in fertilizer use, while the changes in the prices of fertilizer and crops are reviewed in the rest of the chapter.

A. National Trend in Fertilizer Use

During the pre-war period (1926-1939), the demand for commercial fertilizer in Canadian agriculture was in its infancy since nutrients for plant growth were supplied mainly from natural source (manure) and crop rotations. Farmers in Canada as a whole spent only $8.2 million, the average for the period 1926-1939, on fertilizer and lime which was only 2 per cent of total farm operating expenses (Table II). With average annual consumption being 237,677 tons during the fourteen years interval, the use of total fertilizer increased from 180,794 tons in 1926 to a high of 321,207 tons in 1930 and then declined sharply, due to great depression during the 1930's, to a low of 166,407 tons in 1933 (Appendix A). However, since 1941, fertilizer consumption has continuously increased (Figure 1).

TABLE II

CHANGES IN FERTILIZER AND LIME EXPENSES AS PERCENTAGE OF TOTAL FARM OPERATING EXPENSES, CANADA AND REGIONS, 1926-1965*

		Canada[a]	Atlantic	Quebec	Ontario	Prairie	B.C.
		--thousands of dollars--					
1926-39	Total	424,130	22,168	50,761	126,014	209,769	15,422
	Fertilizer	8,160	2,835	1,351	3,181	265	495
	%	1.9	12.8	2.7	2.5	0.13	3.2
1940-45	Total	596,621	33,809	85,499	184,824	268,582	23,908
	Fertilizer	17,235	4,757	4,381	6,290	866	940
	%	2.9	14.1	5.1	3.2	0.32	3.9
1946-50	Total	972,625	52,391	149,012	316,639	411,052	43,531
	Fertilizer	32,569	7,763	6,846	12,484	3,894	1,581
	%	3.3	14.8	4.6	3.9	0.95	3.6
1951-55	Total	1,264,331	63,902	198,784	429,278	517,209	55,156
	Fertilizer	51,246	7,840	8,352	23,964	8,263	2,522
	%	4.1	12.3	4.2	5.6	1.6	4.6
1956	Total	1,425,766	69,983	236,281	500,365	555,514	63,623
	Fertilizer	52,847	7,868	8,713	27,541	6,296	2,429
	%	3.7	11.3	3.7	5.5	1.1	3.8
1957	Total	1,407,262	67,485	232,751	493,922	549,862	63,242
	Fertilizer	54,776	7,736	9,470	27,437	7,523	2,610
	%	3.8	11.4	4.1	5.6	1.4	4.1
1958	Total	1,504,281	71,179	260,218	527,168	577,974	67,742
	Fertilizer	59,558	8,061	10,037	30.136	8.375	2,949
	%	3.9	11.3	3.9	5.7	1.5	4.4
1959	Total	1,600,681	74,712	274,979	566,072	611,415	73,503
	Fertilizer	66,723	7,940	10,528	34,117	11,066	3,072
	%	4.2	10.6	3.8	6.0	1.8	4.2
1960	Total	1,665,675	78,838	281,687	578,295	650,311	76,644
	Fertilizer	70,061	8,344	12,722	32,670	12,862	3,463
	%	4.2	10.6	4.5	5.6	2.0	4.5
1961	Total	1,692,224	80,198	293,708	599,088	640,151	79,079
	Fertilizer	80,429	9,410	15,738	35,951	15,989	3,341
	%	4.8	11.7	5.4	6.0	2.5	4.2

TABLE II (continued)

		Canada[a]	Atlantic	Quebec	Ontario	Prairie	B.C.
1962	Total	1,823,269	80,796	309,371	621,542	725,046	86,514
	Fertilizer	87,099	9,123	15,999	39,568	18,282	4,127
	%	4.8	11.3	5.2	6.4	2.5	4.8
1963	Total	1,954,107	84,347	328,990	667,388	784,245	89,137
	Fertilizer	101,699	9,447	15,334	47,112	25,558	4,248
	%	5.2	11.2	4.7	7.1	3.3	4.8
1964	Total	2,032,175	88,324	338,096	706,974	805,589	93,192
	Fertilizer	122,808	9,464	16,278	54,679	37,957	4,430
	%	6.0	10.7	4.8	7.7	4.7	4.8
1965	Total	2,151,836	93,080	365,413	739,162	855,343	98,838
	Fertilizer	138,600	10,784	18,949	60,284	43,911	4,672
	%	6.4	11.6	5.2	8.2	5.1	4.7

*Source: Computed from "Handbook of Agricultural Statistics," Part II, Farm Income--1926-65, D.B.S., Ottawa.

[a]Excludes Newfoundland.

FIGURE 1

TRENDS IN FERTILIZER USE AND FERTILIZER/CROP PRICE RATIOS, CANADA AND REGIONS, 1927-1965 (1935-1939=100)

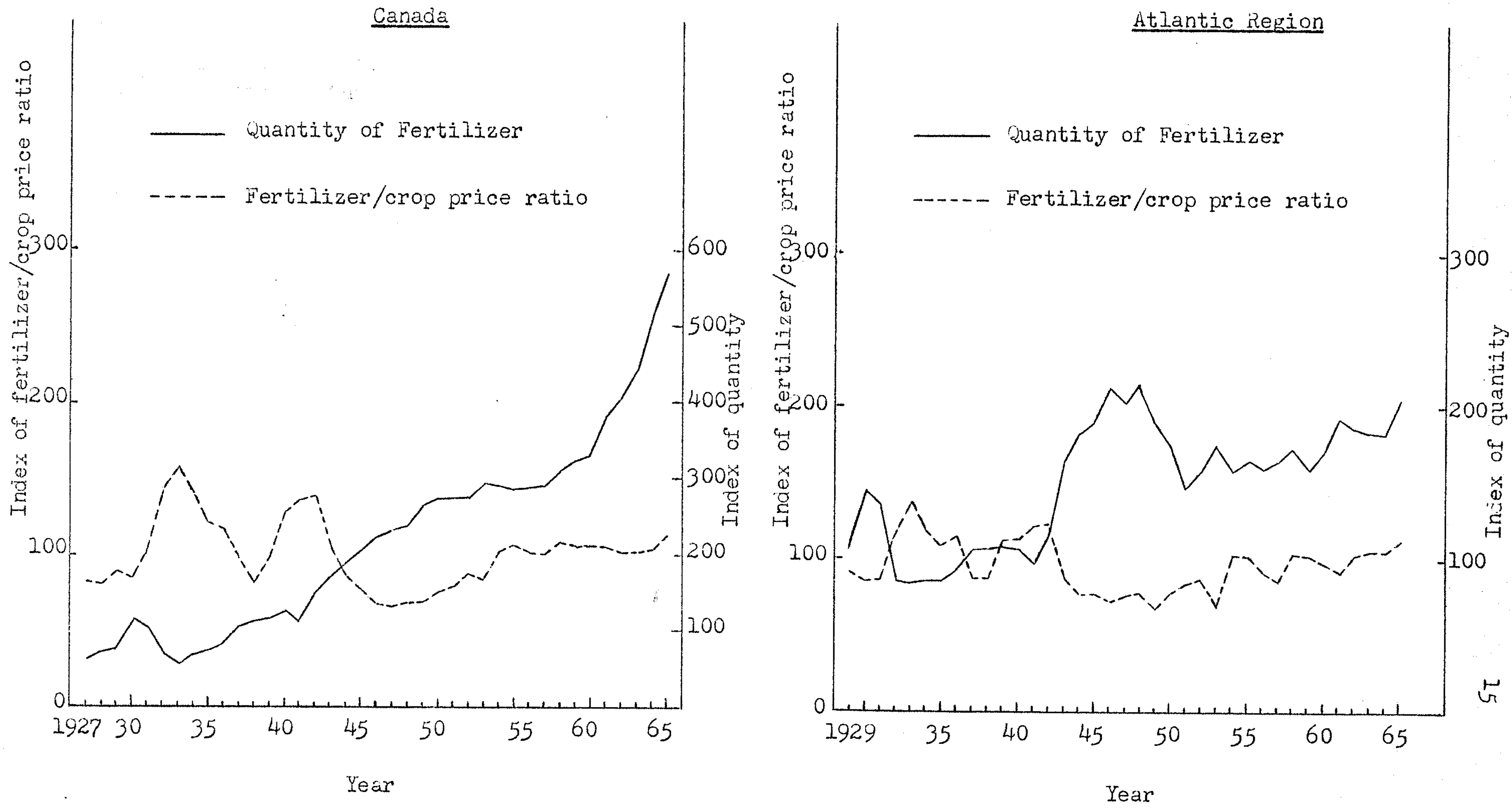
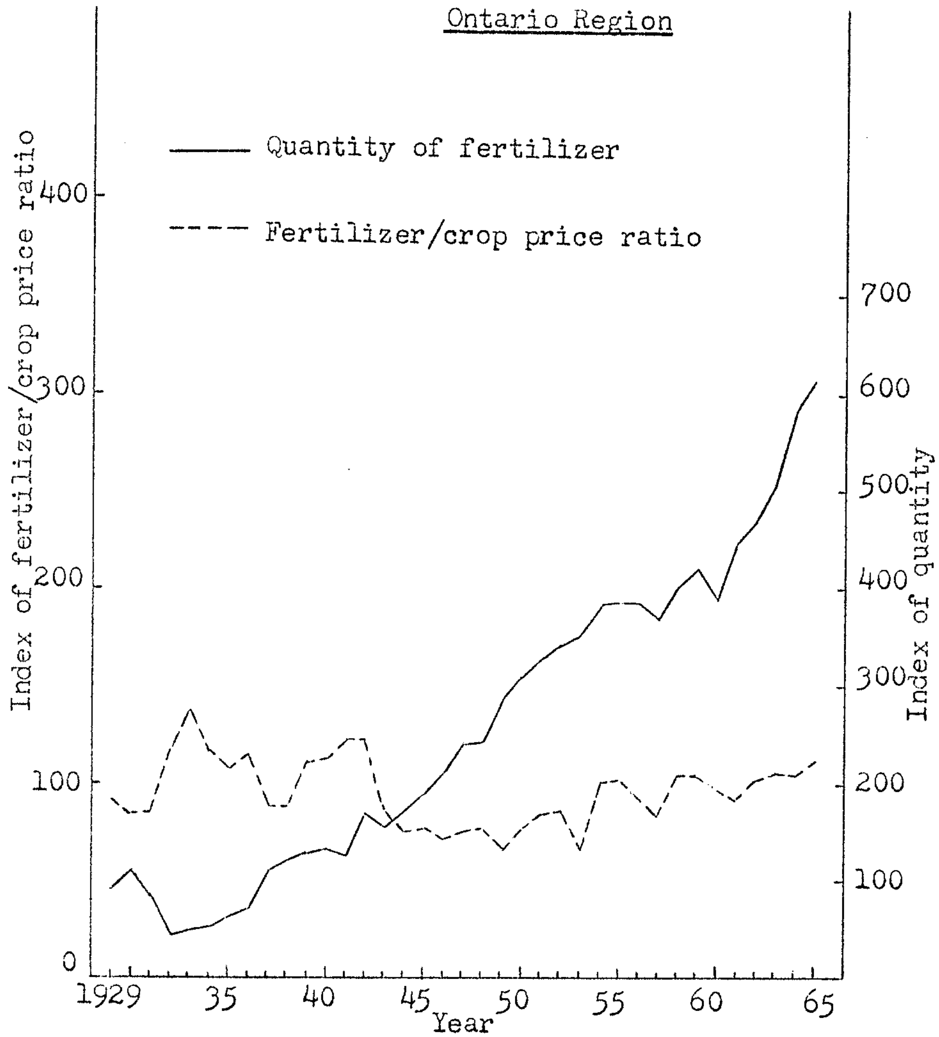


FIGURE 1 (continued)



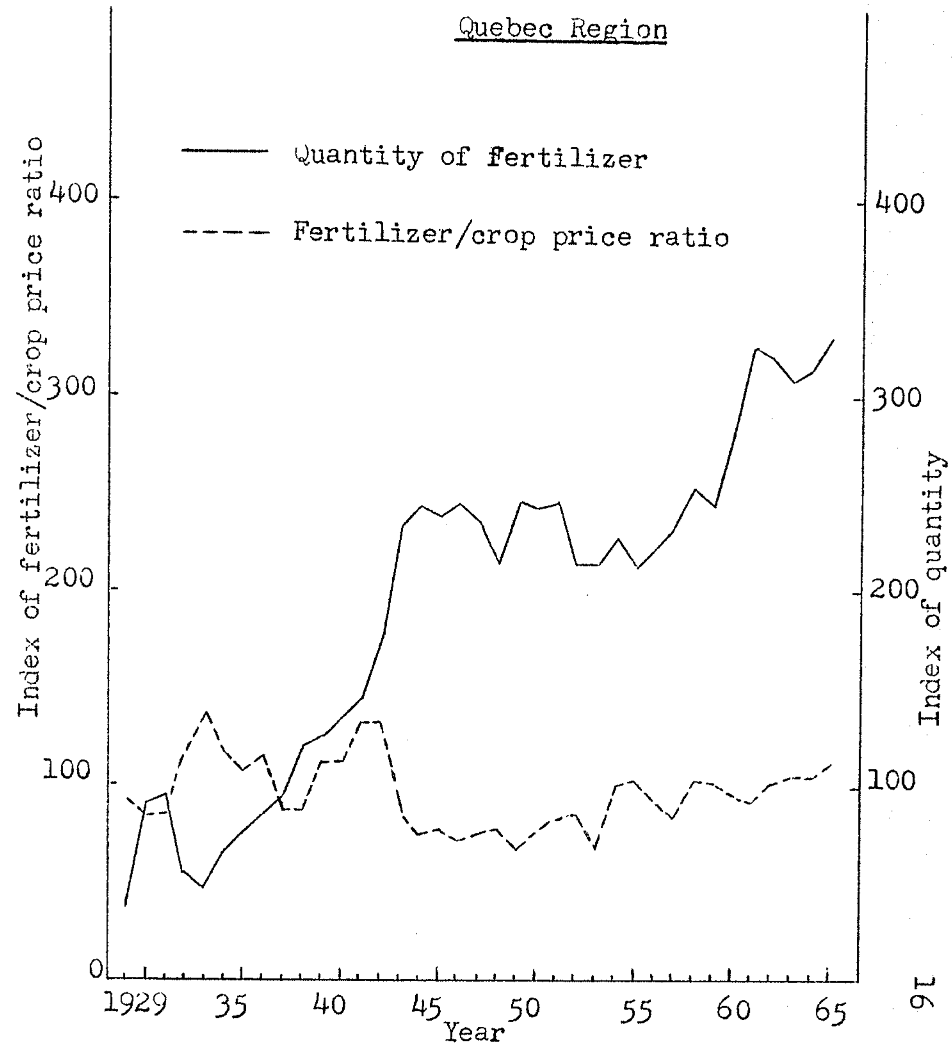
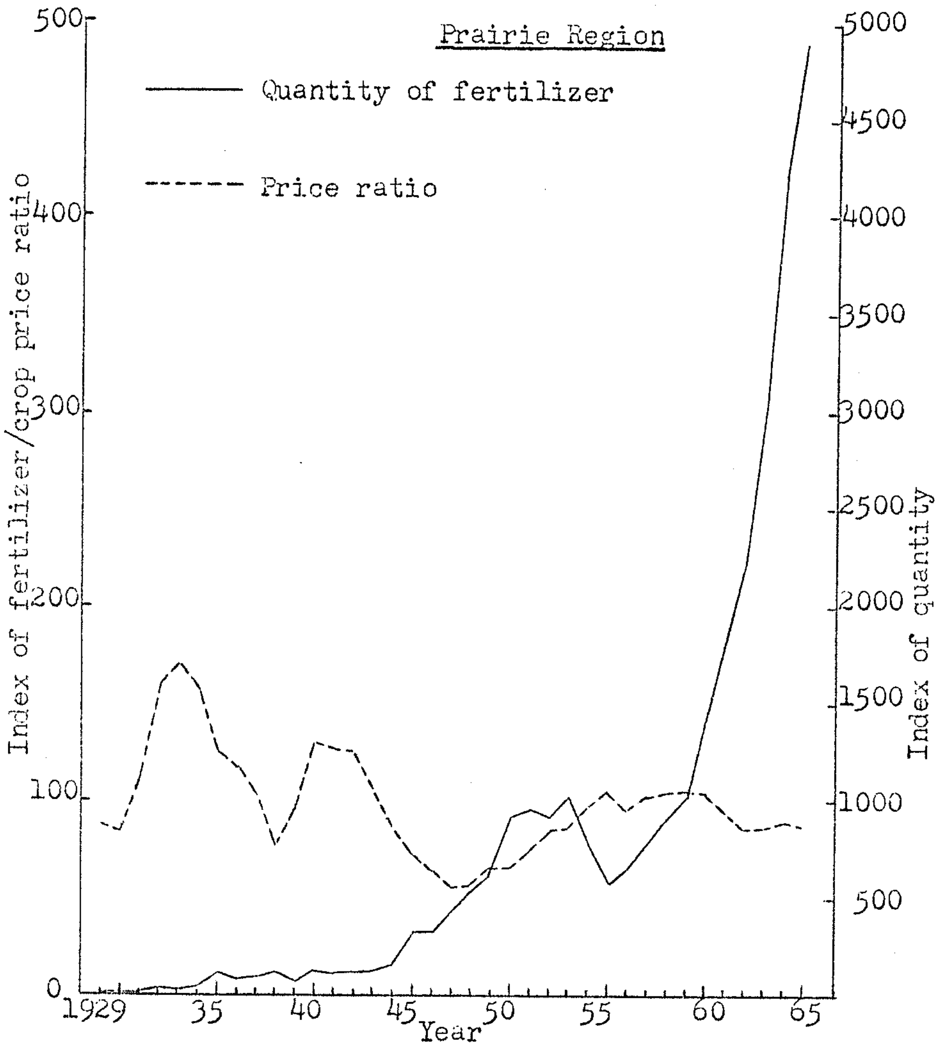
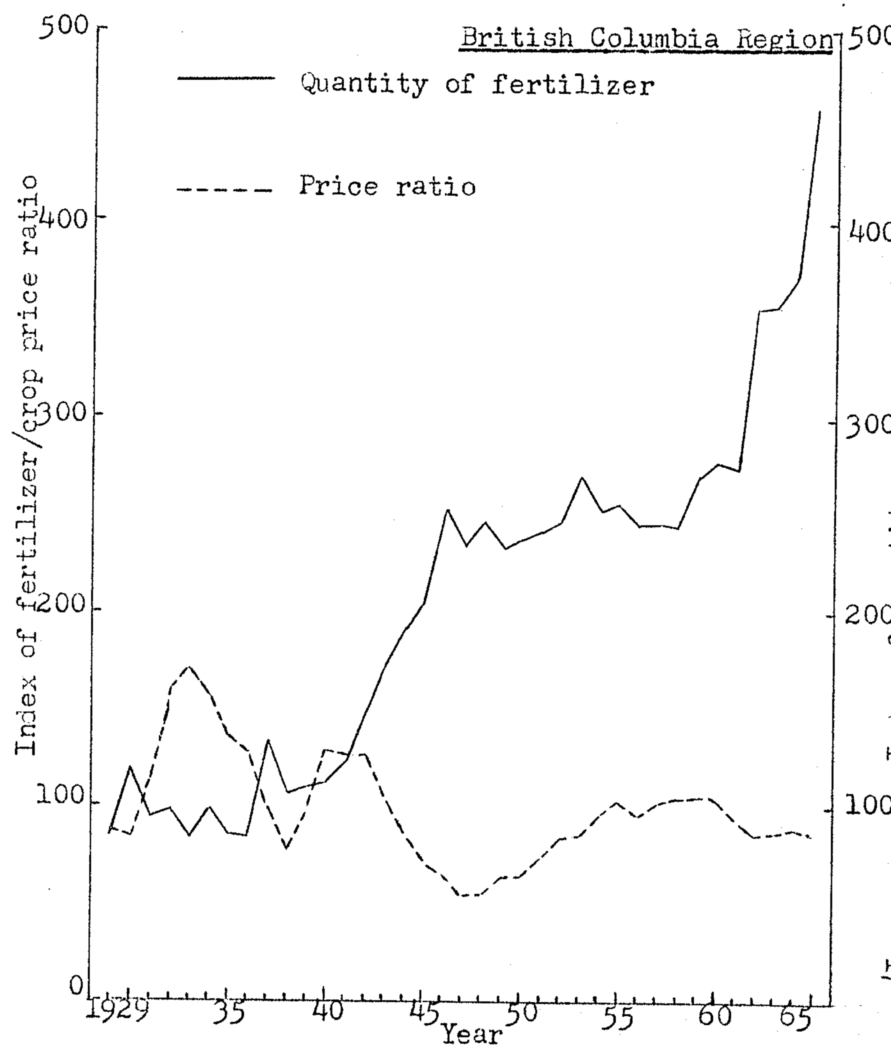


FIGURE 1 (continued)





As shown in Figure 1, the amount of fertilizer use in the wartime period (1940-1945) rose rapidly, from 346,721 tons in 1940 to 575,107 tons in 1945. The year-to-year increase averaged 11 per cent. This sharp increase was the result of an increased demand for food in the period and of adjustment to changes in the resources available for utilization in production.

The situation for the post-war period (1946-1965) is also presented in Appendix A and Figure 1. National consumption of fertilizer, with the exception of 1935-1936, increased more rapidly than before. Moreover, since 1957 the increase was at a relatively constant rate of 8.3 per cent per year. By 1965, commercial fertilizer and lime expenses constituted about 6.4 per cent of total farm operating expenses (Table II).

The increased use of fertilizer during the post-war period has been attributable mostly to technical knowledge reflecting the strong response of crop production to fertilizer input, the relatively favorable price of fertilizer to the price of crops, increased knowledge and improved managerial skills of operations and a favorable income position of farmers. In order to understand the large increase in national consumption of fertilizer, it is useful to examine the distribution of fertilizer use among the five selected regions of Canada. This is done in the following section.

B. Regional Trends in Fertilizer Use

Regional consumption of commercial fertilizer and the distribution of Canadian total sales are presented in Appendix A and Table III, respectively. Historical trends in consumption for various regions are also shown in Figure 1. Every region showed increased consumption of fertilizer in the post-war period as compared to the pre-war period. In the pre-war period (1929-1939), the Atlantic, Ontario, and Quebec regions were the major users. On the average of the 11-year interval, 89,194 tons of commercial fertilizer were used in the Atlantic region, 95,061 tons in Ontario, and 50,149 tons in Quebec. As indicated in Table III, these three regions accounted for 93 per cent of Canadian total (35 per cent in the Atlantic region, 38 per cent in Ontario, and 20 per cent in Quebec). The remaining small percentage of the total, 7 per cent, was shared by the rest of the nation. Only 5 per cent was used in British Columbia and but 2 per cent in the three Prairie provinces. The wide difference in fertilizer use was related to different patterns of farming among regions. Since agricultural production was much more intensive in Eastern Canada than in Western Canada, large amounts of commercial fertilizer were applied to such cash crops as fruits, vegetables, potatoes, tobacco in Eastern Canada. Only farmers in that area have felt that a substantial gain could be obtained through fertilizer. In addition, intensive cultivation usually requires intensive nutrient replacement if production is to be maintained. Farmers in British Columbia, where fruits and vegetables are also grown, have realized the necessity of fertilizer use as well in the pre-war period, although they consumed only about 5 per cent of the Canadian total. However, less intensive crops such as wheat, oats, barley and pasture

TABLE III

CHANGES IN REGIONAL FERTILIZER USE AS PERCENTAGE OF CANADIAN TOTAL
1929-1965*

	Canada	Atlantic	Quebec	Ontario	Prairie	B.C.
			--percentage			
1929-39	100	35.3	19.9	37.7	2.3	4.7
1940-45	100	27.3	26.6	38.8	3.9	4.2
1946-50	100	24.7	20.9	42.0	8.0	4.2
1951-55	100	17.4	17.3	50.5	10;3	3.9
1956	100	17.2	16.9	53.6	7.8	3.7
1957	100	17.4	17.6	51.5	9.3	3.7
1958	100	16.5	17.8	51.8	9.8	3.5
1959	100	15.2	16.6	51.5	12.5	3.6
1960	100	15.9	18.5	46.7	14.7	3.6
1961	100	15.4	18.6	46.3	16.1	3.1
1962	100	13.9	17.1	47.2	18.3	3.8
1963	100	12.5	15.1	45.5	23.1	3.5
1964	100	10.8	13.2	44.8	27.7	3.1
1965	100	11.0	13.3	43.2	29.1	3.0

*Source: Computed from Appendix A.

in the Prairie region depended entirely on the original fertility of the soil.

During the war-time period, fertilizer consumption in all regions increased by more than 37 per cent, as compared with their respective regional averages for the previous period. Consumption in the Prairie region was even as high as 200 per cent above its pre-war average. After World War II, regional consumption has substantially exceeded the pre-war levels. After the 1951-1955 period, the annual sales of all commercial fertilizer, except for some years between 1954 and 1957, have increased continuously over time for all Canada. National sales increased 801,339 tons (from 792,254 tons in 1951-1955 to 1,593,593 tons in 1965). All regions shared the increase, but the share of the older using regions was relatively smaller. Of the total increase, about 5 per cent was in the Atlantic region; 36 per cent in Ontario; 9 per cent in Quebec; almost 48 per cent in the Prairie region; and 2 per cent in British Columbia. The sharp increase in fertilizer consumption during the last ten years has been partly due to a decline in the real price of fertilizer relative to total farm income from farming. In addition, technical improvements in agriculture have been more important in recent years.

C. Changes in the Prices of Fertilizer and Crops

Prices of fertilizer and crops in all Canada have risen after World War II. However, the increase in fertilizer price has been less than the price of crops. A decline of the fertilizer/crop price ratio has been accompanied by an increase in fertilizer purchases since 1943 (Fig. 1). The fertilizer/crop price ratio started to level off and increase after 1949 while the consumption of fertilizer continued to increase. This phenomena could be explained partly by the fact that up till 1952 the prices of fertilizer were still lower than the prices of crops. It is, however, quite possible that increased knowledge of the use of fertilizer by farmers has resulted in greater demand for fertilizer during the last ten years.

In spite of the increase in actual levels, the real prices of fertilizer and crops[1] in all Canada, as illustrated in Figure 2 and Appendix C, have declined in the post-war period as compared with the pre-war situation. The real prices of fertilizer have declined far more than the prices of crops. Compared with the pre-war average, the real price of fertilizer has decreased by 24 per cent since World War II while the real price of crops has decreased by only 9 per cent during the same period. It is worthwhile noting that there has been a great difference, from 1943 to 1953, between the two real price levels. Obviously, this was due partly to a drastic drop in the real prices of fertilizer which was made possible by improvements in the technology of production, marketing of fertilizer, and competition among firms in the fertilizer industry.

For the situation in Eastern and Western Canada, the trends of the real fertilizer prices were, generally speaking, very similar to

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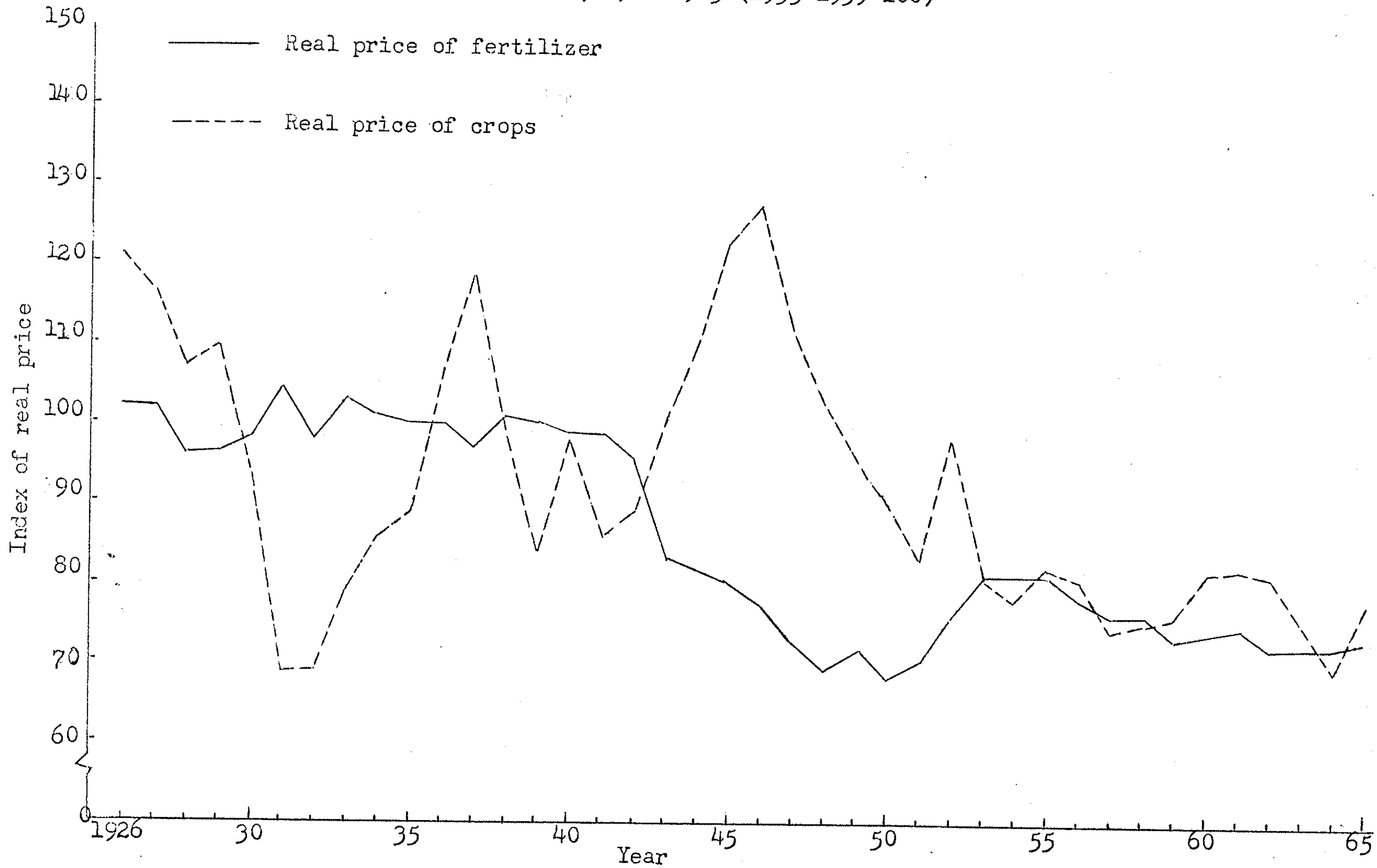
[1]The real price of fertilizer is the fertilizer price index deflated by the composite index. The real price of crops is the crop price index deflated by the general wholesale price index.

FIGURE 2

INDEX OF REAL PRICES OF FERTILIZER AND CROPS, ALL CANADA, 1926-1965 (1935-1939=100)



the national situation in the post-war period. Nevertheless, since 1960 the real prices of fertilizer in Western Canada were decreasing more rapidly than in all Canada and Eastern Canada (Figures 3 and 4). The movement of the real prices of crops in these two parts of Canada does not follow the national pattern. As compared with the pre-war averages, the real prices of fertilizer and crops, during the post-war period, have declined about 30 per cent and 4 per cent respectively in Western Canada; 24 per cent and 6 per cent in Eastern Canada. Since 1942 the real prices of fertilizer have been lower than the real prices of crops in both parts of Canada, except during 1954 (Figures 3 and 4). The downward movement of the real fertilizer price is likely to continue in the future through improved production processes of fertilizer and increased competition among firms.

FIGURE 3

INDEX OF REAL PRICES OF FERTILIZER AND CROPS
EASTERN CANADA, 1929-1965 (1935-1939=100)

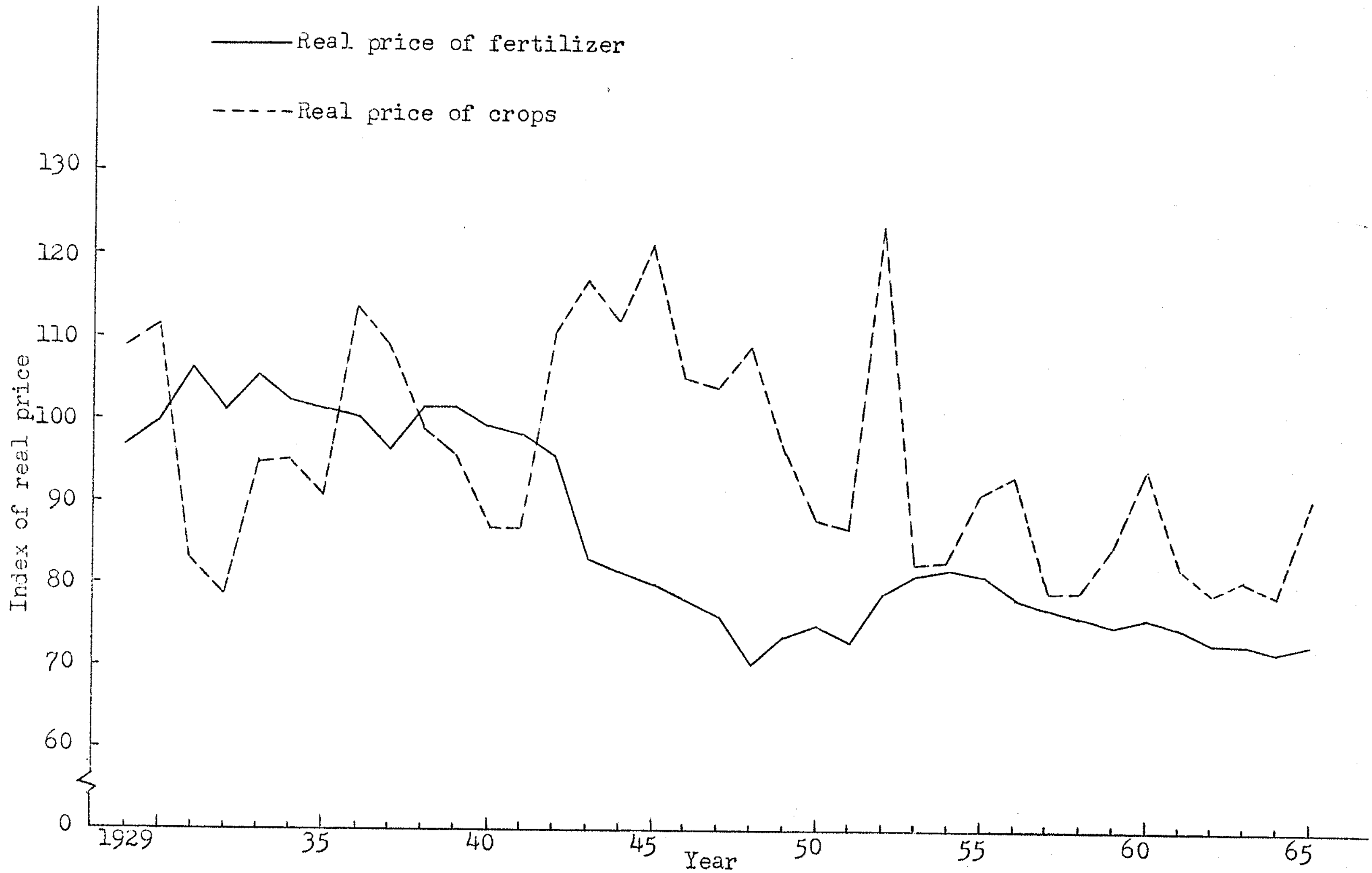
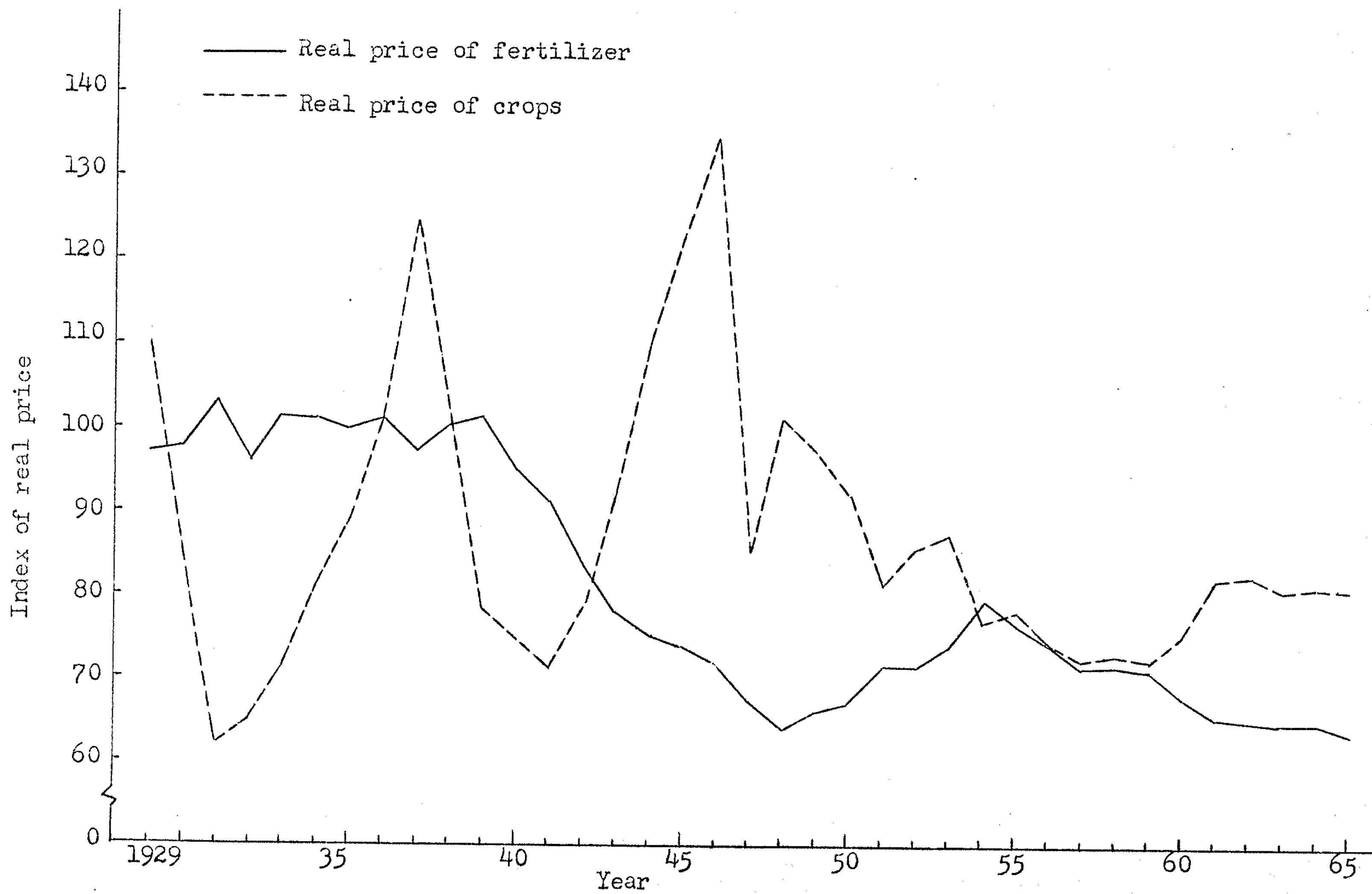


FIGURE 4

INDEX OF REAL PRICES OF FERTILIZER AND CROPS
WESTERN CANADA, 1929-1965 (1935-1939=100)



CHAPTER III

THEORETICAL FRAMEWORK

This chapter is devoted to some considerations of a theoretical nature on which the empirical study of the demand for resources is based. The presentation is divided into two parts. First, the basic theory of demand for factors of production under pure competition is presented; secondly, some concepts of economic dynamics are discussed.

A. Static Theory of Demand for Resources

Although static theory of demand for factors of production under pure competition is somewhat oversimplified, it serves as a useful starting point for construction of a structural model. Heady and Tweeten [26, p. 42] mention that "(a) in some respects agriculture is best represented by the purely competitive market structure, and (b) the firm is a logical beginning point for analysis of more general, dynamic market phenomena."

Static theory assumes perfect knowledge and absence of variables relating to time. Hicks [29, p. 115] states that economic statics are those parts of economic theory where we do not trouble about dating. His definition implies that static theory does not attempt to establish any adjustment. "Statics" refers to situations where equilibrium exists; that is, technology, tastes or preferences, asset distribution and institutional setting are assumed to be unchanged. Two general types of information are necessary to specify the quantity of a particular factor demand. One is the production function, and the other includes the prices of resources and products.

The static theory of demand for inputs under pure competition is well developed [26, p. 43-49; 2, p. 369-374]. A brief sketch is presented here:

Let the production function take the form of

$$Y = f\ (X_1,\ X_2,\ \ldots\ X_i\ \ldots\ X_n) \tag{1}$$

where Y is output and X_1, X_2, . . . X_n represent different resources used to produce output Y.

Suppose profit, π, is defined as the difference between gross revenue and total costs, then the profit function may be expressed as:

$$\pi = f\ (X_1,\ X_2,\ X_i,\cdot\cdot X_n)\ P_y - \sum_{i=1}^{n} P_{x_i} X_i + \lambda\,(K - \sum_{i=1}^{n} P_{x_i} X_i) \tag{2}$$

where P_y stands for the price of output, P_{x_i} for the price of input X_i, K for the given amount of funds available for the firm to spend or invest in resources, and λ for a Lagrange multiplier, representing the marginal rate of return on resource expenditure. Profit will be maximized when the amount added to the revenue of the firm by an additional unit of inputs equals the amount it adds to costs. In other words, all resources are used at such levels that marginal revenue productivity of every input is equal to its marginal cost; i.e., net marginal revenue of each resource is equal to zero [24, Chapter 2-6]. The conditions of profit maximization, as mentioned above, may be algebraically defined in equations (3a) to (3e) by setting the partial derivatives of profit for (2) with respect to each resource X_i and λ equal to zero.

$$\frac{\partial \pi}{\partial X_1} = \frac{\partial Y}{\partial X_1} P_y - P_{x_1} - \lambda P_{x_1} = 0 \tag{3a}$$

$$\frac{\partial \pi}{\partial X_2} = \frac{\partial Y}{\partial X_2} P_y - P_{x_2} - \lambda P_{x_2} = 0 \tag{3b}$$

$$\frac{\partial \pi}{\partial X_i} = \frac{\partial Y}{\partial X_i} P_y - P_{x_i} - \lambda P_{x_i} = 0 \tag{3c}$$

$$\frac{\partial \pi}{\partial X_n} = \frac{\partial Y}{\partial X_n} P_y - P_{x_n} - \lambda P_{x_n} = 0 \tag{3d}$$

$$\frac{\partial \pi}{\partial \lambda} = K - \sum_{i=1}^{n} P_{x_i} X_i = 0 \tag{3e}$$

Arranging equations (3a-e) provides alternative specifications of profit maximization as indicated in equation (4).

$$\left(\frac{\partial Y}{\partial X_1}\right) P_y/P_{x_1} = \left(\frac{\partial Y}{\partial X_2}\right) P_y/P_{x_2} = \ . \ . \ . = \left(\frac{\partial Y}{\partial X_i}\right) P_y/P_{x_i} = \ . \ . \ . \ . = \left(\frac{\partial Y}{\partial X_n}\right) P_y/P_{x_n} = 1 + \lambda \tag{4}$$

In a static framework of perfect knowledge and competition, financial capital would not be limited, implying that the marginal return of that resource is zero. Thus, the conditions of profit maximization defined in (4) become

$$\left(\frac{\partial Y}{\partial X_1}\right) P_y/P_{x_1} = \left(\frac{\partial Y}{\partial X_2}\right) P_y/P_{x_2} = \ . \ . \ . = \left(\frac{\partial Y}{\partial X_i}\right) P_y/P_{x_i} = \ . \ . \ . = \left(\frac{\partial Y}{\partial X_n}\right) P_y/P_n = 1 \tag{5}$$

The quantities which specify the firm's demand or use for resources are obtained by solving simultaneous equations (3a-e). The above conditions provide knowledge about the quantity of any input that is demanded or used by the entrepreneur as determined by the technical condition of production or technical coefficients as shown in equation (1), the structure and the level of prices of inputs and product, and on the amount of funds available for investment.[1] In specifying the quantities of resources used, output also is specified through the production function in equation (1). These conditions and relationships are important and relevant for the firm and the agricultural industry in respect to capital items of a biological nature, such as fertilizer, seed, and insecticides [26, p. 46].

The static demand for resources obtained by solving the "equilibrium" equations (3a-e) may also be functionally expressed as:

$$X_i = f\left(\frac{P_{x_i}}{P_y}, \frac{P_{x_j}}{P_y}, T, X_k\right) \qquad (6)$$

where T represents the technical conditions of production or technical coefficients of resources. X_k is the quantity of fixed inputs. Equation (6) indicates that the quantity demanded for resource X_i is a function of technical coefficients of resources, the factor/product price ratio and the level of fixed inputs. With some further considerations such as time lag and other real world conditions, the relation in equation (6) provides a general basis for empirical study on demand for inputs.

Although the traditional static theory has been useful in dealing with many economic problems, the entrepreneur's or farmer's behavior in

[1]Although financial capital is theoretically assumed to be unlimited in perfect competition it is limited in the realistic condition.

relation to the demand for resources renders static theory somewhat unrealistic. For example, a farmer, due to lack of knowledge, uncertainty, limited capital, may not use resources to the optimum level as envisaged by the static theory. Farmers may not adjust instantaneously the amounts of resources used in response to changes in prices and technology. It is, therefore, inevitable that dynamic considerations must be introduced into the static framework to make an estimation of the demand for resources in its actual dynamic setting.

B. The Dynamics of Demand for Resources

In view of the importance of economic dynamics in the empirical study, this section is designed for discussion of the concept of economic dynamics and the forces which produce the dynamic nature of resource demand.

The concept of economic dynamics. Hicks [29, p. 115], following his definition of economic statics, defines economic dynamics as "those parts of economic theory where every quantity must be dated." Baumol [5, p. 4] regards Hicks' concept of economic dynamics as "statics involving time" rather than "dynamics." He explains that in a model, phenomena are not considered in their relation to preceding and succeeding events; and if the process of change does not concern us, we can consider the situation at a given moment. The moment may be dated, but the analysis of it can be static. Baumol suggests that "economic dynamics is the study of economic phenomena in relation to preceding and succeeding events." From this definition, one may recognize that Baumol's concept of economic dynamics emphasizes structural aspects.

Harrod [22, p. 4] also emphasizes the changing structural relationship in economic dynamics. He suggests that:

> In dynamics, the fundamental conditions will themselves be changing, and the unknowns in the equations to be solved will not be specific magnitudes of output per annum but increases and decreases in the rates of output per annum.
>
> . . . .
>
> Dynamics will specifically be concerned with the effects of continuing changes and with rates of changes in the values that have to be determined [22, p. 8].

Harrod's suggestions emphasize that dynamics should be confined to the analysis of continuing changes as against once-and-for-all changes.

Samuelson [38, p. 352-87] argues that in order to understand economic problems of the real world, one has to study dynamics. His concept of dynamics is best summarized in his own words:

> Statics concerns itself with the simultaneous and instantaneous or timeless determination of economic variables by mutually interdependent relations. . . . It is the essence of dynamics that economic variables at different points of time are functionally related. . . . It is important to note that such dynamic system generates its own behavior over time. . . . This feature of self-generating development over time is the crux of every dynamic process.

It is realized from these concepts that economic dynamics considers how changes in economy take place over time. In investigating changes in an economy, technical progress is indispensable. Klein [32, p. 100] states that "in the period-to-period variations over a long historical stretch, there will be much technical progress." In addition, lagged adjustment should be taken into consideration as well since the adjustments, due to psychological, technological, and institutional causes, may not be instantaneous, but may become perceptible only after a period of time [37, p. 1]. All these considerations are discussed in the following sub-section.

Technical change, lagged adjustment and demand for resources.

Technical change has been described in many ways. Usually, technical change implies the shifting of the production function over time. Solow [42, p. 312] states:

> . . . using the phrase "technical change" as a shorthand expression for any kind of shift in the production function. Thus, slowdowns, speedups, improvements in the education of the labor force, and all sorts of things will appear as "technical change."

Solow's concept suggests that technical change refers to an increase in output produced from a given set of resources or the same amount of output produced with fewer resources. Certain technical changes are designated as "embodied." Solow [43, p. 91] states:

> Improvements in technology affect output only to the extent that they are carried into practice either by net capital formation or by the replacement of old-fashioned equipment by the latest models, with a consequent shift in the distribution of equipment by date of birth.

The above statement implies that an increase in productivity, in the case of embodied technical change, is realized from the improved quality of factor inputs. It is likely that productivity in one period would be higher than in a previous period if the quality of inputs has been improved. The improvements in factor quality could be embodied in labor, for example, through education and training, or embodied in capital inputs such as improved composition of fertilizers and better designed machines [17].

An alternative way of introducing technical change is called "disembodied." If an increase in productivity is due to reorganization of industry, improved techniques of production, superior knowledge etc., rather than increases in inputs, then technical change is "disembodied" [43, p. 90].

So far, some concepts of technical change have been presented. The attempt of this study is to measure the effects of total technical change in crop production and other factors (e.g. fertilizer price, farm cash income) on the demand for fertilizer. Total technical change in crop production is that which results from technical knowledge about improved variety of seeds, fertilization, insecticides, and increased efficiency in the use of capital assets and operating resources used in agricultural production. The introduction of new technical knowledge of crop production through research, education, and other activities gives better response to fertilizer used by farmers. In addition, increased efficiency of farm operation through structural changes in agricultural production such as changes in the farm size and the composition of inputs makes fertilizer application more effective. All these affect the use of fertilizer.

According to the static theory mentioned in section A of this chapter, demand for inputs is a function of input-product price ratios, technical conditions of production and the quantity of fixed inputs. Changes in quantity of inputs demanded are, therefore, related to technical changes. Technical progress will induce entrepreneurs or farmers to employ higher productive factors. Development and adoption of improved seed varieties, development of irrigation facilities, for instance, will make fertilizer application more effective, and hence encourage farmers to increase its use. Owing to increased demand for fertilizer, research will be likely conducted by the manufacturing sector, with economic incentives, on the processing of their own product which may bring about a downward-shifting of cost curves and hence a shift of the supply schedule. With sufficient competition among firms, the impact of a shift of the supply curve may lead to a lower supply price for such particular input. Hence, further growth in demand for fertilizer is expected [26, p. 82].

Figure 5 illustrates the interaction of technical change, demand and supply of input, X, in a dynamic sense. For simplicity, we consider only two time periods, t_1 and t_2. Curve Y_{t_1} is a production function for the time period t_1, while corresponding curves S_{t_1} and D_{t_1} are supply and demand schedules, respectively. Similarly, Y_{t_2} is a production function representing the new technology of production in period t_2 while S_{t_2} and D_{t_2} express supply and demand schedules responding to technical change in production in period t_2. Figure 5a indicates that the shifting of production function will, ceteris peribus, change the optimum use of input X. For instance, at a given price ratio Pr_1, the optimum levels of input X are, as suggested by the static theory, OX_1 and OX_2 for periods t_1 and t_2 respectively. Also, as shown in Figure 5b, the shifting of production function (as shown in Figure 5a) implies a shift of demand schedule for input X (from D_{t_1} to D_{t_2}), because the marginal value productivity curve shifts upward, providing the price of product unchanged. Under the given supply schedule (S_{t_1}), the price of input X may, in the short run, go up from P_1 to P_2. However, it seems very likely to move downward in the long run because the supply

FIGURE 5

TECHNICAL CHANGES AND DEMAND FOR INPUT

FIGURE 5a

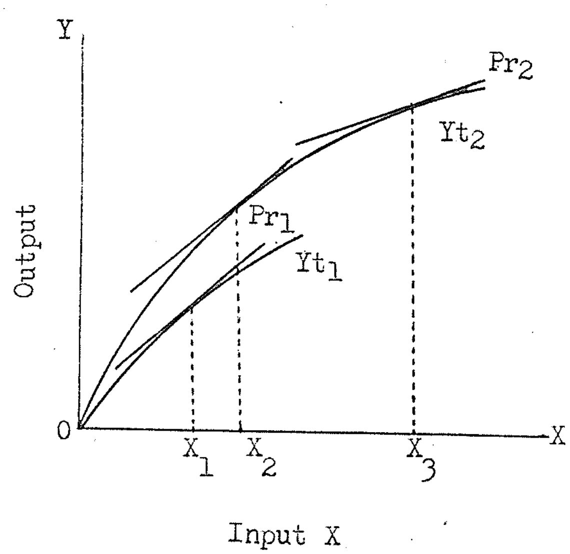
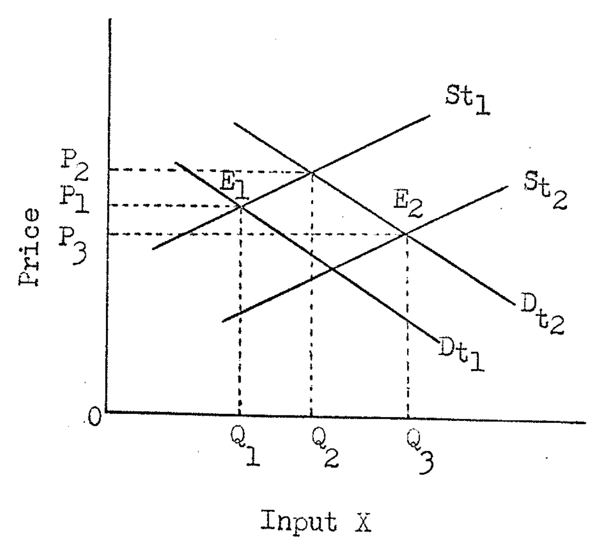


FIGURE 5b



schedule of input X, due to rapid technological improvements in the manufacturing industry, may shift by a greater amount than that for the demand schedule. In this case, the lower price, P_3, in period t_2 will result in a decline in the price ratio, Pr_2, and hence an even higher level of input use, OX_3, as compared with OX_2, if the price of product remains unchanged.

Innovations in both input-using and input-furnishing sectors have, as illustrated above, some influence on the demand or use for inputs. Nevertheless, because of time lags farmers do not adjust their uses of inputs to the optimum level immediately in response to new situations. The idea of lagged adjustment has been well expressed by Scitovsky [40, p. 48-49]:

> The average consumer has fixed consumption habits, which he has acquired on the basis of past price constellations; and it takes time for a changed price to break an old habit and form a new one. When relative prices change or new opportunity arise, the consumer usually continues in his accustomed grooves for a while, because he needs time to learn about a change, to appraise its significance, and more time still to adapt his behavior to it and face the inconveniences or hazards that changing one's behavior often involves. In other words, people's propensity to form habits and their slowness in adapting themselves to changed circumstances render their economic behavior a function not only of current but also of past prices. The equating of marginal values to prices must be conceived of more as a goal constantly aimed at and approximated than as something actually accomplished at every moment of time.

In his study on "Distributed Lags and Demand for Agricultural and other Commodities," Nerlove [37, p. 4] states:

> Distributed lags arise in theory when any economic cause (for example, a price change or an income change) produces its effect (for example, on the quantity demanded) only after some lag in time; so that this effect is not felt all at once, at a single point of time, but is distributed over a period of time.

Extending Nerlove's arguments [37, p. 5-7], some major reasons for farmers not adjusting their uses of resources to new situations are stated as follows:

1. Psychological inertia is a powerful force. It prevents instantaneous adjustments or readjustments of the behavior of farmers. For example, farmers' decision on the use of fertilizer may depend partly on the quantity of fertilizer used in the previous year. In addition, changes in economic variables may be regarded as only temporary. Farmers might wait, to varying degrees, for more information to predict the most likely outcomes of new technology, new inputs, and price trends.

2. Technological reasons: it takes time to acquire and to learn new knowledge which is essential to apply new inputs and improved, or new, technology.

3. Institutional factors such as land tenure and contract arrangements may also produce rigidity in farmers' behavior relating to use of inputs.

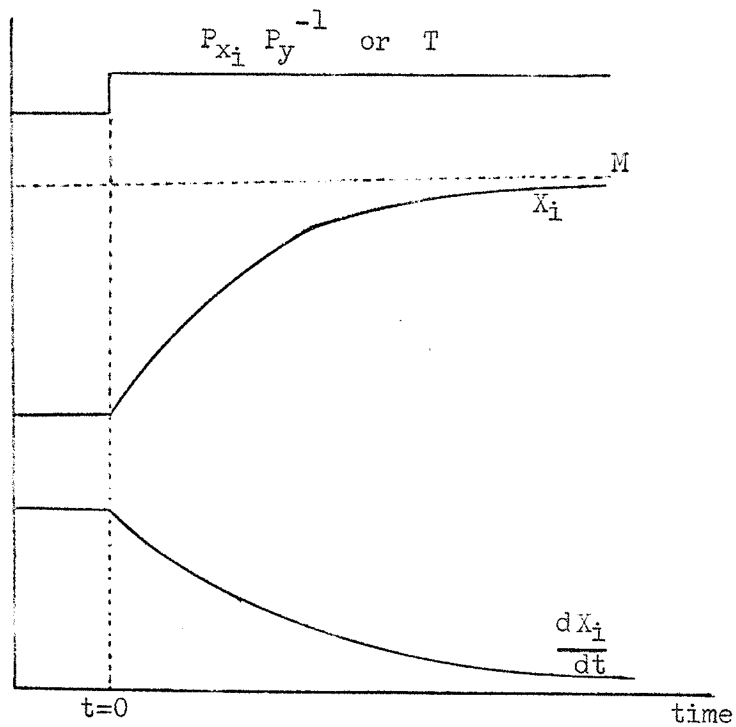
4. Capital limitations may discourage "immediate adoption" of new technology and new resources.

5. Risk avoidance or minimization; because of the dependence of crop production on weather conditions, farmers often hesitate to use new inputs or else initially tend to use amounts of them which are less than optimum levels.

Adjustments in use or demand for resources may take many different time patterns [33, Chapter 2]. To give a simple but rather realistic example, one of the adjustment paths is illustrated in Figure 6.

FIGURE 6

ILLUSTRATION OF ADJUSTMENT RATE AND TIME PATH IN RESOURCE DEMAND



Note: 1. M represents the optimum level of resource use under the new price ratio ($P_{x_i} P_y^{-1}$) or technology (T).

2. X_i represents the quantity of the resource used.

3. $\frac{dX_i}{dt}$ represents the change in resource use relative to time.

Let us consider the static demand function for input X_i, namely:

$$X_i = f\left(\frac{P_{x_i}}{P_y} , \; T , \; X_k \right) \qquad (7)$$

All variables in equation (7) are interpreted as in equation (6). Suppose that the quantity of input used, X_i, is at an equilibrium situation at time t=0, and that there exists a new equilibrium level, M, as changes in price ratio and/or technical conditions take place. According to Koyck [33, p. 10], curve X_i is the adjustment path of X_i and $\frac{dX_i}{dt}$, representing the change in input use with respect to time, is the time-shape of the reaction of X_i on price ratio and technical conditions of production. Figure 6 indicates that, due to some reasons mentioned above, the changes in price ratio and technical conditions of production will lead to a new equilibrium of resource use, as represented by line M. Entrepreneurs or farmers, however, catch up to this level gradually rather than immediately. As shown by the curve of the time-shape, $\frac{dX_i}{dt}$, the rate of adjustment slows down over time as M is approached.

The static theory and the dynamics of demand for inputs have so far been discussed. All these provide the background for the formulation of the models in the next chapter.

CHAPTER IV

THE MODELS AND STATISTICAL CONSIDERATIONS

The purpose of this chapter is to present a discussion of the proposed models, choice of variables, and some statistical considerations.

A. The Models

Two models are used for the analysis of demand for fertilizer. One is designed to derive aggregate fertilizer demand functions which consist of a long-run demand function, an adjustment equation and a short-run demand function. The other one is to measure the relative contributions of factors to the growth of fertilizer use. All these models are formulated according to the previous studies reviewed and these hypotheses postulated in Chapter I, and theoretical background presented in Chapter III.

Model I. By applying the concept of growth rate, a long-run demand function for fertilizer may be developed as follows [23]:

$$g(Y^*) = a_1 g(x_1) + a_2 g(X_2) + \ldots + a_i g(X_i) + \ldots \ldots + a_n g(X_n) + g(U) \quad (8)$$

where $g(Y^*) = \frac{dY^*}{dt} \cdot \frac{1}{Y^*}$: rate of growth of the expected fertilizer use

$g(X_1) = \frac{dX_1}{dt} \cdot \frac{1}{X_1}$: rate of change in the real price of fertilizer

$g(X_2) = \frac{dX_2}{dt} \cdot \frac{1}{X_2}$: rate of change in the real price of crops

$g(X_i) = \frac{dX_i}{dt} \cdot \frac{1}{X_i}$: rate of change in the i-th independent variable,

$g(X_n) = \frac{dX_n}{dt} \cdot \frac{1}{X_n}$: rate of shift in crop production function resulting in the shift in fertilizer demand function,

$g(U)$: a random error term,

$a_i = \frac{\partial Y^*}{\partial X_i} \cdot \frac{X_i}{Y^*}$: the long-run elasticity of demand with respect to X_i ($i = 1, 2, \ldots n$) where Y^* is the expected quantity of fertilizer use, X_1 is the real price of fertilizer,

X_2 is the real price of crops,

X_i is the i-th independent variable as indicated,

X_n is the level of technology in **crop production.**

The magnitude of $a_i g(X_i)$ in equation (8) is the measure of the influence of the X_ith variable on the growth of fertilizer use. The relative contribution of variable X_i can be measured by $a_i g(X_i)/g(\hat{Y}^*)$, where $\hat{Y}^*$ is the estimate of the expected level of fertilizer use.

In order to measure the relative contributions of the associated factors, two assumptions must be made. It is, firstly, assumed that the a_i's($i=1,2,\ldots n$) are fixed parameters over the period of analysis. Secondly, since the level of technology in the crop production is not available, we assume that technical change in crop production was such that the demand function for fertilizer shifted at a constant rate. Under these two assumptions, equation (8) can be rewritten as:

$$g(Y^*) = a_1 g(X_1) + a_2 g(X_2) + \ldots + a_i g(X_i) + \ldots + \gamma + g(U) \quad (9)$$

where $\gamma [= a_n g(X_n)]$ is a constant parameter representing the average contribution to the shifting of the fertilizer demand function.

The solution of the differential equation (9) yields the long-run demand function:

$$Y_t^* = Y_o^* X_{1t}^{a_1} X_{2t}^{a_2} \ldots X_{it}^{a_i} e^{\gamma t} U_t \quad (10)$$

where Y_0^* is the expected quantity of fertilizer use in the initial period, and t is time. Expressed in logarithmic form, equation (10) becomes[1]

$$\log Y_t^* = \log Y_o^* + a_1 \log X_{1t} + a_2 \log X_{2t} + \ldots + a_i \log X_{it}$$

$$+ \ldots + \gamma t + \log U_t \quad (11)$$

This demand function determines the expected quantity of fertilizer use.

Since the expected quantity of fertilizer use, Y_t^*, is not observable, the parameters is equation (11) cannot be estimated directly. However, the estimation may be carried out through the introduction of an adjustment equation developed by Nerlove [36]. Following up Nerlove's assumption the actual quantity demanded, between one period and the next, changes only by some fraction of the difference between the actual level and the expected level, the adjustment process may be expressed by:

---

[1]Logarithm always refers to natural logarithm in this study.

$$\log Y_t - \log Y_{t-1} = \alpha (\log Y_t^* - \log Y_{t-1}) \qquad 0 \leq \alpha \leq 1 \qquad (12)$$

where Y_t is the actual level of fertilizer use in the current year,

Y_{t-1} is the actual level of fertilizer use in the previous year,

α is the coefficient of adjustment indicating that proportion of the complete adjustment to the expected level that is made in one time period.

Substituting equation (11) into equation (12) and solving for $\log Y_t$, we obtain a short-run demand function:

$$\log Y_t = \alpha \log Y_o^* + \alpha a_1 \log X_{1t} + \alpha a_2 \log X_{2t} + \ldots + \alpha a_i \log X_{it} + \ldots + \alpha \gamma t + (1-\alpha) \log Y_{t-1} + \alpha \log U_t \qquad (13)$$

This is the basic equation estimated throughout the study. An estimate of the coefficient of adjustment is obtained by subtracting the coefficient of the lagged dependent variable Y_{t-1} from unity. The ratio of the regression coefficients to the estimates of α are estimates of parameters in the long-run demand function (11).

Model II. The average relative contributions of variables studied to the growth of fertilizer use can be measured from the following formulations:

$a_i \frac{\bar{g}(X_i)}{\bar{g}(\hat{Y}^*)}$: the relative contribution of variable X_i.

$\frac{\gamma}{\bar{g}(\hat{Y}^*)}$: the relative contribution of technical change in crop production where

$\bar{g}(\hat{Y}^*)$ is the estimated average growth rate of fertilizer use,

$\bar{g}(X_i)$ is the average rate of change in variable X_i.

$\bar{g}(\hat{Y}^*)$ and $\bar{g}(X_i)$ can be estimated from the following equations:

$$\hat{Y}^*_t = \hat{Y}_o \, e^{\bar{g}(\hat{Y}^*)t}$$

$$X_i = X_{io} \, e^{\bar{g}(X_i)t}$$

where e is a constant (2.71828).

B. <u>The Data and the Variables</u>

Data used in this study are time series observations made available by various sources: the Dominion Bureau of Statistics, the Board of Grain Commissioners for Canada and the Canadian Wheat Board.

The variables included in the empirical analysis are based on the hypotheses set up in Chapter I and the theoretical background of demand for inputs presented in Chapter III. A description of the variables selected is given as follows:

Y_n = national purchases of total fertilizer by Canadian farmers during one time period, from July 1 in the previous year to June 30 in the current year, and measured in tonnages,

Y_i = regional purchases of total fertilizer by farmers in the i-th region during the period as mentioned above and measured in tonnages,

X_1 = the real price of compounded fertilizer (the fertilizer price index deflated by the composite index for the current year, with 1935-1939 used as the base period) for the nation or regions as indicated,

X_2 = the real price of crops (the price index of crops deflated by the general wholesale price index, with 1935-1939 used as the base period) for the nation or regions as indicated, lagged one year,

X_3 = the index of total farm cash income from crops and livestock deflated by the general wholesale price index, with 1935-1939 used as the base period, for the nation or regions as indicated, and lagged one year,

X_4 = the ratio of current fertilizer price to the price of crops in the previous year, for the nation or regions as indicated,

X_5 = the quantity of export of grains and grain products for Canada, measured in millions of bushels, and lagged one year,

X_6 = the total cropland acreage for Canada in the current year,

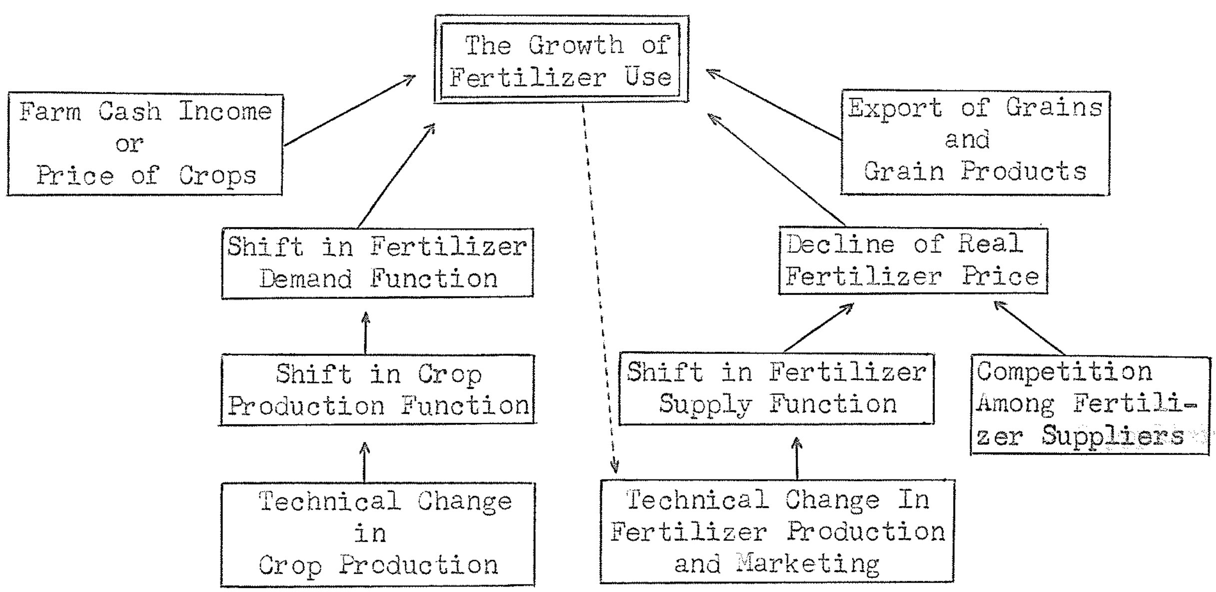
X_7 = the ratio of the fertilizer price to feed price for the nation and regions as indicated

t = time (1, 2, . . . n), relating to improved knowledge of technology.

The cause and effect relationships between fertilizer demand and variables studied are presented in Figure 7. The arrows in Figure 7 show the direction of influence of the factors affecting the use of fertilizer. They show that in addition to the farm cash income and exports of grains, technical changes in crop production and in the fertilizer industry are important factors inducing the growth of fertilizer use. Also, the Figure indicates that there exists interaction between technical changes in the agriculture and the fertilizer industry which accelerates the expansion of fertilizer use.

FIGURE 7

FACTORS ASSOCIATED WITH THE GROWTH OF FERTILIZER USE



C. Statistical Considerations

Time series data are important in an investigation of many dynamic phenomena in the economy. However, problems of multicollinearity and autocorrelation usually arise in time series data. This section discusses these problems and outlines the appropriate statistical estimation procedure used in this study.

Multicollinearity. Multicollinearity is present when two or more of the explanatory variables in a relation are highly correlated. Multicollinearity makes it difficult to disentangle their separate influences upon the explained variable and obtain a reasonable precise estimate of their relative effects [31, p. 201]. If perfect multicollinearity exists (i.e., two explanatory variables are perfectly correlated), then it is impossible to obtain least-squares estimates of the regression coefficients [31, p. 202]. When two or more of the explanatory variables are highly correlated but not perfectly, the standard errors of the estimated parameters are very large. Hence, the estimates of parameters have an unsatisfactorily low degree of precision [31, p.204]. It is possible to have a high value of R^2 but not statistically significant and the test of all coefficients is not significantly different from zero [16, p. 193]. However, when forecasting is a primary objective, then multicollinearity may not be too serious, if it may reasonably be expected to continue in the future [31, p. 207].

Autocorrelated errors and statistical estimation procedures. In regression analysis, the basic statistical problems are to determine the most appropriate estimating procedure and to test the significance of the results. The classical technique is the method of least-squares (L.S.). Under certain assumptions, the L.S. method gives the "best" estimates of the parameters and also provides that the standard t-test of significance is appropriate. But the underlying assumptions may not be plausible. One of the crucial assumption necessary for the application of the L.S. procedure is that the residual errors are not serially correlated, being drawn independently in each time period from a stable normal population [31, p. 106-16]. However, in the case of economic time series, this assumption is not often fulfilled. Cochran and Orcutt [7] list three causes of autocorrelated errors: (1) an incorrect specification of the form of relationship between economic variables, (2) omission of explanatory variables whose influences are reflected by the disturbance term; if the omitted variables are pervasive and if the omitted variables tend to move in phase, then there is a real possibility of an autocorrelated disturbance term, (3) errors of measurement in the data. Autocorrelated errors cause three main consequences in applying the L.S. procedure [31, p. 179]: (1) the sampling variances of the coefficient estimates may be unduly large compared with those obtained by a different method of estimation, (2) the estimates of these sampling variances are likely to be seriously underestimated, and (3) predictions may be inefficient, i.e. they may have needlessly large sampling variances.

In addition to the problems mentioned above, the direct application of the L.S. procedure is inappropriate as well when a lagged endogeneous variable is included as an explanatory variable. Hurwicz [30, p. 365-83] has demonstrated that the L.S. estimates of the coefficients of autoregressive equations (equations utilizing the lagged endogeneous variable as an explanatory variable) are biased in small samples. Therefore, the L.S. estimation of equations derived from Nerlove's distributed leg model are biased estimates of the regression coefficients in small samples even when the errors are independent. Griliches [18] has shown that when autocorrelation arises the L.S. estimates of the regression coefficients are biased even in large samples.

Although several statistical tests such as the Durbin-Watson test [9] and the von Neumann's ratio test [10, p. 335] are available, Ladd and Martin [34] have shown that these tests appear to be weak when an equation contains a lagged value of the dependent variable.

In order to overcome this difficulty, Fuller and Martin [14] have developed "autoregressive least-squares" (A.L.S.) to furnish a more powerful test for autocorrelation, especially in an equation containing a lagged dependent variable. The A.L.S. estimation procedure is one method of obtaining estimates of the parameters of a lag model when errors are assumed to follow an autoregressive scheme. A.L.S. simultaneously yields estimates of the autocorrelation coefficients. The A.L.S. approach is employed in this study and summarized in Appendix D.

CHAPTER V

EMPIRICAL RESULTS AND THEIR INTERPRETATIONS

This chapter provides and evaluates the empirical results derived for the national and regional demand functions for fertilizer estimated by the autoregressive least-squares approach. The presentation consists of three sections. The national demand functions for fertilizer are presented in the first section. The regional demand functions are given in the second section. Following that, a measurement of the relative contributions of the factors studied to the growth of fertilizer use is provided in the last section.

A. The National Demand Function for All Commercial Fertilizer

The results of the national demand functions with three or four variables in Cobb-Douglas form for the time period 1926-1965 (omitting 1940-1945) are given in Table IV. Following this, the numerical results of the national demand functions for the pre-war period, 1926-1939, and for the post-war period, 1946-1965, are also discussed, respectively. Standard errors are given in parentheses below the regression coefficients. The coefficient of determination (R^2), standard errors of estimate (S), autocorrelation coefficients (ρ), and the coefficient of adjustment (α) are also presented in the same Table.

There are two equations (N.1 and N.2) for the time period 1926-1965 (omitting 1940-1945) showing that the R^2 values were all higher than .97 and were significant at the 1-per-cent level, indicating that about

TABLE IV

REGRESSION COEFFICIENTS, STANDARD ERRORS, AND OTHER STAT
RESULTS FOR FERTILIZER DEMAND FUNCTIONS, CANADA
1926-1965

Equation	R^2	S	Log of constant	Log X_1	Log $X_{2,t-1}$	Log $X_{3,t-1}$	Short-run model: Log X_4	Log $X_{5,t-1}$	Log X_6	t	Log Y_{t-1}	Autoc relat coeff ϱ
							The total period, 1926-1965 with 1940-1945 excluded					
N.1	.974**	.122	9.3065	-1.0648**					-.0188	.0228*	.3931**	.246
				(.3141)					(.0264)	(.0094)	(.1113)	(.170
N.2	.988**	.083	7.1817				-.5123**	.1114*		.0318**	.3791**	-.043
							(.0832)	(.0485)		(.0052)	(.0942)	(.019
							The pre-war period, 1926-1939					
N.3	.846**	.121	7.5268				-.6785**			.0174+	.4249**	-.064
							(.1534)			(.0086)	(.1457)	(.038
							The post-war period, 1946-1965					
N.4	.987**	.034	-.4446	-.1955#	.2418*					.0149*	.9961**	.005
				(.1814)	(.1030)					(.0049)	(.1054)	(.003
N.5	.987**	.034	1.9051	-.4435+		.2843*				.0062++	.8808**	.005
				(.2266)		(.1239)				(.0042)	(.1183)	(.003
N.6	.986**	.030	.8775				-.3874**	.0060		.0188**	.8928**	.006
							(.1118)	(.0395)		(.0060)	(.1123)	(.003

Note: 1. Variables interpreted as in the context.
2. Levels of significance
** = 1 per cent
* = 5 per cent
+ = 10 per cent
++ = 20 per cent

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r- on cient	Coefficient of adjustment α	Long-run model							
		Log of constant	Log X_1	Log $X_{2,t-1}$	Log $X_{3,t-1}$	Log X_4	Log $X_{5,t-1}$	Log X_6	t
)	.6069	15.3344	-1.7545					-.0309	.0375
*)	.6208	11.5684				-.8252	.1794		.0512
++)	.5751	13.0878				-1.1798			.0302
++)	.0039	-	-	-	-	-	-	-	-
++)	.1192	15.9823	-3.7206		2.3850				.0520
+)	.1072	8.1856				-3.6138			.1754

97 per cent of the variation in fertilizer use was explained by their corresponding independent variables; namely, the real fertilizer price (X_1), the fertilizer/crop price ratio (X_4), the exported quantity of grains (X_5), the acreage of cropland (X_6), the actual level of fertilizer consumption in the previous year (Y_{t-1}), and the time variable (t) relating to improved knowledge of technology. The remaining 3 per cent of the variation of the dependent variable may have been due to variables which are not included in the equations studied. The regression co-efficients in these two equations were significant at either a 5-per-cent or a 1-per-cent level with the exception of the acreage of cropland and in equation N.1. The mean elasticity for the fertilizer price, in the short-run, was about -1.065, indicating that a 1 per cent change in the fertilizer price in one direction has been associated with a 1.065 per cent change in fertilizer consumption in the other direction for the time period covered, i.e., a 1 per cent decrease in the fertilizer price will, certeris peribus, cause a 1.065 per cent increase in the fertilizer use and vice versa. The mean elasticity with respect to the fertilizer/crop price ratio was about one-half of that for the fertilizer price, implying that while the fertilizer/crop price ratio affects the profitability of fertilizer use, it is possible that farmers are more responsive to a change in the price of fertilizer than to a change in the price of crops. The regression coefficient for the grain exports (X_5) was about .11 and was significant at the 5-per-cent level. This coefficient indicates that a 1 per cent increase in the grain exports was predicted to increase fertilizer consumption by .11 per cent. These findings confirm that

farmers respond not only to the profitability of fertilizer use but also to the potential world market of grains. The sign of the regression coefficient for the acreage of cropland was, as expected, negative, representing an increase in fertilizer use with a decrease in the total cropland acreage.[1] In other words, a substitution effect between the acreage of cropland and the quantity of fertilizer demanded exists. However, the statistical test of that substitutional effect was very weak. The regression coefficients for the time variable were .02 and .03 in these two equations (N.1 and N.2) respectively, suggesting that the demand function for fertilizer has shifted upward during the period analyzed. It seems possible that this upward trend of fertilizer use will continue during the next decade simply because of further technical improvements in crop production and some developments in processing and improving basic materials used in fertilizers. The estimated regression coefficients for the lagged dependent variable (Y_{t-1}) were significant in both equations, indicating that farmers do have inertia in deciding the level of fertilizer use. For example, according to equation N.1, about 40 per cent of fertilizer used in the current year was dependent upon the level of fertilizer used in the previous year. On the other hand, the quantity of fertilizer used by farmers was predicted to be about 60 per cent of its adjustment in respect to a change in the fertilizer price, the farm cash income and improved technical

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[1]The signs of the regression coefficients of the variables in demand function based on *a priori* expectations are: $X_1<0$, $X_2>0$, $X_3>0$, $X_4<0$, $X_5>0$, $X_6<0$, $X_7<0$, $t>0$, $Y_{t-1}\geqslant 0$.

knowledge. In other words, farmers were unable to adjust fertilizer use instantaneously to a new situation. The long-run price elasticity for fertilizer was about one and half times higher than the short-run elasticity, based on equation N.1.

Table IV also shows the results for the national fertilizer consumption for both the pre- and post-war periods. For the pre-war period 1926-1939, the short-run demand elasticity with respect to the fertilizer/crop price ratio was about -.68. It was more inelastic than that in the overall period but was relatively elastic as compared with that elasticity in the post-war period, 1946-1965. On the other hand, in comparison with equations N.3 and N.6, the regression coefficient for the time variable in the long-run model was smaller in the pre-war period than in the post-war period. The results imply that due to greater improvement of technical knowledge, the shift of the fertilizer demand function has been greater in the post-war period than in the pre-war period. This is consistent with fertilizer experiments through the nation which have showed an important yield response from fertilizer application since World War II.

Equations N.4 and N.5 show that the price of crops and the farm cash incomes were also significant factors affecting fertilizer consumption in the post-war period. The short-run elasticity for the price of crops was about .242, indicating that a 1 per cent change in the price of crops has been, other things remaining equal, associated with a .242 per cent change in fertilizer consumption. The short-run elasticity for farm cash income was about .284, suggesting that a 1 per cent increase in farm cash income was expected to result in a .284 per cent increase in fertilizer use. This elasticity reflects the influence of farm cash income in the previous year on the fertilizer purchase in the following year. The exported quantity of grains was also included in equation N.6. Although the regression coefficient indicated a positive effect on fertilizer use in the post-war period, it was not statistically significant because of the high correlation with a time variable.[2]

The coefficients of adjustment, as shown in equations N.3 and N.6, tended to be smaller in the post-war period than in the pre-war period. These findings indicate that due to accumulative effects of adjustment in the use of resources fertilizer demand in the post-war period has heavily depended upon the amount of fertilizer use in the previous year. In contrast, only a small remaining proportion of fertilizer purchase is expected to adjust to a change in the fertilizer price, grain exports, and improved technical knowledge in the current crop year. For example, according to equation N.6 the adjustment coefficient (α) was about .11. It suggests that due to accumulative effects of adjustment in resources use, about 89 per cent of fertilizer consumption has been dependent upon the quantity of fertilizer use in the previous year and due to limited funds available, risk and uncertainty only about 11 per cent of its use was predicted to adjust to a change in the causal variables studied in the current crop year.

Because of the relatively small coefficient of adjustment, the

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[2] $r_{X_5,t}$ = .783, see Table E-7 in Appendix E.

long-run elasticities were, as shown in Table IV, all substantially greater than the short-run elasticities and also greater than those in the pre-war period.[3] Moreover, the regression coefficient for the time variable was nearly six times greater in the post-war period as compared to that in the pre-war period, based on equation N.3 and N.6. This finding suggests that the gradual influences of technical knowledge as represented by the time variable were much stronger since 1946 than before. Due to the declining original nutrient stock in soils and the accumulative effect of fertilizer use during and since the war-time period, the demand function for fertilizer would be expected to shift upward. In addition, the introduction of improved seeds, and the effects of commercial advertisement, extension services would also raise fertilizer demand.

The autocorrelation coefficients (ρ) for all equations were significant at the 20-per-cent or higher levels, indicating that the residuals were autocorrelated. The results support the application of the autoregressive least-squares approach to this study.

B. The Regional Demand Functions for All Commercial Fertilizer

Having analyzed national fertilizer demand functions in the previous section, the numerical results of the regional fertilizer demand

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[3]The regression coefficient for lagged dependent variable (Y_{t-1}) in equation N.4 was not significantly different from one at the 5-per-cent level, implying that the adjustment coefficient (α) was approximately equal to zero. This suggests that there was no adjustment at all. Thus, the long-run elasticities were not derived for this equation.

functions are evaluated in this section and are summarized in Table V, VI, VII and Appendix F respectively.[4]

Regional demand equations for the total period 1929-1965 (omitting 1940-1945) are presented in Table V and Appendix F. The R^2 values were significant at the 1-per-cent level in all regions, ranging from .932 for equation F.1 in the Atlantic region to .985 for equation R.4 in Ontario. These equations, therefore, appear to be a meaningful and useful expression of the demand for fertilizer. The regression coefficients for the fertilizer price (X_1)were significant at the 1-per-cent level in the Prairie region and British Columbia. On the average, the short-run regional price elasticities for fertilizer varied between -2.07 and -.09. In general, the coefficients indicate that the demand for fertilizer was affected greatly by the price of fertilizer in those regions where fertilizer consumption has expanded rapidly such as the Prairie region and British Columbia. On the other hand, the demand for fertilizer was weakly affected by the fertilizer price in the older using regions, i.e., the Atlantic, Quebec and Ontario regions. In equations containing the price of crops, the highest price elasticity, .62, was in Quebec, followed by .58 in Ontario. The elasticity for the crop price was much lower and less significant in British Columbia and it was neither consistent in sign nor significant in the Prairie region. The results suggest that the demand for fertilizer was predicted to be significantly

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[4] Equations indicated by F.i.(i=1,2 ...) are given in Appendix F.

TABLE V

REGRESSION COEFFICIENTS, STANDARD ERRORS, AND OTHER S
RESULTS FOR REGIONAL DEMAND FUNCTIONS FOR FERTI
1929-1965 **WITH** 1940-1945 EXCLUDED

Region and Equation	R^2	S	Log of constant	Short-run model: Log X_1	Log $X_{2,t-1}$	Log $X_{3,t-1}$	Log X_4	Log X_7	t	Log Y_{t-1}	Autocorrelation coefficient ρ
Atlantic R.1	.944**	.079	4.4664	-.0980 (.3895)		.7321** (.1686)			.0033# (.0031)	.3257* (.1302)	.0619+ (.0301)
Quebec R.2	.964**	.100	3.2607	-.2524 (.3704)	.6164** (.1681)				.0249** (.0052)	.4033* (.2875)	.0819* (.0327)
Ontario R.3	.978**	.121	4.0620	-.3068 (.3398)	.5860** (.1963)				.0370** (.0082)	.4919** (.1150)	.0547+ (.0308)
R.4	.985**	.107	5.9188				-.4117* (.1767)	-.2470++ (.1587)	.0398** (.0088)	.4158** (.1225)	.0807* (.0375)
Prairie R.5	.979**	.269	13.3503	-2.0775** (.5901)	-.0841 (.3185)				.0687** (.0221)	.5449** (.1025)	.1862* (.0670)
B.C. R.6	.975**	.088	6.2545	-.5699** (.1439)	.1403# (.1103)				.0203** (.0068)	.5185** (.1492)	.1782# (.1705)

Note: 1. Variables interpreted as in the context.
2. Levels of significance: ** = 1 per cent
* = 5 per cent
\+ = 10 per cent
++ = 20 per cent
\# = 30 per cent

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t	Coefficient of adjustment α	Long-run model						
		Log of constant	Log X_1	Log $X_{2,t-1}$	Log $X_{3,t-1}$	Log X_4	Log X_7	t
	.6743	6.6237	-.1453		1.0857			.0049
	.5967	5.4645	-.4229	1.0330				.0472
	.5081	7.9944	-.6038	1.1533				.0728
	.5842	10.1314				-.7047	-.4228	.0681
	.4551	29.3349	-4.5649	—				.1509
	.4815	12.9896	-1.1836	.2914				.0422

TABLE VI

REGRESSION COEFFICIENTS, STANDARD ERRORS, AND OTHER STATISTICAL RESULTS FOR REGIONAL DEMAND FUNCTIONS FOR FERTILIZER, 1929-1939

Region and Equation	R^2	S	Log of constant	Log X_4	t	V-N ratio
Atlantic R.7	.795**	.108	11.4895	-1.0399** (.2071)	-.0128 (.0219)	2.138
Quebec R.8	.849**	.129	10.5806	-1.2697** (.2467)	.0564* (.0142)	1.964
Ontario R.9	.828**	.179	11.1136	-1.7219** (.3423)	.0639** (.0198)	1.929
Prairie R.10	.827**	.517	6.2606	.7898 (.7063)	.3440** (.0602)	2.408
B.C. R.11	.439	.112	9.4734	-.3307* (.1421)	-.0065 (.0130)	3.144

Note: 1. Variables interpreted as in the context.
2. Levels of significance: ** = 1 per cent
* = 5 per cent

TABLE VII

REGRESSION COEFFICIENTS, STANDARD ERRORS, AND OTHER STATISTICAL RESULTS FOR REGIONAL DEMAND FUNCTIONS FOR FERTILIZER, 1946-1965

Region and Equation	R^2	S	Short-run model: Log of constant	Log X_1	Log $X_{3,t-1}$	Log X_4	t	Log Y_{t-1}	Autocorrelation coefficient ρ	Coefficient of adjustment α	Long-run model: Log of constant	Log X_1	Log $X_{3,t-1}$	Log X_4	t
Atlantic															
R.12	.789**	.057	5.4481	-.6013#	.8106**		.0056+	.4056+	.0154	.5944	9.1657	-1.0116	1.3637		.0094
				(.5025)	(.2324)		(.0029)	(.2139)	(.0161)						
R.13	.644**	.072	3.3717			-.2340#	.0097+	.6870**	.0210+	.3130	10.7722			-.7476	.0310
						(.1803)	(.0052)	(.1741)	(.0110)						
Quebec															
R.14	.839**	.074	5.8077	-.4763#	.3260		.0107++	.5089*	.0205	.4911	11.8259	-.9698	.6638		.0218
				(.4297)	(.5416)		(.0069)	(.2335)	(.0279)						
R.15	.837**	.077	3.3436			-.2430++	.0164*	.6786**	.0125#	.3214	10.4032			-.7560	.0510
						(.1769)	(.0061)	(.1660)	(.0108)						
Ontario															
R.16	.971**	.055	4.4246	.1599	.5001++		.0058	.7043**	-.0055	.2957	1.4359		1.6912		.0196
				(.3946)	(.3182)		(.0104)	(.1942)	(.0067)						
R.17	.967**	.057	4.3156			-.1029	.0174**	.6339*	-.0037	.3661	11.7880			-.2811	.0475
						(.1447)	(.0082)	(.1802)	(.0082)						
Prairie															
R.18	.982**	.114	10.2242	-1.9688**	.2805#		.0308**	.7057**	-.0741	.2943	34.7407	-6.6898	.9531		.1046
				(.3344)	(.2514)		(.0098)	(.0889)	(.1769)						
R.19	.979**	.117	1.6334			-1.0822*	.0628	.7084**	-.0118	.2916	5.6015			-3.7112	.2153
						(.2079)	(.0134)	(.0923)	(.0153)						
B.C.															
R.20	.879**	.067	5.9104	-.4717++	.0036		.0121*	.6435*	.0475	.3565	16.5789	-1.3231	.0101		.0339
				(.3543)	(.3364)		(.0059)	(.2069)	(.0579)						
R.21	.909**	.056	6.1295			-.3735**	.0289**	.6952*	.0424++	.3048	20.1099			-1.2254	.0948
						(.1281)	(.0075)	(.2133)	(.0263)						

Note: 1. Variables interpreted as in the context.
2. Levels of significance: ** = 1 per cent
* = 5 per cent
\+ = 10 per cent
++ = 20 per cent
\# = 30 per cent

responsive to the prices of cash crops such as tobacco, potatoes, corn, vegetables, and fruits but not to the price of small grains in mixed farming areas, e.g., Ontario and Quebec. The mean short-run elasticity of fertilizer use in respect to the farm cash income was significant at the 1-per-cent level in the Atlantic region where the level of farm income more clearly affects funds available for the purchase of fertilizer. The regression coefficients for the time variable ranged from .0687 in the Prairie region to .0033 in the Atlantic region. The coefficients indicate that technical knowledge was a much more important factor affecting fertilizer use in those regions with the most rapid rate of increase in fertilizer use since 1955. The adjustment coefficients (α) ranged from .45 in the Prairie region to .67 in the Atlantic region. In general, they were smaller in the Prairie region and British Columbia than in the Atlantic, Quebec and Ontario regions. As indicated by results, due to accumulative effects of adjustment in resource use fertilizer consumption in the current crop year has depended upon the quantity of its use in the previous year to a greater extent in the newer using regions than in the older using regions. In other words, a relatively small proportion of fertilizer consumption in the newer using regions was expected to adjust to a change in the fertilizer price, farm cash income, and improved technical knowledge in the current crop year.

Since Ontario is a highly diversified agricultural area, farmers with limited capital must decide whether it is more profitable to invest their limited funds in fertilizer or feed for livestock enterprise.

To consider this fact, an additional equation containing the fertilizer/feed price ratio (X_7) was specified. The coefficient for this variable was significant at the 20-per-cent level, indicating that it was also a significant factor affecting fertilizer use in Ontario. Therefore, the increased fertilizer use in Ontario could be partly attributed to the fall of fertilizer price relative to the price of feed, if these were the critical variable costs involved for those farmers making choices between livestock and crops production.

In the long-run, the mean elasticities in respect to the fertilizer price were substantially greater in the Prairie and British Columbia regions than in other regions. However, the long-run elasticities for the price of crops were relatively higher in the older using regions. The demand for fertilizer was also elastic with respect to the farm cash income in the Atlantic region. The coefficient for the time variable was, in the long-run, the highest .15 in the Prairie region, followed by .07 (equation R.3) in Ontario, .04 in Quebec and .04 in British Columbia. The lowest was about .005 in the Atlantic region. The results suggest that the demand function for fertilizer has shifted rightward most rapidly in the Prairie region where technical knowledge about yield response of grains from fertilizer was more recent as compared to the other regions.

For the pre-war period, the application of distributed lag model appears somewhat discouraging because in most equations, as shown in Appendix F, the coefficients for lagged dependent variable (Y_{t-1}) were either insignificant or did not have the correct sign as hypothesized by the distributed lag model. It indicates that the adjustment coefficients (α) were not significantly different from one, implying that all of the adjustments to a new equilibrium was completed within one year, and there was no significant lag in response. Therefore, a theoretical static model involving the fertilizer/crop price ratio and time variable was employed for all regions.

The resulting equations are given in Table VI. Generally speaking, the coefficients of determination (R^2) in all regions except for British Columbia were significant at the 1-per-cent level. In all but the Prairie region, regression coefficients had correct signs and were significant at the 10-per-cent or higher levels. The elasticities for the fertilizer/crop price ratio varied from -1.72 in Ontario to -.33 in British Columbia. In general, the demands for fertilizer were relatively elastic for the fertilizer price in Eastern Canada in the earlier period. The above results were expected because the heavy users of commercial fertilizer were in Eastern Canada. More than 90 per cent of the Canadian total were used in the Atlantic, Quebec, and Ontario regions. Very little fertilizer was used in Western Canada before World War II. Fertilizer was seldom recommended for the grain crops in the earlier period since the original soil nutrient stock was abundant. Thus, farmers in Western Canada were not responsive to the relative price of fertilizer. The estimate of the coefficient for the time variable, .334, in the Prairie was much greater than one would expect on a priori grounds because the level of technical knowledge about fertilizer was very low in this region during the pre-war period. The time variable included the effects of other variables which were not included in the equation. The coefficients for time were .064 and .056 in Ontario and Quebec respectively. The results appear to be quite reasonable since fertilizer use has been widespread in these areas in the earlier period. Fertilizer consumption was considerably affected by technical knowledge in this period. The coefficients for time were negative in the Atlantic and British Columbia regions and were not consistent with our hypothesis.

Von Neuman's Ratio was used to test autocorrelation for the static demand functions. The test indicates that no autocorrelation exists in residuals in all regions.

The empirical results for the post-war period indicate that the demand elasticities with respect to either fertilizer price or fertilizer/crop price ratio tended to be greater in the regions which have increased fertilizer use mostly since 1946; namely, the Prairie region and British Columbia. It is true that fertilizer is a new factor of crop production in Western Canada, especially for grain production. Fertilizer use in this area is expected to be relatively responsive to price change. The positive price elasticity for fertilizer with high standard error was not significant in Ontario. Also, the 95 per cent confidence interval of this elasticity was between -.686 and 1.006. Hence, this positive relationship between fertilizer consumption and fertilizer price in the post-war period was likely meaningless. The elasticities with respect to the farm cash income were still higher in the older using regions than in the newer using regions, ranging from .811 in the Atlantic region to .0036 in British Columbia. These elasticities suggest that demand for fertilizer was considerably influenced by the level of farm cash incomes from such cash crops as tobacco, potatoes, fruits and vegetables. Demand for fertilizer in the Prairie region was also responsive to farm cash incomes, because, like the Atlantic region, farm cash incomes increased slowly during the post-war period. The regression coefficients for the time variable, in general, were relatively greater in the newer using regions as compared to the older using regions. Based on the first equation in each region, it was the greatest, .031, in the Prairie region, followed by .012 in British Columbia. The smallest, .005, was in the Atlantic region. Again, these results indicate that demand functions for fertilizer have shifted upward most rapidly with time in areas where technical knowledge about fertilizer use was more recent. Due to depletion of soil nutrient stocks and due to improvements of new varieties of seeds and farm practices, commercial fertilizer needs have substantially increased. Improvements of technical knowledge about fertilizer use certainly have been relatively important along with the fall of the real fertilizer price in the newer using regions. While technical knowledge has also increased in the older using regions, it probably has been relatively less important.

The adjustment coefficients (α) in all regions were smaller than those for the total period. These findings have the same implications as those for the national results. That is, due to accumulative effects of adjustment in resources use, extensive research and extension services over the past two decades, fertilizer consumption in the post-war period has been strongly influenced by the level of fertilizer use in the previous year. In contrast, only a small remaining amount of fertilizer purchase in the current crop year was expected to adjust to a change in those variables studied. After World War II, because of rapid improvements of technical knowledge, the use of fertilizer became more acceptable to farmers.

The long-run elasticities with respect to the fertilizer price, fertilizer/crop price ratio, and farm cash incomes were all greater than those in the short-run. The magnitudes of the difference between the long-run and short-run elasticities depend upon the size of the adjustment coefficients. In general, the long-run price elasticities for the fertilizer price tended to be greater in the newer using regions as compared to the older using regions. These results indicate that during the past two decades the declining real fertilizer price along with rapid improvements of technical knowledge of fertilizer response have become more influential factors causing a strong upward trend in the use of fertilizer. In contrast, the long-run elasticities with respect to farm cash income were generally higher in the older using regions than in the newer using regions. They suggest that the farm cash income have clearly affected funds available for purchase of fertilizer in these regions.

C. A Measurement of Relative Contributions of Factors to the Growth of Fertilizer Use

Since the situation in the post-war period is of much interest to the study, the relative contributions of factors to the increase in fertilizer use were measured for this period only. According to the statistical findings presented in the previous section, the real fertilizer price, real farm cash incomes and improved technical knowledge about fertilizer use have been realized to be the most important factors affecting fertilizer use. Thus, relative contributions have been measured for these three factors. By applying a simple growth model as given in Chapter IV, the average rates of change in the real fertilizer price and the real farm cash income were estimated for the post-war period and were presented in Table VIII. The negative average rate of change in the real fertilizer price indicates that the real fertilizer price was decreasing in the period 1946-1965. On the average, it was decreasing at about .19 per cent per year in all Canada, .14 per cent in Eastern Canada and .37 per cent in Western Canada. On the other hand, the real farm cash income has grown at an average rate of about .5 per cent a year. There are regional differences in average farm cash income trends. The highest average growth rate was about 1.1 per cent per year in Ontario, as compared with .05 per cent in the Prairie region. By using the model proposed in Chapter IV and the estimates shown in Table VIII, the relative contributions of these factors are evaluated as shown in Table IX.

With an average growth rate of expected fertilizer use as 100 per cent, for Canada as a whole about 10 per cent was attributable to the decline in the real fertilizer price which was caused by technical progress in the fertilizer industry, about 17 per cent was attributable to the increase in the farm cash income, and about 72 per cent to the improvements in the technical knowledge of crop production which

TABLE VIII

ESTIMATED AVERAGE RATE OF FALL IN REAL FERTILIZER PRICE, AVERAGE GROWTH RATE OF REAL FARM CASH INCOME, AND AVERAGE CONTRIBUTION OF THE DEMAND SHIFT, CANADA AND REGIONS, 1946-1965

Region	$\bar{g}(x_1)$	$\bar{g}(x_3)$	γ[a]
Canada	-.00190	.00498	.0520
Atlantic	-.00143	.00061	.0094
Quebec	-.00143	.00898	.0217
Ontario	-.00143	.01147	.0196
Prairie	-.00366	.00056	.1046
B.C.	-.00366	.01159	.0339

[a]The values of γ were copied from Tables IV and VII.

TABLE IX

AVERAGE RELATIVE CONTRIBUTIONS OF FACTORS ASSOCIATED WITH THE GROWTH IN FERTILIZER USE, CANADA AND REGIONS 1946-1965

	Average growth rate of expected fertilizer use $\bar{g}(Y^*)$	Contribution of fall in real fert. price $a_1\bar{g}(X_1)X100$	Contribution of increase in farm cash income $a_3\bar{g}(X_3)X100$	Contribution of technical change in crop production Υ X100	Contribution of other factors
Relative contribution					
Canada	100	10.00	16.76	73.24	
Atlantic	100	12.07	6.90	81.03	
Quebec	100	4.77	20.49	74.74	
Ontario	100	7.88[a]	45.61	46.51	
Prairie	100	18.88	.41	80.71	
B.C.	100	12.37	.26	87.37	
Adjusted relative contribution					
Canada	(R^2=.987)100	9.87	16.54	72.29	1.30
Atlantic	(R^2=.789)100	9.52	5.45	63.93	21.10
Quebec	(R^2=.839)100	4.00	17.19	62.71	16.10
Ontario	(R^2=.971)100	7.65	44.29	45.16	2.90
Prairie	(R^2=.982)100	18.54	.40	79.26	1.80
B.C.	(R^2=.879)100	10.87	.23	76.80	12.10

[a] Long-run price elasticity of demand for fertilizer (a_1=-2.3216) is estimated from the lower limit of 95 per cent confidence interval for short-run price elasticity.

resulted in a continuous shift of the fertilizer demand function. The remaining portion, about 1 per cent, was due to other factors not included in the model studied. On the regional results as shown in Table IX, the relative contribution of the real fertilizer price to the growth of fertilizer use was greater in Western Canada than in Eastern Canada, ranging from about 18 per cent in the Prairie region to 4 per cent in Quebec. This is because during the priod 1946-1965, the real fertilizer price in Eastern Canada was decreasing more moderately than in Western Canada. Since price competition among fertilizer-furnishing firms has already existed in Eastern Canada for a long time, it is likely that firms are all devoting attention to services associated with sales in order to maintain and extend their own markets. The major forms of such activities have consisted of efforts to provide improved knowledge of fertilizer use, improvement of fertilizer quality, and promotional advertising. However, the fertilizer industry in Western Canada has been responding to expected fertilizer demands through expansion of existing and new entering firms during recent years. As a result, firms have apparently engaged in price competition in an attempt to establish their market positions which is now being increasingly supplemented by services and promotional activities. Contrary to the result of fertilizer price contribution, the real farm cash income accounted for a larger contribution in Eastern Canada than in Western Canada. The highest, 44 per cent, was in Ontario and lowest, .23 per cent, was in British Columbia. The results indicate that the expansion of fertilizer use in Eastern Canada has been largely attributable to the increase in the real farm cash income from cash crops and livestock. Improved technical knowledge has been found to be the greatest contributor among these three factors. Its relative contribution was the largest, about 80 per cent in the Prairie region, followed by 77 per cent in British Columbia, 64 per cent in the Atlantic region, 63 per cent in Quebec and 45 per cent in Ontario. The results confirm the hypothesis that rapid improvement in technical knowledge of fertilizer use has affected a marked expansion of fertilizer use in all regions, particularly in the newer using areas.

CHAPTER VI

PREDICTIONS OF FERTILIZER DEMAND TO 1975 AND THEIR IMPLICATIONS

Following the empirical results of the national and regional fertilizer demand presented in the previous chapter, this chapter intends to describe probable future trends in total demand for fertilizer if past and present tendencies continue. Projections of these trends are carried to the years 1970 and 1975. Assuming that logical models were derived and reasonable results obtained in the previous chapter, they will provide reliable estimates of the regional demand for fertilizer ten years in the future. The national fertilizer consumption is the summation of the quantities demanded by the individual regions. Information of this type will aid the fertilizer producers in planning their operations and give a partial indication of the average price situation to be expected. In other words, some adjustments will have to be made both on the production and marketing side and on the consumption side of fertilizer use in order to achieve a partial equilibrium.

A. Statistical Predictions

Since several demand equations with different combinations of causal variables, as shown in Chapter V, have been specified, certain criteria are necessary, for the purpose of prediction, to select that function which represents the closest approximation of actual demand relationships. The criteria are [25, p. 102-107]:

1. The number of significant independent variables and the levels of their significance--in a statistical sense, more confidence would be attached to the more significant regression coefficients in estimating the variation in dependent variable.

2. The size of the coefficient of determination (R^2) and its significance--since R^2 value indicates the approximate proportion of variation in dependent variable (Y) which can be explained by the independent variables involved in a demand function, the larger value of R^2 might be taken to indicate the equation which is most appropriate for prediction.

3. The magnitude of the standard error of estimate--the standard error of estimate also serves as a guide to select the most adequate demand function for prediction, because its magnitude indicates the dispersion of actual observations around the regression line. Therefore, the smaller value of the standard error of estimate might be taken to show the closeness of the estimated regression to the true line.

According to these criteria, equations R.12, R.14, R.17, R.18, and R.20 in the post-war period were selected for predicting the regional fertilizer consumption. A comparison of the actual fertilizer consumption with that predicted from these equations is graphically shown in Figure 8. Generally speaking, the predicted quantities of fertilizer were reasonably close to the actual quantities and the direction of these predicted curves was almost consistent with the actual curves over the period analyzed. Therefore, these equations are chosen to serve as a guide to forecasting future fertilizer consumption.

FIGURE 8

ACTUAL AND PREDICTED QUANTITIES OF FERTILIZER USE, CANADA AND REGIONS, 1947-1965

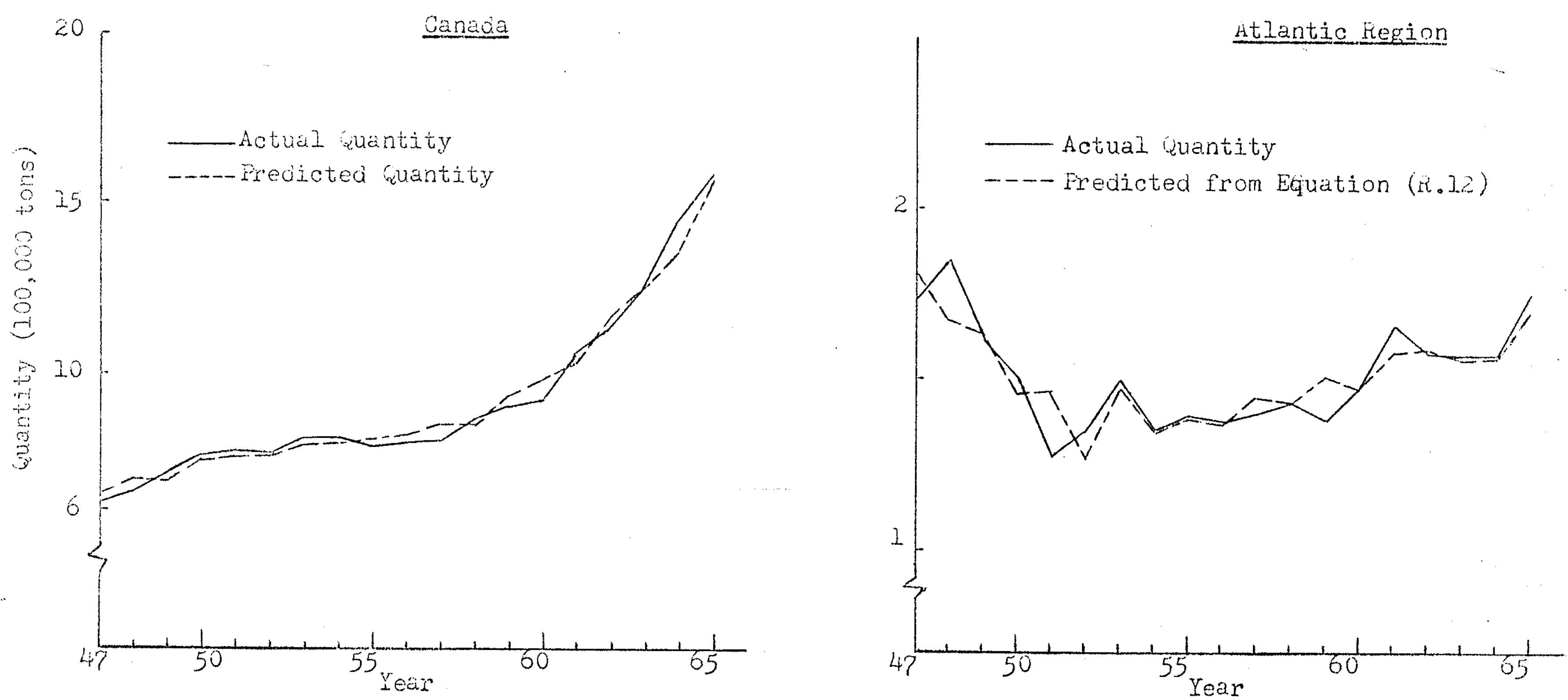


FIGURE 8 (continued)

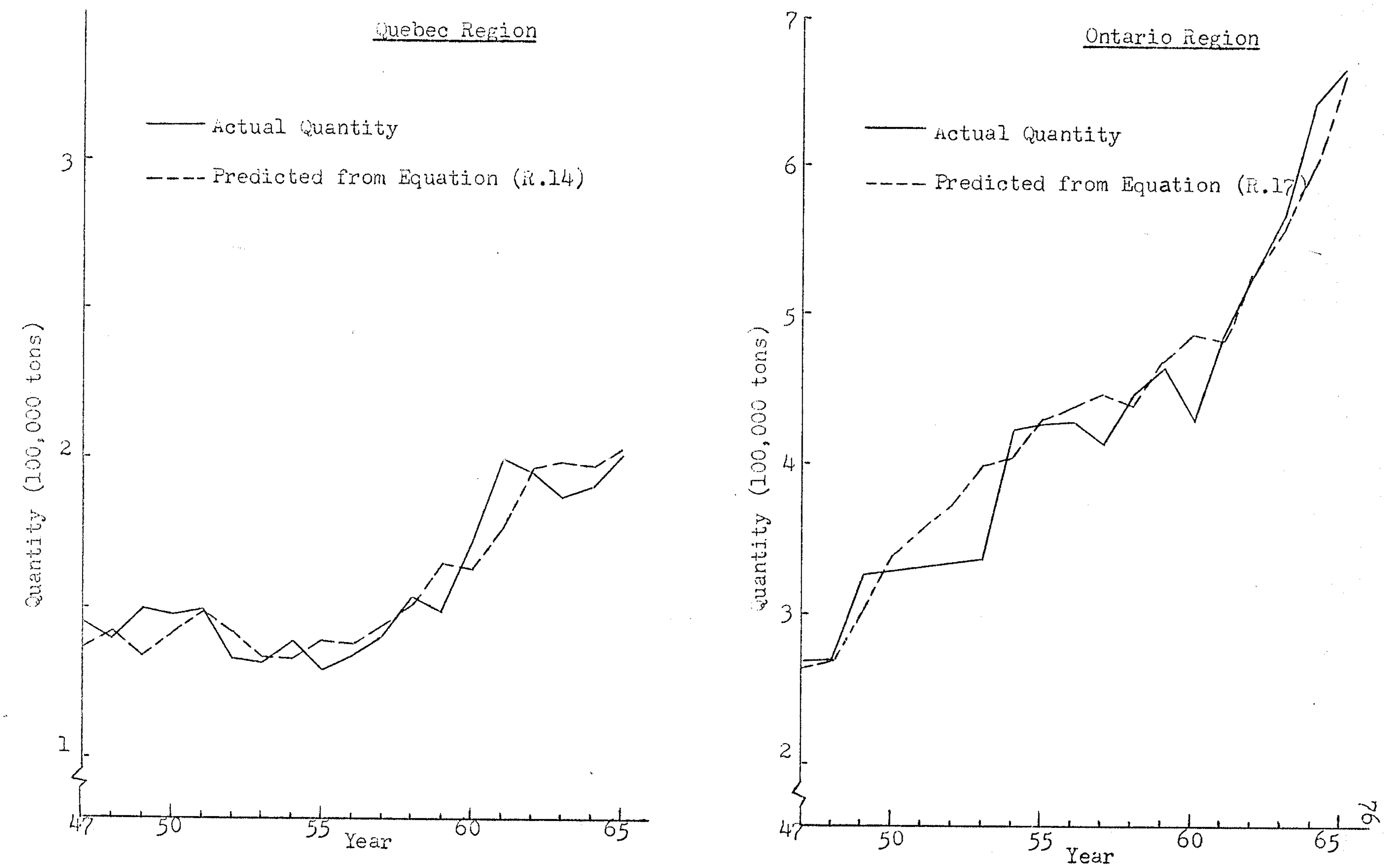
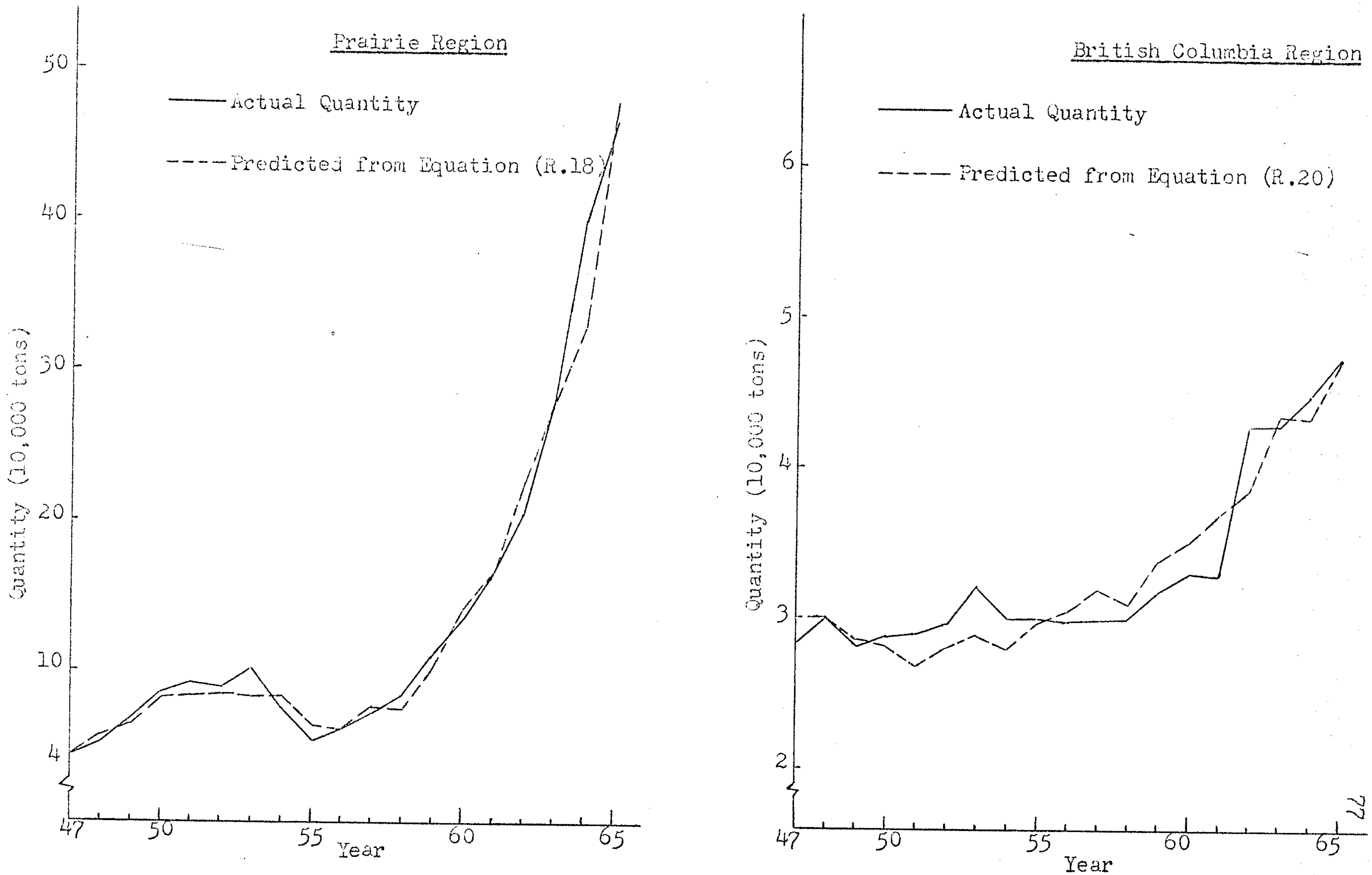


FIGURE 8 (continued)



B. Projections of All Commercial Fertilizer Demand for 1970 and 1975

Looking several years ahead, one may wish to foresee the magnitudes of the forces governing the use of all commercial fertilizer. This section then attempts to project the expected quantity of fertilizer use for 1970 and 1975. Equations R.12, R.14, R.17, R.18 and R.20 along with their associated adjustment equations are used as guides to estimate reliable projections. There are two different sets of assumptions which serve as guides to simulate reliable projections.

Case I. The first set of assumptions is:

1. The demand relationships represented by the selected equations will be assumed to hold in the future, at least until 1975.

2. There will be no sudden economic and political upheavals to interfere with the normal situation of the economy.

With these assumptions, a forecast of fertilizer consumption for 1970 and 1975 will be worked out by projecting past trends of the independent variables into the future. According to the indication of scatter diagrams, the trends of independent variables are estimated by fitting different types of equations to the data from 1946 to 1965 in different regions as shown in Table X.

TABLE X

TYPES OF EQUATION USED TO FIT VARIOUS INDEPENDENT VARIABLES IN DIFFERENT REGIONS

Variable	Atlantic	Quebec	Ontario	Prairie	B.C.
X_1	L.	L.	-	L.	-
X_3	-	G.	-	-	-
P_f^a	-	-	C.	-	C.
P_c	-	-	L.	-	L.

Note: L.: $\hat{x} = a + bt$; G: $\hat{x} = ae^{bt}$; C.: $\hat{x} = at^b$ where t is time

[a] Pf and Pc refer to the actual price of fertilizer and the actual price of crops, respectively. The projected Pf and Pc are used to compute the fertilizer/crop price ratio (X_4).

Table XI shows the projected values of independent variables. Extending 1946-1965 linear trends, the real fertilizer prices in Eastern Canada are predicted to decrease about 2.1 per cent in 1970 and 2.9 per cent in 1975 as compared with the 1946-1965 average; while corresponding decreasing percentages are 5.3 per cent and 7.6 per cent in Western Canada. From 1946-1965, the real farm cash income was growing at an average rate of .89 per cent per year in Quebec. Based on this growth rate, the projected real farm cash incomes in 1970 and 1975 increase about 22 per cent and 27 per cent from 1965 to 1970 and 1975. The predicted fertilizer/crop price ratios are 1.063 in 1970 and 1.104 in 1975 for Western Canada while corresponding projected fertilizer/crop price ratios are 1.060 and 1.083 for Eastern Canada. Since the real farm cash income in the Atlantic and the Prairie regions were fairly stable during the past two decades, the ten years average, 1956-1965, farm cash incomes, \$117 million and \$1,436 million in the respective regions, are used. In real terms, they are 142.2 and 212.6, respectively (1935-1939=100).

TABLE XI

PROJECTED LEVELS OF INDEPENDENT VARIABLES FOR 1970 AND 1975
(1935-1939=100)

Year and variable	Atlantic	Quebec	Ontario	Prairie	B.C.
1970:					
x_1	74.4	74.4	-	65.7	-
x_3	142.2	287.8	-	212.6	-
P_f	-	-	219.2	-	195.4
$P_{c,t-1}$	-	-	206.6	-	183.8
1975:					
x_1	73.8	73.8	-	64.5	-
x_3	142.2	300.8	-	212.6	-
P_f	-	-	228.3	-	203.5
$P_{c,t-1}$	-	-	210.8	-	184.3

In general, the trend in the use of fertilizer seems to be continuously upward in all regions. From Table XII, the expected level of fertilizer use in Canada as a whole is projected to be 2,318 thousand tons in 1970 and 3,450 thousand tons in 1975, or about 45 per cent and 116 per cent more over the 1965 level. A regional projection of the expected quantity of fertilizer purchase is an increase of about 5 per cent in the Atlantic region, 23 per cent in Quebec, 67 per cent in Ontario, 287 per cent in the Prairie region and 27 per cent in British Columbia for the ten years after 1965. Among regions, the highest percentage increase in the Prairie region would be mainly due to a continued development of the fertilizer industry in Western Canada which will reduce the unit costs of fertilizer production, leading to (a) further decline of the real fertilizer price, assuming a similar pattern of keen market competition, (b) greater improvements in technical knowledge of fertilizer

TABLE XII

PROJECTIONS OF EXPECTED QUANTITIES OF FERTILIZER USE FOR 1970 AND 1975

	Canada	Atlantic	Quebec	Ontario	Prairie	B.C.
			--thousands of tons--			
Case I						
Actual 1965 level	1,593	175	212	689	464	47
Projected 1970 level	2,318	178	232	903	955	50
Annual percentage change	+9.1	+.3	+1.9	+6.2	+21.2	+1.3
Projected 1975 level	3,450	184	261	1,150	1,795	60
Annual percentage change	+11.6	+.5	+2.3	+6.7	+28.7	+2.7
Case II						
Actual 1965 level	1,593	175	212	689	464	47
Projected 1970 level	2,723	189	234	940	1,310	54
Annual percentage change	+14.2	+1.6	+2.1	+7.3	+36.4	+3.0
Projected 1975 level	4,847	211	263	1,232	3,073	70
Annual percentage change	+20.4	+2.0	+4.8	+7.9	+56.2	+4.9

use through research, commercial communications, extension services. The lowest percentage increase in the Atlantic region can be related to the shortage of capital.

Case II. The second set of assumptions is based upon the rate at which fertilizer was used during the last ten years. As shown in Table XIII, the rate of increase in the use of fertilizer in all regions was higher in the period 1956-1965 than in 1946-1965.

TABLE XIII

AVERAGE RATE OF INCREASE IN THE USE OF FERTILIZER BY REGIONS, 1946-1965

	Atlantic	Quebec	Ontario	Prairie	B.C.
		--percentage--			
1946-1965	.86	1.51	6.96	16.55	2.58
1956-1965	1.73	2.48	7.71	25.22	5.70

The rapid rate of increase in the use of fertilizer during the past decade, in general, has resulted from changes in technology, capital use, and in the agricultural structure. Specifically, rapid improvement of technical knowledge about fertilizer use would be the most important factor. If this assumption can be realized, then an upward shift of the crop production function will likely result in a rapid shift in demand function for fertilizer in the future ten years after 1965.

With assumptions mentioned in Case I and the estimates of average rate of increase in the use of fertilizer for the period 1956-1965, a second set of projections for the fertilizer use is also shown in Table XII. The results indicate that due to greater technical improvements in crop production alone, the expected levels of fertilizer consumption are projected to be increased in all regions for the period under consideration. In comparison with the projected levels in Case I, the expected levels of fertilizer consumption in Canada as a whole will increase 17.6 per cent and 40.5 per cent more in 1970 and 1975 respectively. Regionally, the corresponding percentage increase will be 7.4 per cent and 14.7 per cent in the Atlantic region, .9 per cent and .8 per cent in Quebec, 4.1 per cent and 7.1 per cent in Ontario, 37.2 per cent and 72.2 per cent in the Prairie region, 8.0 per cent and 16.7 per cent in British Columbia. Therefore, the trends in the use of fertilizer in all regions studied are confidently expected to be upward in the future ten years after 1965.

CHAPTER VII

SUMMARY AND CONCLUSIONS

In view of the results presented in Chapters V and VI, some conclusions relating to the demand for fertilizer are:

1. In Canada as a whole, the demand for fertilizer was responsive to either fertilizer price or the fertilizer/crop price ratio. Both variables were statistically significant at the 10-per-cent or higher levels. This significant response implies that the changes in fertilizer price or the fertilizer/crop price ratio have been significantly associated with the variation of fertilizer use. The fertilizer demand was also responsive to the exported quantities of grains and grain products, suggesting that an increase in the exports of grains will result in an expansion of fertilizer use. In addition, improved technical knowledge played an important role in the use of fertilizer. This factor appeared to be more important since 1946. The adjustment coefficient was much higher for the pre-war period than for the post-war period. The results suggest that due to accumulative effects of adjustment in resources allocation fertilizer demand in the post-war period has heavily depended upon the amount of fertilizer use in the previous year. In contrast, only a small remaining proportion of fertilizer purchase is expected to adjust to a change in fertilizer price, grain exports, and improved technical knowledge in the current crop year.

2. Regression analysis of the regional demand for fertilizer has also been conducted. Again, demand for fertilizer was responsive to the

real fertilizer price or the fertilizer/crop price ratio in all regions. The mean short-run elasticities with respect to the fertilizer/crop price ratio were higher in the older using regions namely, the Atlantic region, Quebec and Ontario than in the newer using regions namely, the Prairie region and British Columbia. It was also responsive to the fertilizer/feed price ratio in Ontario. This was so because agriculture is quite diversified in Ontario, farmers must decide whether it is more profitable to invest limited funds in fertilizer or other items such as feed for livestock. Improvements in technical knowledge were much more important in Western Canada where fertilizer use has increased greatly during recent years than in Eastern Canada. The adjustment coefficient was different among regions. It was lowest in the Prairie region (.384). The result implies that due to accumulative effects of adjustment in resources use, fertilizer use in the Prairie region has been strongly influenced by the quantity of fertilizer use in the previous year and relatively small amount of its use in the current crop year was expected to adjust to a change in fertilizer price, farm cash income and technical knowledge. While the price elasticities for fertilizer were higher in the older using regions than in the newer using regions for the pre-war period, the reverse was the case for the post-war period. Since fertilizer is a new factor of crop production in Western Canada, especially for grain production, farmers in these areas are expected to be much more responsive to price change than in Eastern Canada. On the other hand, the elasticities with respect to the real farm cash incomes were higher in the older using regions than in the newer using regions, suggesting that demand for fertilizer was strongly affected by the level of farm cash income in Eastern Canada. The regression coefficients for the time variable varied between .031 in the Prairie region and .005 in the Atlantic region, implying that demand function for fertilizer has significantly shifted upward with time in the area where technical knowledge has been rapidly improved during the post-war period.

3. The relative contributions of the real fertilizer price, real farm cash income and improved technical knowledge have been measured. For all Canada, about 10 per cent was attributed to the decline in the real fertilizer price, about 17 per cent to the increase in the real farm cash income and about 72 per cent to the improved technical knowledge. The regional results indicate that more than 87 per cent of the increase in fertilizer use was due to improvements in technical knowledge and the fall of the real fertilizer price in the newer using regions. In contrast, the relative contributions of these two factors accounted for about 73 per cent or less in the older using regions. The contribution of real farm cash income tended to be relatively large in the older using regions, ranging from about 44 per cent in Ontario to 5 per cent in the Atlantic region.

4. Under two different sets of assumptions, projections of the expected fertilizer use in all regions are carried out to 1975.

a) Extending 1946-1965 trends, the expected level of fertilizer use in Canada as a whole is projected to increase 116 per cent in the ten years after 1965. On the regional basis, the projected percentages of increase in the expected fertilizer use ranged from 287 per cent in the Prairie region to 5 per cent in the Atlantic region in 1975.

b) By incorporating the average rate of increase in fertilizer consumption for the period 1956-1965 into trends of the period 1946-1965, the expected levels of fertilizer use in all regions are predicted to increase more than those in Case I. Again, the highest percentage increase is expected in the Prairie region where the use of fertilizer has increased most rapidly among regions during the past decade.

In conclusion, it appears that there is a signal of an increase in fertilizer use in Canada in the future ten years. A marked expansion of fertilizer use could be realized in all regions if a further decline in the real fertilizer price (reflecting in additional improvements of technology in the fertilizer industry) occurred together with good prospects in the grain export markets and rapid improvement of technical knowledge about fertilizer use from the standpoint of farmers.

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Appendix

APPENDIX A

SALES OF FERTILIZERS, YEARS ENDED JUNE 30, CANADA AND REGIONS 1926-1965*

Year	Canada	Atlantic	Quebec	Ontario	Prairie	B.C.
			--tons of 2,000 pounds--			
1926	180,794	-	-	--	-	-
1927	169,564	-	-	-	-	-
1928	214,738	-	-	-	-	-
1929	223,750	90,829	22,738	99,855	317	10,011
1930	321,207	126,004	55,544	124,827	325	14,507
1931	284,217	119,039	57,743	94,198	1,776	11,461
1932	179,983	71,429	38,758	51,902	5,849	12,045
1933	166,407	69,708	29,931	53,792	2,914	10,062
1934	194,851	72,667	40,398	64,752	4,992	12,042
1935	212,479	73,881	45,261	72,219	10,765	10,353
1936	233,840	79,683	51,736	83,949	8,438	10,034
1937	298,276	92,465	58,763	124,100	9,280	13,668
1938	323,376	92,094	73,996	133,913	10,432	12,941
1939	334,003	93,338	76,774	142,169	8,393	13,327
1940	346,721	91,546	81,925	147,970	11,899	13,381
1941	324,201	84,319	88,326	126,933	9,562	15,061
1942	419,547	98,022	107,903	186,813	11,281	15,528
1943	489,861	139,311	142,539	176,481	10,814	20,716
1944	535,108	156,722	148,165	193,018	14,149	23,054
1945	575,107	163,701	146,185	211,526	28,699	24,997
1946	632,943	183,223	151,308	237,080	31,202	30,130
1947	660,721	173,254	145,223	272,536	41,489	28,219
1948	672,171	185,943	130,487	274,506	51,211	30,024
1949	741,726	162,710	150,716	327,949	67,812	28,047
1950	764,581	151,482	148,036	346,568	85,451	28,830
1951	770,507	127,922	150,364	368,296	90,020	29,194
1952	768,545	135,533	132,952	378,949	86,496	29,827
1953	819,803	150,006	131,446	399,380	101,476	32,649
1954	811,641	135,835	139,211	426,611	75,122	30,413
1955	790,774	140,953	130,057	428,752	54,880	30,808
1956	800,680	138,000	135,507	429,449	62;711	29,669
1957	808,251	140,672	141,974	415,986	74,786	30,050
1958	870,539	143,694	154,785	451,316	85,677	30,133
1959	908,214	138,040	150,424	467,617	113,911	32,692
1960	935,428	148,624	173,166	437,132	137,243	33,639
1961	1,077,412	166,024	200,559	498,705	173,480	33,196
1962	1,144,000	158,993	196,085	530,048	209,804	43,290
1963	1,256,841	157,521	189,469	571,671	289,834	43,302
1964	1,454,332	157,566	192,487	650,817	403,371	45,004
1965	1,593,593	175,583	212,561	688,846	463,864	47,421

*Source: The Fertilizer Trade, Dominion Bureau of Statistics, Ottawa.

APPENDIX B

INDEX OF FARM CASH INCOME FROM FARMING OPERATIONS,[a] CANADA AND REGIONS, 1926-1965*
(1935-1939=100)

Year	Canada[b]	Atlantic	Quebec	Ontario	Prairie	B.C.
1926	153.9	114.6	117.6	129.5	191.5	97.3
1927	150.6	113.1	117.3	129.8	183.5	105.4
1928	170.6	115.4	128.3	136.7	217.1	120.9
1929	149.2	113.6	126.8	135.3	172.1	123.8
1930	102.8	109.9	106.3	112.4	93.8	110.3
1931	75.6	80.1	85.9	90.1	61.9	79.6
1932	65.5	61.1	68.1	69.2	62.8	65.9
1933	67.2	71.0	66.3	71.6	63.9	69.7
1934	80.2	79.5	78.3	78.9	82.5	80.3
1935	85.3	89.3	82.9	84.7	85.9	84.0
1936	94.1	99.4	93.3	92.9	94.6	91.8
1937	102.3	108.5	103.1	106.3	98.2	105.6
1938	104.1	103.2	106.1	105.9	101.9	108.2
1939	114.3	98.6	114.7	110.1	119.4	110.3
1940	118.6	108.2	127.8	113.6	121.1	112.2
1941	144.9	123.5	154.6	144.6	146.4	130.9
1942	185.2	163.2	192.4	188.4	150.6	164.2
1943	228.1	199.5	214.5	204.9	253.0	208.6
1944	292.1	212.3	238.0	216.3	372.9	246.5
1945	266.2	218.0	251.3	233.1	298.8	264.3
1946	272.1	237.6	258.7	243.1	299.3	274.5
1947	310.0	243.7	301.9	281.8	339.4	309.3
1948	384.7	278.9	370.6	342.4	437.2	341.8
1949	386.8	266.7	356.6	342.6	445.7	328.4
1950	342.1	279.9	372.7	342.3	341.7	328.4
1951	438.1	314.1	436.5	412.9	475.1	391.0
1952	449.0	353.1	440.5	389.3	508.4	393.5
1953	434.0	291.6	406.9	377.0	500.4	405.7
1954	367.6	306.1	409.0	365.3	360.8	402.3
1955	363.9	293.3	417.6	381.2	342.6	388.8
1956	405.9	320.7	421.8	378.4	428.5	419.6
1957	403.2	307.4	436.5	399.7	405.5	423.2
1958	450.7	320.7	480.8	440.8	464.8	444.3
1959	444.6	321.9	476.8	444.0	449.5	456.1
1960	450.1	333.5	466.9	447.9	459.1	466.5
1961	468.6	311.2	484.7	460.3	486.9	486.1
1962	508.0	319.6	513.1	486.7	540.3	541.6
1963	514.5	324.2	526.7	524.9	524.4	544.9
1964	560.4	359.2	532.9	537.3	608.8	561.3
1965	611.5	435.2	590.9	581.3	659.8	604.4

*Source: Computed from Handbook of Agricultural Statistics, Part II. Farm Income-1929-65, D.B.S., Ottawa.

[a]Farm cash income from farming operations includes those from crops, livestock and its products, and supplementary payments.

[b]Excluding Newfoundland.

APPENDIX C

INDEX OF REAL PRICES OF FERTILIZER AND CROPS,[a]
CANADA, EASTERN AND WESTERN CANADA, 1926-1965*
1935-1939=100

Year	Canada		Eastern Canada		Western Canada	
	Real price of fertilizer	Real price of crops	Real price of fertilizer	Real price of crops	Real price of fertilizer	Real price of crops
1926	102.1	121.6	103.0	138.8	101.3	111.3
1927	102.1	117.3	102.3	119.9	101.9	116.1
1928	96.5	106.9	97.4	104.6	95.7	108.1
1929	96.8	110.1	96.8	109.6	96.8	110.4
1930	98.6	93.7	99.5	111.6	97.8	84.9
1931	104.7	69.2	106.1	83.4	103.4	62.1
1932	98.3	69.5	100.9	78.9	95.9	64.9
1933	103.5	79.3	105.4	94.7	101.7	71.6
1934	101.7	86.2	102.5	95.4	101.1	81.7
1935	100.6	89.4	101.1	90.7	99.8	88.8
1936	100.0	105.7	100.0	113.9	101.6	101.4
1937	97.2	119.6	96.1	109.4	96.9	124.7
1938	101.4	99.0	101.7	88.9	100.1	103.8
1939	100.8	84.3	101.1	95.9	101.6	78.6
1940	98.8	98.6	98.9	87.6	94.7	74.9
1941	98.9	76.2	98.3	86.8	91.3	71.2
1942	95.9	89.0	95.7	110.7	83.8	78.5
1943	83.8	100.6	82.7	116.9	78.2	92.9
1944	82.0	110.4	81.7	111.6	75.4	110.2
1945	80.2	122.7	79.9	121.8	74.1	123.6
1946	78.5	127.8	78.2	114.9	71.8	134.6
1947	76.6	112.5	76.3	103.9	67.5	85.4
1948	71.7	103.5	70.4	109.1	64.5	101.1
1949	74.2	96.5	73.7	96.1	66.2	97.1
1950	75.2	90.9	74.9	88.4	67.3	92.1

APPENDIX C (continued)

Year	Canada		Eastern Canada		Western Canada	
	Real price of fertilizer	Real price of crops	Real price of fertilizer	Real price of crops	Real price of fertilizer	Real price of crops
1951	73.3	83.4	73.0	87.4	71.5	81.4
1952	79.3	98.7	79.0	124.4	71.5	85.9
1953	80.8	81.3	81.3	82.5	74.0	80.7
1954	81.5	78.7	81.8	82.8	79.1	76.8
1955	80.8	82.3	80.7	91.0	76.4	78.0
1956	78.5	80.5	78.5	93.1	74.1	74.3
1957	76.8	74.4	76.9	78.8	71.2	72.3
1958	76.1	75.2	76.3	79.6	71.7	73.1
1959	75.3	76.4	75.2	84.7	70.7	72.3
1960	76.4	81.9	76.7	94.3	67.9	75.8
1961	75.1	82.2	75.5	82.1	65.3	82.2
1962	72.9	81.5	72.9	79.5	64.8	82.5
1963	73.6	80.6	73.5	80.8	64.3	80.5
1964	72.4	76.3	72.3	79.2	64.4	81.5
1965	73.6	78.4	73.6	90.7	63.4	80.7

*Source: Computed from Index Numbers of Farm Prices of Agricultural Products, Cat. No. 62-002 and Price Index of Commodities and Services Used by Farmers, Cat. No. 62-004, D.B.S., Ottawa.

[a]The real price of fertilizer is the fertilizer price index deflated by the composite index. The real price of crops is the crop price index deflated by the general wholesale price index.

APPENDIX D

AUTOREGRESSIVE LEAST SQUARES

This appendix is designed for a summary of the autoregressive least-squares estimation procedure developed by Fuller and Martin. Autoregressive least squares is an iterative technique which reestimates the values of all parameters in the model, including those of the autoregressive structure until they converge to stable values.

Suppose that equation to be estimated is of the form:

$$Y_t = a_o + a_1X_{1t} + a_2X_{2t} + a_3Y_{t-1} + U_t \qquad (1)$$

Assuming that the U_t follows a first order autoregressive scheme, i.e.,

$$U_t = \rho U_{t-1} + \epsilon_t \qquad (2)$$

where ϵ_t satisfies the following assumptions

$$E\ (\epsilon_t) = 0 \qquad (3)$$

$$E\ (\epsilon_t\epsilon_{t-j}) = 0 \qquad j \neq 0 \qquad (4)$$

$$E\ (\epsilon_t^2) = \sigma^2 \qquad \text{for all } t \qquad (5)$$

$$E\ (X_{it}\epsilon_t) = 0 \qquad \text{for all } i \qquad (6)$$

$$E\ (Y_{t-j}\epsilon_t) = 0 \qquad j \geq 1 \qquad (7)$$

Solving equation (1) for U_t and lagging each variable one time period gives

$$U_{t-1} = Y_{t-1} - a_o - a_1X_{1t-1} - a_2X_{2t-1} - a_3Y_{t-2} \qquad (8)$$

Substituting equation (8) into (2) and then replacing U_t of equation (1) by the resulting expression yields:

$$Y_t = b_o + b_1X_{1t} + b_2X_{2t} + b_3Y_{t-1} + b_4X_{1t-1} + b_5X_{2t-1} + b_6Y_{t-2} + \epsilon_t \quad (9)$$

where $b_o = (1-\rho)\, a_o$

$$b_1 = a_1$$

$$b_2 = a_2$$

$$b_3 = a_3 + \rho$$

$$b_4 = -\rho a_1$$

$$b_5 = -\rho a_2$$

$$b_6 = -\rho a_3 \quad (9a)$$

If $\rho = 0$, equation (9) reduces to equation (1) and we obtain the least squares estimates of parameters. If $\rho = 1$, equation (9) reduces to an equation of the form (1) where the variables are expressed in first differences.

The direct application of the method of least squares to equation (9) is possible, but will, in general, yield conflicting estimates of the original parameters since the system (9a) is composed of seven equations in five unknowns.

To circumvent this problem an iterative technique has been developed by Fuller and Martin. First, an initial set of estimates is selected for the unknown parameters. The number of parameters to be estimated can be reduced from five to four by expressing all the variables as deviation from their respective means. The ordinary least squares solution of equation (9) utilizing equations (9a) affords an acceptable set of estimates.

Let the initial set of estimates be indicated by

$$P_o = (\theta_{10}, \theta_{20}, \theta_{30}, \theta_{40}) \tag{10}$$

where $\theta_{10} = a_1$, $\theta_{20} = a_2$, $\theta_{30} = a_3$, $\theta_{40} = \rho$

The second subscript on θ_{io} denotes the iteration number. For instance, θ_{10} represents the start value of parameter a_1.

Next, expand equation (9) about P_o in a Taylor series retaining only the first order term. This provides:

$$Y_t - Y_{to} = Z_{10}\Delta\theta_{10} + Z_{20}\Delta\theta_{20} + Z_{30}\Delta\theta_{30} + Z_{40}\Delta\theta_{40} \tag{11}$$

where $Y_{to} = \theta_{10}X_{1t} + \theta_{20}X_{2t} + (\theta_{30} + \theta_{40})Y_{t-1} - \theta_{10}\theta_{40}X_{1t-1} - \theta_{20}\theta_{40}X_{2t-1} - \theta_{30}\theta_{40}Y_{t-2}$

$$Z_{10} = X_{1t} - \theta_{40}X_{1t-1}$$

$$Z_{20} = X_{2t} - \theta_{40}X_{2t-1}$$

$$Z_{30} = Y_{t-1} - \theta_{40}Y_{t-2}$$

$$Z_{40} = Y_{t-1} - \theta_{10}X_{1t-1} - \theta_{20}X_{2t-1} - \theta_{30}Y_{t-2}$$

The Z_{io} are the first derivatives of equation (9) with respect to each unknown parameter, and the $\Delta\theta_{io}$ are the deviations of the θ_{io} from the true parameters. The variable $Y_t - Y_{to}$ is regressed on the Z_{io} to obtain estimates of the $\Delta\theta_{io}$.

If the estimated $\Delta\theta_{io}$ thus obtained are not small, the process is repeated using as the second start point:

$$P_1 = \left[(\theta_{10} + \Delta\hat{\theta}_{10}), (\theta_{20} + \Delta\hat{\theta}_{20}), (\theta_{30} + \Delta\hat{\theta}_{30}), (\theta_{40} + \Delta\hat{\theta}_{40}) \right] \tag{12}$$

where the $\Delta\hat{\theta}_{io}$ are the least-squares estimates of $\Delta\theta_{io}$. Iteration is carried on until the $\Delta\hat{\theta}_{ij}$ become insignificantly small and thus converge to a final solution.

APPENDIX E

TABLE E-1

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION, CANADA, 1926-1965 (1940-1945 EXCLUDED)

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	$X_{5,t-1}$	X_6	Y_{t-1}	t
Y	1.000								
X_1	-0.872	1.000							
$X_{2,t-1}$	-0.421	0.224	1.000						
$X_{3,t-1}$	0.886	-0.946	-0.119	1.000					
X_4	-0.131	0.359	-0.763	-0.442	1.000				
$X_{5,t-1}$	0.568	-0.459	-0.128	0.620	-0.109	1.000			
X_6	0.368	-0.374	-0.202	0.416	-0.090	0.253	1.000		
Y_{t-1}	0.993	-0.886	-0.454	0.889	-0.115	0.564	0.401	1.000	
t	0.951	-0.901	-0.484	0.863	-0.082	0.468	0.961	0.961	1.000

TABLE E-2

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION, THE ATLANTIC REGION, 1929-1965 (1940-1945 EXCLUDED)

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	Y_{t-1}	t
Y	1.000						
X_1	-0.879	1.000					
$X_{2,t-1}$	0.099	0.187	1.000				
$X_{3,t-1}$	0.918	-0.893	0.133	1.000			
X_4	-0.594	0.430	-0.732	-0.620	1.000		
Y_{t-1}	0.904	-0.881	-0.008	0.873	-0.537	1.000	
t	0.738	-0.892	-0.430	0.762	-0.141	0.710	1.000

TABLE E-3

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION, QUEBEC REGION, 1929-1965 (1940-1945 EXCLUDED)

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	Y_{t-1}	t
Y	1.000						
X_1	-0.929	1.000					
$X_{2,t-1}$	-0.247	0.178	1.000				
$X_{3,t-1}$	0.960	-0.964	-0.210	1.000			
X_4	-0.310	0.430	-0.376	-0.376	1.000		
Y_{t-1}	0.974	-0.941	0.963	0.963	-0.284	1.000	
t	0.950	-0.892	0.943	0.943	-0.141	0.941	1.000

TABLE E-4

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION, ONTARIO REGION, 1929-1965 (1940-1945 EXCLUDED)

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	X_7	Y_{t-1}	t
Y	1.000							
X_1	-0.859	1.000						
$X_{2,t-1}$	-0.415	0.178	1.000					
$X_{3,t-1}$	0.943	-0.853	-0.233	1.000				
X_4	-0.135	0.892	-0.732	-0.342	1.000			
X_7	-0.473	0.751	-0.109	-0.575	0.566	1.000		
Y_{t-1}	0.991	-0.848	-0.446	0.935	-0.117	-0.436	1.000	
t	0.977	-0.892	-0.416	0.945	-0.141	0.751	0.975	1.000

TABLE E-5

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION, THE PRAIRIE REGION, 1929-1965 (1940-1945 EXCLUDED)

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	Y_{t-1}	t
Y	1.000						
X_1	-0.639	1.000					
$X_{2,t-1}$	-0.224	0.055	1.000				
$X_{3,t-1}$	0.613	-0.929	0.102	1.000			
X_4	-0.223	0.607	-0.666	-0.698	1.000		
Y_{t-1}	0.988	-0.644	-0.237	0.634	-0.227	1.000	
t	0.766	-0.895	-0.248	0.827	-0.407	0.781	1.000

TABLE E-6

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION, BRITISH COLUMBIA REGION, 1929-1965 (1940-1945 EXCLUDED)

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	Y_{t-1}	t
Y	1.000						
X_1	-0.929	1.000					
$X_{2,t-1}$	-0.132	0.055	1.000				
$X_{3,t-1}$	0.964	-0.953	-0.033	1.000			
X_4	-0.504	0.607	-0.666	0.585	1.000		
Y_{t-1}	0.973	-0.925	-0.158	0.960	-0.487	1.000	
t	0.951	-0.895	0.935	0.935	-0.407	0.951	1.000

TABLE E-7

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION CANADA, 1946-1965

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	$X_{5,t-1}$	Y_{t-1}	t
Y	1.000							
X_1	-0.450	1.000						
X_2	-0.623	0.031	1.000					
$X_{3,t-1}$	0.635	-0.323	-0.001	1.000				
X_4	0.647	0.324	-0.926	0.089	1.000			
$X_{5,t-1}$	0.447	0.350	-0.277	0.487	0.479	1.000		
Y_{t-1}	0.988	-0.403	0.899	0.582	0.701	0.484	1.000	
t	0.883	-0.292	-0.292	0.368	0.886	0.783	0.899	1.000

TABLE E-8

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION ATLANTIC REGION, 1946-1965

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	Y_{t-1}	t
Y	1.000						
X_1	-0.431	1.000					
$X_{2,t-1}$	0.426	0.200	1.000				
$X_{3,t-1}$	0.653	0.119	0.768	1.000			
X_4	-0.244	-0.102	-0.539	-0.539	1.000		
Y_{t-1}	0.690	-0.579	0.404	0.404	-0.332	1.000	
t	-0.144	-0.209	-0.488	-0.488	0.847	-0.329	1.000

TABLE E-9

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION QUEBEC REGION, 1946-1965

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	Y_{t-1}	t
Y	1.000						
X_1	-0.164	1.000					
$X_{2,t-1}$	-0.748	0.188	1.000				
$X_{3,t-1}$	0.769	-0.329	-0.398	1.000			
X_4	0.844	-0.102	-0.908	0.629	1.000		
Y_{t-1}	0.652	-0.569	-0.435	0.742	-0.569	1.000	
t	0.962	-0.209	-0.732	0.828	-0.209	0.687	1.000

TABLE E-10

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION ONTARIO REGION, 1946-1965

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	X_7	Y_{t-1}	t
Y	1.000							
X_1	-0.227	1.000						
$X_{2,t-1}$	-0.704	0.188	1.000					
$X_{3,t-1}$	0.819	-0.757	-0.424	1.000				
X_4	0.812	-0.102	-0.908	0.617	1.000			
X_7	0.516	0.332	-0.306	0.469	0.605	1.000		
Y_{t-1}	0.977	0.535	-0.748	0.762	0.844	0.535	1.000	
t	0.953	-0.209	-0.732	0.789	0.847	0.620	0.962	1.000

TABLE E-11

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION PRAIRIE REGION, 1946-1965

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	Y_{t-1}	t
Y	1.000						
X_1	-0.593	1.000					
$X_{2,t-1}$	-0.290	-0.098	1.000				
$X_{3,t-1}$	0.418	-0.415	0.335	1.000			
X_4	0.229	0.343	-0.829	-0.392	1.000		
Y_{t-1}	0.984	-0.503	-0.319	0.412	0.385	1.000	
t	0.792	-0.329	-0.829	0.029	0.458	0.782	1.000

TABLE E-12

SIMPLE CORRELATION COEFFICIENT MATRIX FOR VARIABLES IN FERTILIZER DEMAND FUNCTION BRITISH COLUMBIA REGION, 1946-1965

	Y	X_1	$X_{2,t-1}$	$X_{3,t-1}$	X_4	Y_{t-1}	t
Y	1.000						
X_1	-0.561	1.000					
$X_{2,t-1}$	-0.286	-0.098	1.000				
$X_{3,t-1}$	0.814	-0.576	-0.060	1.000			
X_4	0.247	0.342	-0.829	0.168	1.000		
Y_{t-1}	0.891	-0.499	-0.310	0.771	0.290	1.000	
t	0.805	-0.329	-0.689	0.657	0.721	0.796	1.000

APPENDIX F

REGRESSION COEFFICIENTS, STANDARD ERRORS, AND OTHER STATISTICAL RESULTS FOR REGIONAL DEMAND FUNCTIONS FOR FERTILIZER, 1929-1965

Region and Equation	R^2	S	Log of constant	Log X_1	Log $X_{2,t-1}$	Log X_4	t	Log Y_{t-1}	Auto-correlation coefficient ρ
			The Total Period, 1929-1965 with 1940-1945 excluded						
Atlantic F.1	.932**	.086	5.9861			-.4804** (.1195)	.0133* (.0027)	.4253** (.1128)	.0718* (.0267)
Quebec F.2	.976**	.097	5.5488			-.5606** (.1370)	.0282** (.0058)	.4068** (.1168)	.1175** (.0338)
Prairie F.3	.968**	.331	4.3750			-.2343# (.1867)	.0443** (.0105)	.6174** (.0623)	-.3301** (.1133)
B.C. F.4	.969**	.096	4.8057			-.2339* (.0927)	.0240** (.0063)	.4356** (.1523)	.0751* (.0362)
			The Pre-war Period, 1929-1939						
Atlantic F.5	.849*	.110	7.9935			-.7131+ (.2975)	.0068 (.0186)	.2511 (.2525)	.1012 (.1260)
Quebec F.6	.924**	.108	5.9337			-.8719* (.2783)	.0605* (.0205)	.3321++ (.1813)	.1440++ (.0783)
Ontario F.7	.950**	.114	5.3449			-.8607* (.3230)	.1313+ (.0717)	.0909 (.1000)	.4461# (.3739)

APPENDIX F (continued)

Region and Equation	R^2	S	Log of constant	Log X_1	Log $X_{2,t-1}$	Log X_4	t	Log Y_{t-1}	Auto-correlation coefficient ρ
				The Pre-war Period, 1929-1939					
Prairie F.8	.867*	.537	5.0082			.3798 (1.2036)	.1179 (.3883)	-.4279++ (.2297)	.5836** (.2161)
B.C. F.9	.601	.112	14.1806			-.3208* (.1261)	-.0053 (.0118)	.0124 (.0385)	-.5180# (.4099)
				The Post-war Period, 1946-1965					
Atlantic F.10	.702**	.068	4.9915	-.3834 (.5865)	.3579+ (.1695)		.0096* (.0043)	.5548* (.2451)	.0211 (.0218)
Quebec F.11	.831**	.078	7.3783	-.6994# (.5868)	.2129++ (.1694)		.0166* (.0095)	.6751** (.2205)	-.0033 (.0103)
Ontario F.12	.966**	.059	4.2609	-.1606 (.3808)	.0698 (.1549)		.0142++ (.0095)	.6751** (.2205)	-.0033 (.0103)
Prairie F.13	.981**	.116	9.1012	-1.8487** (.4470)	.2744 (.2915)		.0330** (.0117)	.7424** (.0837)	-.0336 (.0906)
B.C. F.14	.880**	.067	5.8546	-.4181# (.3320)	.0925 (.2072)		.0151+ (.0081)	.5037+ (.2463)	.0437 (.0392)

Note: 1. Variables interpreted as in the context.
2. Levels of significance: ** = 1 per cent; * = 5 per cent; + = 10 per cent; ++ = 20 per cent; # = 30 per cent